POOL WATER TREATMENT ADVISORY GROUP

NET ZERO CARBON POOLS

Water treatment issues

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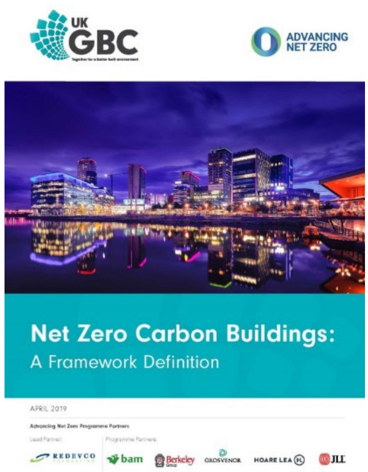
1 INTRODUCTION

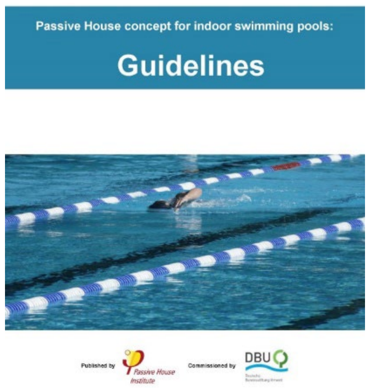
We are in a climate emergency and urgently need to reduce carbon emissions. In the UK the operation of buildings accounts for around 30% of emissions, and when taking account embodied carbon, this figure rises to around 49%. There can be no doubt that the 3,170 swimming pool sites in the UK have a significant role to play in this.

Organisations including the World Green Building Council, the London Energy Transformation Initiative (LETI), the UK Green Building Council (UKGBC), the Chartered Institute of Building Services Engineers (CIBSE) and Architecture 2030 believe that in order to meet our climate change targets all new buildings must operate at net zero carbon by 2030, and all buildings by 2050. These are seriously challenging targets and LETI states: ‘The built environment industry, together with current regulations and practices, are seriously lagging behind the carbon trajectory required to protect life on planet earth’.



UK GBC Net Zero Carbon Buildings: A Framework Definition

LETI Climate Emergency Design Guide



Passive House concept for indoor swimming pools: Guidelines

A few of the many publications and guidelines on net zero carbon

1.1 Scope of this paper

The UKGBC Framework Definition identifies three approaches to net zero carbon – construction, operational energy and whole life. Net zero carbon in operation is defined: 'when the amount of carbon emissions associated with the building's operational energy on an annual basis is zero or negative. A net zero carbon building is highly efficient and powered from on-site and/or off-site renewable energy sources, with any remaining carbon balance offset'.

There is a clear and present challenge to reduce the carbon footprint of both the construction and operation of swimming pools. This challenge involves many stakeholders including designers, contractors, operators, trainers, auditors and maintenance service providers. This paper focuses on operational energy.

The scope of this paper is to address what can be done to provide a net zero carbon in the operation of a pool water treatment system, while at the same time providing a safe and appealing environment for bathers and on-site staff.

The paper provides a resource that can be used to inform policy in this specialist area, to be integrated into broader-based documents and guidelines that cover wider aspects of making swimming pools energy-efficient. That will include the energy source, the building envelope, heating, ventilation and water consumption.

The first section discusses the principles involved in quantifying the use of energy and water in the treatment of pool water. The aim is to provide a means of establishing targets that focus on the aims of water treatment, and how these might be achieved using least energy and water. Key issues addressed include the amount of pump power required to circulate sufficient water to achieve satisfactory water treatment, and similarly for water usage.

The section on implementation reviews the roles of the various stakeholders in the design, construction, operation and refurbishment of swimming pools when implementing energy-efficient water treatment.

The report aims to be accessible to all parties. The main commentary in these two sections aims to be easily readable without complex technical content. Where such content is needed, it is in appendices referred to in those sections.

2 PRINCIPLES

Energy and water consumption in water treatment processes

2.1 Electricity used for pool water circulation

The amount of energy required to circulate water to maintain good pool water quality is the product of two parameters:

- the power required to circulate each m3/h of water
- the amount of circulated water that is required to ensure that the water is safe and appealing (ie that well-defined water quality targets are met).

There is considerable scope for designing pools that will substantially out-perform the majority of existing pools in this respect. The Passive House guidelines (Guidelines: Passive House concept for indoor swimming pools) provide very ambitious, but achievable targets for energy use in water circulation.

The first target in the Passive House document is the amount of electrical power required to generate unit flow rate: 25-40W per m3/h of circulating water. This target reflects the hydraulic efficiency of the circulation system.

There are also power targets related to the area of the pool:

- 10-17W per m2 of pool area in the case of a regular pool with 4.5m2 per bather at maximum bather number
- 17-29W per m2 of pool area in the case of a learner pool with 2.7m2 per bather at maximum bather number.

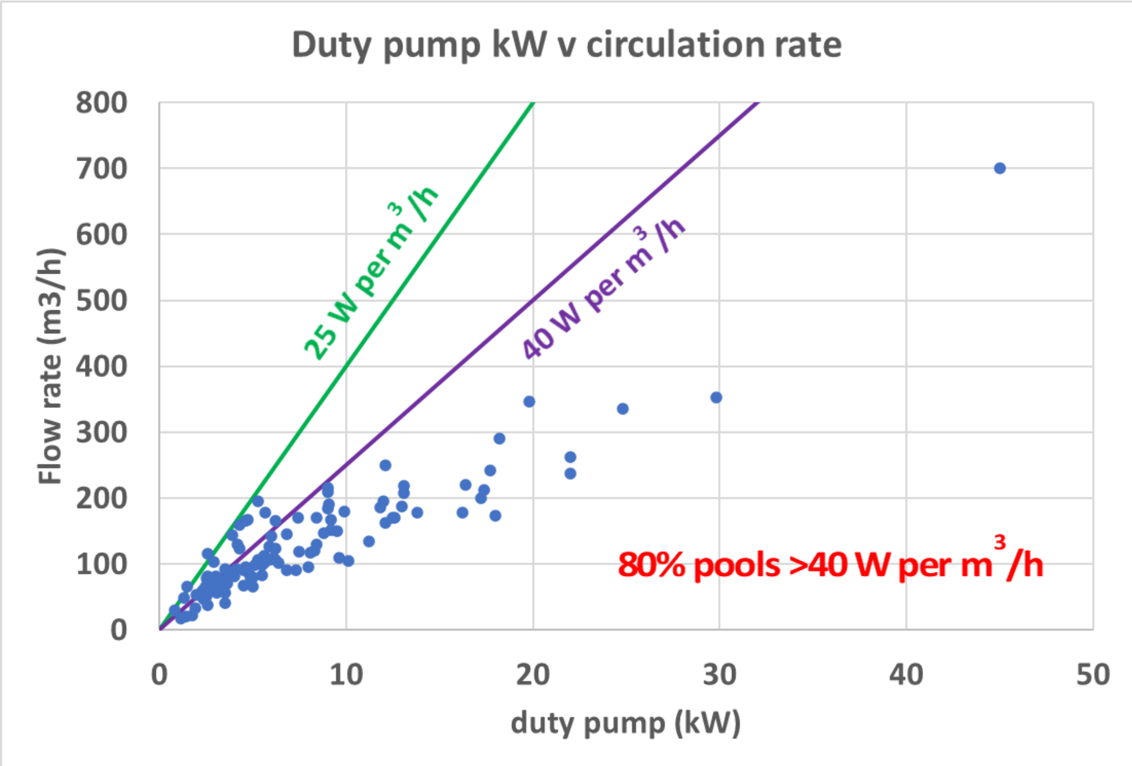
These area-based targets account for the hydraulic efficiency but also include consideration of the rate of circulation needed to ensure satisfactory water quality.

The equivalence of these targets can be demonstrated by using the idea which underpins the circulation guidelines in PWTAG's book Swimming Pool Water and its Code of Practice: there is a minimum of 1.7m3 of water that needs to be circulated through the filtration system per bather. The method by which this is deduced is covered in Appendix 2, which shows that there is consistency between the PWTAG circulation requirement and the Passive House energy/power targets on a unit pool area basis.

2.1.1 Power required to circulate each 1m3/h of water flow

The Passive House target is for 1m3/h of flow to require between 25 and 40W. How does this compare with the current situation in leisure centres across the UK?

The graph on page 5 illustrates the wide variation that exists among commercial leisure centre pools in the UK. These data were obtained from surveys of sites where the power consumption by the circulation pumps on duty was available from variable speed drive operating data, and where flow rates were reliably measured using a clamp-on ultrasonic flow meter.



Power consumption at different leisure pool circulation rates

Although many of the sites were built over 30 years ago, not all of the poorly performing sites were old stock. There were many reasons why some sites were using excessive amounts of power per unit flow. Examples include:

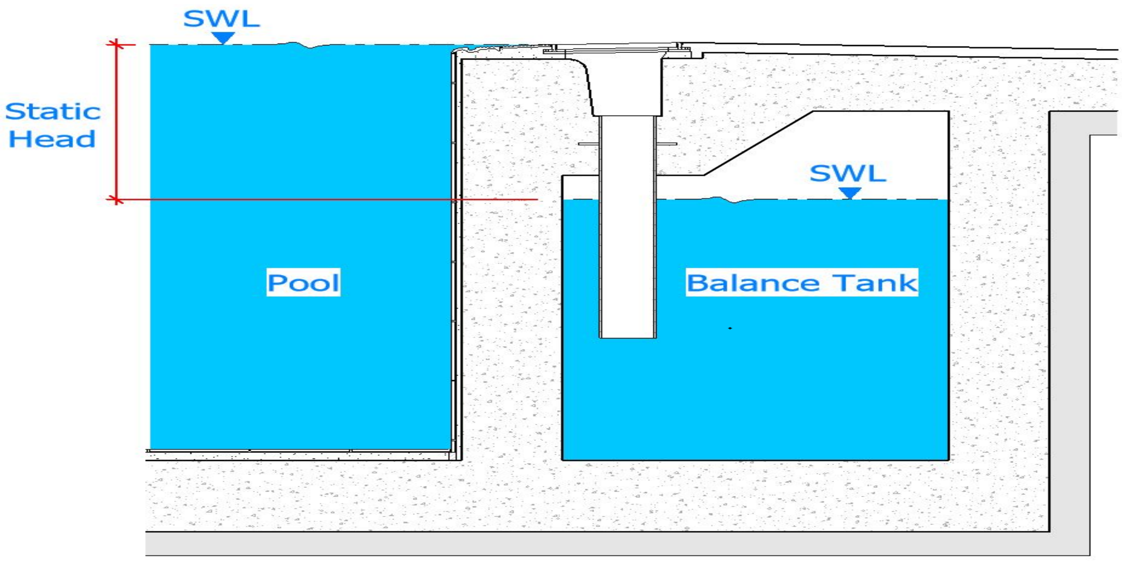
- throttled valves on the main circulation pipework to divert flow into bypass loops or to provide back pressure to supply water to elevated water bodies
- inadequately-sized suction pipework strangling the water supply to the pumps
- poorly installed pumps where the pre-pump suction pipework caused turbulent water entry into the pumps
- poor operation and maintenance issues – partially blocked UV strainers, partially blocked non-return valves on balance tank pick-up pipes, filter media in poor condition, valves throttled for no good reason
- pool sumps that gravity-drained into deep balance tanks, meaning that 100% of the circulating water was having to be lifted back into the pool
- circulation pumps above (or only very slightly below) the water level in the pool.

Though the majority of pools illustrated in the graph above fall way short of the Passive House guidelines, there are some that are achieving high standards of efficiency.

The amount of power needed to circulate 1m^3/h of flow depends on many factors, that in essence fall into three categories:

- anywhere in the circulation that water drops by gravity
- energy required to overcome frictional resistance in the system
- the efficiency of the conversion of electrical into hydraulic power by the pump (including the efficiency of the motor and any variable speed drive).

Gravity If there is anywhere in the circulation that water drops by gravity – eg water dropping into a balance tank from a waterfall feature or a water body at higher elevation to the main water body, then this will impose an energy requirement to lift the water back up.



Static head loss between pool and balance tank

On a deck-level pool with transfer channels and a balance tank, the water will flow from the pool's static water level (SWL) into the transfer channel under gravity, and then from the transfer channel into the balance tank, again under gravity. The height the water drops (the static head) – from the pool static water level to the balance tank static water level – should be kept to a minimum, to minimise the power required to lift the water back up. This requires careful hydraulic design of the transfer channels and the balance tank. In some pools, water from the sumps also drains into the balance tank through gravity, creating an easily avoidable need for energy to lift the water back into the pool.

Frictional resistance Energy is required to overcome the frictional resistance of the system (also referred to as head loss due to friction) so consideration needs to be given to minimising this resistance in all components of the circulation system.

On a standard pool these normal components will typically include:

- pipework
- pipework fittings such as valves, flow meters, pool inlets and outlets
- strainers
- diffusers after pumps
- filters – sand, ceramic micron, regenerative media
- UV systems
- ozone systems.

In any part of the system where there is frictional resistance, the magnitude of the resistance (and hence the power required to push water through that part of the system) varies with the square of the water velocity. So if the flow rate is doubled, the power requirement increases four-fold. Hence minimising water velocities (eg by increasing pipe size or reducing flow rate) is a key tool in creating more energy-efficient systems.

Loss of head along the suction pipework is particularly critical because there is usually very little pressure on the water as it enters the suction pipework. So any significant loss of pressure as water approaches the pump, and within the pump itself, can reduce the pressure to the point where the water is effectively boiling, causing dramatic loss of hydraulic efficiency and cavitation.

With filters, there are many factors that determine the frictional resistance, including the design, the filtration velocity and the frequency of backwashing/cleaning. But the pressure drop across a well-managed sand filter will be a small proportion of the total head loss across the circulation system. Ceramic and regenerative filters tend to have lower frictional resistance than sand.

In addition to the normal components, many pool circulation systems have deliberate restrictions to flow on the main circulation pipework, using partially closed valves to divert a small proportion of the main circulation around a bypass loop or similar. Typical applications for partially closed valves include:

- a bypass loop to circulate a portion of the water through the heat exchanger or to the chemical store/dosing area
- a diversion to feed the inlets of a small water body such as a spa or toddler pool that is elevated above the main pool.

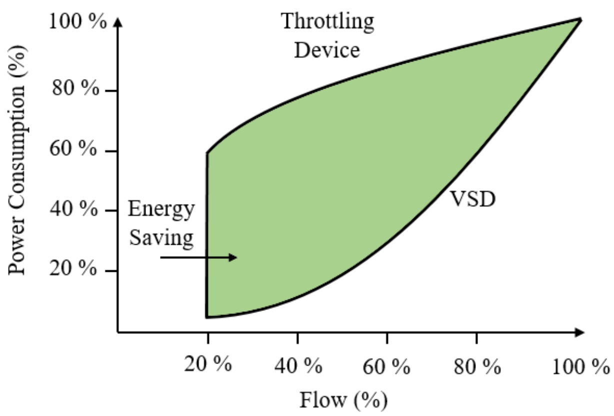
Such partial closing of valves on the main circulation will usually be very inefficient in terms of energy use, and careful consideration should be given to avoiding the need for such bypass loops or using a small booster pump to generate the bypass flow.

Passive House suggest a total head loss target, for both static and friction, of 5-10m.

Pump efficiency – The purpose of a circulation pump (or pumps) is to convert electrical power into the hydraulic power required to achieve the desired circulation rate. Both electrical and hydraulic power are measured in Watts or kW. The hydraulic power required to circulate water at the target flow rate is determined by the flow rate (m^3/h), the weight of the water and the hydraulic head that the pump needs to add to the water in order to push it round the system at the required flow rate (H in m hydraulic head).The efficiency of this conversion can be a very significant factor in the electricity used for pool water circulation, and should not be underestimated.

Overall pump efficiency depends on an array of factors including the efficiency of the motor (and any variable speed drive), the speed of rotation, the design of the impeller and the housing, the materials used, the net positive suction head (NPSH), the risk of cavitation and the degree of wear. Centrifugal pump performance curves indicate how a pump will perform with regard to pressure (head) and flow, the NPSH requirement and the percentage of motor shaft power that is converted into hydraulic power (often called pump efficiency). The performance of the pump should match that needed by the system, in terms of delivering the head and flow requirements. The choice of pump should also take into account maximizing efficiency, as this can vary widely even with pumps delivering the same head and flow. See Appendix 3.

Variable speed drives (also called inverters) play a key role both for fine tuning flow rates and for operating at reduced flow rates, for optimum energy efficiency. The alternative to a VSD is to use throttling valves to control the flow rate, where the pump will be operating at full speed regardless of the system demand, purposely wasting energy. See Appendix 3.



Energy saving using a VSD versus a throttling device

VSDs can also give the option to use multiple pumps in parallel. In some circumstances this allows a reduction in the rate of water flow through each pump, to:

- enable the pump to operate closer to its best efficiency point (usually in the mid range of the flow capacity of the pump)
- reduce the suction generated in the eye of the impeller. This can sometimes eliminate the risk of being at (or close to) the point of cavitation, where pump efficiency is severely diminished.

2.1.2 Volume of circulating water required to meet water treatment targets
Important alongside the power required to circulate water is the amount of water that needs to circulate in order to maintain safe and appealing water. A number of steps are involved in this:

- identifying what aspects of water treatment depend critically on the rate of circulation of water
- setting targets for the water quality performance indicators that depend critically on the circulation of water
- quantitatively relating these water quality performance targets to circulation rate in order to put a value on the circulation rate that is required.

The two aspects of water treatment that depend most critically on the rate of circulation of water are:

- the delivery of pool water to the water treatment plant (filters, UV etc)
- the distribution of chemicals and heat added to the water delivered to the pool inlets, of which the most critical is the distribution of disinfectant.

Pool designers should aim to ensure that both of these processes are achieved satisfactorily with the minimum rate of water circulation. This has particular implications for the deployment of pool inlets and outlets, and other factors that affect pool mixing. Both of these quite different processes need to be incorporated into pool design.

The water circulation requirement for effective filtration
Circulation is required to move water containing suspended particles and colloidal matter from the pool to the filters, where a proportion of those materials will be removed. That proportion will depend on the effectiveness of the filtration system.

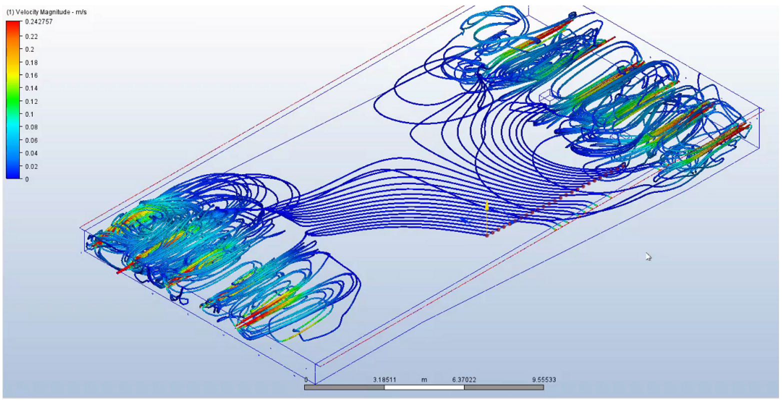
The main issue is the removal of turbidity and of *Cryptosporidium* oocysts, and ideally targets need to be set for maximum values for these. PWTAG has specified a maximum acceptable turbidity of 0.5NTU, but at present there is no such equivalent value for *Cryptosporidium* oocysts.

In the case of turbidity, the question is: what circulation rate is required to maintain turbidity below 0.5NTU even when the bathing load is at the maximum limit for prolonged periods? This is discussed in detail in Appendix 4.

This analysis concludes that the PWTAG guideline of a circulation requirement of 1.7m^3 per bather is reasonable. It should ensure acceptable water clarity, even in pools where the maximum bathing load is maintained for long periods of time and where the filter removal efficiency is less than expected for well-maintained filters.

The impact of water circulation on the distribution of material within the pool tank
Circulation is also required to ensure sufficiently rapid distribution around the pool tank of introduced chemicals and heat (introduced via the inlets), and also for the dispersal of localised concentration of pathogens (particularly *Cryptosporidium* oocysts).

At present this distribution is normally assessed by a dye test. A weakness with dye tests is that it is not always clear what is happening deep in the pool, as water is normally introduced nearer the surface. A recent development has seen the use of computational fluid dynamics (CFD) models to understand better how the performance of a dye test relates to the bulk circulation rate.



CFD showing early-stage particle trajectory in a transient model of a 25m pool

2.2 Electricity used for other water treatment processes

2.2.1 Bypass loops

The circulation of water through bypass loops such as heat exchangers or chemical store loops is often effected by throttling the main flow with a diverter valve. This can be highly inefficient as the entire main flow is throttled in order to boost a relatively small portion of the water.

The optimum approach is normally to use booster pumps that are properly sized for the hydraulic load. The criteria set out on page 7 under *Pump efficiency* also apply here.

2.2.1 Ultraviolet (UV)

UV is widely used for pool water treatment, to assist in the destruction of chloramines and as a secondary disinfectant; it is particularly effective against *Cryptosporidium*. UV can be energy intensive, so its application needs to be carefully addressed.

There are two key fundamental performance criteria for UV systems:

- to achieve a minimum 3-log (99.9%) reduction in the number of infective *Cryptosporidium parvum* oocysts per pass through the UV system, third party validated
- the unit to be sized to provide a UV dose of 60mW/cm^2 (60mJ/cm^2) at the end of lamp life

Once these criteria are satisfied then there are a number of other energy performance criteria that can be addressed at the design and operation stages, to minimise the energy consumption.

2.2.3 Other uses

There are many other processes that can be considered such as full flow ozone with activated carbon filtration, slip-stream ozone, trickle ozone and Uvazone (UV and ozone combined). Full flow ozone provides probably the best water quality but also at the highest use of energy. It is also generally regarded as more expensive to install and more complex in operation than UV.

2.3 Water used for water treatment

In order to maintain excellent water quality, there are quite separate requirements:

- the water required for satisfactory dilution, primarily for control of total dissolved solids (TDS)
- the water required for effective backwashing.

2.3.1 Control of TDS

The principal sources of TDS are the chemicals introduced as part of the water treatment process and the products of resulting chemical reactions.

A key issue is the chlorine use per bather, which can vary widely from 2 to 9g chlorine equivalent per bather per hour. The input of TDS this equates to will vary with the chlorine donor. It is higher for sodium hypochlorite than calcium hypochlorite, and higher still when sodium hypochlorite is generated by on-site electrolysis (though the lower caustic content of this will require less pH correction chemical). The TDS level of the pool water needs to be controlled. The PWTAG guideline (for pools that are not using on-site electrolysis of brine) is that it should not exceed the TDS of the incoming mains by more than 1000mg/l.

The analysis carried out in Appendix 5 suggests that the current guideline – 30l of dilution per bather, and preferably more – is more than is necessary in many pools to ensure adequate TDS control. It is sometimes suggested that some pools will not find that extra dilution over that done by backwashing is needed to achieve the required dilution for TDS control. Such judgments rely on TDS meters being properly calibrated.

In conclusion, there is scope for optimising the requirement of water dumping for the purpose of TDS control.

2.3.2 Backwashing/cleaning filters

Compliance with PWTAG guidelines effectively sets a benchmark for the minimum amount of water that needs to be used in backwashing, depending on the pool volume and type of pool.

2.3.2.1 Traditional sand filters

The minimum area of filter required for compliance is that which achieves the required rate of circulation (equivalent to the maximum number of bathers per hour multiplied by the requirement for $1.7m^3$ per bather) without the filtration velocity exceeding $25m^3/h$ per m^2 of filter area – usually abbreviated to m/h. The typical backwash flow rate recommended for fluidisation of the media is 35m/h (recommendations vary from 30 to 40m/h) from which the amount of water being dumped during a given duration of backwash can be calculated.

Worked example
Calculating the minimum requirement for backwash water.
Consider a pool designed to have a maximum bathing load of 120 bathers per hour.

- *The required circulation rate to treat 1.7m^3 of water per bather is 1.7 x 120 = 204m^3/h.*
- *At 25m/h filtration velocity this would require 204/25=8.2m^2 of filter area.*
- *If the backwash flow rate is 35m/h, the overall backwash flow rate requirement is 8.2 x 35 = 287m^3/h, which is likely to be split between a number of filters.*
- *In a 6-minute backwash, this flow rate would dump 287 x 6/60 = 28.7m^3 of water.*
- *If the site is adhering to the guideline of backwashing at least weekly, then 28.7m^3 per week would be the minimum dumping of water to maintain compliance.*

Given these constraints, what opportunities are there for reducing the backwash water use provided this is not compromising the TDS control requirement?

- In lightly loaded pools, can backwashing intervals be safely extended beyond one week? Recent particle-counting studies have shown that filter removal efficiencies tend to improve in the period between backwashes. It is very rare in the *in situ* measurements made in pools for the filters to become loaded to the point where there is increased breakthrough of particles into the filtrate.
- Can backwash procedures be adapted to ensure that backwashing is stopped when there is evidence that the filters are sufficiently clean, rather than 'over-running'?
- To what extent can water be saved by backwashing only at some appropriate filter pressure differential, rather than by backwashing on fixed days?

2.3.2.2 Regenerative media filters
Within the filter, the long tubes or septa are coated with perlite media, which traps the pollution from the pool water. This media is typically replaced once a month, by 'bumping' – dropping the media off the septa – and then draining the filter vessel of the water volume and the contaminated perlite. The 'backwash' water volume is therefore quite small compared to a traditional sand filter, and for the worked example above would equate to about 2m^3. The water will also contain the perlite or diatomaceous earth.

Where the backwash water volume only has been replenished, the TDS levels can rise to 5,000mg/l or more. Proactive dilution is therefore required to control TDS.

2.3.2.3 Ceramic membrane filters
The filters are backwashed using air and water several times per day. Initial research indicates that the backwash water volumes required for the filters is similar to that for sand filters.

2.4 Water and heat recovery from backwashing
2.4.1 Water recovery
Backwash water volumes from both sand and micron filters at 24m^3 per week (as in the worked example in 2.3.2.1) are significant. With regenerative media filters, similar water

volumes will need to be removed following dilution. Water that is recovered offers two potential savings – in fresh and waste water.

Backwash water recovery, where it is to be used for irrigation or toilet flushing or similar, requires a relatively low level of treatment – typically filtration and potentially one or more pathogen barriers (Reference BS 8525:2010 Grey water systems). How cost effective this is does need to be evaluated.

Where backwash water is to be recovered for use in the swimming pool, then a much higher level of treatment will be required. This will include a double pathogen barrier and treatment to remove TDS – eg reverse osmosis (RO). Given the relatively low level of costs for fresh water and waste water in this country, it is unlikely that this level of treatment would be economically viable; RO membrane maintenance is also labour intensive.

2.4.2 Heat recovery

Heat can be recovered from the warm backwash water. The amount recovered equates to 1.16kWh from each cubic metre of water per 1°C drop in temperature. This can be effected either passively using a heat exchanger or actively with a heat pump. Either way an intermediate water storage tank is required so that the waste water is saved and routed for heat recovery only when cold mains water is being supplied to the pool.

Recent investigations reported by Passive House (Reference 5) indicate that passive heat recovery systems are more cost effective than the more capital intensive active system.

2.5 Auditing and verification

There are many stages in the delivery of an energy-efficient water treatment system including design, installation, commissioning and operation. These stages are often treated as unconnected, whereas they are in fact intrinsically linked. For example, if the operator is going to operate the plant properly, they will need to understand the design intent. Auditing and verification are therefore crucial processes for each of these stages in order to check and verify that the original intent has been achieved, from the detailed design right through to the operation. This is dealt with in more detail in the next section, on implementation.

3 IMPLEMENTATION

The role of stakeholders in the design and operation of low-carbon-footprint water treatment processes

3.1 Designers – new and refurbishment systems

The main area where designers can exert most influence on advancing net zero for operation, is on the elements that affect the electricity used, both for water circulation and for other water treatment processes. The water treatment elements that can be addressed by design are scheduled below.

3.1.1 Establishing energy targets

Identifying and getting client commitment to targets is an essential first step. Passive House identify reasonable and achievable energy targets.

3.1.2 Plant size

The electricity used for pool water circulation is the product of the energy required to circulate each m^3 of water x the volume of circulating water required to meet water treatment targets. The former is largely determined by the efficiency of the system design. The latter is determined largely by the design of the plant size, which should be informed by the proposed operation. The plant needs to be big enough for the design bather load, but if it is too big then it will be circulating more water than required. An oversized plant is inefficient in both operational and construction (embodied) carbon. Getting the plant size right in relation to bather load is crucial for optimum energy efficiency.

3.1.3 Plant location

The location of the plant in relation to the pool and the balance tank, both in plan and in elevation, is important in order to minimise the lengths of pipework between the elements. It requires energy to pump water through pipework, to overcome the head loss due to friction, so the shorter the pipe lengths the better. This is particularly true of suction pipework, where even small head losses can result in pumps operating very inefficiently if the pressure inside the pump falls low enough.

3.1.4 Balance tank location

Water will fall under gravity from the pool tank static water level, into the transfer channel and then into the balance tank. This loss of static head will need to be pumped back up to the pool static water level, so the design should minimise this loss of static head. The balance tank should be located adjacent to the pool, and at the same level as the pool, so that the balance tank design static water level can be as close as possible to the pool tank design static water level.

3.1.5 Balance tank design

Balance tanks on deck level pools serve three purposes:

- facilitate continuous surface water removal
- accommodate bather water displacement
- accommodate backwash water so that surface water removal can continue after a backwash (this is optional).

The balance tank design static water level will be the water level when there are no bathers in the pool; this level should be designed to be as close to the pool design static water level as possible. Small but deep balance tanks should be avoided as they will result in large variations in water level. Also to be avoided are designs where the sumps drain by gravity into the balance tank.

3.1.6 Transfer channel design

The transfer channel should be located immediately above the balance tank, so that water can be transferred between the two. The transfer channel should be no deeper than required to transfer the water to the balance tank.

3.1.7 Pump flooded suction

Main circulating pumps should always have a flooded suction – ie providing a positive hydrostatic head to the suction side of the pump located below static water level. This adds to the atmospheric pressure (equivalent to a 10m head at sea level) that is already pressurising the water supply to the pump. It is this pressure (minus any head loss along the suction pipework) that meets the Net Positive Suction head (NPSH) requirement for the pump to operate without threat of cavitation. Extended diffusers will minimise head loss on the discharge. NPSH is addressed in Appendix 3.

3.1.8 Pump efficiency

Pumps should be selected for overall efficiency; this will depend on an array of factors including the efficiency of the motor, the speed of rotation, the design of the impeller and the housing, the materials used, and the degree of wear. Swimming pool pumps are often required to generate flows of the order of 100-200m^3/h or more, but only against a low hydraulic head, and this can hugely reduce pump efficiency. Most of the pumps in the surveys referred to in 2.1.1 were operating at efficiencies way below 50%, down as low as 20% – whereas modern pumps operating close to their best efficiency point (BEP) can be over 80% efficient. This demonstrates a real conflict of requirements and highlights the challenge for designers to get the optimum design.

If the system requires a head of 10m at the pump discharge to circulate water at the target rate (ie the upper end of the range recommended by Passive House) then the pump will be requiring to deliver 27 Watts of hydraulic power to circulate each m^3/h flow rate. So an overall pump efficiency of 67.5% (including motors and VSDs if present) would be needed to hit the least challenging Passive House target of using no more than 40 Watts of electrical power to circulate each m^3/h of flow. (see Appendix 3, page 28 for the formula.) The combined efficiency of the motors and VSD is typically 87%, so the pump efficiency would have to exceed 77% to meet the target. This is a major challenge, especially given the low head operating conditions that should maintain in an efficient system.

Self-priming pumps should not be used as they are highly inefficient in energy use, with typical efficiency of 50-60%. In any case they are not needed in flooded suction installations.

3.1.9 Pump variable speed drives

Variable speed drives play a key role, primarily in energy efficiency but also in fine tuning of the system flows and plant longevity. For energy efficiency there are very significant benefits to using VSDs to reduce system flow as opposed to using throttling valves. System design should consider the use of VSDs on all centrifugal pumps. See also Appendix 3.

There is more to VSDs than just using them to slow down circulation to save energy. When using multiple pumps operating in parallel at reduced speed to give the target flow rate, the reduced water velocity through the pumps themselves can drastically reduce the NPSH requirement, and can also (but not always) move the pump operating point close to the point of best efficiency. Such impacts of VSDs are very predictable.

3.1.10 Pipework layout

The objective is to have a compact pipework layout, so as to minimise the distance the water has to travel, and hence to minimise the head loss

3.1.11 Pipework velocities

Pumping water through pipework requires energy to overcome the head loss (or pressure drop) due to the friction between the water and the inner surface of the pipework. The head loss is proportional to the velocity of the water squared, so keeping water velocities down is the key to minimising the energy load. The Passive House guidelines propose pipework water velocity of 1-1.3m/s.

3.1.12 Pipework fittings

Every pipework fitting, such as an elbow or a diffuser or a valve, will result in some head loss or pressure drop on the system. So the first consideration is to lay out the pipework in order to minimise the number of fittings. A straight run of pipe is more efficient than one with a number of fittings.

Then where fittings are required, they should be selected for minimum head loss or pressure drop; for example, a mitred 90-degree bend can result in three times more head loss than a long-radius bend. Flow meters should be of the non-intrusive type and valves should be selected with narrower disks.

3.1.13 Filtration

There are three main options for water filtration in the UK – sand/glass, ceramic membrane and regenerative media. While sand is the traditional and most widely used approach, it normally exerts a higher pressure drop on the system than either membrane or regenerative media. For minimum head loss, ceramic membrane and/or regenerative media can be considered.

3.1.14 Filtration backwashing

Backwashing of sand filters requires that water is passed through the sand bed at a minimum velocity in order to fluidise the sand bed. Depending on the filter size, this normally results in a requirement for a large volume of backwash water in a relatively short period of time. This in turn may require larger capacity in the balance tank, and a holding tank for the backwash water going to waste.

Regenerative media does not backwash as such, and requires a much smaller water volume to clean the filter; therefore water replacement and the effect on dilution are lower; additional water will be required for dilution.

Ceramic membrane filters have overall backwash volumes similar to traditional sand, but have mini backwashes several times a day, so do not require much additional capacity in the balance tank, or a holding tank for the backwash water going to waste. These lower infrastructure requirements do not affect the operational energy required, but do reduce the embodied or construction carbon.

3.1.15 UV system
The design of the UV system should take into account:

- correct sizing – if the lamp is undersized it will not treat the water properly; if it is oversized it will waste energy
- lamp to be installed in the main circulation pipework after the filters and prior to the heat exchanger(s), chlorine and acid dosing points
- pipework to the unit to be full bore
- indicators to be provided for power on, lamp ok, UV low
- an automatic system to clean the lamp sleeve(s)
- UV intensity sensors
- stainless steel chamber with Internal surface to be to 0.8Ra
- power switching to the lamp to provide UV dose control at the actual flow rate
- controlled automatic bypassing of the UV system during periods of light use and overnight
- bypass valve, complete with a position indicator that inhibits the operation of the UV system unless the bypass is fully shut.

3.1.16 Backwash water recovery
This is a potentially complex area. The proposed water re-use, the level of treatment and the associated cost will need to be evaluated on each project. The higher level of treatment required if water is to be re-used in the pool may result in capital costs that would render this approach unviable. Uses requiring less treatment will have a higher chance of being used. Interfaces of the system with the rest of the project will need to be addressed – such as drainage and water storage.

3.1.17 Backwash water heat recovery
As with the backwash water recovery system, the key to viability is simplicity. A passive approach using plate heat exchangers and water holding/storage tanks should be considered.

3.1.18 Monitoring, commissioning, measuring, recording
Monitoring of the construction should be done on a regular basis to check that the construction is in accordance with the design for all elements.

The design should incorporate all elements necessary to facilitate measuring of the performance of the system including pressure gauges, flow meters, electricity usage meters, water level indicators, water usage meters and the means for recording the data over time periods, such as a building management system (BMS).

The purpose of commissioning is to check whether the designed functions are working and performing correctly. The design should establish clear commissioning and handover requirements for each part of the system, including monitoring criteria after handover to check that operational design criteria are being met.

3.2 Contractors – new and refurbishment systems

3.2.1 Familiarity with the design

Highly energy-efficient water treatment systems will be a new approach for many pool contractors. It is crucial that the contractor understands the approach being used, the targets and the key roles they have in making the project a success – from design through to monitoring in use.

3.2.2 Completion of the design

Good contractors will have a lot to offer when completing the design for the construction phase of the works. System drawings should be completed in Revit or similar so that all pipes and fittings are detailed in 3D, with full consideration given to optimum routing for all pipe and system elements.

3.2.3 Installation of the design

Once the construction phase drawings are complete, then the installation should be carried out in strict accordance with the drawings, unless specifically agreed otherwise.

During construction, the contractor should facilitate detailed checking of all the system components, so that they can be independently verified as in accordance with the design.

3.2.5 Testing and commissioning

The plant should be properly tested and commissioned. This is a crucial stage in the implementation and should be given ample time and resource. The consultant should have established the main commissioning criteria for the contractor to complete; the contractor may also have their own/additional criteria to address.

Initial monitoring of the system performance and comparison with design energy targets should form part of the testing and commissioning. Ongoing monitoring during operation should be done to assess performance over time.
It is important to note that the three parties involved – designer, contractor and operator – need to prepare well and work together for a satisfactory commissioning.

3.2.6 Training of operatives

The appropriate operation of the system is the final part of the entire process. To facilitate this, a competent operator must be appointed, familiar with the design intent and targets, and they should be trained in the specifics of the system and the role they will play in meeting the performance targets.

3.3 Operators

Once the system is designed, installed, commissioned and handed over, it is then for the operator to ensure the plant meets the water quality performance criteria. Energy efficiency must not be at the expense of water quality. There are certain criteria that must be in place to facilitate this; the operator should:

- be competent to operate the plant
- be trained in the specifics of the plant and in particular the energy efficient aspects
- understand the energy efficiency performance targets
- understand the system design to meet the energy efficiency targets.

Once those criteria are in place, the operator can:

- operate the plant to meet the energy efficiency performance targets, maintaining water quaity
- provide feedback on the monitored performance to the consultant and the contractor
- provide feedback on areas for improvement
- while maintaining water treatment targets, carefully manage circulation with the VSDs, dilution, backwashing intervals and duration, balance tank levels, night-time setback of circulation
- as identified in the Passive House guide, bypass the balance tank in the evening when there are no bathers, to eliminate the static head loss between the pool and the balance tank.

There are many other matters that can be considered for carbon reduction:

- the use of calcium hypochlorite versus sodium hypochlorite or other disinfectants
- the use of sodium hypochlorite in carboys versus bulk
- managing deliveries of chemicals to achieve the optimal balance between amounts delivered, storage capacity and shelf life with the aim of reducing the carbon footprint of transport)
- salt generation of sodium hypochlorite versus bulk
- optimum dilution rates for hydrochloric and sulphuric acid
- backwashing intervals and backwashing on pressure differential rather than weekly; this would require that good quality gauges are used and are well maintained
- greater onus on pre-swim showering and toileting to minimise the pollution load
- effect of UV on chemical usage
- less management of calcium hardness and alkalinity.

3.4 Trainers

Trainers play a number of fundamental roles in the industry:

- providing training on pool water treatment to PWTAG standards
- providing training on system specifics including energy efficiency
- generating feedback on industry good practice throughout the UK and abroad.

3.5 Servicing companies

Water treatment systems require regular maintenance to ensure that they continue to operate in an efficient and effective manner. Servicing companies normally fulfil this role. There should be increased emphasis on ensuring that plant is operating efficiently – for example checking that pump performance is not deteriorating, and checking that there is no significant head loss across post-UV quartz strainers from filter sand that may have passed through the filters.

3.6 Auditors

Independent auditors, normally consultants, can provide a number of services on new and existing systems:

- checking new plant before handover, for installation and commissioning
- checking the operators understand the plant and how to efficiently and effectively operate it
- checking regularly the performance of the system including monitoring of utilities, flow and other data outputs.

Appendix 1

Summary of treatment elements and stakeholder responsibilities

Treatment elements for energy efficiency	Stakeholder responsibilities					
	Client/local auth /enforcing body	Consultant / Designer	Contractor	Operator	Trainer	Maintainer
Design						
Establish energy targets	X	X				
Plant size		X				
Plant location		X				
Balance tank location		X				
Balance tank design		X				
Transfer channel design		X				
Pump flooded suction		X				
Pump diffusers		X				
Pump efficiency		X	X			
Pump variable speed drives		X				
Pipework layout		X	X			
Pipework velocities		X				
Pipework fittings		X	X			
Filtration		X				
UV system design		X				
Backwash water recovery		X				
Backwash water heat recovery		X				
Construction						
Completion of design for construction			X			
Installation of design			X			
Commissioning of design		X	X	X		

Operation						
Operator training			X	X	X	
Operation for energy efficiency			X	X	X	
Night time circulation setback				X		
Strainer cleaning				X		
Backwashing				X		
Dilution				X		
Balance tank bypass				X		
Managing chemical deliveries/storage				X		
Monitoring		X	X	X		
Maintenance						X

Appendix 2

Equivalence of Passive House targets and consistency with PWTAG circulation rate

The Passive House targets are:

- 25-40W per m^3/h of circulating water
- 10-17W per m^2 of pool area in the case of a regular pool with 4.5m^2 per bather at maximum bather number
- 17-29W per m^2 of pool area in the case of a learner pool with 2.7m^2 per bather at maximum bather number.

These area-based targets account for the hydraulic efficiency, but also consideration of the rate of circulation needed to ensure satisfactory water quality.

The equivalence of these targets can be demonstrated by using the idea which underpins the circulation guidelines in the PWTAG Code of Practice that there is a minimum volume of water that needs to be circulated through the filtration system per bather. The figure used by PWTAG is 1.7m^3 per bather. As PWTAG confirms: 'The figure of 1.7 has no theoretical basis; it has been arrived at from good practice over the years'. However, recent research (Reference 6) has now provided a theoretical basis for this figure.

The following steps show how the calculation of the power requirement per unit pool area might be achieved.

- Compute the maximum bather number at any time from the minimum allowable area per bather.
- If the pool is operating continuously at maximum bather number, then the number of swimmers occupying the area of the pool in one hour would be the maximum bather number divided by the average swim time in hours.
- Divide this number by the area of the pool to give the number of swimmers occupying 1m^2 of the pool in 1 hour.
- Multiply this number by 1.7 to give the volume of water (in m^3) that needs to be treated in one hour for each m^2 of pool area to meet the water treatment requirements.
- Multiply this number by the target power required to circulate 1m^3 of water (ie 25-40W per m^3/h) to give the target power requirement per m^2 of pool area.

This worked example uses the PWTAG requirement of 1.7m^3 water per bather, and assumes an average swim time of 54min. It gives calculated power requirements per unit area which are very similar to the ranges quoted in the Passive House Guideline (ie 10-17W/m^2 for the swimmer pool, 17-29 W/m^2 for the learner pool). So there is consistency between the PWTAG circulation requirement and the Passive House energy/power targets on a unit pool area basis.

	Regular pool		***Learner pool***	
Minimum area per bather (m^2)	*4.5*	*4.5*	*2.7*	*2.7*
Pool area (m^2)	*300*	*300*	*80*	*80*
Maximum bather number	*66.7*	*66.7*	*29.6*	*29.6*
Average swim time (h)	*0.9*	*0.9*	*0.9*	*0.9*
Number of bathers per hour	*66.7/0.9=74.1*	*74.1*	*29.6/0.9=32.9*	*32.9*
Number of bathers per hour occupying each m^2	*74.1/300=0.247*	*0.247*	*32.9/80=0.412*	*0.412*
Water treatment requirement per hour for each m^2	*0.247x1.7=0.420*	*0.420*	*0.412x1.7=0.700*	*0.700*
Power target to circulate 1m^3/h (Wh/m^3)	***25***	***40***	***25***	***40***
Power target per m^2 pool area	***25x0.420=10.5***	***16.8***	***17.5***	***28.0***

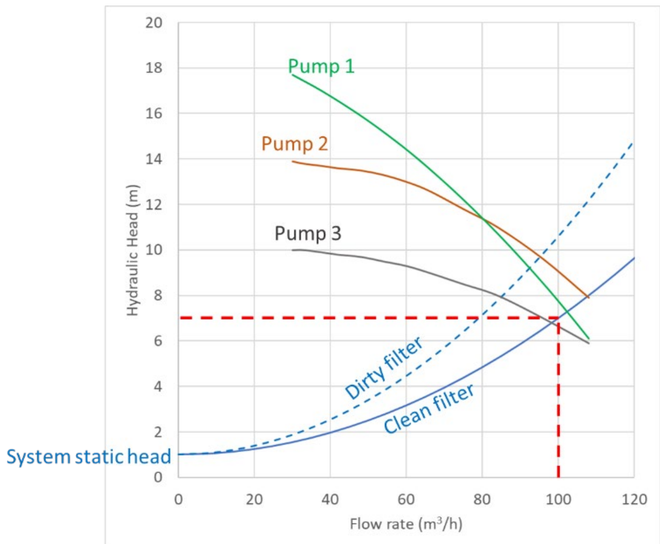
Appendix 3

Pump efficiency and variable speed drives

Pumps convert electrical power into hydraulic power. This appendix discusses the factors that determine the efficiency of this conversion. The guidance from Passive House is that the combined efficiency of the overall system (ie the pump itself, the motor and any variable speed drive) should exceed 70%. There will be some waste of energy (mainly as heat) within the VSDs and motors – where the efficiency of a VSD is typically 95% and an 11kW IE3 motor will have an efficiency of close to 92%. Hence to achieve the target overall efficiency of 70%, the pump itself should be converting 80% of the power of the pump shaft into hydraulic power. This is known as the pump efficiency. Achieving such high pump efficiency presents a considerable challenge.

Pumps vary widely in their efficiency, depending on their design (particularly of the impeller and volute) and construction material. Pump efficiency also depends heavily on the rate of flow being generated by the pump. Pump selection is a critical process in making pool circulation energy-efficient.

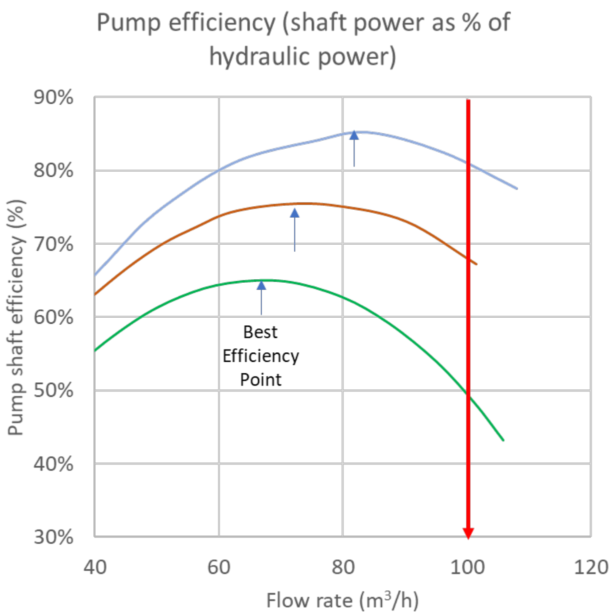
The starting point for pump selection is to know the target flow rate (and the associated hydraulic head requirement). This requires knowledge of the performance of the system with respect to flow and hydraulic head, as shown by the blue lines in the graph below. The solid line is the performance of the system when the filters are clean; the dashed blue line is when the filters are in need of backwashing. A pool with a balance tank will require the pump to generate sufficient head to raise water from the balance tank surface water level to the pool surface water level before water can start to circulate. This is known as the system static head (1m in the example below). The smaller the system static head, the less work the pump will need to do. Once there is sufficient head to generate flow, the upward direction of the head v flow curve is because the frictional resistance (and hence the head requirement) increases with the square of the flow rate.



The graph shows an example of selecting a pump capable of generating a target flow rate of 100m^3/h. This requires a head of 7m at the pump discharge when the filters are clean, as shown by the dashed red line. This is known as the target operating point. The green, brown and grey curves show the pump performance curves for three pumps that might be considered suitable, though they differ in the rate at which the head at the pump discharge decreases as the flow rate increases. In each case the actual operating point that would be achieved is where the system and pump curves intersect. So the green and grey pumps would be very close to the target operating point. The brown pump curve would slightly over-deliver, but could be matched to the desired operating point using a VSD to slow the pump down.

Note that when the filter gets dirty, each pump's flow reduces as the hydraulic head at the intersection point rises. But the magnitude of the drop in flow when the filter is dirty depends on the shape of the pump curve. This is a second factor to take into account in pump selection.

Though these three pumps can deliver the flow and head requirements needed, the graph below shows that they are very different in terms of pump efficiency – an important factor in pump selection.



The pump efficiency varies with flow rate, and is at the best efficiency point (BEP) somewhere in the middle of the range of flow rate the pump is designed to deliver. There are many reasons why the efficiency drops off either side of the BEP, mostly related directly or indirectly to turbulence and vibration. Operating close to the BEP is good for pump efficiency, but also for the longevity of the pump.

One conundrum in trying to minimise the energy requirement for pool water circulation is that pool circulation systems require pumps that can deliver a high flow rate at low head. One way to cut the energy cost of circulation is to reduce the head further still, but this is likely to reduce pump efficiency.

Of particular concern is that a pump circulating water at a rate approaching its maximum flow rate causes cavitation, which is particularly damaging and drastically reduces pump efficiency. For this reason, the pump curves published by the manufacturer go up only to a flow rate that they consider to be its maximum. This maximum 'permissible' flow rate (and the associated minimum permissible hydraulic head) is known as the run-out point. As the graph above shows, making water flow more easily around the system can reduce the pump efficiency, and possibly exceeding the run-out point.

In swimming pool applications there is usually little by way of hydrostatic head to overcome in order to circulate water, and the frictional head loss is also low. The consequence is often that circulation pumps are running beyond their run-out point, with the risk of cavitation. This may partly explain why pool circulation pumps at some sites frequently need repair or replacement, and why there is excessive energy consumption at some sites.

CAVITATION AND THE IMPORTANCE OF GOOD PUMP WATER SUPPLY

The lowest water pressure in the circulation system is at the point where the water enters the suction side of the pump impellor. Cavitation happens when the water pressure in the eye of the impellor falls below the vapour pressure of water. Under such conditions the water effectively boils, with the creation of coalescing bubbles of water vapour. These can obstruct the flow of liquid water, reducing the pump efficiency. Perhaps more important, vapour bubbles clinging to the impellor will implode violently when pressurised, causing large erosion cavities in the impeller that can drastically affect pump performance. One of the symptoms of cavitation is a gravelly noise. The photo below shows the damage that can be caused by cavitation.

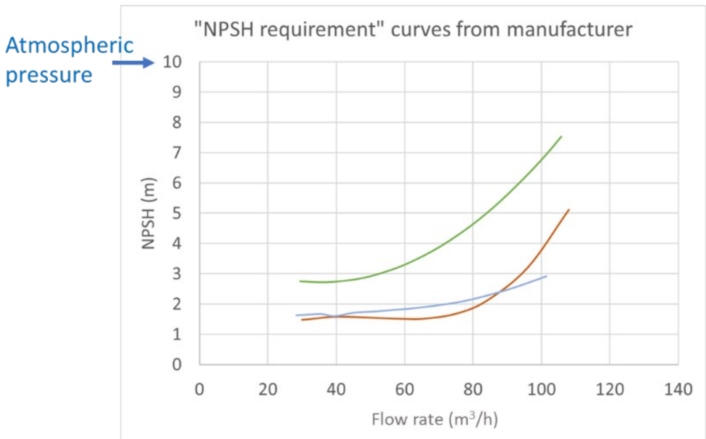
The key to avoiding cavitation is to ensure that the pressure in the eye of the impellor is always above the water vapour pressure – preferably by some margin. This depends **first** on the pressure of water as it enters the pump inlet, and **second** on the pressure drop within the pump itself.

1 The pressure of the water as it enters the pump depends primarily on the elevation of the water source relative to the pump inlet (ie the hydrostatic head of the water source, which can be negative if the pump is mounted at deck level, pulling water up from a balance tank) and the head loss due to friction across the suction pipework between the source water and the pump inlet. It is useful to express the pressure of water as it enters the pump inlet in terms of the amount this pressure exceeds the vapour pressure. This quantity is the net positive suction head *available* (NPSHA).

2 The drop in hydraulic head of water within the pump as water moves from the pump inlet to the eye of the impellor where the hydraulic head will be at its lowest is the net positive suction head *required* (NPSHR).

To avoid cavitation, inefficient pumping and premature pump failure, a minimum guideline suggested (there are others) is that the NPSHA at fastest design flow rate is 10% greater than NPSHR. So an important aim in pool design is to maximise the NPSHA by lowering the elevation of the pump(s) relative to the water level of the source water and minimising the frictional resistance in the supply pipework and fittings. The latter includes ensuring sites of potential clogging like non-return valves and strainers are clear and routinely checked. Having maximised NPSHA, appropriate pumps should be selected and laminar flow into the pumps ensured as far as possible, with at least 10 pipe diameters length of straight pipe, and streamlined reducers.

As with other aspects of pump performance, pumps vary widely in their NPSH requirements, as shown in the graph below for the same three pumps considered in the graphs above. In particular, the green pump – which at the target flow of 100m^3/h has an NPSH requirement of 7m – contrasts with 4m or less for the other two pumps. If the pump is located 1m below the source water, this would give an absolute pressure (ie adding in atmospheric pressure) of 11m. There would then be a loss of head due to frictional resistance along the suction pipework which could reduce the pressure of water at the pump inlet to the point where cavitation and very low pump efficiency is likely to be a threat.



QUANTITATIVE ANALYSIS OF THE FACTORS AFFECTING ENERGY COSTS

An analysis of the factors that affect the Watts of electrical power consumed per m^3/h of circulation (which is the key performance indicator for the Passive House guidelines for pools[3]) provides the following equation:

$$\text{Watts per unit flow rate} = \frac{2.725\ \text{H}}{\text{E}}$$

– where the unit flow rate is in m^3/h, H is the hydraulic head added to the pool water as it leaves the pump discharge (in metres) and E is the overall efficiency of the

VSD/motor/pump system (expressed as a fraction). So, in a system where the H is 8m and the overall efficiency is 0.7, the W per m^3/h will be 2.725 x 8 / 0.7 = 31.1W per m^3/h, which is well within the Passive House guidelines (no more than 25-40 W per m^3/h of flow). Note that the lower the value of H (or the higher the value of E), the lower the amount of electrical energy that is used to circulate water. The aim should therefore be to minimise H and maximise E, consistent with operating pumps within their comfort zone (and avoiding cavitation).

Table 1 Values for W (W per m^3/h) for various combinations of hydraulic head (H) and pump efficiency. Numbers in red exceed the Passive House target. Values in green are more efficient than the most ambitious Passive House target of <25 W per m^3/h.

	Overall efficiency				
	0.2	0.4	0.6	0.8	1
H (m)					
4	55	27	18	14	11
6	82	41	27	20	16
8	109	55	36	27	22
10	136	68	45	34	27
12	164	82	55	41	33
14	191	95	64	48	38

The table shows that if the hydraulic head being added by the pump is 10m (a readily achievable value for a typical pool), then the overall efficiency would have to be approaching 0.8 (ie 80% conversion of electrical power into hydraulic power) in order to meet the Passive House target for the power requirement for circulation of 40W per m^3/h.

This presents a challenge for pump engineers: to design and provide pumps that can provide the required flow rates at very low hydraulic heads associated with pools, as discussed above.

There may well be a role in this for variable speed drives and for considering parallel pumping where the flow rate can be shared between multiple pumps. This is because most pool pumps will be operating well to the right of the BEP, resulting in loss of pump efficiency due to the very rapid flow of water through the pump. Parallel pumping provides a way of reducing the flow through each pump, and thereby raising the pump efficiency while delivering the same overall flow rate.

VARIABLE SPEED DRIVES (VSDs)

Variable speed drives provide a means of reducing the AC frequency supplied to the pump below the 50Hz that is the mains frequency in the UK. This reduces the shaft speed of the pump. Provided the pumps are operating well away from the risk of cavitation, and that the head requirement for flow is dominated by frictional resistance (ie low system static head) then the affinity laws state that:

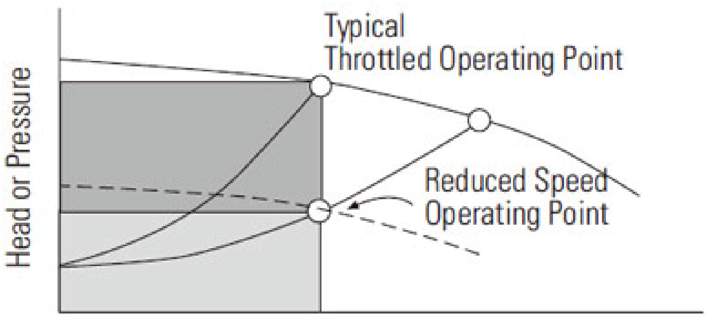
- flow is proportional to shaft speed (and to operating frequency)
- the head added to the water is proportional to the square of the shaft speed
- the power is proportional to the cube of shaft speed

ENERGY SAVING

This immediately gives the first obvious application of VSDs as it suggests that if you reduce the shaft speed to 80% then you reduce the flow rate to 80%, but reduce the energy consumption to 80% x 80% x 80% = 51%. This is why, for example, small night-time reductions in pump speed can give large energy savings. At 60% speed there would be only 22% of the power consumption.

Enhanced system control is the second reason. VSDs are able to fine tune and make small corrections to a system's operation with a greater deal of accuracy than throttling valves. One example was evident in the first graph in this appendix: pump selection may give a pump that slightly over-delivers the required flow rate, and so slightly slowing the pump down could give the flow required and save energy in the process.

There may be good reason to operate at lower flow rate than would be delivered by the pump operating at full speed. This could be done by throttling a valve on the discharge side of the pump, but that would raise the head requirement and in doing so raise the hydraulic power that the pump needs to deliver. There might be a slight improvement in pump efficiency if the flow through the pump is reduced, but this will not compensate for the extra hydraulic power being delivered. One reason for throttling the pump discharge is if the pump is operating close to cavitation. Achieving the same reduction in flow rate using a VSD would reduce energy consumption.



The effect of throttling valves on required operational power

VSDS AND NPSH REQUIREMENT

There is a third area where VSDs can be very useful. Because the NPSH requirement of a pump depends on the frictional resistance within the pump, reducing the rate of flow through the pump can have a disproportionate effect on the NPSH requirement, as shown in the NPSH curves above. For example, the green pump shown in the earlier figure has an NPSH requirement of 7m at 100m^3/h, but falls to 3m at 50m^3/h. So operating two of these pumps in parallel to deliver the target flow of 100m^3/h would reduce substantially the risk of cavitation for the green pump. There would be much less benefit for the grey pump, demonstrating the need to have a good understanding of the whole system when assessing the benefit of VSDs.

PARALLEL PUMPING

Parallel pumping (ie using two or more pumps to share the flow rate) through using VSDs to obtain the required combined flow delivery may or may not have other benefits. For example, the earlier graph of the impact of flow rate on pump efficiency shows that operating the green pump at $100m^3/h$ gives a pump efficiency of 50%. Sharing this flow between two pumps would raise this efficiency to 65% (ie a 30% improvement) if the flow through each pump was reduced to $50m^3/h$. By contrast, the same operation of the grey pump would move the operating point to the left of the BEP, such that parallel pumping would result in a slight *loss* of efficiency. This once again demonstrates the difficulty with making general statements about whether or not a given strategy is beneficial. Each case needs examining on its merits through good understanding of how pumps and systems interact.

Improved system longevity and reliability is a major advantage offered by VSDs. Operating a pump unit at lower speed has the potential to enhance the pump longevity and useful life through the reduction of wear, such as the bearing and seals. And a VSD allows for soft starting, which reduces the initial current load and torsional forces and reduces power surges in start-up; this can be extended to soft stopping capabilities as well to reduce hydraulic shock.

Note

Some of the material in this Appendix derives from an EU-funded project with Bangor University – *Distributing our Water Resources: Utilising Integrated, Smart and low-Carbon Energy*; and also collaboration with Loughborough University.

Appendix 4

Volume of water to be treated to maintain acceptable water clarity

What circulation rate is required to maintain turbidity below 0.5NTU even during prolonged periods where the bather load is at the maximum limit for the pool?

To answer this question, assume that as bathers continue to use the pool the turbidity will rise, and as the NTU value rises so will the rate it is removed because the water being delivered to the filters is dirtier. Eventually the turbidity will rise to some plateau value where the rate of **input** of turbidity forming material equals the rate of **removal**. This is referred to as the **equilibrium** state.

The **input** is the product of:

- the number of bathers per hour (B, in units of /h)
- the average amount of turbidity-forming material added by a single bather (K, in units of NTUm^3) – ie the rise in NTU if this amount of turbidity-forming material is added to 1m^3 of water.

The **removal** is the product of:

- the rate of flow of water into the filters (Q, in units of m^3/h)
- the turbidity of the water delivered to the filters (which after a prolonged period of peak bathing load will be the equilibrium concentration C_{eq}, in units of NTU)
- the fraction of turbidity that is removed from water in a single pass through the filter (the removal efficiency E_{filter}).

At **equilibrium** (ie after operating for many turnover periods at maximum bathing load) the removal will equal the input so:

$$B\,K \;=\; Q\,C_{eq}\,E_{filter}$$

It is necessary to establish the amount of water that needs to be treated per bather to guarantee the NTU stays below 0.5NTU even at prolonged peak bathing load. With effective filtration, the filter removal efficiency should be at least 0.9 (90% removal). The value of K for fairly dirty bathers is around 0.7NTUm^3, so the equation above can be rearranged to show that the amount of water required to be treated per bather (ie Q/B) is:

$$\frac{Q}{B} = \frac{K}{C_{eq}E_{filter}} = \frac{0.7}{0.5*0.9} = 1.55\text{m}^3\,per\ bather$$

The PWTAG guideline of 1.7m^3 per bather corresponds approximately to a filter removal efficiency of 80%. This guideline errs on the side of caution for several reasons.

- It will take several water turnovers for this equilibrium state to be approached.
- The turbidity of the water delivered to the filters is likely to be higher than the whole pool average, especially in a deck-level pool with most water coming from surface draw off.
- Even if a pool is circulating water at 1.7m^3 per bather on average, there may be areas of the pool where the local circulation is less than this.

It is reasonable to conclude that an appropriate circulation guideline is that 1.7m^3 of water should be filtered per bather in order to maintain the pool water at <0.5 NTU (even if the maximum bathing load is maintained for long periods of time).

One note of caution is that in cases where there are multiple water bodies served by the same circulation system, it is necessary to ensure so far as possible that the water requirement of 1.7m^3 per bather is satisfied for *each* water body, as well as when averaged over the whole pool.

Appendix 5

TDS and water dilution

The principal source of TDS is the chemicals introduced as part of the water treatment process, and the products of resulting chemical reactions. Empirical rules of thumb can be established between the input of TDS and the amount of chlorine added (in terms of *chlorine equivalents* to facilitate conversions between different chlorine donors). These empirical values are obtained from readily available information of the weekly input of chlorine, and the weekly removal of TDS. (This is calculated as the product of the pool TDS and the volume of water dumped to waste each week in backwashing/dilution and any other routes such as controller sample water running to waste.)

A useful starting point is to consider how much water needs to be dumped per bather to remove the amount of TDS a bather adds to the pool on average through the chlorine consumption they generate in the water. Values for the chlorine use per bather can vary widely, from 2 to 9g chlorine equivalent per bather per hour (typical values being 4-5g per bather per hour in a leisure pool, and the high end of this range in a spa due principally to the greater input of sweat).

The input of TDS this equates to will vary with the chlorine donor, being higher for sodium hypochlorite than calcium hypochlorite, and higher still when sodium hypochlorite is generated by on-site electrolysis of sodium chloride, where there is inevitably some addition of brine to the pool. Examples of the range of values determined empirically for the weight of salts added from all sources per unit weight of chlorine equivalent used are shown in the table below.

Chlorine donor	g TDS added per g chlorine equivalent
Calcium hypochlorite	0.8-1.2
Sodium hypochlorite	2-2.5
Salt generation	3-5

The PWTAG guideline is that the TDS should not exceed the TDS of the incoming mains by more than 1000mg/l. At this concentration, the net dumping of TDS (difference between what comes into the pool as fresh water and what leaves the pool as dumped water) will equate to 1000mg of TDS removed for every litre of water dumped to waste.

Worked example
Calculating the water requirement per bather for TDS control
Consider the case of an average bather generating an input of 5g (5,000mg) of chlorine equivalent during a one-hour swim in a pool using sodium hypochlorite. In this case 2g of TDS is added per g of chlorine equivalent dosed and the TDS addition per bather is 5000mg x 2 = 10,000mg. If the water being dumped in backwashing or other dilution activities is removing 1000mg TDS per litre, then 10 litres of water will be required to remove the TDS added by the average bather.

The table below shows the dilution requirement (litres of water per bather) for other combinations of the chlorine use per bather and the weight of salts added per unit weight of chlorine dosed.

	g TDS/g Cl equivalent				
Chlorine equivalent use per bather during a swim (g)	**1**	**2**	**3**	**4**	**5**
2	2	4	6	8	10
5	5	10	15	20	25
10	10	20	30	40	50
15	15	30	45	60	75

This table suggests that the current guideline to ensure 30 litres of dilution per bather (and preferably more) is more than is necessary in many pools to ensure adequate TDS control. Indeed, some pools do not find it necessary to carry out the extra dilution over that done by backwashing to achieve the required dilution for TDS control; regular calibration of TDS meters is important.

In conclusion, there is scope for optimising the requirement of water dumping for the purpose of TDS control from simple consideration of the salt balance of the pool, and allowing the TDS to rise to an equilibrium value at the upper end of the acceptable range. However, it should be noted that there may be other considerations that will require more water to dumped than this.

Consideration should also be given to what might be done to reduce the accumulation of TDS in the pool. This might include:

- improving pre-swim hygiene to reduce the chlorine demand per bather
- the use of alternative supplementary oxidisers as well as a chlorine donor.

References

1 Swimming Pool Water: treatment and quality standards for pools and spas, Pool Water Treatment Advisory Group (PWTAG) 2017

2 Net Zero Carbon Buildings: A Framework Definition, UK Green Building Council (UKGBC),

3 LETI Climate Emergency Design Guide, London Energy Transformation Initiative (LETI)

4 The 2019 State of the UK Swimming Industry Report

5 Guidelines: Passive House concept for indoor swimming pools, Passive House

6 Revisiting the Gage-Bidwell Law of Dilution in relation to the effectiveness of swimming pool filtration and the risk to swimming pool users from Cryptosporidium, Lester P. Simmonds, Guy E. Simmonds, Martin Wood, Tim I. Marjoribanks and James E. Amburgey. Water 2021, 13(17); https://doi.org/10.3390/w13172350

7 BS 8525:2010 Grey water systems

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