Biological Water Purification for indoor swimming pools

towards chlorine-free swimming

- June 30th 2014 -

By Justin Djin Liem,
student number 1373501
j.d.liem@student.tudelft.nl

Biological Water Purification for indoor swimming pools

towards chlorine-free swimming

By Justin Djin Liem, student number 133501 | j.d.liem@student.tudelft.nl | June 9th 2014

Abstract

This paper is a research for the implementation of water efficient water treatment systems for a spa-complex or swimming pool. The use of biological water treatment systems for public outdoor pools is increasing, mainly in Germany, Swiss and Austria. The pools, called Natural Swimming Pools (NSP), do use less installations and most important no chlorine is used in the pools. With a research for the methods of biological water treatment and research for the implementation of biological water treatment for indoor pools in the Netherlands this research is a tool or handbook for the design of this new typology of spa-complexes.

keywords: biological water purification, natural swimming pools

1. Introduction

A lot of swimming pools are about to be closed due to several problems. Energy costs are from big importance for that. For this reason less heating costs, less chlorine, better temperature savings and less maintenance costs have to be researched. [18] Swimming pools have a year round very high energy demand which results behind loaning costs for the most costs of swimming pools. This is caused by the required amount of heat for heating the air and the pool water and also for the ventilation of the swimming hall. This high energy costs are also the reason for many public swimming pools to be on the verge of closing. Another problem is not only a problem for swimming pools, but is more a problem for the environment and for the visitors. The use of chlorine for the disinfection of swimming pool water can lead to serious health issues.

In Germany, Austria and Swiss Natural Swimming Pools (NSP) are more and more popular, both for public use and for private use. [21] Short investigation showed that all these NSPs are outdoor, except a few private pools. These NSPs don't use any chlorine for the treatment of the water for swimming pools. They only use biological water treatment methods and no chlorine. These NSPs also use less installations and less water needs to be pumped due to the lower circulation rate of NSPs.

The FLL- guideline from Germany is now the only guideline which now is used for the making of (private & public) NSPs. In the Netherlands, NSPs are not possible with the nowadays regulations, because according the regulations every circulation pool (not surface water) have to have a certain amount of chlorine in the swimming water for disinfection. What says nothing about the quality of water in fact. But the industry association VGH is now trying to implement these FLL-guideline in the Dutch swimming water regulations. This could mean that the awareness of the possibility for chlorine-free swimming will increase and that NSPs are also allowed in the Netherlands for public use. [21]

The knowledge of natural swimming pools is increasing and this knowledge is also necessary to reduce the costs and the chemical use in swimming pools. Chlorine-free swimming pools are the future, both for the visitors in terms of comfort (no irritated eyes) and for the swimming pools, because the lower costs for the swimming pools.

This research paper will focus on the implementation of biological water treatment methods in public indoor pools to reduce the chlorine, energy and water use. The research question is: How can we implement biological water purification in public indoor pools to reduce water and energy use and to exclude the use of chlorine?

The result will be a comparison with conventional pools in the energy and water use and also some guidelines for spatial implementation.

1.1 Methods

This research will start with first a preliminary literature study on the process of biological water purification and a investigation on the parameters for indoor pools by a reference study. Second, used methods and systems are investigated for the biological water purification process. And third, a research will be done on conventional swimming pools to investigate the climate within a swimming pool and the water and energy demand. This will be compared with a design proposal of a system for a indoor public NSP.

For the comparison and calculation of systems some design parameteres are by forehand decided in order to compare the different systems. For the implementation of biological water purifcation the swimming pool is 200m^2 (360m^3) and designed for 80 persons per day. The design location is in the province Zeeland in the Netherlands, where is a temperate humid climate.

Because the FLL-guidelines in other countries are used in regulations, for this research also these guidelines will be used as guideline. It must be said that these FLL-guidelines are made for outdoor pools. Indoor pools are not mentioned in these regulations. To limit the amount of parameters for this research, the focus will lie on the removal of phosphorus (TP) and E.coli. The particals are also in the FLL-guidelines mentioned as important factors for the design of NSPs.

Fig. 1: Natural Swimming Pool by Biotop [12]

1.2 Background:

Natural Swimming Pools (NSPs)

Natural Swimming Pools do use biological water purification for the treatment of water. Depending on the occupancy, space and quality of the water, natural swimming pools can be categorized into 5 categories. In the most simple situation (1), no technical installations are needed. Nature does all the work. In the most advanced category (5), less area is needed for the purification of water, but more advanced installation are needed to quarantie the quality. The installation which could be used for the improvement of the water purification are pumps to improve and control the circulation of water, filters for the improvement of purification and possible desinfection installations. [11]

Biological Water Purification

The biological water purification process is a chemical free process. It's "based on the natural role of bacteria to close the elemental cycles (e.g. Carbons, Nitrogen, Phosphorus) on earth." [2] Nutrients which are normally removed with water purification and which are important for the quality of water include Phosphates, Nitrogen and bacteria like E. coli and Legionella. Because some nutrients are soluble, separation with solid-liquid methods are not sufficient enough. The removal of phosphorus and nitrogen (responsible for the creation of algae) is for that reason important for the design of the water treatment. [2] The removal of nitrogen and phosphorus is a biological process and is mainly the third phase of treatment. In the secondary phase, which is also biological, the organic material is degraded.

Bacteria like E. coli and Legionella are crucial for the safety of the water, they are the cause of many diseases in swimming pools. Disinfection in the last phase of the treatment process is needed to remove these bacteria. tion.

Table 2 in the appendix shows the different methods for the removal of the different materials and particals.

Guidelines & restrictions

In NSPs in the basis only helophytes were used for the treatment of the swimming pool water. The FLL-guideline explaines the outdoor pools with biological water purification as "artificially created ecosystems in which the conditions of natural bodies of water are to be reproduced. " However also additional installation are possible to improve the NSPs.

The FLL-guideline has included a list with parameters for the right water quality. (see Table 1) The parameters are subdivided into physical, chemical, biological and sanitary-microbiological parameters. According the guidelines, both rainwater as drinking water can be used to fill-up the water.

For every guest the guideline mentions an addition of 74mg total phosphorus per guest and for E.coli 120.000 cfu per guest. The maximimum in NSPs is 100cfu/100ml, but for the design 50cfu/100ml should be used as basis. [11]

Indoor Natural Swimming Pools (reference study)

A reference study (see appendix) on natural indoor pools proved that natural indoor pools are possible. Natural indoor pools are rare and except one, only for private use. Because public natural pools, and natural pools in general are more developed in Swiss, Germany and Austria, the indoor pools probably also found only in those countries.

In all the indoor pools additional filters were used for the removal of phosphorus.The use of helophyte filters was used in most cases for the estheatics.

Nevertheless, in the only public indoor pool, the role of helophyte filters is more important than in the other pools, where mostly bio filters are used. For the use of helophyte filters, the indoor conditions are very important, in terms of temperature and light. They should create the right environment for the plants. For this pool, what had to be a subtropic pool, the

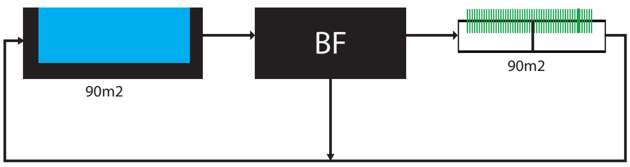


Fig. 2: Scheme of indoor public NSP [own illustration]

Parameters	Values
pH value	6.0-9.0
Acid capacity $K_{S\,4,3}$	$\geq$ 2 mmol/l
Total phosphorus	$\leq$ 0.01 mg/l P *
Conductivity	$\leq$ 1000 µS/cm at 20 °C **
Nitrate	< 50.0 mg/l
Ammonium	< 0.5 mg/l
Iron	< 0.2 mg/l
Manganese	< 0.05 mg/l
Hardness	> 1mmol/l

Table 1: Chemical parameters for fill-up water in public pools. [11]

Fig. 3: Indoor 'Schimmteich' with wetland and additional artificial lighting. (source)

plants were from different continents. Probably to fit the subtropic indoor environment. This resulted in additional energy use for the artifical lighting, needed for 12 hours of light a day.

One of the pools was using a reverse osmosis system (RO). Which filtrated all the nutrients. The choice for this system is striking, the energy use for RO was very high. This is may due to the fact that this pool was designed for private use.

The reference study learned that additional phosphorus removal in indoor pools is always needed and that wetlands are not necessary. The choice of the plants for indoor swimming pools are different because of the different indoor circumstances. A well balanced climate with temperature, lighting and ratio between plants, filters, pumps and swimming area is important for a sufficient indoor NSP.

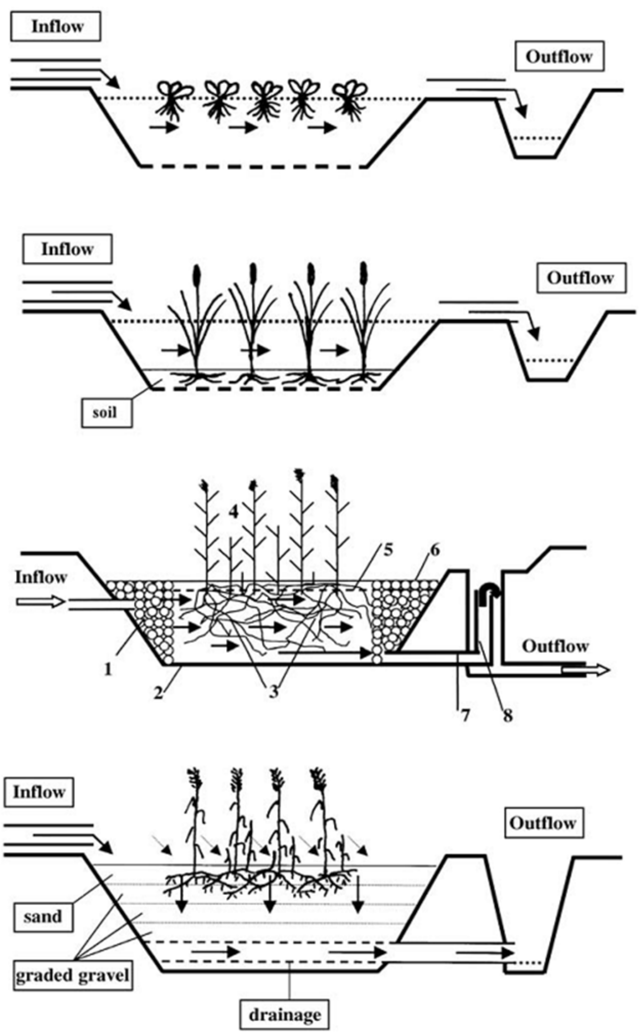


Fig. 5: Constructed wetlands for wastewater treatment (from top to bottom): CW with free-floating plants (FFP), CW with free water surface and emergent macrophytes (FWS), CW with horizontal sub-surface flow (HSSF, HF), CW with vertical sub-surface flow (VSSF, VF)" [5]

2. Biological water purification systems & methods

The biological water purification is possible with diffent systems. In this chapter these systems will be described and analyzed. First constructed wetlands will be described, these are often used for the purification of ponds and pools and are a simple solution for the purification. Second, Bio-filters will be described. These Bio-filters are more and more used as substitute for constructed wetlands or as additional improvement. As third will be described the disinfection methods. WIth all this information, the chapter will be the handbook for the next chapter. Last will be described the so called 'Living Machines'. These small scale water treatment systems are a combination of different methods and are infact a small scale water treatment system.

2.1 Constructed wetlands

The biological water purification in swimming pools has started from the principle of helophytes. In nature, the so called natural wetlands have these helophyte plants located in the soil with a low water surface above the soil.

Typologies

To increase the efficiency of the wetlands, different adjustments could be made to the wetlands. These wetlands could be divided into subsurface flow wetlands (SSF)and free water surface wetlands (FWS). [4] In SSF-wetlands the water flows below the roots of the plants. Because there is more contact between the medium, bacteria and the plant roots and the water, the efficiency of the wetland increases. SSF-wetlands can also be designed in two ways. With the horizontal SSF the water flows horizontal through the soil, in vertical SSF wetlands the water begins at the surface above and flows vertical along the roots. [5]

Improving the SSF wetland is still possible with the addition of oxygen (aeration). These type of wetlands are then called aerated (SSF) wetlands. The addition of oxygen will result i a small increase of the energy use. [19] The energy use is around 0,19 kWh/m^3, while for a normal wetland 0,12-0,13 kWh/m^3 is needed. [1]

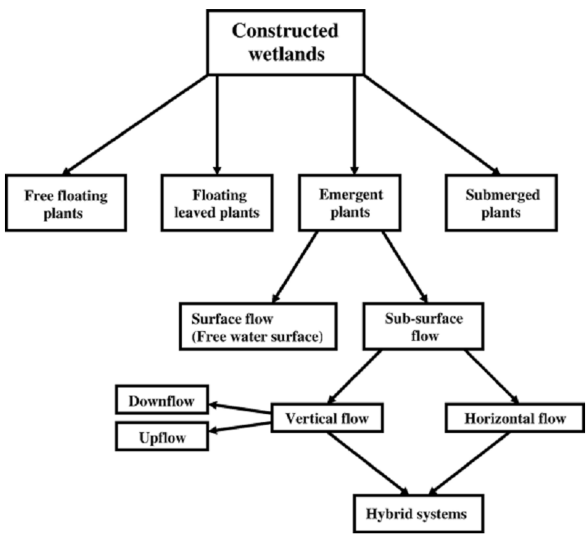


Fig. 4: Different types of constructed wetland [5]

Research for the removal of E.coli with constructed wetlands showed that aerated and H-SSF wetlands were better in the removal of E.coli than non-aerated and V-SSF wetlands. [15]

Other research proved however that the V-SSF and H-SSF helophyte filters do have different impacts on the nitrification process, BOD removal and suspended solids removal. In fact they complement eachother and the hybrid system with both V-SSF and H-SSF wetlands behind eachother seems to be the best treatment. [16]

Substrate

Further improvements for the removal of Phosphorus can be done with the right material in the substrate. The substrate is the part below the helophyte plants. Materials for the substrate are normally sand, gravel or crushed rocks (lava).

For the removal of phosphorus sand combined with 10% iron oxide was appropriate to reduce the phosphorus (TP) in the water. With an input of 0,5mg P/l a reduction to 0,1-0,2 could be reached with a flow of 0,1m3m-2d-2. [22]

Others materials like zeolite, which also will be discussed in the next chapter about filters, and Bauxite are good materials for the removal of Nitrogen and Phosphorus. Zeolite has higher removal rated for organic matter and nitrogen and Bauxite has higher efficiencies for phosphorus. A mixture of both zeolite and bauxite is the best, but is not adviced for the use as substrate for V-SSF. Probably due to the too short time of contact between the waste water and the material. A seperated use is preferred. [9]

The removal of phosphorus is low in all sorts of wetlands. Only with special substrates higher removal loads are reached. Better performances are measured for the removal of nitrogen. While the removal of N is in most cases between 250-630g/m2/year, the removal of P is between 45-75g/m2/year. [5]

Plants

The removal of the nutrients is also dependant on the species of plants. While for phosphorus the soil is from big importance on the removal of phosphorus, for nitrogen the plants are the most important. See Table 2 in the the appendix. With the selection of plants phosphorus uptake could be increased to 66 and at least 173 mg P/m2/d with the use of Canna Lily and Pontederia cordata plants. [10] Several websites about ponds however suggest to varie the plants, because the plants performance depends on for example the flowrate, the amount of waste in the stream, the substrate material, the temperature, and the light conditions. The Canna Lily is a plant for example that comes from the tropics but which is also able to survive in temperate climates, when they have at least 6 - 8 hours of light. [23]

Because there is a big variety in plants, but a selected group which is suitable for the right conditions, it is very hard now to select the right plants. Further advice by a gardener is needed, but the research and the reference study showed already that it is possible to find the right plants.

Spatial

The demanded area for wetlands is least with the use of hybrid wetlands, when the efficiency of the wetlands are increased. Based on several researches for outdoor wetlands the area for the use of only wetlands is. Still for indoor wetlands it is more hard to define the right criteria, because of the different use and conditions.

For the reduce of energy for pumping, the use of gravity is possible to create a water flow. The water brought to the beginning of the wetland, from where it will flow through the different wetlands. In this way, pumping the water have to be done only in the first stage.

Conclusion

For the removal of phosphorus, the constructed wetlands are best designed with a hybrid system, using horizontal and vertical flow wetlands. The wetlands do need a substrate made of sand with 10% iron ions . Additional Zeolite filters for the removal of phosphorus is better to make seperately from the wetland as pollishing method.

For the wetland itself it is the best to make a hybrid system, which could purify the water the best. The best plants for this system depends on the conditions, but with a wide variety of plants there is proven to be already enought good plants for the removal of phosphorus.

Which is possibly due to the high occupation. With the use of gravity for the wetlands, energy and space could be reduced.

Fig. 6: Some possible plant species

2.2 Phosphorus filters

The increasing demand for biological water treatment systems has resulted in developments to reduce the size of the area required, to make the process less dependant on plants and climate and to increase the water quality and specially the amount of phosphorus in the pools.

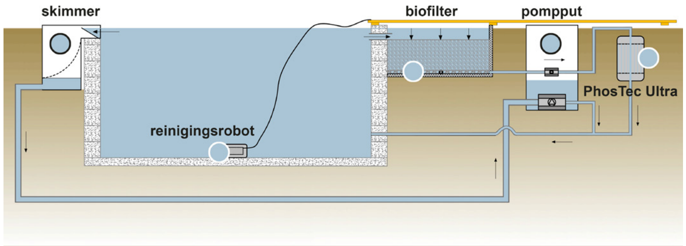


Fig. 7: Phostec Ultra

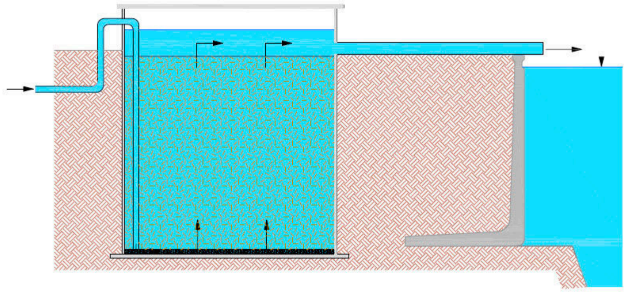


Fig. 8: Biofilter?

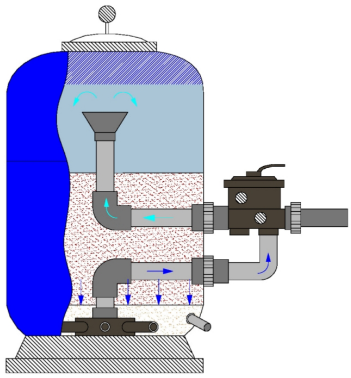


Fig. 9: Biofilter Phostec Ultra

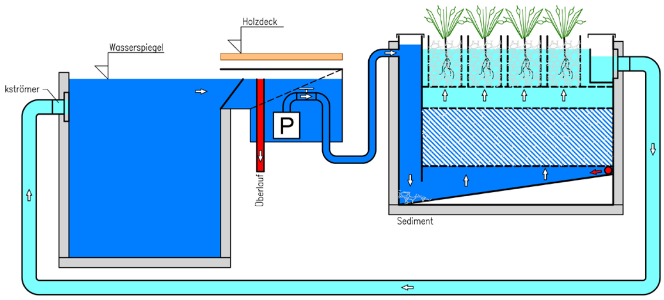


Fig. 10: Biofermenta filter [14]

Adsorption with Zeolite

Zeolite is one of the materials which is often used for the adsorption of phosphorus. Not only phosphorus, but also ureum and ammonia will be removed by adsorption into the material. These materials are not yet implemented in conventional public swimming pools. But for natural pools, ponds and aquariums they already in use.

There are several products on the market now for the reduction of phosphorus: by Biotop (Phostec Ultra) and Biofermenta (Cartridge filter and fluid bed filter). With these products the phosphorus removal can improve with the use of for example Zeolite.

Cartridge filter (Biofermenta)

Biofermenta makes a cartridge filter. With this filter the sorption material can be replaced in a few minutes. It is said that for 100m3 of swimming water, 1m2 of filter material is needed. In private swimming pools, the cartridge should be replaced yearly. In the first pool made by CWR, 4 of these cartridge filters were used. CWR now claimes the cartridge filters to be expensive in use. [14]

Fluid bed filter (Biofermenta)

Another filter by Biofermenta is with a fluid bed, like a substrate below the plants. Here with an area of 8m2 and 4m3 can take up 0,2 gr/h P in continious use with a flow of 10m3 per hour. This filter can be combines with a constructed wetland, where it works as filter material underneath the helophytes. [14]

Backflush filter: Phostec Ultra (Biotop)

In other filters for the removal of phosphorus, no cartridges are needed. The material could be replaced easy because of the design. The design of this filter makes it possible to backflush the material in the filter. With the backflush the materials filtered and saturated in the filter are then flushed away with a stream in the opposite direction. [12]

Comparison

About the performance of the different filters is not a lot of information available. The comparison for that reason could for that reason only argument the different spatial solutions. In that case the different should be made for the integral solution with a fluid bed filter or a seperated filter. When there is an intensive use for the pool for public use, a seperated filter seems a logic choice to refresh the filter material regularly. For private pools the filter materials seems to be replaced yearly, depending on the use. For public pools this may be several times a year.

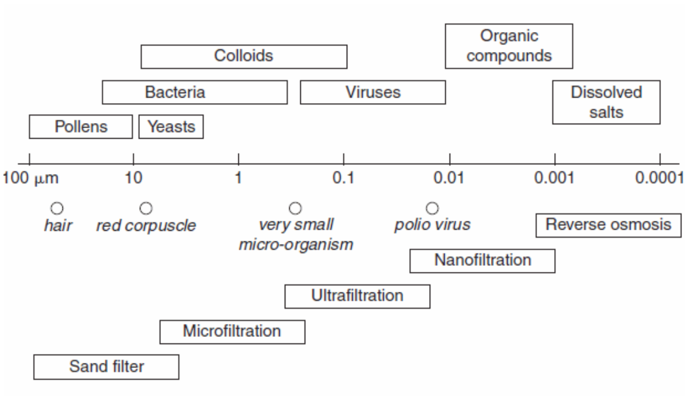


Fig. 11: different filtration methods. [26]

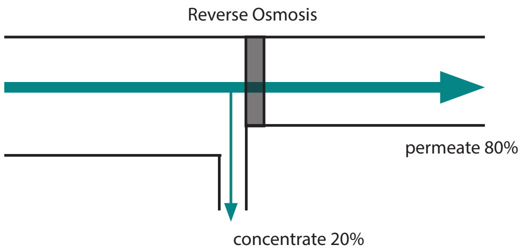


Fig. 12: waterflow in reverse osmosis system [own illustration]

2.3 Desinfection

The disinfection of the swimming water seems to be not only possible with helophytes. To remove E.coli filtration is needed. Several gradations of filtrations are showed in Fig. 11. Another option is UltraViolet (UV-systems).

Reversed Osmosis (RO) is already investigated. With RO it is possible to reuse the water and to use this water for the suppletion. It is not necessary to treat all the water. RO can also be used as a parallel water cycle. One of the advantages is that with RO the waste water what should be recycled has already high temperatures. [7]

The RO proces uses a very fine filter the water needs a pre-treatment to avoid satturation of the filter. To reduce the satturation, the filter works parallel to the flow and the filtered material will be moved in a waste stream, called the concentrate. The fresh water stream is called the permeaat. The concentrate is so concentrated, that this is part of chemical waste. This high concentration of waste have to be treated or brought to the municipaly for further treatment. [7]

With the RO disinfection, the energy demand can be reduced by the use of water with high temperatures. The suppletion of water can be done with the recycled water. During the process, the temperature of the water drops only 1,5ºC. [7] Because the heating of the suppletion water is mostly a very energy consuming part, a lot of energy can be saved. For sure when the water normally needs to be heated from 12 to 28 ºC.

With Reverse Osmosis the energy consumption is due to the pressure which is necessary for pushing the water through the filter. The energy demand is also dependent on the source water. For brackish water the energy consumptinon of RO is much lower (between 0,55-1,59 kWh/m3) than for salt sea water (2,5-7 kWh/m3). It have to be mentioned that for low temperatures, RO works less efficient. [1]
In the zoo in Emmen, it it just that waste what is treated in the living machine. See the appendix for a diagram.

2.4 Living Machine

The 'living machine' is a principle invented by John Todd. It's also based on the biological principles for water treatment (sedimentation, filtration, adsorption, etc) and it also uses no chemicals. Besides helophyte filters, also animals (fish) are part of the system. With a combination of treatment components specific characteristics of the waste water can be treated more in detail. This system can be used outside, but also in greenhouses for reliable operation in temperate climates with colder temperatures. [3] In fact, living machines is a name for water treatment systems for building use.

In Fig. 14 an example of the living machine in Zoo Emmen. The process contains a series of wetlands (aerated) together with an anoxic and a aerobe tank with several wetlands (h-ssf and v-ssf).

In the whole system, see Fig. 13, the living machine is seen with all the water cycles in the zoo Emmen. In this case the from the animals is filtered and the concentrate is brought to the living machine. Behind the living machine another filtration with UV is used to make the water usefull for again the animals and the toilets.

The existing living machines do have a capacity of about 10m3 per day till 750m3 per day (Emmen Zoo). [6] The living machines are only costs competitive with normal waste water treatment in warm climates where greenhouses are not necessary according to John Todd. The use and build of a greenhouse makes this system more expensive. [3]

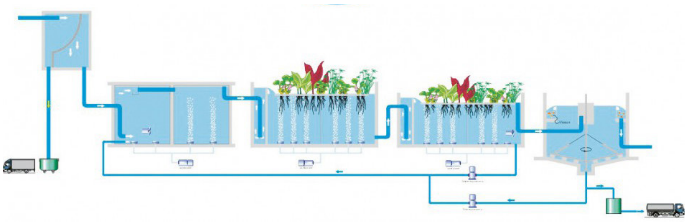


Fig. 14: Scheme of the Living Machine in Zoo Emmen, see also appendix [6]

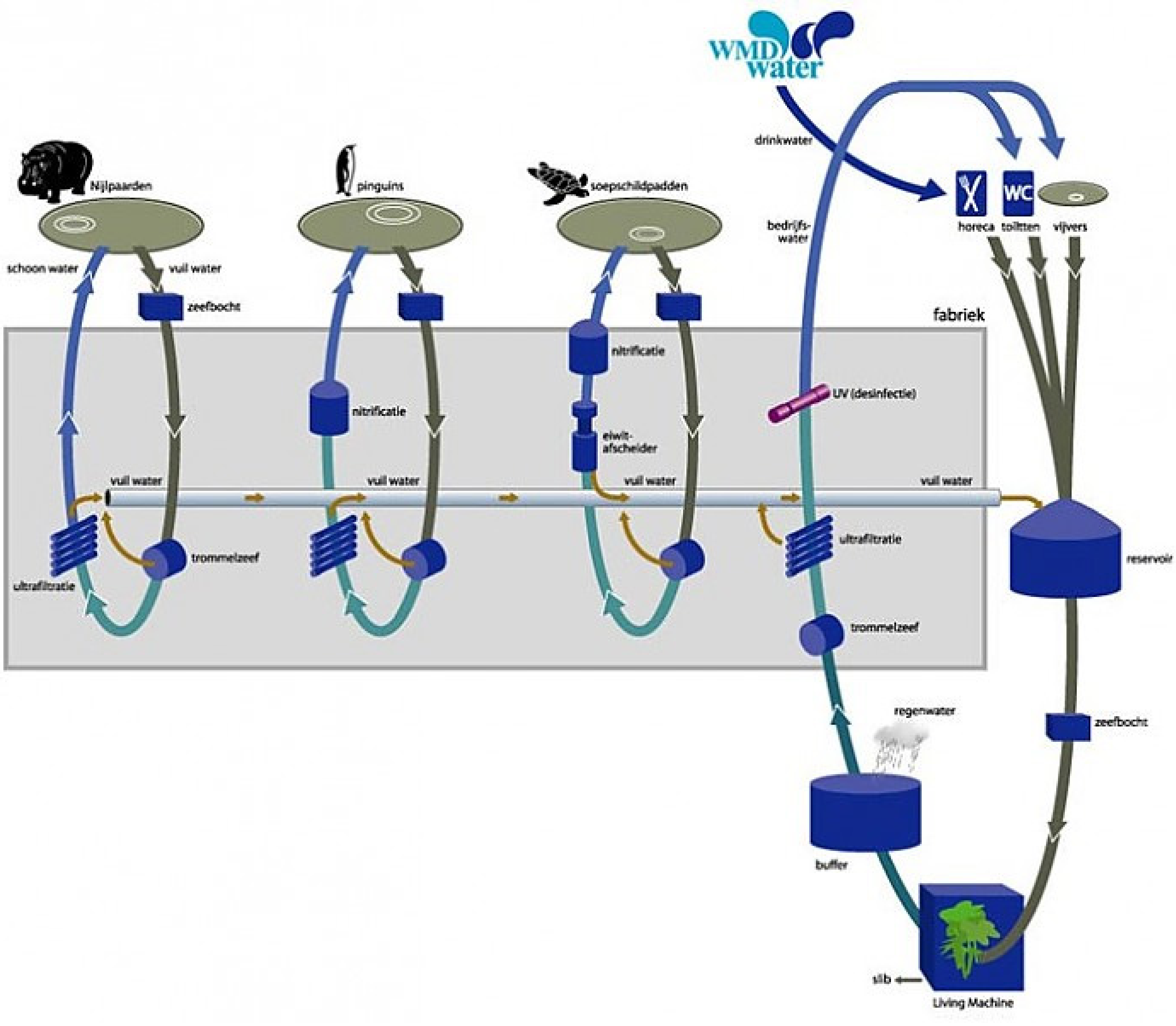


Fig. 13: Scheme of the total water cycle in Zoo Emmen [6]

3. Biological water purification in swimming pools

To make conclusions about the implementation of biological water purification systems in indoor swimming pools, this chapter contains first a literature and reference study on conventional swimming pools to identify the water and energy usage, the climate conditions and the spatial affects in swimming pools. Second a reference and literature study will be done on NSPs, including indoor pools in particular.

3.1 Conventional pools vs. indoor NSPs

Water demand

In swimming pools it's common to measure the water consumption in swimming pools based on the number of visitors. Following the website milieubarometer.nl, the water consumption per visitor is about 84 liter per visitor (with a range between 56-110 liter per visitor).

Suppletion: one of the important aspects here is that for the water quality already 30 liters of fresh water per person have to be added at least, so called suppletion water. But the average is still 33-88 liters per visitor. The costs for the suppletion water are between 3,10 - 5 euros. This costs are build up of costs for the water (m3), heating, chemicals, and discharging costs and tax [28][29] With 80 visitors a day and 30 liters per visitor, this already means 2400 liters. In new regulations this could be reduced to 15 liters, when the water quality is good enough.

Evaporation: evaporation is another source of water consumption. The evaporation is swimming pools result. Using the evaporation calculator from Climate Solutions Holland (csh.nl), for a swimming pool of 200m2, the amount of evaporation can be about 607 liter/day. Also this amount of water have to be supplied to the pool.

Toilet: flushing the toilet demands almost 9 liters of water per flush. In traditional toilets this was almost 12 liters per flush. With the newest toilets this can be reduces to almost 6 liter. For flushing the toilet other sources than fresh drinking water are possible. [8]

Showering: showering in swimming pools is necessary to keep the water clean. Research done by Maarten Keuten from the TU Delft showed that 15-20 seconds (3,2 liters of water) showering before going to the pool can decrease the amount of pollution with 50%. 50% less pollution in the water can result in 50% less use of chlorine in normal swimming pools.

Also the FLL guidelines recommend to place showers to remove nutrients from the skin like sweat, soaps, sunscreen etc. for natural swimming pools. [27]

Based on this literature, an approximation is made for the water consumption per person, see Fig. 16. The difference between the average from literature and the calculated amounts is written down as rest water. The rest water use is probably for cleaning and maintenance is not taken in to account, just like water used for cooking, drinking and washing in the restaurant and water used for make-up after swimming. A further argumentation about the choice for these watercycles is described in the next paragraph.

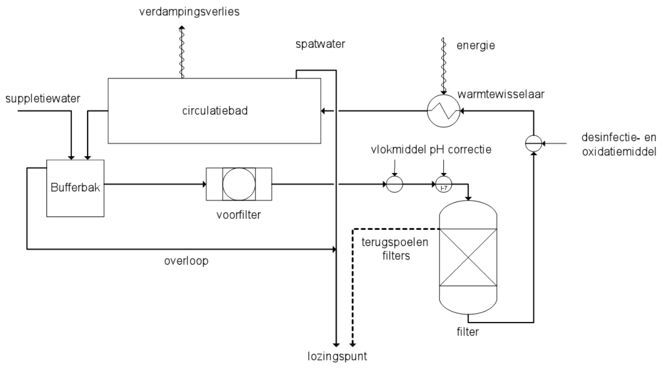


Fig. 15: typical scheme of water circulation swimming pool. [13]

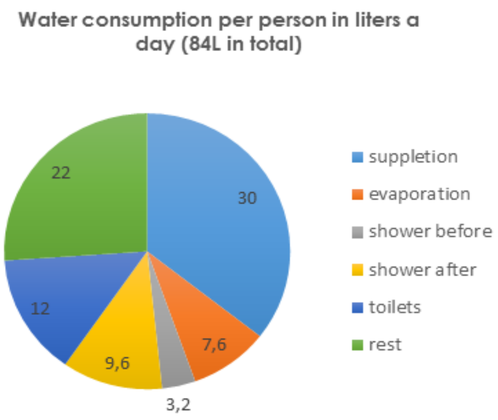


Fig. 16: water consumption per person in liters a day. [own illustration]

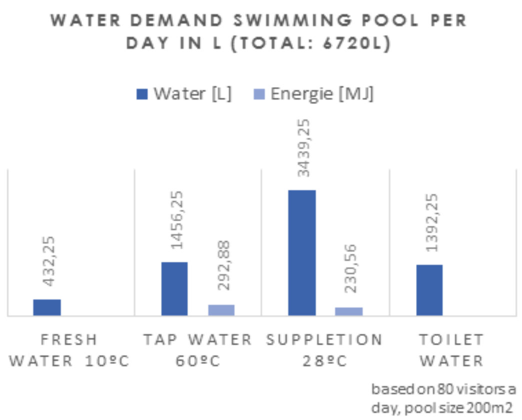


Fig. 17: water demand swimmming pool in total (rest water is divided over these 4 water cycles) [own illustration]

Another appromication is made for the total water demand in Fig. 17. The restwater is divided proportionally over the different water cycles. It showes that the suppletion water is indeed the biggest water consumer and that the water demand for the toilets is almost the same amount as the fresh water which is needed. For the suppletion, the values of evaporation and suppletion (by regulations) is combined. With the use of rainwater for the suppletion and toilet water, seperation of suppletion and toilet water from the fresh water company, the fresh water consumption for swimming pools can be reduced with ***71,8%*** in this calculation.

With biological water purification the water used for suppletion can also be reduced because for biological water purification systems suppletion of water is only used to compensate water lost by evaporation and the reversed osmosis system. (BRON) The evaporation loss in NSPs with regenerationzones with plants is higher, because of larger water area. [21]

Water loss from the concentrate of RO can be catched up with a second water cycle of biological water treatment system, like in the Zoo Emmen. The water loss in the total system of a swimming pool building will be then reduced to a minimum.

Heat demand for water

For the calculation of the heat demand for the water, as reference for the drinking water a temperature between 12ºC is used. This means that every water above this temperature have to be heated. To heat water only one degree is an energy amount of 4,19kJ/kg is needed.

For showering the water in the hot water-system needs to be at least 60ºC to avoid legionella. For the swimming pool the water should be in the end around 28ºC. With an additional water system for the toilets (not potable water) this results in 4 water streams based on temperature and quality.

1. Fresh drinking water of 10ºC;
2. Hot tap water of 60ºC;
3. Swimming water of 28ºC;
4. Toilet water.

Based on these temperatures, about 292,88 MJ should be needed for hot tap water per day and 230,56MJ per day for suppletion water. This is however without heat recovery.

With the use of reversed osmosis also a lot of water can be used as fresh water. While the use of RO can use 0,55-1,59 kWh/m3, the saving for heating the water are usefull. The water doesn't have to be heated, so savings could reach 800x16x4,19 = 56.632kJ/m3 -> 15,7kWh./m3(20 percent loss)

Electricity demand

Electricity is needed for probably additional lighting for the plants and possible for the pumps for the water circulation.

For normal swimming pools the turnover period (time for circulation) is 4 hours [7] , wat means that in one day, 6 times the whole volume of water is circulated. Based on swimming pools pumps found on a lot of websites, pumps for 100m3/h uses about 5kW. In NSPs with a circulation rate of 2, a reduction of 66% should be possible in this way.

When RO is used based on the addition of water for evaporation, with 1kWh/m3 only about 2kW have be used on a day for 2m3. But when the RO have to remove all the E.coli which was added by guests, then for 80 guests, 9.600.000 cfu have to be removed. This result in a 12m3 fresh water per day (wihouth E.coli). (9.600.000/320m3= 30cfu/100ml, in total 80cfu/ml, 9.600.000/800.000=12m3 on a day)

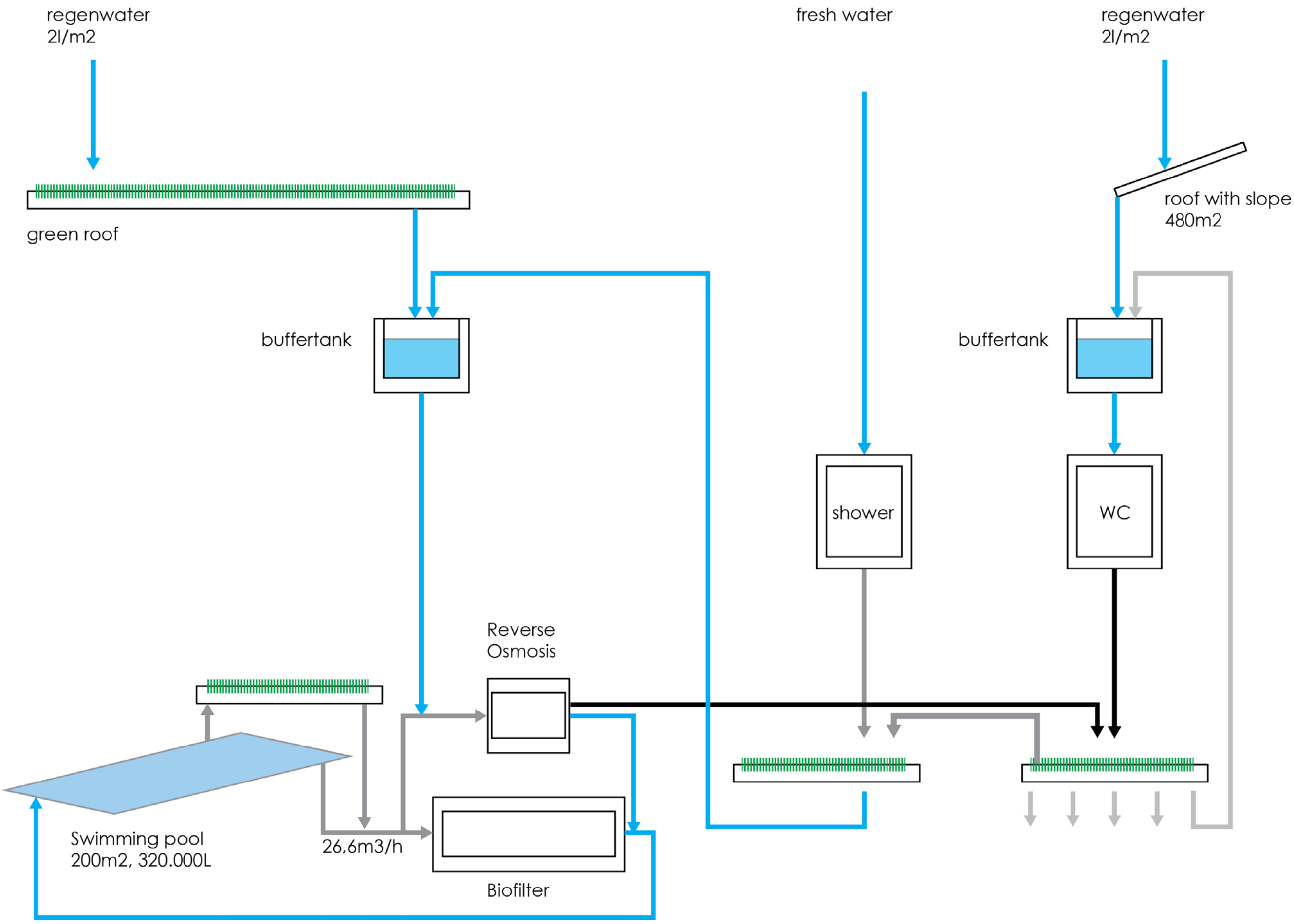


Fig. 18: Indoor NSP water cycles [own illustration]

3.2 Natural Swimming Pools

Spatial

Based on the removal of phosphorus by an input of 74mg total phosphorus per guest [11] and a removal rate of in total 2160.8 grams (74mg x 80 visitors x 365 days) have to be removed per year. For wetlands an is required of at least 48m^2. (based on the removal rate of 45gr/m2/year, see page 4).

Rainwater harvesting

The use of rainwater for flushing the toilet is mentioned a lot and already implemented in quite a few buildings. The design of the roof can have a big impact on the water quality. Research showed that the first flush water in particular contains a high concentration of microbial and chemical contaminants. The use of green roofs results in the lowest concentration of metals compared to other materials like metal, tiles or asphalt fiberglass. The only reason they give to not use green roofs is the highest value for DOC (Dissolved Oxygen Content). [24] But other research arguments that the high removal rate for green roofs should be a good reason to do just that. Only for high water demands, green roofs may not provide the right amount of water. Between 60-80 % of the rainfall may never reach the collection tank. [25] For biological water treatment in swimming pools, a decision should be made for the use of the rainwater harvesting. For toilet flushing, the water quality may not be leading. For more quality water, green roofs are preferred.

4. Conclusion

This research showed that biological water purifcation is possible in indoor swimming pools and that chlorine is not necessary for public indoor pools.

In this research special attention is paid for the removal of phosphorus and E.coli for the design. For the design of the swimming pools can be concluded that special attention should be paid for the indoor climate, in terms of temperature and lighting and that this should be in harmony with the chosen plants. Also the the helophytefilters should be designed with V-SSF and H-SSF wetlands with substrates of sand with iron. Addition treatment should be done with biofilters with Zeolite and partly Bauxite.

Because the helophyte filters and the biofilter could remove a lot of the nutrients, RO is needed for the disinfection. However this doesn't have to result in higher comsumption of energy and water. RO can reuse heated water and the concentrate can be reused in the wetlands for new purification.

For the biological purifcation of water in an indoor pool of 200m2 with 80 visitors a day. 48m2 wetlands should be used for the removal of Phosphorus. The removal of E.coli is preferred with Reversed Osmosis, where for a installation is needed for 12m2 per day. Because it is possible to reuse the already heated water with RO there is not a high energy loss. With the scheme on the previous page a proposal is done which will reduce the fresh water demand with almost 70% in the total water system of the building. For this case rainwater have to be used as new water supply for swimming and toiletwater.

5. Discussion & recommendation

However further research can be done for other parameters for the quality of water. Also the removal of nitrogen, ureum and ammonia for example may lead to other design guidelines. Better investigation in the heat recovery could also lead to better results. A big improvement can then be made possibly. The energy use for pumping is also calculated simplified, but pumping costs are normally about 6% of the energy use, so better attention could be paid for the heating of water.

6. Literature list

[1] **Plappally, a. K. & Lienhard V, J. H. (2012)** Energy requirements for water production, treatment, end use, reclamation, and disposal. Renew. Sustain. Energy Rev. 16, 4818–4848.

[2] **Henze, M., Loosdrecht, M. C. M. van & Ekama, G. A. (2008)** Biological Wastewater Treatment: principles, modelling and design. (IWA Publishing,

[3] **United States Environmental Protection Agency. Wastewater Technology Fact Sheet. (2001)**.

[4] **Group, W. E. (2011)** Helophyte filters : Sense or Non-Sense ? A study on experiences with helophyte filters treating.

[5] **Vymazal, J. (2007)** Removal of nutrients in various types of constructed wetlands. Sci. Total Environ. 380, 48–65.

[6] **Machine, L. & Machine,** T. L. LIVING MACHINE ® SYSTEMS.

[7] **Abeele, L. Van Den, Vercaemst, P. (2000)** Beste Beschikbare Technieken (BBT) voor de Zwembaden Eindrapport.

[8] **infoMill. Informatieblad Zwembaden.** (PlantijnCasparie).

[9] **Stefanakis, A.I., Tsihrintzis,V.A. (2012)** Microporous and Mesoporous Materials 155 p106–116

[10] **DeBusk, T.A., Peterson, J.E. & Ramesh Reddy, K. (1995)** Use of aquatic and terrestrial plants for removing phosphorus from dairy wastewaters. Ecological Engineering 5 (1995) p.371-390

[11] **FLL-guideline**

[12] **Biotiop company** http://www.biotop-benelux.com/

[13] **Abeele, L. Van den , Meynaerts, E., Huybrechts, D. (2011)** Beste Beschikbare Technieken (BBT) voor zwembaden. BBT-kennis-centrum

[14] **Biofermenta company** http://www.biofermenta.com/

[15] **Headley, T., Nivalaa, J., Kassaa, K., Olsson, L., Walleced, S., Brix, H., Afferdana, M., Müller, R. (2013)** Escherichia coli removal and internal dynamics in subsurface flow ecotechnologies: Effects of design and plants. Ecological Engineering 61P (2013) 564– 574

[16] **Tiemen, T.A. (2011)** A study on experiences with helophyte filters treating

[17] **Moshiri, G.A.** Constructed Wetlands for Water Quality Improvement

[18] **Koets, A., (2011)** Budgetneutrale energieslurpende zwembaden opwaarderen, B&G magazine

[19] **Belucht verticaal helofytenfilter.** at <http://www.groenblauwenetwerken.com/measures/aerated-vertical-helophyte-filters/#cite-0>

[20] **Linnemans, F. (2009)** Het gebruik van nieuwe energie: duurzame energie & zwembaden, presentation NPZ managersmeeting

[21] **VHG positionpaper (2012)**

[22] **Martín, M., Gargallo, S., Hernández-Crespo, C., Oliver, N. (2013)** Phosphorus and nitrogen removal from tertiary treated urban-wastewaters by a vertical flow constructed wetland. Ecological Engineering 61 (2013) 34–42

[23] **http://en.wikipedia.org/wiki/Canna_(plant)**

[24] **Mendez, C. B., Afshar, B. R., Kinney, K. & Ph, D. (2010).** Effect of Roof Material on Water Quality for Rainwater Harvesting Systems Report by Texas Water Development Board Report Effect of Roof Material on Water Quality for Rainwater Harvesting Systems.

[25] **Williams, B. D., Kinder, J. & Llc, P. D. (2010)**Coupling Rainwater Collection with Living Roofs : A Water Quality Review. at <www.greenroofs.com/content/guest_features016.htm>

[26] **Cleanwaterstore**: http://www.cleanwaterstore.com/technical/how-to-remove-sediment-from-well-water.php

[27] **Douchen voor een chloorvrij zwembad (2009)** http://www.zwembadkeur.nl/?sid=29&mod_id=268

[28] **Poolwatertreatment company** http://www.poolwatertreatment.com/freetext.asp?content=&ftmod=freetext_000000007&id=000000017

[29] **Verslaggeving managersmeeting NPZ (2009)** http://www.infomil.nl/publish/pages/82628/zwembaden_e_kwadraat_verslag_managersmeeting_2009_1.pdf

7. Appendix 1

Table 1. Removal Mechanisms in Macrophyte-Based Wastewater Treatment Systems

Wastewater constituent	Removal mechanisms
Suspended Solids	Sedimentation/filtration
BOD	Microbial degradation (aerobic and anaerobic)
	Sedimentation (accumulation of organic matter/sludge on the sediment surface)
Nitrogen	Ammonification followed by microbial nitrification and denitrification
	Plant uptake
	Ammonia volatilization
Phosphorus	Soil sorption (adsorption-precipitation reactions with aluminum, iron, calcium, and clay minerals in the soil)
	Plant uptake
	(Phosphine production)
Pathogens	Sedimentation/filtration
	Natural die-off
	UV radiation
	Excretion of antibiotics from roots of macrophytes

From Watson, J. T., S. C. Reed, R. H. Kadlec, R. L. Knight, and A. E. Whitehouse. in *Constructed Wetlands for Wastewater Treatment*. D. A. Hammer, Ed. 319, 1989. With modification.

Table 2: Removal Mechanisms [17]

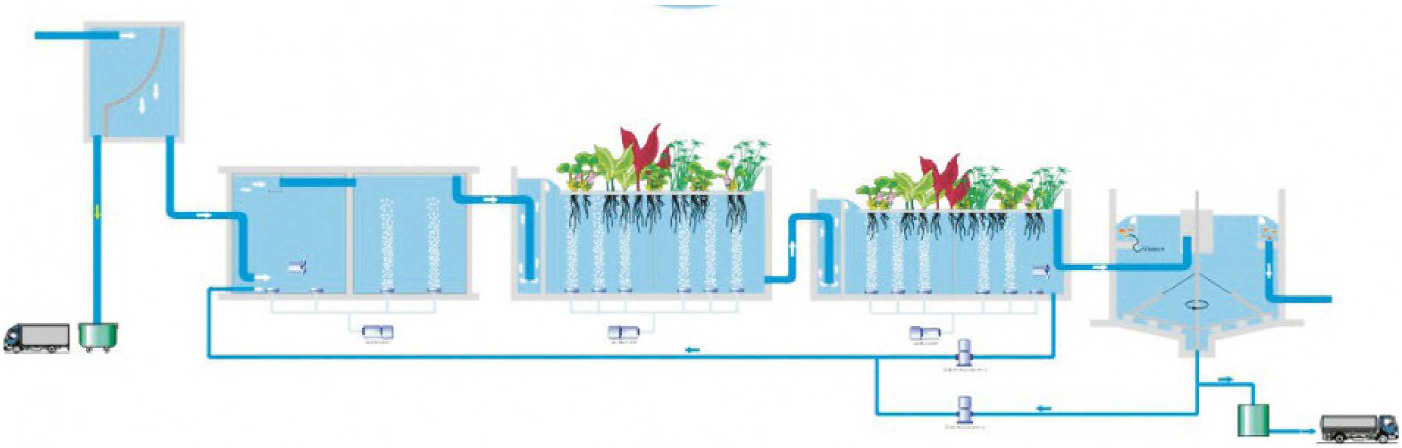


Fig. 19: Scheme of the Living Machine in Zoo Emmen, see also appendix [6]

References

Camping Arterhof

Name	Camping Arterhof
Locatio n	Germany
Design	Architectenburo Würmseher (http://www.architekt-wuermseher.de/)
Design pool	www.naturerlebnisbad.de
	http://www.egligartenbau.com/biopool.htm (Bionova)

This is mentioned as the first public indoor natural pool from Germany.

The swimming hall is a tropical poolhall, with water between 28°C and 32°C. The regeneration zone with plants is located in the same swimming hall next to the swimming area. The size of the regenerationzone is almost the same as the area for swimming. A small cabin for the technique seems to be located next to the regeneration zone.

The 'Natur-Hallenbad' also has different saunas and the possibility for massages or fitness.

Very important in this design was the choice for the right plants. The plants should be appropriate for temperatures to 30°C and they should be able to treat the water the whole year. To treat the water the whole year, the regeneration zone is located in the swimming hall with subtropic temperatures. Plants which were suitable for this swimming hall were found from different continents.

Another important design issue is the amount of light which is needed for the plants. A special light concept is therefore also necessary. The special plants need light about 12 hours a day. For the winter months, artificial light is necessary.

The water treatment system works with two water cycles. First the water is captured in 1,35m deep bassins and then moves to a gravity sewer with a fine filter. There the water is separated in two volume flows. With the first flow, a third is moved to the biological filter. There the flow is separated again in two equal flows. The first flow moves to the first filter tank under the root bed, through the soil to the surface. From here the water flows to the second filter, where the water flows from the surface, through the soil to below the root bed.

Another current is heating the water to 32°C for an inlet for massage.

Hygienic problems has been occurred only once. Lowering the temperature was a sufficient solution.

http://www.arterhof.de/naturhallenbad.html?&L=2

http://www.egligartenbau.com/biopool.htm

Wellnesshaus Reichelt

Name	Wellnesshaus Reichelt
Location	
Design	
Design pool	

http://www.haus-reichelt.at/wellness.html

Swiss indoor pool

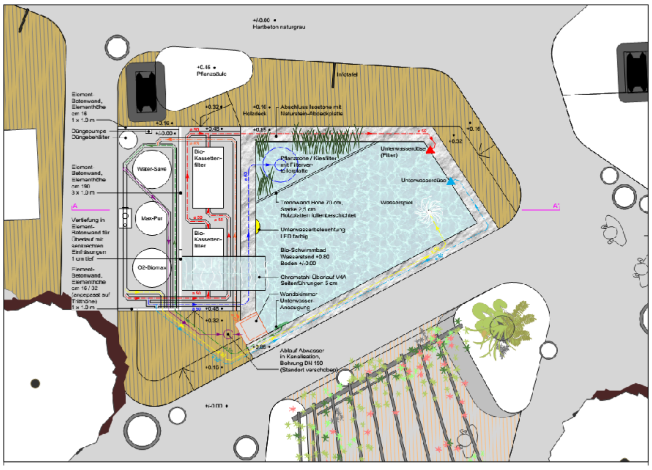
Eco-pool.ch

http://www.svbp.org/topic10739/story45628.html

Name	Swiss indoor pool
Location	Swiss
Design	
Design pool	Abderhalden Gartenbau (Eco-pool)

Made by and Schweizerischer Verband für naturnahe Badegewässer und Pflanzenkläranglagen (SVBP)

Umwelt Arena



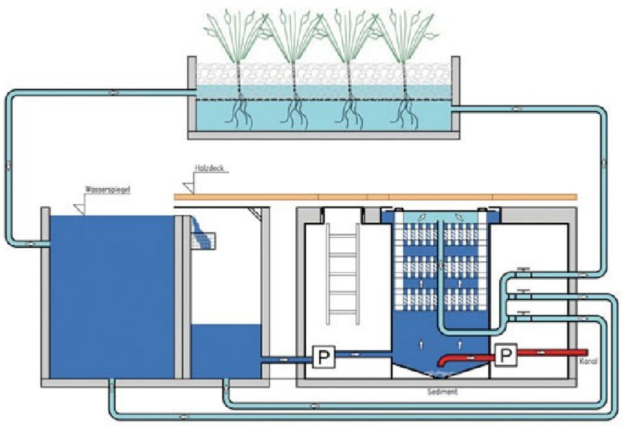
Name	Umwelt Arena
Location	Germany
Design	-
Design pool	Natural Blue

For the Umwelt Arena building Natural Blue designed a small indoor pool. Because of the very small size of of the pool, this seems to be more a sample of a indoor swimming pool than a real indoor pool. It only measures a few square meter.

The pool works with a self-developed cartridge filter.

http://www.naturalblue.ch/images/content/news/Umweltarena_1203061.pdf

Hallenbad Aargau



http://www.graf-gartenbau.ch/Schwimmteich/Indoor%20bio%20Hallenbad.htm

Name	Hallenbad
Location	Kanton Aargau, Germany
Design	Firma Zebra http://www.zebrapool.ch/
Design pool	Graf-gartenbau (Bio Nova)

This swimming pool is made for private use. The owner really wanted a pool with plants. The pool is quite large for a private indoor pool. The size is about 10 by 4 meters. Next to the swimming pool are located the sauna, changing rooms and a technical room.

The regeneration for this swimming pool is quite small, with about 10m2 is it only 25% of the swimming area. The other part of the filter zone is in the technical room, which houses an cartridge filter (from the company Biofermenta) of about 10m3 substrate for the use of zeolite. The filter for the substrate needs to be replaced every year.

The description on internet mentioned the following cycles:

1. Via a skimmer to a 4m3 buffer tank;
2. The renerationzone;
3. Filter circuit.

In the beginning, there were several problems:

- The paste to clean the swimming pool (the steel tub) was containing a lot of phosphates. These were crucial for the nutrients.
- With an reversal osmosis system the water could be completely treated before filling the pool.

They concluded that indoor natural pools are possible for sure. Also the hygienic levels were very good. While this is for private use less important, they also mention that for public pools this principle could also work. The chemical and physical levels were not exceeded.

Natural indoor pool Tregulland, UK

Name	Indoor NSP, uk
Location	Tregulland, UK
Design pool	Clear water revival

This pool in the UK is made by Clear Water Revival. They also have made the new biofilter for natural swimming pools. This indoor pool has water heated to 28°C. The pool is designed for groups up to 22 people, which is quite a lot. This indoor pool uses cartridge filters instead of helophyte filters. In this way the system could be kept small. The company CWR says on the website that the pool doesn't use any energy consuming UV filters and the costs for this pool are 10 times less than for conventional swimming pools, also because of the low energy pump. With the introduction of the new biofilter (instead of the cartridge filter) they also say that this costs about 1000 pounds yearly to run.

Zwembad de Geusselt

Name	De Geusselt
Location	Maastricht (NL)
Design	Koppert & Koenis
Technical advisor	Technion, Heerenveen

Swimming pool de Geusselt in Maastricht is one of the newest swimming pools in the Netherlands. The swimming pool contains 4 different pools (1650m2), but also horeca, fysio and offices. The total floorspace is about 14.000m2.

For the heating for this swimming pools, three options were considered: 1. Cogeneration based on bio-oil, 2. Biomass installation on wood and 3. electric heat pumps with groundwater. For the cradle2cradle principle which was implemented in the Geusseltbad, the first two options didn't fit, because incineration of waste is downgrading. Bio-oil and wood could also be used for the fabrication of other things.

The swimming pool is an all-electric building, what means that no gas is used. The building only uses earth heat and electricity. For the heating the building uses solar collectors, together with heat pumps connected to the groundwater. For the spaces, mostly air heating is used, except from a few places where floor heating is used.

Groundwater is used for as well the swimming pools as well for the toilets. For the water treatment ultra filtration and reverse osmosis is applied. In total 5 heat pumps are installed in the swimming pool. The water from the source is 5,5°C and will be returned with 11°C. The heat pump heat the water with electricity to about 50°C.

For the showers and drinking water drinking water is supplied by the water company. This water is heated with two heat pumps, combined with PV-panels and heat recovery from the shower water.

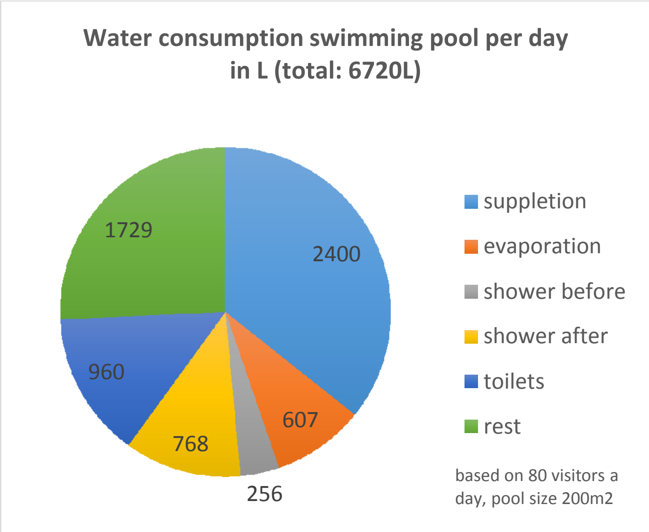
The water for the outdoor pool is heated with 300m2 of solar collectors.

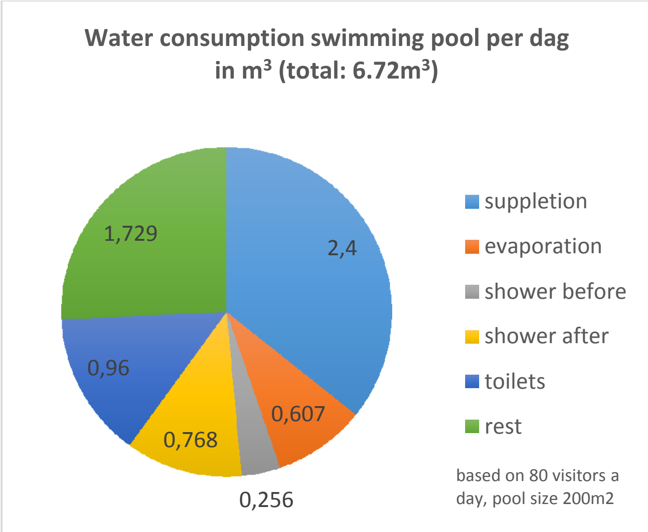
PV panels on the roof provide in a part of the electricity demand, when there are high peaks, the overload will be returned to the net. Due to the electric heating, the electricity demand is quite high.

- Gas use: 0 m3;
- Electricity: 175 kWh per m2 BVO per year (1,6 milion kWh per year);
- Water: 1,5m3 per m2 BVO per year (which is less than 30 liters per visitor)

Sources:

- Installatie & bouw, 2013 (2)
- Energie+, 2010 (6)


Water consumption swimming pool per day in L (total: 6720L)
2400
607
256
768
960
1729
suppletion
evaporation
shower before
shower after
toilets
rest
based on 80 visitors a day, pool size 200m2


Water consumption swimming pool per dag in m³ (total: 6.72m³)
2,4
0,607
0,256
0,768
0,96
1,729
suppletion
evaporation
shower before
shower after
toilets
rest
based on 80 visitors a day, pool size 200m2