EcoWater

Meso-level eco-efficiency indicators to assess technologies and their uptake in water use sectors

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Innovative technologies for eco-efficiency improvement

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Abstract

This deliverable contains information about innovative technologies with the potential to increase the eco-efficiency in urban water value chains. Technologies were identified according to the situation in two case study sites: Sofia, Bulgaria and Waedenswil, Zurich, Switzerland. The technical descriptions of the technologies include information about the working mechanisms, the environmental performance, cost data, technological maturity and justification for the necessity.

The technologies are structured according to the application – innovative technologies for the water supply and discharge chain and innovative technologies for the water use stage.

Technologies suggested for the case study of Sofia are

- Pressure reduction valve with hydropower generator
- Solar drying of sludge
- Water saving appliances
- Solar water heating
- Drain water heat recovery

Technologies suggested for the case study of Waedenswil, Zurich are

- Pressure reduction valve for the water supply system
- Smart pumping for the water supply system
- Micropollutant removal technologies
- Advanced phosphorus recovery technologies
- Water reuse for domestic/non-domestic users
- Water saving appliances for domestic/non-domestic users

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Abbreviations

AC	Alternating current
DC	Direct current
DMA	District meter areas
DHW	Domestic hot water
DWHR	Drain water heat recovery
EPA	Environmental protection agency
NRW	Non-Revenue Water
O&M	Operation and management
PaT	Pump as turbine
PRT	Pressure reducing turbine
PRV	Pressure reducing valves
SWH	Solar water heating
SWOT	Strengths, Weaknesses, Opportunities and Threats
WEI	Water exploitation index
SWWTP	Sofia wastewater treatment plant
WWTP	Wastewater treatment plant

1 Introduction

Eco-efficiency is a relative tool for comparison of different systems or alternatives (ISO14045, 2012). In the EcoWater project it has been used to compare the current product system, called the “baseline scenario” with other scenarios in which different innovative technologies and practices replace some of the existing ones. The overall purpose is to promote the implementation of eco-efficient technologies and practices, in order to contribute to regional sustainable development.

The product systems which are assessed are the urban water system of Sofia and the one of Wädenswil, Canton Zurich.

The study has three core phases:

- Baseline eco-efficiency assessment;
- Selection of appropriate innovative technologies;
- Eco-efficiency assessment of the scenarios, involving implementation of one technology or a combination of some selected technologies.

The first phase is described in EcoWater Deliverable 3.2.

This report describes the second phase – selection of appropriate innovative technologies. It has four main chapters: i) objectives; ii) water supply and discharge chain technologies; iii) water use technologies and iv) conclusions.

The last phase will be studied in the next project year.

2 Innovative Technologies for Sofia urban case study

2.1 Technology implementation objectives

The eco-efficiency assessment of the baseline scenario for Sofia urban water system revealed the environmentally weakest stages. For this purpose twelve indicators were used. The % distribution of their magnitude among the urban water stages is given in Deliverable 3.2 and is shown here for the sake of clarity (Fig.1).

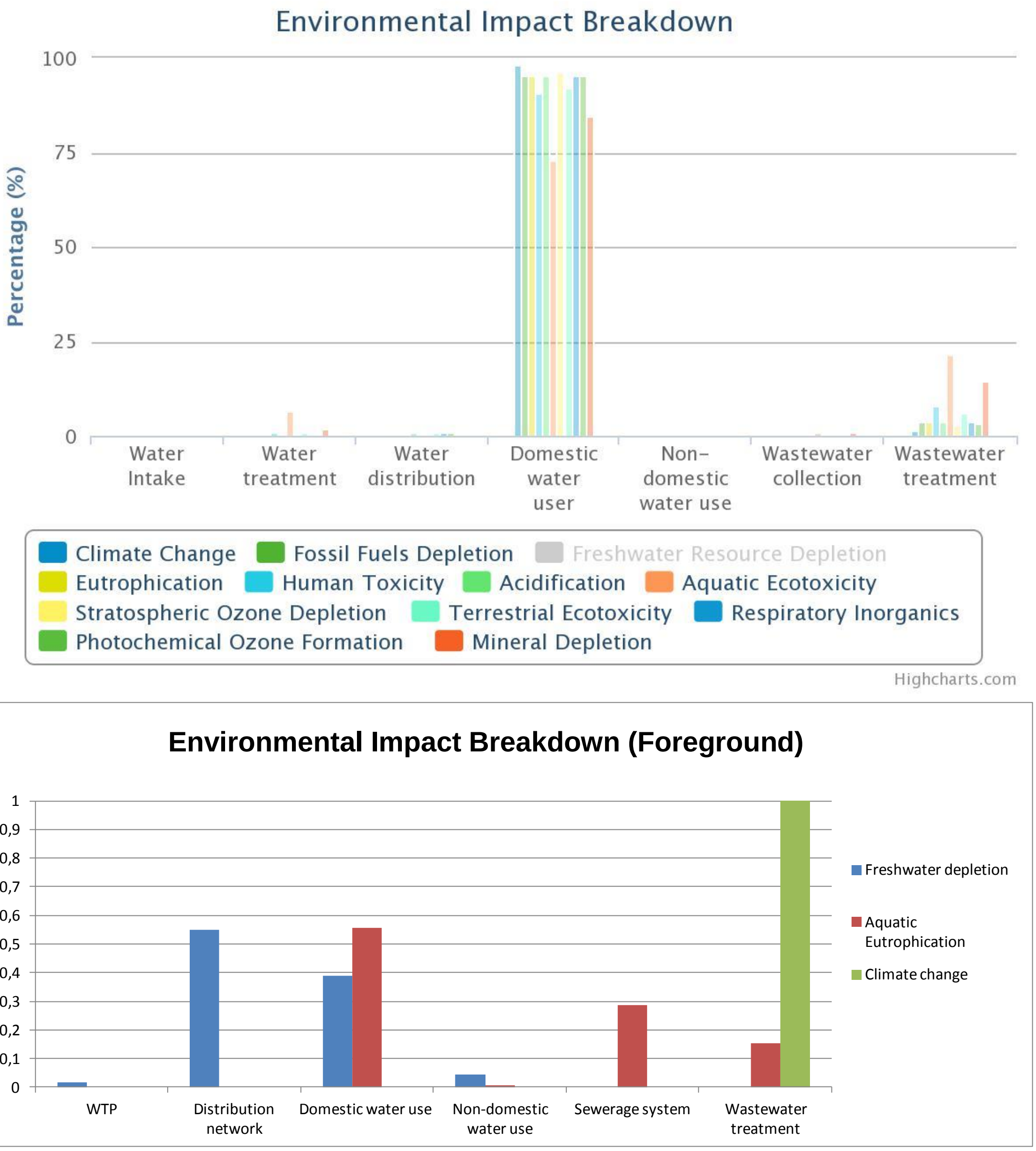


Figure 1. Environmental performance of the stages in Sofia urban water system; a) background system; b) foreground system

Domestic water use stage is responsible for the highest negative environmental impact regarding: i) background system (all indicators have the highest values in this stage as shown in Fig.1a) and ii) the indicator "aquatic eutrophication" in the foreground system as shown in Fig.1b). The analysis of the system reveals that the bad performance is a result of water heating and the use of electrical water appliances. Therefore, it is worth investing on technologies for more environmentally friendly ways of water heating or energy resources.

Another stage with high negative environmental impact is the wastewater treatment plant and again this is mainly due to the high energy consumption. However, here the big quantity of the sludge to be transported out of the WWTP is another reason for environmental pollution from the fuel combustion.

The third stage with not satisfactory environmental performance is the **distribution network**. It has the lowest values for the most important indicator of the foreground system – the freshwater ecosystem impact. In Sofia urban water system, the leakages are high, more that 50% of the abstracted water. Therefore, measures are necessary for reduction of these leakages.

The **non-domestic water users** are not fully considered because the variety of the production chains could not be modeled. They are included in the overall model only regarding their water consumption and BOD pollution.

Based on this analysis, five technologies were selected to be studied further. They are shortly described in Table 1. Each of these technologies will be described in separate chapters below.

Table 1. Overview of the innovative technologies, which will be studied in Sofia urban case study

N	Technology name	Unit of implementation	Reason for selection
Stage: Water supply and discharge chain			
T1	Pressure reduction valve, which acts as hydropower generator	Distribution network	Will lower the losses due to the high pressure, thus will lower the value of the indicator "freshwater ecosystem impact". In addition, will produce renewable energy and thus improve the energy balance, which will reduce the relevant environmental impacts concerning energy production.
T2	Solar drying of the sludge	WWTP	Will lower the values the indicators associated with fuel combustion during sludge transportation.
Stage: Water use			
T3	Water saving appliances (low flushing toilets, shower heads, dishwashers)	Households	Will lower the amount of abstracted water and the value of indicator "freshwater ecosystem impact" respectively. Replacing the old water appliances with energy and water efficient ones will lower the energy demand and it will reduce all environmental indicators relevant to electricity production and heat production.
T4	Solar water heating (SWH)	Households	Will lower the non-renewable energy consumption for water heating. The environmental impact indicators relevant to electricity and heat production will be reduced.
T5	Drain water heat recovery (DWHR)	Households	The same as T4

2.2 Water supply and discharge chain technologies

Two technologies will be studied, one in the water supply sub-chain and the other one in the wastewater collection and treatment sub-chain. The general objectives are:

- To reduce the leakages in the water distribution network;
- To reduce the volume of the sludge transported out of the WWTP.

In the next chapters environmental and economic benefits of these technologies are given in more detail.

2.2.1 Technology 1. Pressure reduction valve (PRV) - hydropower generator

A. Justification of the necessity

Water Loss or Non-Revenue Water (NRW) represents inefficiency in water delivery and measurement operations in transmission and distribution networks. For some systems, the water loss can amount to a sizeable proportion of total water production. The Water Losses for a whole system or for a partial system are calculated as the difference of Systems Input Volume and Authorised Consumption.

The Water Losses consist of Real and Apparent Losses:

- Real Losses are physical losses of leaks, bursts and overflows from the pressurized system, up to the point of metering on the service connections.
- Apparent Losses consist of all types of meter inaccuracies (input, output, and customer meters) and unauthorised consumption (theft and illegal use). They are also termed as commercial losses (Prowat, 2008).

Table 2 gives an overview of the abstracted water, delivered water and the water losses in Sofia water distribution network since 2006.

Table 2 Water losses in Sofia water supply system (taken from Deliverable 3.1)

Year	Abstracted water	Delivered water	Water losses	% of the losses
	$10^6 m^3$/year	$10^6 m^3$/year	$10^6 m^3$/year	
2006	239.53	91.82	147.72	61.7
2007	242.02	93.11	148.92	61.5
2008	224.66	91.46	133.21	59.3
2009	214.96	89.51	125.45	58.4
2010	206.63	89.15	117.47	56.9
Average	**225.56**	**91.01**	**134.554**	**59.56**

Source: National Statistical Institute

Data in Table 2 show over 50% losses every year, which is a very high rate compared to the average in EU. These high values have a negative economic, social and ecological impact, which requires measures to be taken to overcome the problem (Dimitrov, 2004).

One possible solution is the installation of Pressure Reducing Valves (PRV). This type of solution can be adopted, as a mitigation method to control the system losses, in particular, the available overload, which has to be dissipated to avoid leakage or rupture occurrence in the pipe system.

The purpose of using pressure reducing valves in water distribution systems is to maintain pressure variation in controlled manner by isolating water pipe systems in different district meter areas (DMA), as identified by pressure classes according to the topographical variation of the zone where the system is implanted. Each DMA is required to maintain a guaranteed pressure range either by interconnected reservoirs or by using pressure reducing valves at the entrance of each active DMA. Since water supply and distribution systems have, in general, faced serious problems from leakage, the control of pressure has become a fundamental issue for an optimized and sustainable system management (Ramos et al., 2010).

Recently PRV have been combined with micro-hydro systems. They provide a better approach as a sustainable solution in terms of controlling the system pressure as well as a provider of a non-negligible income by producing clean energy (Ramos et al., 2010). This technology was one of the selected to be studied in Sofia system. It is described below.

B. Description

Hydropower generator, which functions as a pressure reducing valve, allows controlling the pressure with a rotable barrier device, which is harvesting the energy from the pressure drop and turns it into clean green electricity.

Water power is a combination of head and flow. In reality, the generation of electricity is simply the conversion of one form of power to another. The turbine converts water power into rotational power at its shaft, which is then converted to electrical power by the generator. Some of the power is lost through friction at every point of conversion. Efficiency is the measure of how much energy is actually converted. The net power is the product of gross power and efficiency as shown in Eq.1 (Canyon Hydro, 2013).

$$\text{Net Power} = \text{Gross Power} \times \text{Efficiency} \quad (1)$$

The major components of a hydro system are turbine, drive system, generator and control system.

The turbine is the heart of the hydro system, where water power is converted into the rotational force that drives the generator (Figure 2). It is arguably the most important component in the system, because its efficiency determines how much electricity is generated (Canyon Hydro, 2013).

Figure 2 Pressure Reduction Turbine (Source: www.zeropex.com)

There are many different types of turbines. A proper selection requires considerable expertise. The turbine system is designed around Net Head and Design Flow. Net Head is the pressure available to the turbine when water is flowing and Design Flow is the maximum amount of flow the hydro system is designed to accommodate.

These criteria not only influence which type of turbine to use, but are critical to the design of the entire turbine system. The drive system couples the turbine to the generator. At one end, it allows the turbine to spin at its optimum rotating frequency given in rounds per minute (RPM). At the other end, the drive system drives the generator at the rotating frequency given in RPM that produces correct voltage and frequency. The generator converts the rotational power from the turbine shaft into electrical power. Efficiency is important at this stage too, but most modern, well-built generators deliver good efficiency (Canyon Hydro, 2013). Smaller plants with output powers less than 5 MW may have efficiencies between 80 and 85 % (Electropaedia, 2013). Governors and other controls help to ensure that the generator constantly spins at its correct speed. The most common types of governors for small hydro systems accomplish this by managing the load on the generator (Canyon Hydro, 2013).

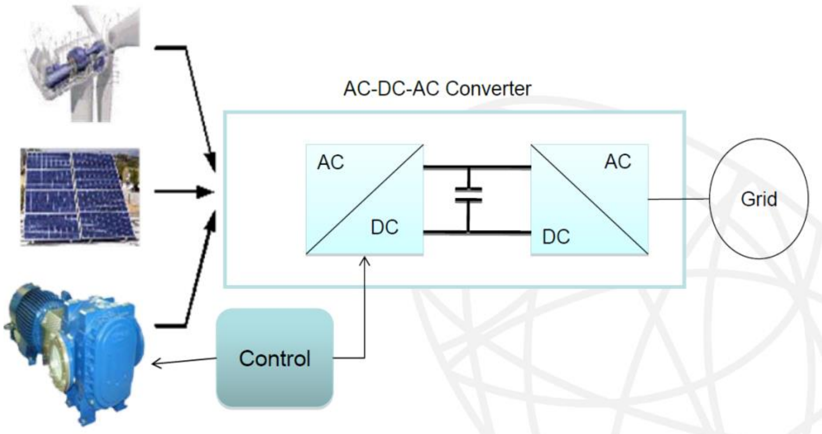


Figure 3 Connection of PRT to the grid (Source: www.zeropex.com)

The Pressure Reducing Turbine (PRT) could be connected to the grid in the same way as wind turbines as shown in Figure 3 (Zeropex, 2013).

As opposed to wind, solar, tidal and wave, PRT provides predictable power supply. In a drinking water supply system, the power supply responds to energy demand levels and pricing (Zeropex, 2013).

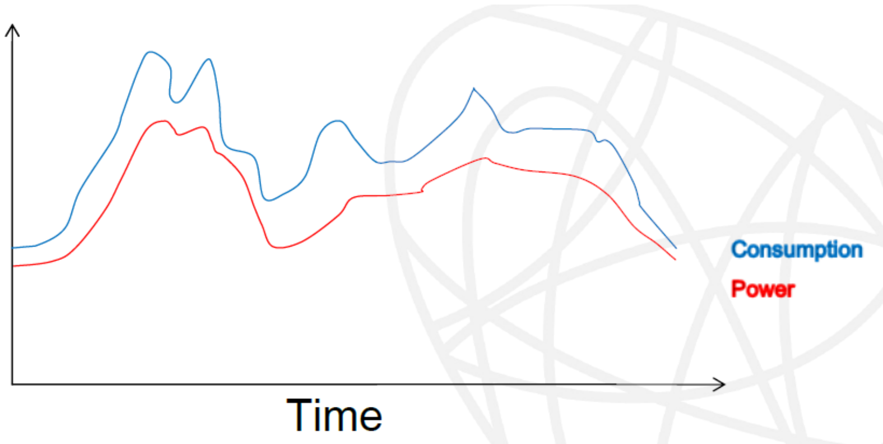


Figure 4 Water consumption vs. power produced in water main with installed PRT *(Source: www.zeropex.com)*

Zeropex Difgen is a patented solution for converting pressure to electricity. It is a complete system consisting of turbine, asynchronous generator and frequency converter. The required downstream pressure is programmed (easy to change). The torque on the generator is adjusted to achieve the required downstream pressure. Variations of flow and upstream pressure will result in an adjustment of the torque, so that downstream pressure is maintained as required.

Features:

- Multiple operational modes
  - Up/downstream pressure control
  - Flow rate or level control
  - Pumping/boosting capability
- Built-in flow rate meter
- High efficiency over wide variation in flow and pressure
- Pulsation free by design to eliminate water hammer
- Easy to install with standard flange connections
- Simple maintenance, service like a pump/motor
- Robust and rugged, long life expectancy, 20+ years
- Control software interfaces with customer's SCADA system
- Integrated system design approach

Table 3 Configurations of PRT (www.zeropex.no)

MODEL	Flow rate min-max [l/s]		Max inlet pressure [bar] 1)	Max diff. pressure [bar]	Max diff. pressure 10-pole gen	Min operat. diff. pressure
DG13-14	7	35	14	10	N/A	1.5
DG13-21	11	53	12	10	N/A	1.5
DG13-28	15	70	10	8	N/A	1
DG18-13	15	70	16	10	N/A	1.5
DG18-18	21	100	14	10	N/A	1.5
DG18-26	30	140	12	9	10	1.5
DG18-36	45	200	10	6.2	7.2	1
DG18-52	60	240	7	4.5	5	1
DG18-73	85	300	4	2.8	3	1
DG18-13L	15	70	13	13	N/A	1.5
DG18-18L	21	100	13	12	13	1.5
DG18-52HP	60	240	12	4.5	5	1
DG18-73HP	85	300	8	2.8	3	1

Configurations:

- Unit sizes range from 10 kW to 150 kW; pressure ranges up to 12 bar; flows up to 320 l/s;
- Can be installed in parallel to maximize energy offset and in series for larger pressure drops;
- Standardised systems for below and above ground installations, typically skid-mounted.

Different configurations depending on flow rate and differential and inlet pressures are shown in Table 3 (Zeropex, 2013).

A cheaper alternative to turbines are centrifugal pumps running in reverse. Pumps used as turbines (PaT) for short offer huge advantages such as low investment outlay as well as low service and maintenance costs (KSB, 2012).

Figure 5. Pump as turbine (KSB, 2012)

Depending on variation of flow rate and head the systems can be adjusted to the desired operating point by the following means:

- Pumps with fixed speed. – If the system is operating without significant fluctuations of pressure and flow, the right PaT for a given flow rate and head is selected. For other operating conditions, additional throttling elements or a bypass could be applied. The PaT system is technically simple, easy to handle and, most of all, extremely cost-effective.
- Pumps with variable speed - Variable speeds allow the operator to fully utilize the existing energy potential without the need for additional throttling. An energy recovery-type frequency inverter can also be used.
- PaT operated in parallel - Cascade operation is a good way to take full advantage of the energy potential – in particular, if the flow rate varies. It involves splitting the total flow among several PaT running in parallel at fixed speed. (KSB, 2012)

Benefits of PaT

- Low investment costs and short payback period respectively
- Low service and maintenance costs
- Adjustment to fluctuating water levels is possible by splitting the total volume among several pumps of different sizes
- Pumps are decidedly easier to service and handle than “real” turbines

A hydraulic selection chart for pumps used as turbines is shown in Figure 6.

C. Economic data

The **pressure reduction turbine** provides pressure management with a payback. This means its initial capital cost will be recovered within three to seven years through improved performance and electricity generation. The payback depends on flow, power installation cost and electricity price. After that, savings on power bills and/or earnings from electricity sales provide a straightforward income stream for at least 20 years (Zeropex, 2013). According to International Energy Agency the **operation costs** are about 1.5 – 2.5% of the investment cost per year.

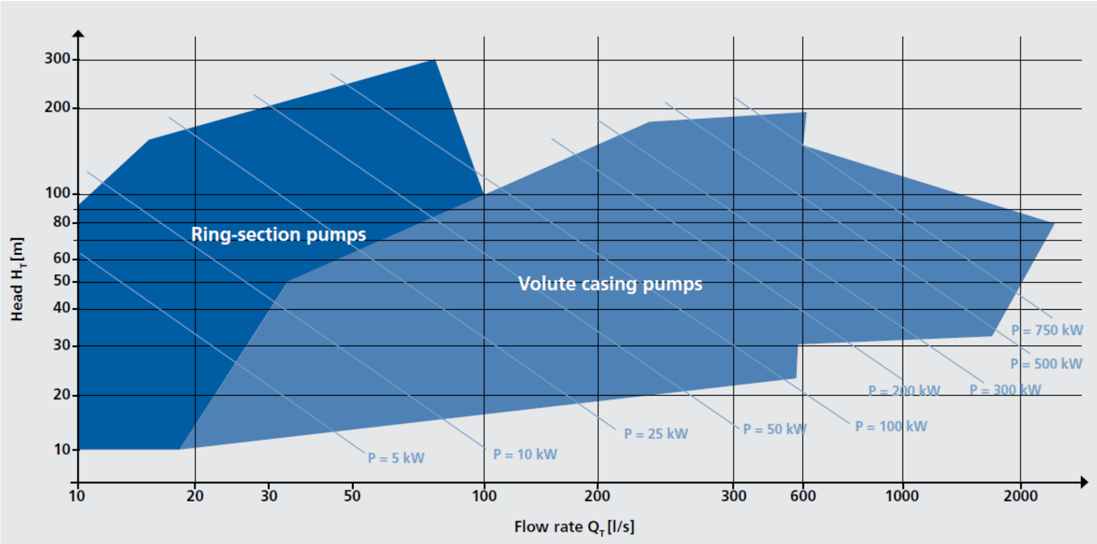


Figure 6 Hydraulic selection chart for pumps used as turbines

D. Environmental performance

The main positive effect of installing of pressure reducing valves (with or without turbines) is that they mitigate water losses in the distribution network, thus, reduce the negative environmental impact, measured with the indicators “freshwater ecosystem impact”. However, when the pressure reducing valve is combined with hydropower generator, there is an additional positive effect, connected with the production of “green energy”. In the urban water system it will contribute to reducing the negative environmental impact in regard to the indicators associated with energy production from non-renewable sources.

In summary, the combined equipment has the following benefits:

- Superior pressure control accuracy and responsiveness when compared with PRV’s
- Improve leakage management in water mains
- Generates revenue stream from energy production
  - Excellent Net Present Value compared to alternative investments
  - Predictable production corresponding to water consumption patterns
  - Qualifies for feed-in tariffs and other incentives, where applicable
- Utilizes is possible above or below ground assets
- Reduced energy purchases
- Reduce carbon footprint.

E. Maturity and availability

The technology has already been in place. Below, examples of its applications in practice are given.

Application 1: Flow control of raw water entering the treatment process.

Figure 7 Difgen PRT in operation (www.zeropex.no)

Key facts:

- Differential pressure: 9-10.5 bar
- Flow range: 10-30 l/s
- Power output: 8-17 kW
- Annual revenue: 34,263 €
- Payback period: 2.8 years

Application 2: Control of raw water pressure entering the treatment process. (Devon)

Figure 8 Difgen PRT (www.zeropex.no)

Key facts:

- Differential pressure: 7 bar
- Flow range: 50-250 l/s
- Power output: 30-120 kW
- Annual revenue: 114,619 €
- Payback period: 1.34 years

Application 3: Pump as a Turbine, Municipal Services, Kufstein, Austria

Figure 9

Key facts:

- •Generated electricity: 180,000 kWh per year
- •The total capital outlay: 90,000 €

Application 4: Pump as a Turbine, “Tubishof” energy recovery system, Luxembourg

Figure 10

Key facts:

- Flow Rate: 28 l/s
- Differential pressure: 11.5 bar
- Generated electricity: 200,000kWh per year

2.2.2 Technology 2. Solar drying of the sludge

A. Justification of the necessity

The general technological scheme of the sludge treatment in Sofia WWTP is presented on Figure 11.

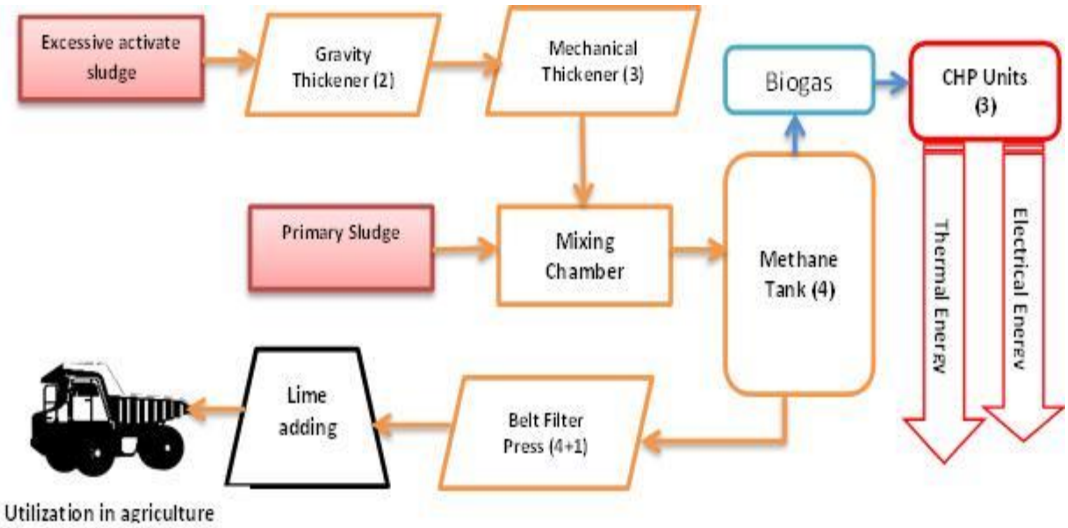


Figure 11 Technological scheme of sludge treatment at Sofia WWTP

Although the technology includes dewatering, the trend is towards increasing the amount of the sludge (Figure 12). The reasons for this trend are (SMS, 2010):

- Extension and rehabilitation of the wastewater collecting network within the town of Sofia;
- Connection of neighboring villages within the Sofia city areal to SWWTP, namely: Bankya, Novi Iskar, Chepintzi, Negovan, Svetovrachane, Kubratovo,

Benkovski, Orlandovtzi, Pancharevo, Gorubljane, Simeonovo, Dragalevtzi, Kinocentar, Boyana, Vrazdebna, Manastirski Livadi and Knyazhevo.

- Construction of local WWTPs at several small villages that will transport the produced sludge to SWWTP for further treatment. These are the following villages: Lozen, German, Bistritza, Zeleznitza, Vladaya, Marchaevo, Plana, Kokalyane, Dolni Pasarel, Malo Buchino, Voluyak, Mramor, Ziten, Trebich, Mirovyane, Dobroslavtzi, Balsha, Katina, Gnilyane, Podgumer, Vojnegovtzi, Lokorsko.

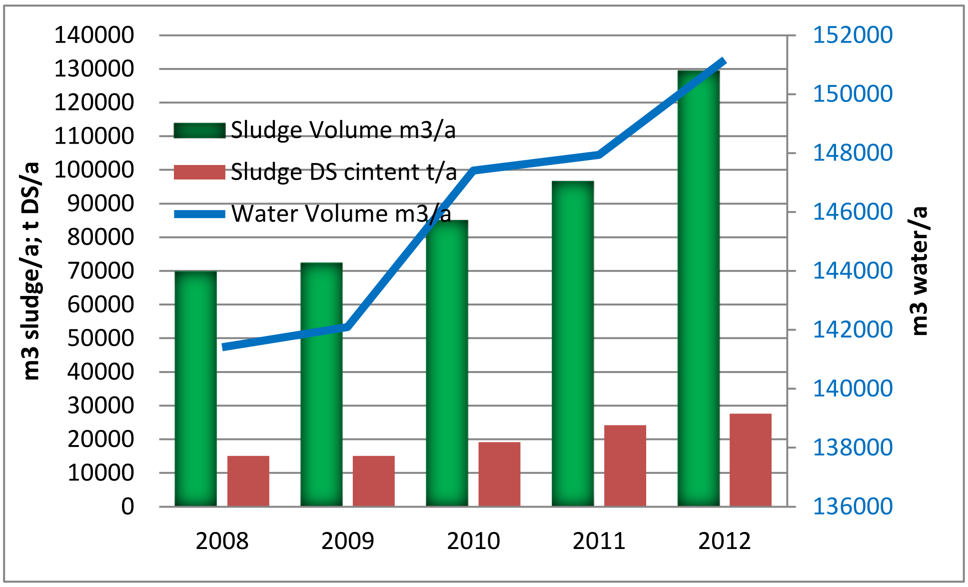


Figure 12 Trends in sludge production in SWWTP for the period 2008-2012

In the past the sludge was disposed on the landfill, but this option is no longer available due to EU policy restrictions (CEU, 1999). At present the sludge from Sofia WWTP is applied on agricultural land in compliance with the requirements of the Ordinance on the order and way of WWTP sludge utilization through its application on agricultural land (SG, 2004). The sludge is transported to the recipient agricultural land at about 25 km distance (in one direction).

The baseline eco-efficiency assessment identified that this method of sludge disposal leads to negative environmental effect due to the air emissions resulting from sludge transportation as well as transportation of lime for its treatment (see Deliverable 3.2). In addition, there are other disadvantages and further risks:

- The sludge disposal depends on the quality of the produced sludge and the willingness of the agricultural land owners to accept sludge;
- The arable land that can be used as recipient is limited; further sludge can be applied once in five years at the same arable land, assuming that both the quality of sludge and arable land allow this procedure;
- Change of EU policy framework concerning wastewater sludge application on agricultural land is possible due to population's negative attitude and the raising concern on the presence of micro pollutants in sludge.

The problem of final disposal of the sludge is pressing for Sofia WWTP. The capacity of sludge drying beds is limited to 80,000 t sludge per annum. By 2025 the sludge amount is expected to reach about 32,500 t DS/a (25% DS). If the present status of sludge treatment and final agricultural application continues, new terrains for temporary sludge storage (sludge drying beds) have to be allocated (about 18 ha). Therefore it is critical to implement a treatment unit which either decreases the sludge amount or makes the sludge appropriate for utilization for other purposes (e.g. incineration).

In 2010 the managing staff of Sofia WWTP together with experts form Sofia Municipality developed the "Strategy for management of sludge produced during the treatment of wastewater of Sofia Municipality until 2025". Within the strategy several options for sludge polishing and final disposal have been analyzed:

- Changing the operation of methane tanks from mesophyll (35-37 °C) into thermophile (50-55°C) regime of digestion;
- Introduction of sludge pasteurization at 60°C temperature for 2 hours in autoclaves before entering the methane tanks;
- Sludge composting before utilization in agriculture or further treatment to obtain a product appropriate for burning;
- Sludge drying (to 10% DS) with addition of energy by burning of wooden chips;
- Sludge burning with addition of energy by burning:
    - Gas fuel;
    - Wooden chips;
- Temporary sludge disposal at landfill or other terrain outside SWWTP:

Strengths, Weaknesses, Opportunities, and Threats SWOT analysis has been performed for each of the proposed measures. Sludge pasteurization and sludge burning were rejected as inappropriate options due to extremely high energy demand. The rest of the technologies were evaluated relatively according to several criteria. The conclusions are summarized in Table 4.

Table 4 Evaluation of the proposed measures in the Sludge Management Strategy of Sofia WWTP (SSM, 2010)

Measure	Capital Investment	Legislative compliance	O&M expenses	Hierarchy of preference	Negative social effect	Total evaluation
Existing Situation	10	1**	5	6	4	26
Thermophile regime	4	1**	1	8	3	17
Composting	1	10	6	10	10	37
Sludge drying	3	10	10	10	10	43
Sludge burning (wooden chips)	2	10	8	4	1	25
Sludge disposal	5	1	2	1	1	10

Note:
* The evaluation is 1 to 10, as 10 is the most favourable
** When reaching the project capacity of the sludge facilities, the requirement of 12 months temporary disposal on the sludge drying beds cannot be reached.

Based on the evaluation criteria Option 4: Sludge drying (to 10% DS) with addition of energy by burning of wooden chips has got the highest score. The key benefit of Option 4 is that it significantly reduces the sludge volume due to sludge dewatering. Figure 13 presents the effect of sludge dewatering on the sludge volume: a sludge having 1000 kg dry solids content can reduce its volume almost 3 times by increasing the dry solids content from 25% to 70%.

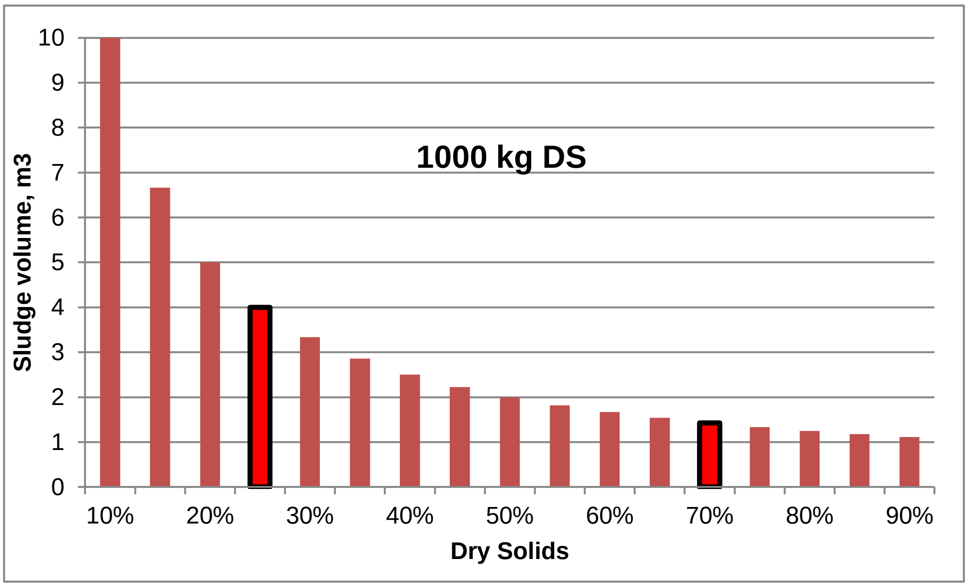


Figure 13 Decreasing of sludge volume due to sludge dewatering

Within the EcoWater Project the team from the UACEG proposes an **innovative technology of sludge drying by using solar energy** as alternative to Option 4. It is described below.

B. Description of the innovative technology

The driving force of drying is the difference between the partial vapor pressure of the water inside the sludge and the ambient air. In the course of drying the water evaporates and increases the humidity of the ambient air. In order to avoid equilibrium between the vapor pressure inside and outside the sludge, the air has to be regularly evacuated and replaced by fresh air. The key parameters that govern the solar sludge drying are: (1) the drying air temperature, (2) the drying air humidity, (3) the air flow velocity over the sludge, (4) the surface structure of the sludge and (5) the sludge temperature. Following these key parameters, the general design of solar sludge systems is based on the following principles:

- Provision of appropriate premise for sludge drying with a greenhouse effect;
- Provision of appropriate ventilation in order to have homogeneous distribution of the air inside the greenhouse with replacement of humidified air with fresh one;
- Regular (manual or automated) turning over of the sludge in order to facilitate the process of water evaporation from the sludge body;
- Provision of additional heating (optional) inside the greenhouse in order to speed up the process of drying and mitigate the negative effect of cold climate;

Depending on the mode of operation the solar sludge drying system can be designed as:

- Continuous mode - sludge is continuously supplied at the one end of the greenhouse and withdrawn at the other end;
- Batch mode – once the greenhouse premise is loaded with the design sludge quantity the sludge is turned over and mixed within the chamber; when it has reached the desired final dry solids concentration, the sludge is removed from the chamber and ready for its end use.

The general construction of a solar sludge dryer consists of a greenhouse equipped inside with drying fans. The greenhouse is made of transparent material (glass or polycarbonate plates) and a concrete floor, where the sludge is spread over the floor in thin layers. Depending on the raw sludge water content the floor might be equipped with a drainage system. Figure 14 presents a general scheme and Figures Figure 15 and Figure 16 present a general view of solar sludge drying systems.

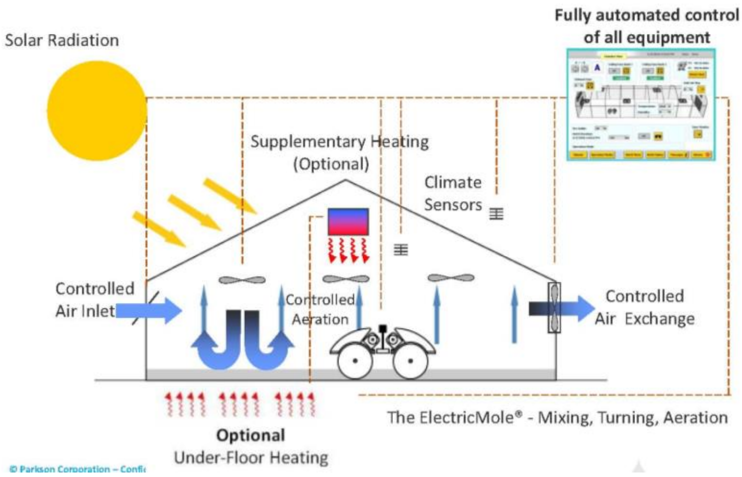


Figure 14 Scheme of Thermo-System, Parkson Corporation (www.parkson.com)

Although the physical process of drying happens also at open air, in this case the process is strongly dependent on the climate factors like air temperature, wind and rainfall events. During the rainy season the effect of sludge drying can be quickly neutralized by the amount of rainfall or snowfall water that has fallen over the sludge. That's why open air sludge drying is not a preferable option for countries with moderate climate.

Figure 15 Thermo-System installed in Okeechobee, Florida, USA (www.parkson.com)

Figure 16 WendeWolf system installed in Managua, Nicaragua (www.wendewolf.com)

The engineered solar sludge drying systems require appropriate ventilation (Figure 17). It is a combination of fans that provide controlled exchange of inside/outside air and uniform air temperature and humidity inside the greenhouse. Usually the ventilation system consists of:

- Natural or motor driven roof ventilation through openings on the roof or at the upper edge of the cross side walls. The air flow is automatically controlled based on the inside/outside temperature and air humidity;
- Axial fans - placed inside the hall to create air turbulence above the entire sludge surface, blowing away the moist boundary layer above the sludge surface and providing equal temperature and humidity of the ambient air;
- Side openings – installed at the side walls of the greenhouse to allow entrance of fresh air into the greenhouse. Their operation is usually synchronized with the roof ventilation.

Figure 17 Roof and axial fans of Thermo-SystemTM, (www.parkson.com)

In order to boost the drying process, sludge has to be turned over inside the greenhouse once or several times a day manually or automatic. During this process the sludge is also aerated, which further contributes not only to sludge drying but also to enhancing the quality of the final product (e.g decreasing of organic content). The automatic turnover of the sludge can be realized in different ways and there are several smart solutions on the market so far (Figure 18).

a) Electric Mole TM, Thermo-System TM, Parkson Corp. b) Reversing and conveying machine, WendeWolf®. c) SOLIAMIXTM windrower, Veolia Water

Figure 18 Devices for automatic turnover of sludge in the greenhouse

The solar sludge drying process is influenced to great extent by the outdoor climate conditions. In moderate climate the results from the systems in operation show that there is always difference in the performance during summer and winter season, as in the winter the time needed for achieving the desired sludge quality is much longer (Bux et al., 2001; Salihoglu et al., 2007; Mathioudakis et al., 2009). This characteristic requires relatively large area for greenhouses installation to ensure satisfactory performance of the system throughout the year. In order to make the process relatively independent by the outdoor conditions and thus to decrease the required area for sludge drying, an excessive source of heat can be applied to the system. It can be a solar/water heater, infrared lamps, heat pumps or adding thermal energy from other processes in the WWTP (e.g. the heating energy from CHP unit). On Figure 19 is presented a general scheme of solar sludge drying installation, assisted by a heat pump, developed by Slim et al. (2008). The heat pump is intended to boost the sludge drying especially in the period of non-favorable climatic conditions by transferring heat to two water circuits, as the first water circuit integrated is in the greenhouse floor, and the second one heats the air before entering the greenhouse. Thus the surrounding air and the floor are heated which results in improving evaporation conditions and the moisture transport from sludge inside to the surface throughout the year.

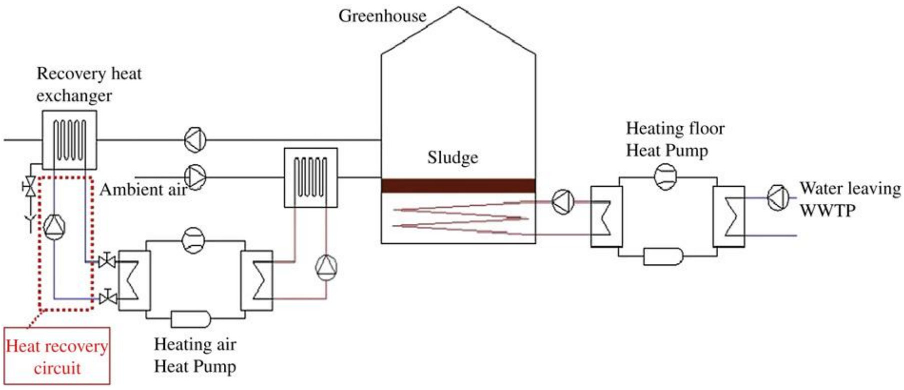


Figure 19. Schematic diagram of the Solar and Heat Pump Sludge Drying System, developed by Slim et al., 2008.

Depending on the sludge quality (i.e. water content) the sludge can be transported to the greenhouse either by pipes or by vehicles. Figure 20 visualizes sludge transportation by vehicle with dry solids content >20% (i.e. similar to the dry solids content of Sofia WWTP). The sludge is withdrawn from the greenhouse using vehicles.

WWTP Reignier, France
(www.wendewolf.com)

WWTP Palma de Malorca, Spain
(www.parkson.com)

Figure 20. Different ways of sludge transportation to the solar drying system

Solar Sludge Drying System Design Parameters and Performance

As mentioned above, the performance of the solar sludge drying systems depends to great extent on the water content of the input sludge and the climate conditions in the region. Nevertheless, based on pilot and full scale investigations in Europe and USA several important design parameters can be outlined:

- *Height of the sludge layer*

The sludge is spread in thin layers usually with 0.15 to 0.30 m height depending on the water content of the raw sludge (Table 5).

Table 5 Height of filling of the solar drying (Bux M. et al., 2009)

Dry Solids Content, %	Maximum Height of Filling, cm
10-15	15-20
15-20	20-25
>20	20-30

- *Amount of evaporated water*

The amount of evaporated water depends on the sludge water content, the effectiveness of the inside ventilation system and the outdoor conditions. A study on solar sludge drying systems in southern Germany shows that the annual drying capacity varies between 700 - 800 $kg_{evap,\ water}/m^2.a$, while in southern climates, such as Australia, it can reach up to 2000 $kg_{evap,water}/m^2.a$ (Luboschik U. (n.a)). Similar figures - 800 - 900 $kg_{evap,water}/m^2.a$ are quoted by WendeWolf® system based on successful operation of full scale plants in the European climate (www.wendewolf.com). Slim R. (2008) reports for the French city Agen (approximately the same longitude as Sofia) that the greenhouse drying performances evaluated in terms of mass of water evaporated per unit area and per day range between 0.5 $kg_{evap,water}/m^2.day$ (in winter) and 5.5 $kg_{evap,water}/m^2.day$ (in summer), i.e. in average around 1000 $kg_{evap,water}/m^2.a$.

- *Area required*

Depending on the local climate conditions, final DS content and sludge characteristics, in purely solar operation (without utilization of waste heat) the following approximate quantities are reported by Thermo-System (www.thermo-system.com):

- Liquid sludge (2 - 6% DS): 2 - 6 t of sludge/m^2/a
- Pre-dewatered sludge (25 - 30% DS): 0.5 - 3 t of sludge/m^2/a

When waste heat from other processes is utilized (e.g. from a Combined Heat and Power (CHP) unit) the throughput can be greatly increased and the area requirement reduced.

- *Electric Power Requirements*

90% of the required energy is provided by the most environment friendly source, without any CO_2 emissions – the sun. The rest of the energy required for the ventilation and the turning of the sludge is in the range of 10 to 40 kWh per ton evaporated water. Compared with the energy required for thermal dryers, which is in the range of 700-1000 kWh per ton evaporated water, the solar sludge drying system is extremely efficient and economic friendly, since it is a low CO_2 emission technology (Bux et al, 2001; Voskens and Zegers, 2005).

Solar Sludge Drying System Performance

Depending on the seasonal weather conditions the expected sludge dry solids content may vary from 50% to 90%.

Many studies report a significant decrease of pathogen content in sludge in a way that the sludge can reach the requirements of Environmental Protection Agency (EPA) for bio solids class A (Bux et.al., 2001; EPA, 2007; Salihoglu N.K 2007; Mathioudakis et. al 2009).

Bux et. Al (2001) has found that the volatile solids content was reduced during the drying process from 61 to 37% w/w for aerobically digested sludge and from 52 to 43% w/w for anaerobically digested sludge in the treatment process.

Place of Solar Sludge Drying System in the treatment process

The system is using processed sludge that has undergone treatment and dewatering (optional). In case of Sofia WWTP the sludge after the filter press would be subject to solar sludge drying. So, the eventual implementation of the system will not necessitate any change of the existing technological processes of water and sludge treatment. The eventual implementation of the system will require however plenty of space. Currently the open sludge drying beds occupy about 90,000 m^2 area. A part of the sludge drying beds can be replaced by solar sludge drying system.

C. Economic data

Economic Benefits

- Low operational cost - the sun energy, which is a free of charge source, covers about 90% of the energy demand of the process;
- Significantly reduced costs for sludge hauling due to decreased sludge volume ;
- Decreased operational costs for chemical sludge treatment (lime adding) for getting into compliance with the sanitary requirements;
- Low staffing costs – the drying process is almost fully automated and its monitoring do not require highly trained staff.
- Appropriate for energy production - the heating value of the dried sludge (75% DS) is approximately the same as raw brown coal. The sludge might be used as an energy source in cement producing industries or power stations for generating electricity.

Investment Costs

It is reported that the investment cost range between 350 – 500 €/m^2 partly due to civil engineering works and partly due to mechanical equipment (e.g fans, sludge mixer) (Slim R., 2008). The machinery part of the total investment covers about 20%, with expected lifespan of the machinery 15 years. The expected lifespan of the other elements of the system is reported to be 30 years. It has to be noted that the reported costs are based on prices in old EU countries. In Bulgaria, it might be expected that the cost of civil engineering works is less.

Operation Costs

As reported above the additional energy requirement ranges between 10 and 40 kWh per ton evaporated water. This presents less than 5% of the energy that would be required if thermal dryers are applied, i.e. 700-1,000 kWh per ton evaporated water

Maintenance Costs

The personal costs are very low, since the system is almost fully automated. 1-2 persons operational staff is required, not highly qualified for approximate time of 4 hours per day during the loading and emptying of the system.

D. Environmental performance

Environmental Benefits

Significantly decreased air emissions compared with classical drying. The sun is a natural energy source without any CO_2 production. The rest of the energy demand which is about 20 to 40 kWh/ton evaporated water is incomparable with the energy demand of thermal dryers - 700 – 1,000 kWh/ton evaporated water (www.wendewolf.com);

Further decreased air emissions by reducing the hauling costs due to decreased sludge volume;

The technology is not using water resources and has no harmful emissions to the environment.

Table 6 Examples for application of the technology in big WWTPs

Place	Design parameters	Solar Sludge System applied
Palma de Mallorca, Spain; 600,000 PE; 40 MGD	Sludge: 33,000 t/a (20-30% DS); Approx.: 11,000 tDS/a Target DS: 60-80%	***Thermo-System*** ***TM*** Area: approx. 20,000 m^2 Additional heat input : 0-500 kWh, year of construction : 2010
WWTP Nicaragua, Managua 1,100,000 PE; 297,000 m3/d; BOD5 50,000 kg/d	Sludge: 26,000 m3/a (28% DS); Approx.: 7,250 t DS/a Target DS: > 60%	***WendeWolf*** ***TM*** Area: approx. 8,760 m^2 Additional heat input :No, year of construction : 2009
WWTP Dubai	Sludge: 140,000 m^3/a (15-20% DS) 70,000 m^3/a will be processed at the first stage Target DS: up to 90%	The contract is commissioned to ***Thermo-System*** ***TM in 2013***. The project is in progress.

E. Maturity and availability

In the early 1990s, the technology of solar sludge drying has been introduced in Europe and recently more than 150 installations have been constructed all over the world (Hill, 2011;. Luboschik, (n.a)).

- Thermo-System ™, Parkson Corporation – more than 200 installations over the world;
- WendeWolf ™, IST Anlagenbau GmbH – more than 80 installations over the world as more than 50% were built since 2006;
- Solia™, Veolia Water – around 10 installations'.

In the past the solar sludge drying system was used mostly for small and middle size WWTPs. The ever increasing requirements for sludge quality, the limitations on the

CO_2 emissions and the demand for sustainable management of the produced sludge has recently turned the interest of solar sludge system also to bigger WWTPs (> 100,000 P.E)

Examples of successful application of solar sludge drying systems for bigger WWTPs are presented in Table 6.

2.3 Water use technologies

Three technologies will be studied with the following general objectives:

1. To reduce the water amount consumed by domestic users;
2. To reduce use of energy generated from non-renewable sources, which is used for domestic needs, associated with water use

More details about the environmental and economic benefits, derived from these technologies are given below.

2.3.1 Technology 3. Water saving appliances

A. Justification of the necessity

The urban water system of Sofia is the highest consumer of fresh water in the Upper Iskar river basin (Figure 21 and Figure 22).

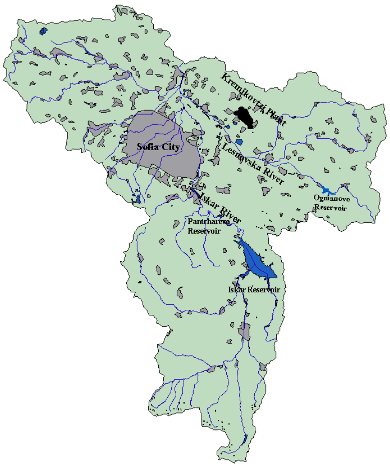


Figure 21 Geographical borders, rivers (in blue) and settlements (in gray) of Upper Iskar catchment

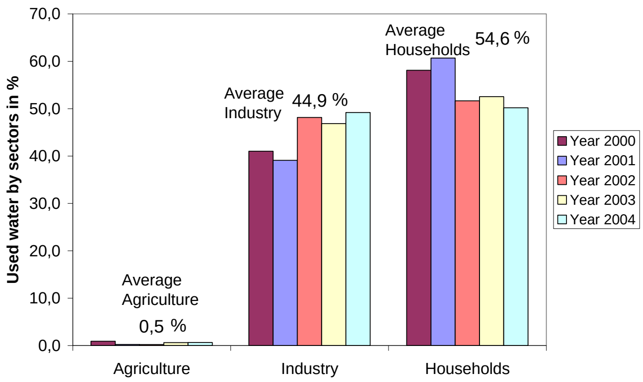


Figure 22 Water used by sectors for the years 2000-2004 (data from the National Statistical Institute)

Data provided by the National Statistical Institute on our request for the years 2000 to 2005 show that water exploitation index (WEI) in the Upper Iskar varies between 0.41 and 0.46, which indicates water stress (EEA, 2003). These years were characterized with usual temperatures and rainfalls for the moderate climate zone. However, 100 years data series show that there are many periods with less than average precipitation. During these periods severe water stress is indicated.

The domestic users are the predominant water consumer not only at the catchment level, but in Sofia urban water system itself as well. Therefore, improving of the domestic water consumption towards eco-efficient performance would have a significant impact over the whole urban water system and catchment. The socio-economic development of Sofia prompts that in the future the potable water needs in

Sofia will increase, on the other hand there are significant potentials for water saving in the households.

Table 7 presents the average water consumption per person per day for the last 5 years.

Table 7 The average water consumption in the households in Sofia in liters per capita per day (taken from Deliverable 3.1)

	2006	2007	2008	2009	2010
Water used by population per capita - (l/ca/day)	143.0	146.1	141	140	140

Data Source: National Statistical Institute

Although there is a trend for decreasing of water consumption per capita per day in Sofia, it is still higher (with about 40%) than the average one for the country (Figure 23).

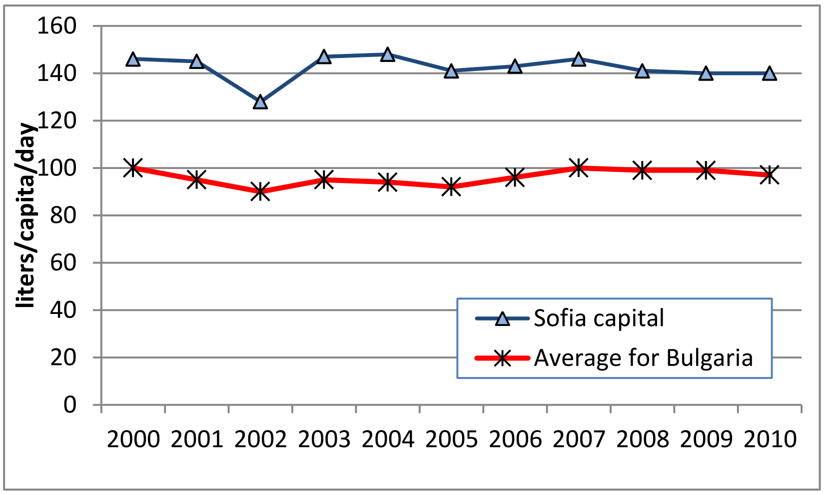


Figure 23 Water consumption in the households in Bulgaria, (www.nsi.bg)

Sustainable water use is a world concern. Table 8 demonstrates well the historical trend towards manufacturing of appliances consuming less water.

Table 8 Water usage rates for domestic fixtures, (FEMP, 2002)

Technology	Unit	Pre-1990 Usage	Pre-EPAct Usage	EPAct Requirement (1994–1997)	2000 Efficient Models
Faucet	Liters per minute	18.9-26.5	15.1	9.5	1.9
Showerhead	Liters per minute	17–30.3	13.2	9.5	5.7
Tank toilet	Liters per flush	15.1–26.5	13.2	6.1	3.8
Flushometer toilet	Liters per flush	17	13.2	6.1	3.8
Clothes washer			170.3-208.2	170.3	94.6
Dishwasher	Liters per unit		56.8	37.9-56.8	17–22.7

Within the EcoWater project application of water saving appliances will be studied as one of the selected innovative technologies.

B. Description

B1. General considerations

Household indoor demand is dependent on a wide range of variables. The most important factors affecting indoor household water consumption are:

- The type of water intensive household appliance installed (Mayer et al., 2004; Decook et al., 1988)
- Household occupancy (Mitchell, 2001; Turner et al., 2005);
- Household income (Jones and Morris, 1984; Moncur, 1987);

Other factors like the age distribution of the population may also affect the amount of water use since some age groups tend to have higher per capita water usage than others (Flörke and Alcamo, 2004). There is also a difference observed between water consumption patterns in urban versus rural areas (Flörke and Alcamo, 2004).

Higher water prices are also known to dampen the demand for water in households and businesses (Hansen, 1994; Dalhuisen et al., 2003).

In EcoWater project, the first factor (installing of water saving household appliances) will be the main target. However, the other two factors (household occupancy and household income) will be considered so that to make a prognosis of the number of household, which potentially will change their appliances.

Although the type and the frequency of use of different household appliances is very individual the largest water users within a household are the bathing, the toilets flushing, followed by the clothes and dish washers (Figure 24).

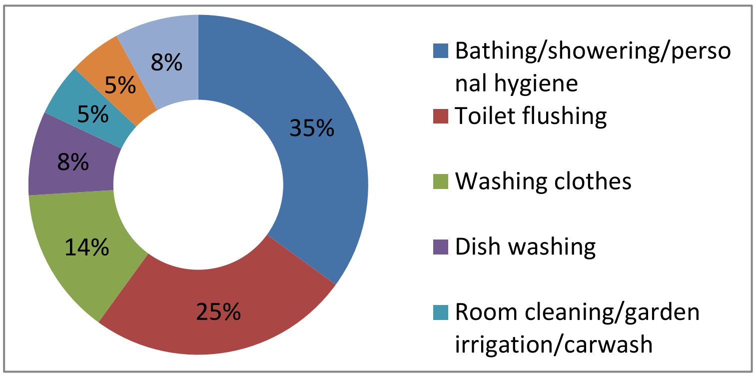


Figure 24 Residential water use in the EU (Mudgal et al, 2012)

Water consumption data of commonly used household appliances in some EU member states were collected within a BIO Intelligence service study (2009). The results are summarized in Table 9.

Table 9 Water consumption of commonly used water appliances in residential buildings (Mudgal et al, 2009)

WuP	Average water consumption per use	Frequency of use per day	Average water consumption per day (l/household/day)	Range of water consumption per day (l/household/day)
WCs	6.0 - 9.5 l/flush	7.0 - 11.6	101.8	84.8 - 118.8
Showers	25.7 - 60 l/shower	0.75 - 2.5	91.8	37.5- 146
Taps	2.3 - 5.8 l/use	10.6 - 37.9	74.6	61.9 - 87.2
Clothes washers	39.0 - 117.0 l/use	0.6 - 0.8	65.6	48.6 - 82.6
Dishwasher	21.3 - 47.0 l/use	0.5 - 0.7	24.3	15.1 - 33.4
Outdoor use[8]	0 - 48.5 l/use	0 - 0.89	21.8	0 - 43.5

Table 10 presents some examples of water saving calculations based on a study on water performance of buildings (Mudgal et al, 2009).

Table 10 Water saving calculations in buildings (Mudgal et al, 2009)

(a) Baseline case

	kitchen tap	basin tap	shower	bath	WC full	WC short
vol/flow	12.00	12.00	12.00	225.00	6.00	6.00
use factor	0.67	0.40	5.00	0.14	0.33	0.67
uses/person/day	4.00	3.00	0.60	0.40	1.58	3.21
CHS factor	2.68	1.20	3.00	0.06	1.58	3.21
fudge factor	0.67	0.67	1.00	1.00	1.00	1.00
TOTAL /person/day	**21.55**	**9.65**	**36.00**	**12.86**	**9.50**	**19.28**
	washing machine	dishwasher	bidet	water softener	outside	TOTAL
vol/flow	49.00	13.00	1.00	1.00	8.12	
use factor	1.00	1.00	2.64			
uses/person/day	0.20	0.20	2.00			
CHS factor	0.20	0.20	5.28	12.50		
fudge factor	1.00	1.00	1.00	1.00		
TOTAL /person/day	**9.80**	**2.60**	**5.28**	**12.50**	**8.12**	**147.13**

(b) With efficient fixtures

	kitchen tap	basin tap	shower	bath	WC full	WC short
vol/flow	8.00	6.00	8.00	160.00	6.00	3.00
use factor	0.67	0.40	5.00	0.14	0.33	0.67
uses/person/day	4.00	3.00	0.60	0.40	1.58	3.21
CHS factor	2.68	1.20	3.00	0.06	1.58	3.21
fudge factor	0.67	0.67	1.00	1.00	1.00	1.00
TOTAL /person/day	**14.36**	**4.82**	**24.00**	**9.14**	**9.50**	**9.64**
	washing machine	dishwasher	bidet	water softener	outside	TOTAL
vol/flow	40.00	12.00	0.00	0.00	8.12	
use factor	1.00	1.00	2.64			
uses/person/day	0.20	0.20	2.00			
CHS factor	0.20	0.20	5.28	12.50		
fudge factor	1.00	1.00	1.00	1.00		
TOTAL /person/day	**8.00**	**2.40**	**0.00**	**0.00**	**8.12**	**81.87**

These results show that the potential of water saving in households through implementation of efficient appliances is significant and may lead to reduction of water consumption with about 40% in total. Among the commonly used appliances the biggest potential for reduction is in the basin taps (50%) and WC short (50%); the appliances with 100% expected reduction are the bidet and the water softener.

Below innovative appliances, which consume less water, energy or both, will be briefly presented. The order of the presentation follows their importance in regard to their % of the total household water use (Figure 24)

B2. Water saving showerheads

The average consumption of hot water for shower is around 60% of the total water used (Dimitrov, G., 2004).

Modification 1

Conventional showerheads typically deliver 11 – 30 liters of water per minute. Conservation is accomplished by restricting water's flow rate through the showerhead. Showerheads with reduced flows as low as 8 liters per minute (lpm), at normal household water pressure, have been designed to give an acceptable shower and reduce water use. They can be sensitive to low water pressure and sudden changes in temperature; consequently, proper pressure-balanced mixing valves are necessary. Exiting water temperatures normally need to be slightly higher because the smaller droplets cool quickly. Slightly hotter water does not negate the substantial energy savings achieved by low-flow showerheads. Replacing conventional 11 lpm showerheads with the low-volume, 9 lpm models saves approximately 3,800 liters of water per year per person (Pennstate, 2004).

Modification 2 - Go Green shower head

It works according to the "turbulent flow" principle and provides a powerful "massage" of more than 8 million water drops per minute. It uses only 4 to 8 liters of water per minute without decreasing the shower comfort. Actual water savings: 9052 liters/person/year (Water saving).

B3.Faucets

Home water works suggests an aerator, which is easy to fix either in kitchen faucets or to bathroom faucets. It restricts the maximum flow rate of water from the faucet. Because hot water is frequently drawn from faucets, reducing flows also reduces hot water use which means energy savings (Home water works, 2013).

Low-flow aerators save water simply by reducing the flow from the faucet while mixing water with air. Many low-flow faucets are designed to maintain a flow at the standard 9.5 lpm rate, and some operate at even lower rates - 2, 4, 6 lpm. With water saving aerator it is possible to save up to 85% of the running water (FEMP, Water saving).

The price per item is below 1 Euro.

B4. Toilets

A huge variety of innovative toilets is available in the market. Here three modifications will be described, considering the awards, which they possess (http://www.consumersearch.com/toilets/toto-drake-ii-cst454cefg-01).

Modification 1 – Best standard toilet

Toto Drake CST744SG-01

It removes a hefty 1,000 grams of solid waste or more with a single flush, using only 6 liters of water, and there is ion-barrier glaze reduces bacteria and debris build-up. The price is 250 USD.

Modification 2 – Best water-saving toilet

Toto Drake II CST454CEFG-01

It uses just 4.8 liters of water per flush. Double Cyclone flushing technology and Toto's SanaGloss bowl coating prevent bacteria buildup, making this toilet one of the most efficient at removing waste. Owners say it rarely clogs and does an exceptional job of cleaning the bowl with every flush. The price is 330 USD.

Modification 3 – Best designer toilet

Roca W+W

The Roca W+W (washbasin and water closet) has won multiple design awards for its unique shape, which combines a toilet and sink in one sleek form. It uses about 25 percent less water than standard low-flow toilets, recycles wastewater from the sink to be used in the bowl, and has a built-in disinfecting system to cut down on odors. It also attaches to a wall, making it a great choice for a small bathroom. The price is 4000 USD.

B5. Washing machines and dishwashers

Regarding the electrical sanitary appliances (washing machines and dishwashers) higher standard towards their energy consumption have been set. The COMMISSION DELEGATED REGULATION of 28.9.2010, introduced energy efficiency index (EEI). It is an energy labeling scheme which provides standardized information on energy consumption of household water appliances by means of a ranking of products on a scale from A to G. Table 11 presents the values for the EEI for washing machines and dishwashers in relation to their energy class.

Table 11 Energy efficiency for washing machines and dishwashers

Energy efficiency class	EEI for washing machines	EEI for dishwashers
A+++	EEI<50	EEI<46
A++	50<EEI<56	46<EEI<52
A+	56<EEI<63	52<EEI<59
A	63<EEI<71	59<EEI<68
B	71<EEI<80	68<EEI<77
C	80<EEI<90	77<EEI<87
D	EEI>90	EEI>87

C. Economic data

The investment in water efficient household appliances is strongly dependent both on the residents will to install such devices and their economic ability to afford buying such appliances and installing them.

According to an EU Report “Study on Water Performance of Buildings” (Mudgal et al, 2009) the water consumption can be decreased by three levels of retrofitting (Table 12)

- **First Level of Retrofitting** can be achieved by changing with more efficient showerhead (12 to 8 liters/min) and more efficient taps (12 to 10 liters). This action may lead to a rough 20-25 % saving at a reduced cost.
- **Second Level of Retrofitting** can be reached with fixture changes as toilets (3/6 l dual flush), reduction of bath size and investments in more efficient white goods (marginal part of the saving, for a high cost, which explains the high variability of cost mentioned on this line). With such changes one could save around 35-45% of water as compared to the base case.
- **Third Level of Retrofitting** can be achieved in significant modifications in the water system, such like water reuse installations, or rainwater harvesting, etc. These modifications can help achieving 10% more of water consumption, after of course the other retrofits have already taken place.

Table 12 Potential water saving with buildings (Mudgal et al, 2009)

Water consumption within household	No behavioural changes		With assumed moderated behavioural changes	With assumed higher behavioural changes	Estimated cost per capita (assumption : 2.7 inhabitants)
	l/capita/day	% changes	% changes	% changes	€
No fixture changes (base case)	150	0	20%	30%	0
First level retrofitting	120	20%	33%	40%	15 – 35
Best efficiency fittings of key fixtures	90	40%	50%	55%	100 – 300
Best fittings, plus water reuse	75	50%	55%	60%	1 200 – 2 000

The figures are taken by the assumptions that:

- One household consists of 2.7 people;
- Water consumption units are: 6 l/toilet/per flush; 12 l/min shower and tap consumption, bath taken 1/week and outdoor uses 8 m^3/a.

The same study also quotes the payback periods for direct saving investments in a dwelling (Table 13).

In Sofia the water and sewerage service price is much lower than the quoted data (around 0.80 EUR/m^3) therefore the payback period for the households will be longer and a case specific investigation need to be developed.

D. Environmental performance

The approach of water-efficient plumbing fixtures and appliances for home will effect towards the global issue of water conservation that will further contribute to reducing water and energy use, as well as waste flows to sewage treatment plants. Household water and energy conservation are inescapably linked: by saving water the energy needed to get it and treat it is preserved. By reducing the use of hot water the saving effect is even higher, since the energy consumed in heating water ranks second behind that used for home heating and cooling. The energy conservation will further help to alleviate major environmental problems such as global warming and acid rain (Sharp and Swistock, 2004).

Table 13 Payback period for direct saving investments in a dwelling (Mudgal et al, 2009)

No behavioural changes			Water price = average EU 2008 = 2 €/m^3		Water price = most expensive EU 2008 price = 4.5 €/m^3	
	Average Investment costs	Annual m^3 saved	Annual savings (€)	Payback period (year)	Annual savings (€)	Payback period (years)
First level retrofitting	**25**	11.0	21.9	1.1	49.3	0.51
Best efficiency fittings of key fixtures	**250**	21.9	43.8	5.7	98.5	2.5
Best fittings, plus water reuse	**1700**	27.4	54.8	31.1	123.2	13.8

Table 14 Estimated water and energy savings from various water saving fixtures (Pennstate, 2004)

	Frequency of Use (per person)	Daily Water Use Without Water Conservation Device (gal/person)*	Daily Water Use with Water Saving Device (gal/person)	Daily Water Savings with Water Saving Devices (gal/person)	Annual Water Savings (gal/person)	Estimated Annual Energy Savings of kilowatt-hours (per person)
Low-flush Toilet (1.6 gpf)	5.1 flushes/day	20.4	8.2	12.2	4,453	0
Low-volume Showerhead (2.5 gpm)	5.3 minutes/day	15.9	13.3	2.6	949	123
Low-volume Faucet (rated flow 1.5 gpm)	4 minutes/day	12	6	6	2,190	125
Front-loading Washing Machine (27/gpl)	0.37 loads/day	18.9	10	8.9	3,249	316
Water-Efficient Dishwasher (7.0 gpl)	0.1 loads/day	1.1	0.7	0.4	146	36
Total		**68.3**	**38.2**	**30.1**	**10,987**	**600**

Table 14 presents some data on water and energy saving from various water saving fixtures.

E. Maturity and availability

There is an increase of public support for water saving through the use of efficient products; however nowadays there is abundance of household water appliances on the world market. In order to facilitate the consumers in their choice for efficient household water appliance, the Water Label Company Ltd (http://www.europeanwaterlabel.eu) is suggesting the development of so called universal labeling of water using products. Similarly to other voluntary labeling schemes to facilitate purchase decision for consumers (e.g EcoLabel) the labeling is proposed to be extended to include also sanitary tap ware. Thus the consumers can see how much water and energy their household appliances will use. The scheme on Figure 25 provides easy access to a database of bathroom products which when installed and used correctly will use less water, save energy and save money (Water label).

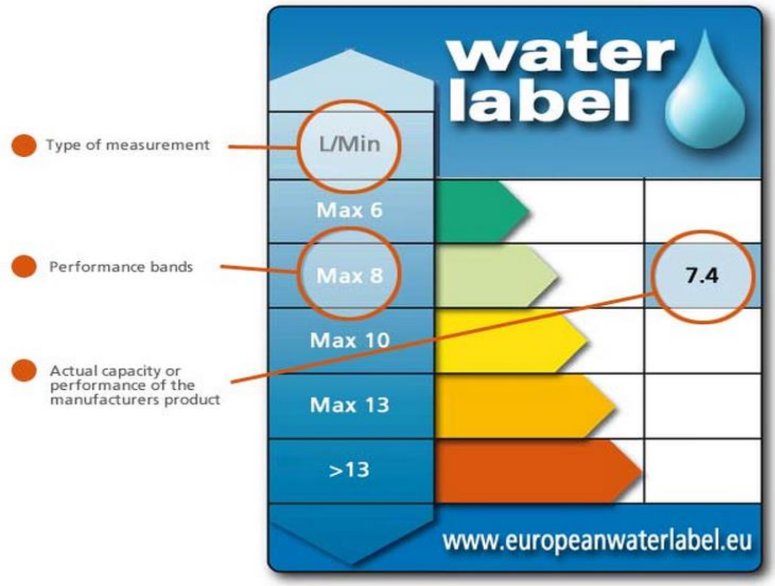


Figure 25 Water label

In Australia the WELS standard requires products to meet a certain water efficiency standard to obtain the label with e.g 25% of water saving generated for showers. Standards exist for tap equipment, flow controllers, toilets etc. In the UK the Bathroom manufacturing association (BMA) Water Efficient Product Label has up to now been awarded to 28 brands of water using products (Mudgal et.al, 2012)

2.3.2 Technology 4. Solar water heating (SWH)

A. Justification of the necessity

The baseline eco-efficiency assessment showed that reducing the water consumption will have more than one environmental benefit. It is easy understandable and logical that when people use less water, less water will be taken from the nature, therefore freshwater ecosystem negative impact will be reduced. However, it is not always realized that there is strong relationship between the water, consumed and the energy associated with it - for heating the water, for using dishwashers and washing machines.

Figure 1 shows that it is namely water use stage with highest negative contribution. Heating of the water is the biggest GHG emitter and second biggest emitter in regard to the energy consumed in an average household (Figure 26). Therefore, it will be useful to study innovative technologies for water heating. Technologies 4 and 5 were selected for this purpose.

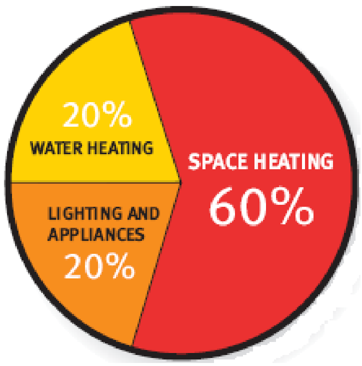


Figure 26 Energy consumption in households (Efficiency NB)

B. Description

B1. General considerations

The sun's average power represents 10,000 times the power required for the world's population (Cariou, 2010). Solar resource is measured by the solar radiation intensity of an area. The power of solar radiation entering the atmosphere, or the "solar constant," is 1,367 W/m^2. Within the atmosphere, this power is reduced by absorption, scattering, and reflection effects to about 1,000 W/m^2 on the earth's surface if there is a clear sky. The amount of solar energy available for heating water varies by geographical location. The solar radiation that reaches the earth's surface is further reduced by clouds, which reflect part of the radiation back into space, and absorb another part (US Army Corps of Engineers, 2011).

Heating water with solar energy can be a cost effective and environmentally responsible way to generate hot water, minimizing the expense of electricity or fossil fuels to heat water and reducing the associated environmental impacts. Solar water heating systems use solar collectors to capture sunlight to heat water (or an antifreeze liquid) that is then moved from the collector to storage and then to its point of use. There are two types of systems, active and passive.

- **Active systems** use electricity for pumping the fluid and have a reservoir or tank for heat storage and subsequent use.
- **Passive systems** rely on natural convection and water pressure during draw to move fluids, and require no circulation hardware.

Table 15 Comparison of water heaters (http://www.energystar.gov)

Comparison of Water Heaters					
High Efficiency Water Heater Type	**Energy Savings vs. Minimum Standards**	**Best Climates**	**Expected Energy Savings Over Equipment Lifetime**	**Expected Lifetime**	**Major Advantages**
High Efficiency Storage (Tank) (Oil, Gas, Elec.)	10%–20%	Any	Up to $500	8–10 Years	Lowest first cost
Demand (Tankless) Using Gas or Elec.	45%–60%	Any	Up to $1,800	20 Years	Unlimited supply of hot water
Heat Pump	65% (Compared to electric resistance)	Mild-Hot	Up to $900	10 Years	Most efficient electric fuel option
Solar with Electric Back-Up	70%–90%	Mild-Hot	Up to $2,200	20 Years	Largest energy savings using a renewable energy source

The systems may be used to heat water in homes, businesses, and for industrial uses. In many climates, a solar hot water system can provide up to 80% or more of the energy needed to heat water. Solar water heating systems almost always require a backup system for cloudy days and times of increased demand. Conventional natural gas or electric water heaters typically provide backup, so hot water is always available, regardless of the weather (FEMP, 2012).

A comparison of commonly used water heaters is shown in Table 15. It can be seen that the biggest energy savings are achieved with solar water heating.

Table 16 Monthly solar irradiation (JRC)

Month	Hh	Hopt	H(90)	Iopt	T24h	NDD
Jan	1550	2410	2390	62	0.0	542
Feb	2370	3320	2950	54	2.0	435
Mar	3540	4390	3300	43	5.7	351
Apr	4560	4920	2950	27	10.8	147
May	5570	5490	2670	15	16.2	37
Jun	6260	5890	2520	9	19.7	10
Jul	6460	6240	2750	13	21.9	4
Aug	5770	6090	3250	24	21.7	19
Sep	4150	4960	3450	38	16.7	86
Oct	2840	3960	3400	52	12.3	268
Nov	1870	2990	2960	62	6.5	433
Dec	1380	2090	2070	61	1.2	545
Year	3870	4400	2890	34	11.2	2877

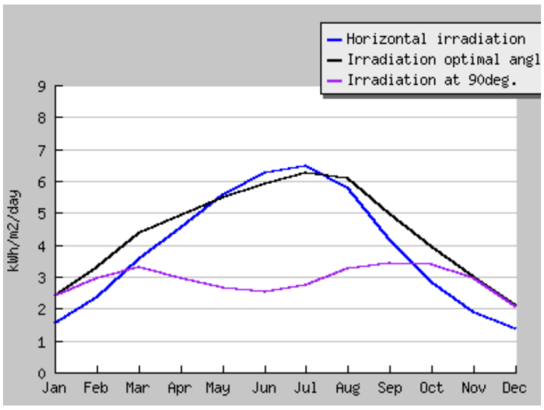


Figure 27 Monthly solar irradiation

Hh: Irradiation on horizontal plane (Wh/m²/day)
Hopt: Irradiation on optimally inclined plane (Wh/m²/day)
Iopt: Optimal inclination (deg.)
T24h: 24 hour average of temperature (°C)
NDD: Number of heating degree-days (-)
H(90): Irradiation on plane at angle: 90deg. (Wh/m²/day)

In Bulgaria the average annual period of sunshine is about 2,100 hours, in some of its regions it may reach 2,500 hours (i.e. the range is from 1,450 to 1,600 kWh/m² annually) (Figure 28). The solar monthly radiation changes during the year from 41-52 kWh/m^2 in January till 200-238 kWh/m^2 in July (Table 16 and Figure 27) (Sofia Energy Centre).

B2. Basic components of most common residential SWHs

The most common residential SWHs have 5 basic components, shown in Figure 29.

- **Solar thermal collector(s)** - flat-plate and evacuated tube collectors are the most typical.
- **Storage system** - to meet the thermal energy demand when solar radiation is not available.
- **Heat transfer system** - piping and valves for liquids; pumps, fans, and heat exchangers (HXs), if necessary.
- **Control system** - to manage the collection, storage, and distribution of thermal energy.

Back up Heating - to provide supplemental heat when solar energy is not sufficient to meet demand. This is typically a conventional electric resistance or natural gas storage tank WH (Hudon et al. 2012).

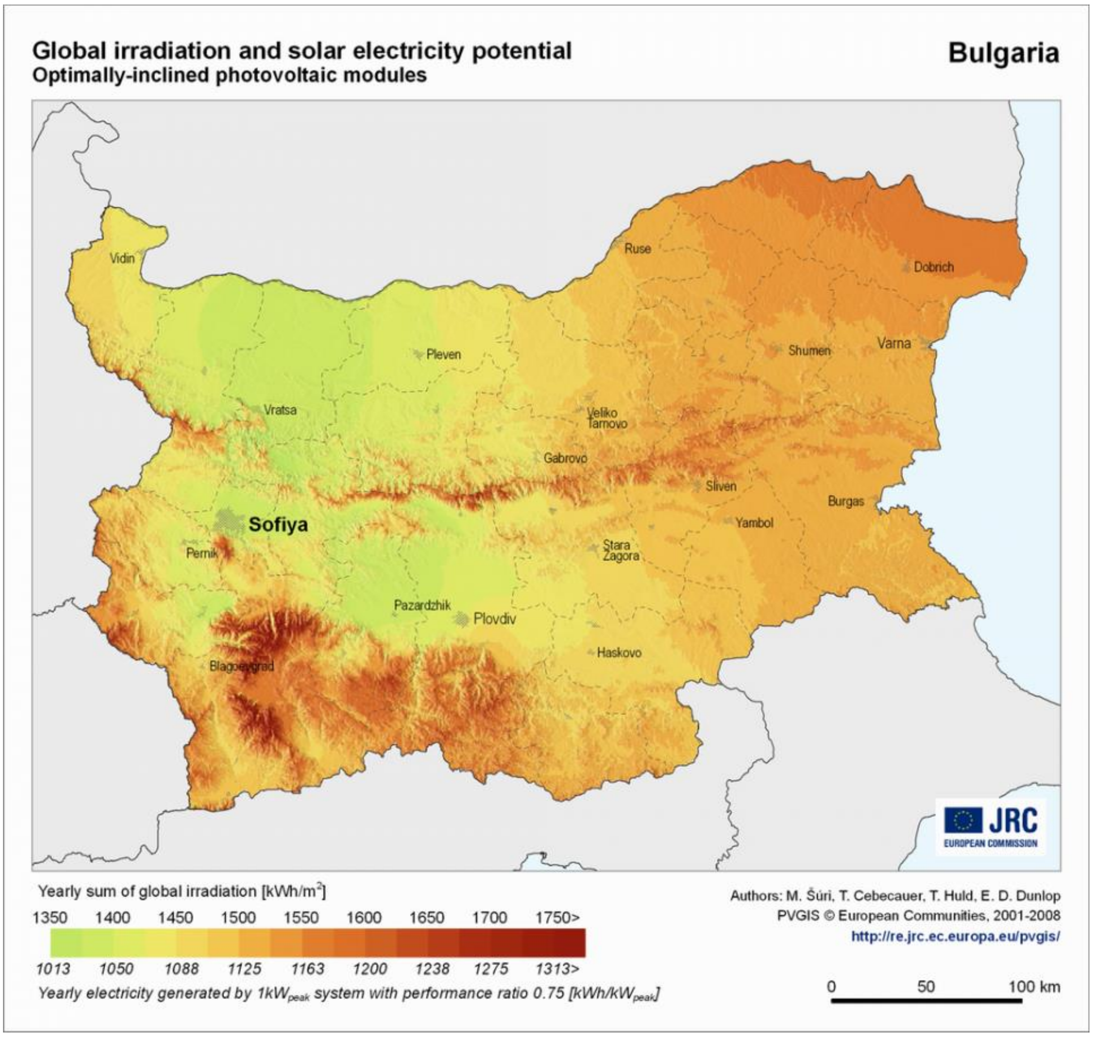


Figure 28 Solar irradiation in Bulgaria (JRC)

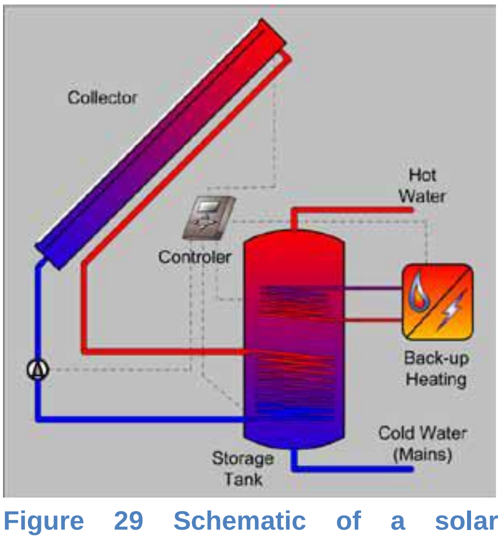


Figure 29 Schematic of a solar domestic hot water system (US Army Corps of Engineers, 2011)

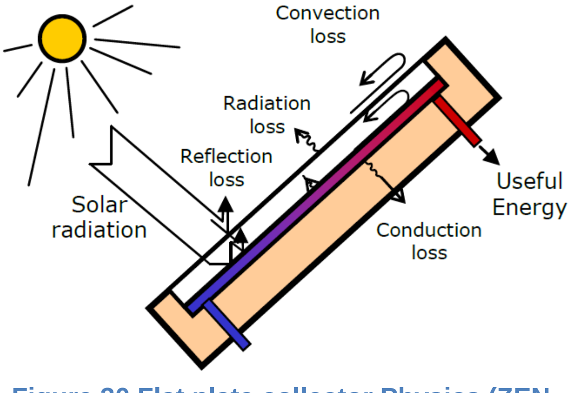


Figure 30 Flat plate collector Physics (ZEN, 2008)

B2.1. Collectors

There are primarily three types of solar collectors used for common solar water heating systems: unglazed flat plate, flat plate, and evacuated tube.

- **Unglazed flat plate collector** - Unglazed flat plate collectors are usually plastic collectors that are rolled out onto a roof and that are generally used for low temperature heating of such things as swimming pools or preheating of domestic hot water (Figure 30). Due to the absence of a glass cover they have no optical losses and therefore are most suitable for low temperature applications since heat losses increase more with higher temperatures compared to the other collector types. The manufacturers use plastic materials that reduce production and installation costs. They are generally less expensive and less efficient (US Army Corps of Engineers, 2011).
- Conventional **flat-plate collectors** are insulated boxes with glass covers that contain a dark thin copper plate used to absorb the sun's heat underneath. The collector housing is typically steel or aluminum (Hudon et al. 2012).

The thermic absorber converts sunlight into heat by means of a spectral selective layer.

The spectral selective layer absorbs 96% of sunlight. Further, the copper absorber conducts 96% (fin-factor) of this solar heat into the heat transport fluid. The spectral selective layer reduces radiation heat losses to 8-12%. The glass cover together with the back and side insulation reduces the convection heat losses to a minimum.

The overall efficiency of the thermic collector is 79% with a heat loss coefficient of 3.5W/°Cm² (ZEN, 2008).

Flat plate collectors are most commonly used for commercial or residential domestic hot water systems. These collectors generally increase water temperature to as much as 71 °C (US Army Corps of Engineers, 2011).

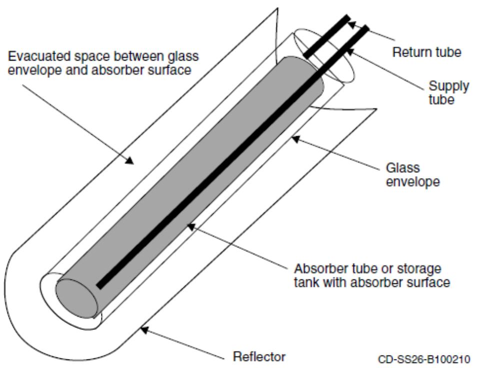


Figure 31 Evacuated tube collector

Evacuated tube collectors can be designed to increase water/steam temperatures to as high as 177 °C (Figure 31). They may use a variety of configurations, but they generally encase both the absorber surface and the tubes of heat transfer fluid in a vacuum sealed tubular glass for highly efficient insulation. Evacuated tube collectors are the most efficient collector type for cold climates with low level diffuse sunlight (US Army Corps of Engineers, 2011).

B2.2. Storage tanks

A challenge in applying renewable energies is often the mismatch between the time energy is needed and the time energy is available. Thus storage tanks are a necessary part of any hot water system since they couple the timing of the intermittent solar resource with the timing of the hot water load. For small systems, storage is most often in the form of glass-lined steel tanks. Bigger commercial solar hot water systems are basically the same as those used for homes, except that the thermal storage tank, heat exchanger, and piping are larger. Most systems include a backup energy source such as an electric heating element or they are connected to a gas or fuel fired central heating system that will heat the water in the tank if it falls below a minimum temperature setting, enabling the system to work year-round in all climates (US Army Corps of Engineers, 2011).

B2.3. Control system

The controller controls the flow of the heat transfer fluid in the collectors by modifying the pump operation. Normally the pump is just turned on/off in small systems. The most common pump controller used in solar thermal systems is the “differential controller.” This controller requires two different temperature settings, one for “on” (upper band) and one for “off” (lower band). The system temperatures are measured on an absorber in a collector and in the storage tank (US Army Corps of Engineers, 2011).

Various performance characteristics are used to assess and compare solar thermal systems. The most important ones are the “solar fraction” (SF), the “specific solar energy yield” (SE), and the “solar system efficiency” (SN). To improve the seasonal solar energy collection, the solar collector can be tilted so that it would be more perpendicular to the sun's path when the heating demand is greatest. Tilting of collectors (from horizontal) should be done to maximize the radiation collection skewed for usage (US Army Corps of Engineers, 2011)’

For Bulgaria the optimal inclination angle is 34 degrees (JRC).

Central solar water heating installations for home and commercial use provide heated water in very large quantities by using an array of collectors. The number and size vary according to the water heating requirements. These installations are the perfect solution for apartment buildings, hotels, hospitals and industrial plants. They are also generally backed up by conventional energy sources. Central installations can be operated with small individual storage tanks for each consumption unit (Figure 32) or with large storage tanks of over 1000 liters (Figure 33) (Chromagen, 2011).

Figure 32 Central water heating installations with small individual storage tanks (Chromagen)

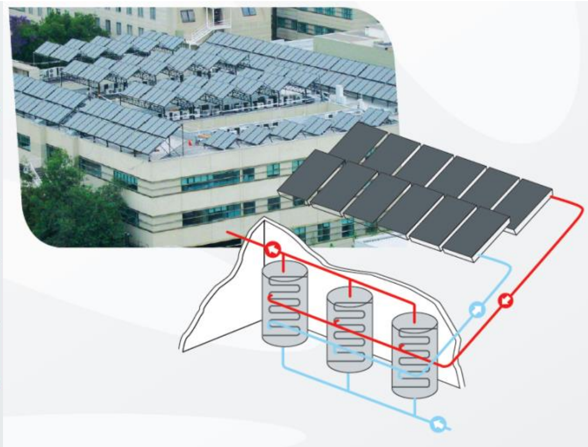


Figure 33 Central water heating installations with large storage tanks (Chromagen)

The most important considerations for collector placement are to encourage integration in existing infrastructure and to avoid shading at periods when solar radiation is plentiful and heating is needed. For large central systems the option of creating a large collector field is usually chosen. This system can be integrated with carport roofing or placed on the flat roof of a large building.

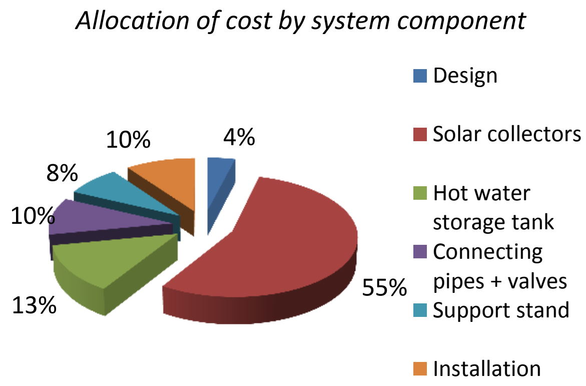
Large central solar water heating systems are normally more cost effective due to economies of scale in installation, operation and maintenance compared to several small systems. This includes higher efficiencies possible for backup heating systems in centralized systems (US Army Corps of Engineers, 2011).

C. Economic data

The allocation of the cost by a system component of a solar thermal system equipped with Bulgarian produced elements in percentage is shown in Table 17. The pay-back period varies between 3 and 8 years, calculated at an average accepted price for the electricity, at the moment, of 0.07 Euro/kWh (Sofia Energy Centre, 2002).

Table 17 Allocation of cost by system component (Sofia Energy Centre, 2002)

Cost Component	Cost (%)
Design	4
Solar collectors	55
Hot water storage tank	13
Connecting pipes + valves	10
Support stand	8
Installation	10
Total	100



A comparison between solar water heating and conventional system is shown in Table 18.

Table 18 Comparison between solar water heating systems and conventional systems (Spiru et al.,2012)

	Solar Water Heater	Gas or Electric Water Heater
Initial Investment	€1650 - €2600	€200 - €400
Annual Operating Costs	€30 - €45	€350 - €470
Typical Lifetime	15 - 40 Years	8 - 20 Years
Lifetime Operating Cost	€400 to €1600	€3000 to €9500
Total Lifecycle Cost	€2100 - €4300	€2800 - €9800
Emissions	Zero	Fossil Fuel Emissions
Return on Investment	10 to 30%	None

According to Delap and Waller EcoCo the investment costs are as follows:

- Up to 10 m^2: 700-1,000 Euro per m^2
- Between 10 m^2 and 50 m^2: 600-800 Euro per m^2
- > 50 m^2: 500-750 euro/m^2

Maintenance costs: 0.5-1% per year.

D. Environmental performance

According to Spiru et al. (2012) the use of solar energy covers approximately 35-50% of the thermal energy needs for water heating from October to April and 80-100 % from May to September.

Solar water heating reduces air pollution due to carbon dioxide, nitrogen oxides, sulfur dioxide, etc. and pollution of wastes created from the utility that generates power used to heat the household water. When a solar water heater replaces an electric water heater, the electricity displaced over 20 years represents more than 50 tons of avoided carbon dioxide emissions.

E. Maturity and availability

In Bulgaria solar thermal systems for domestic needs are utilized mainly in single-family houses along the seacoast or in the mountains for domestic hot water (DHW) in the period April – October. In this case flat plate collectors and simple systems are implemented (Sofia Energy Centre, 2002).

Large solar systems for DHW in Bulgaria are implemented generally in the hotel sector. An example for such application is given for hotel “Ambassador” in Sofia (Sofia Energy Centre, 2002). Other applications are shown in Table 20.

Table 19 Data from the application of DWH for hotel "Ambassador" in Sofia (Sofia Energy Centre, 2002)

Site conditions • Annual solar radiation (tilted surface) – 1.25 MWh/m^2; • Annual average temperature - 10°C; • Desired load temperature - 60°C; • Hot water use – 3,000 l/day; • Energy demand for 12 months analyzed – 63.72 MWh;	**Costs** The initial cost of the investment comes up to EUR 42,014 (i.e. 934 Euro/m^2). The project life is estimated to be 25 years, where the years to positive cash flow are 8.8 and the simple payback is 14 years. The annual life-cycle savings are EUR 9,418.
Solar collector • Collector type - evacuated; • Area per collector – 3 m^2; • Number of collectors / total area of collectors - 15/45 m^2	***Storage*** • Ratio of storage capacity to collector area - 100 1/m^2; • Storage capacity – 4,500 l;
Balance of system • Heat exchanger / antifreeze protection - yes; • Heat exchanger effectiveness - 85 %; • Pipe diameter – 25 mm; • Pumping power per collector area - 5 W/m2; • Piping and solar tank losses - 3 %; • Losses due to snow and dirt - 1 %;	***Annual energy production*** • Pumping energy (electricity) – 0.55 MWh; • Specific yield - 688 kWh/m^2; • System efficiency - 55 %; • Solar fraction for 12 months - 49 %; • Renewable energy delivered – 30.94 MWh;

Table 20 Summary of selected other solar system installations (US Army Corps of Engineers, 2011)

Location	Type Collector	Size sq ft (m^2)	Storage Vol. gal (L)	Cost	Solar Energy Collected, MBtu/yr/sq ft (kWh/m^2)	System Temp., out/in °F (°C)
Austria - AEE						
Gneis Moos, Salzburg	Flat Plate	4,412 (410)	26,420 (99,999)	$218,530	119.9 (377)	149(65) / 86–95 (30–35)
Wasserwerk Andritz	Flat Plate	41,481 (3,857)	17,067 (64,599)	$1,950,000	131.6 (415)	167–248 (75–120) / 140 (60)
UPC arena Graz-Liebenau	Flat Plate	15,139 (1,407)	-	$223,860	114.2 (360)	167–248 (75–120) / 140 (60)
Demark- ARCON						
Ulsted, Denmark	Flat Plate	53,929 (5,015)		$1,700,000	377.1 (1,189)	167– 248 (75–120) / 140 (60)
Strandby, Denmark	Flat Plate	86,769 (8,069)	396,423 (1,500,461)	$2,900,000	314.0 (990)	194–185 (90–85) / 68–50 (20–10)
Frederikshavn, Denmark	Flat Plate	1,614 (150)	1,320 (4,996)	$50,000	149.1 (470)	140 (60)/60 (16)
Skørping, Denmark	Flat Plate	5,918 (550)	396,423 (1,500,461)	$190,000	124.7 (393)	149 (65) / 77 (25)
Braedstrup, Demark	Flat Plate	86,769 (8,069)	528,564 (2,000,614)	$2,500,000	125.9 (397)	158–194 (70–90) / 95–101 (35–38)
Frankfurt/Main, Germany	Flat Plate	2,712 (252)	775 (10,503)	182,838E	83.1 (262)	DHW
Old Slaughterhouse Speyer, Germany	Flat Plate	5,864 (545)	26,428 (100,029)	357,020E	59.4 (187)	153 (67) / 90–99 (32–37)
Residential area Speyer, Germany	Flat Plate	3,077 (286)	6,607 (25,007)	189,200E	92.9 (293)	160–180 (71–82) / 126–140 (52–60)
Residential area Nordemey, Germany	Flat Plate	2,098 (195)	2,640 (9,992)	208,851E	97.9 (309)	149–176 (65–80) / 132–135 (56–57)

2.3.3 Technology 5. Drain water heat recovery (DWHR)

A. Justification of the necessity

(See 2.3.2 A)

B. Description

Greywater is the term given to household drainage water that comes from the bath tub, shower, wash basin and washing machine. Greywater can provide heat at approximate temperature of 20-30°C on a continuous basis. With the greywater a significant quantity of heat energy disappears into the drains each day (Kleven, 2012).

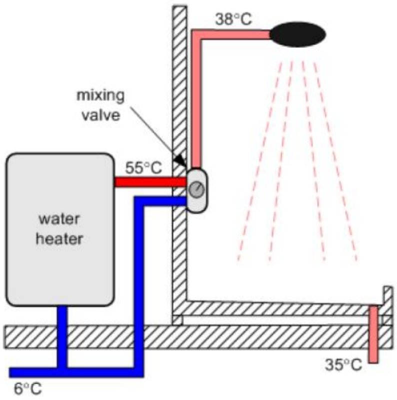


Figure 34 Temperatures in waters (Kleven, 2012).

This grey-water heat can be recovered and reused. Hence, this can decrease heat demand for hot tap water. In addition, recovering of the grey-water heat could reduce high variations in the heat demand in buildings. The heat from the grey-water is recovered with the help of a complex system of filters and heat exchangers. Application of the grey-water heat recovery may require modifications to the plumbing system. The grey-water heat recovery has been implemented in the process industry, and it is becoming an interesting technology for buildings (Kleven, 2012).

The DWHR systems commercially available for domestic use can be divided into the following four groups:

Vertical systems

The vertical system typically consists of a large diameter copper pipe through which the drain water flows. The water clings to the copper surface as a thin film, which allows good heat transfer into the copper. The cold water to be preheated flows in a smaller diameter copper pipe which is wrapped around the drain pipe. Alternatively, the cold water flows in a thin area between the drain pipe and a pipe with a slightly larger diameter fixed around it. This is also called pipe in pipe heat exchanger (Meander, 2011).

Vertical systems are available in various lengths up to 2 meters (6 ft.). They need to be installed below the shower, although some horizontal displacement is allowed. Due to the height they are often installed in the basement. Of all types of DWHR, the vertical units are the most effective.

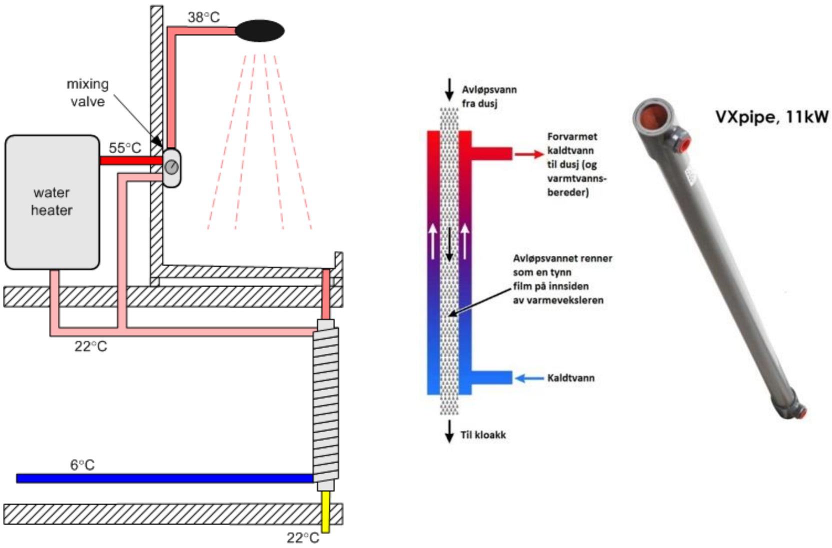


Figure 35. Vertical (tubular) DWHR system (http://www.heatsnagger.com)

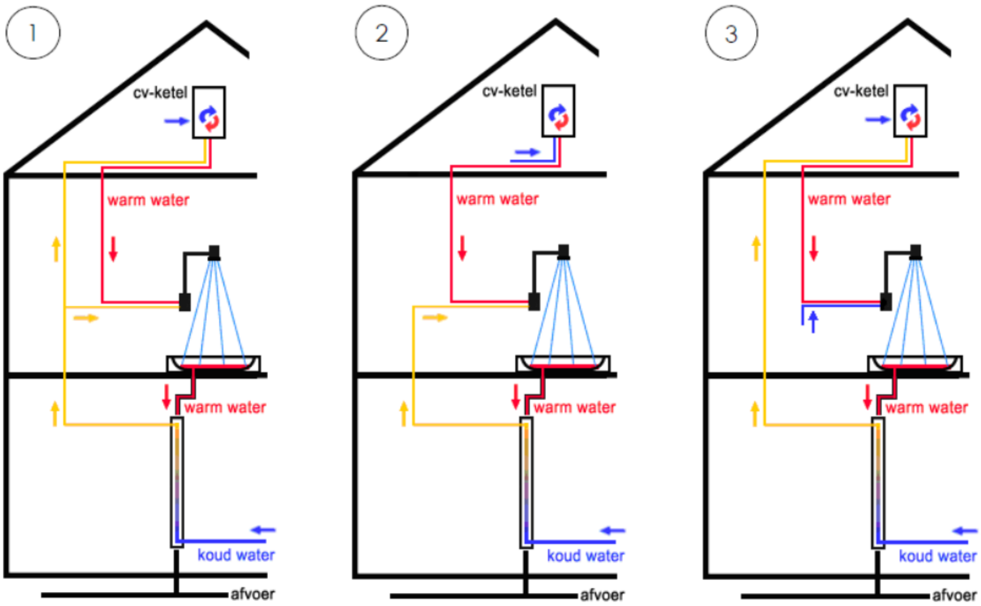


Figure 36 Connection of vertical DWHR

For connection to the existing pipe system the shower DWHR unit is connected to the “cold” side of the shower mixer tap and the cold water inlet of the combination boiler. Connecting the DWHR unit in this way achieves the greatest efficiency. If connection to the combination boiler involves too much work, it is possible to connect the DWHR unit to the shower tap only (Figure 36, diagram 2). In this case, the DWHR unit will be roughly 15% less efficient. If the DWHR unit is connected as shown in diagram 3 of Figure 36, performance will be reduced by roughly 25%.

Shower platform with integrated heat exchanger

The second type of DWHR system, shower platform with integrated heat exchanger, is not as common. They can be used whenever the vertical DWHR is not possible to install. They are typically more expensive and not as effective as the vertical systems (Meander, 2011).

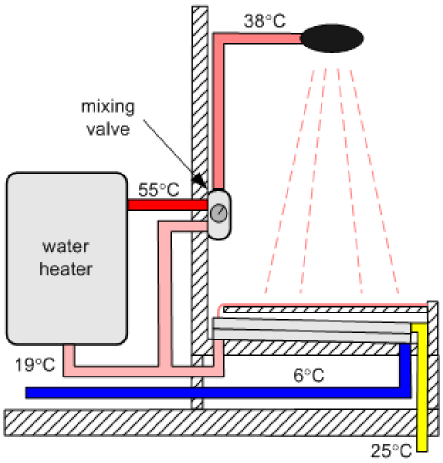


Figure 37 Shower platform with integrated DWHR (http://www.heatsnagger.com)

Horizontal systems for installation under the shower

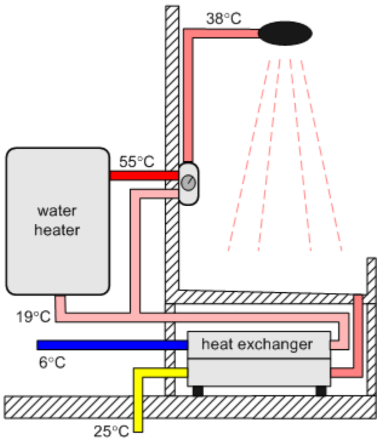


Figure 38 Horizontal DWHR system (http://www.heatsnagger.com)

Horizontal units that can be placed close by or under a shower rely on easy access to drain and cold water, but then provide very easy installation. They are most suited as add-ons for shower cabinets and are presently not so common (Meander, 2011).

Tank based systems

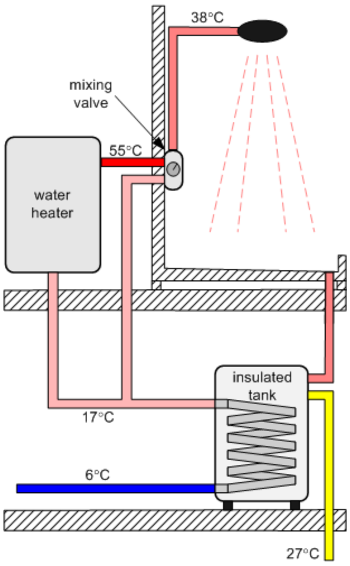
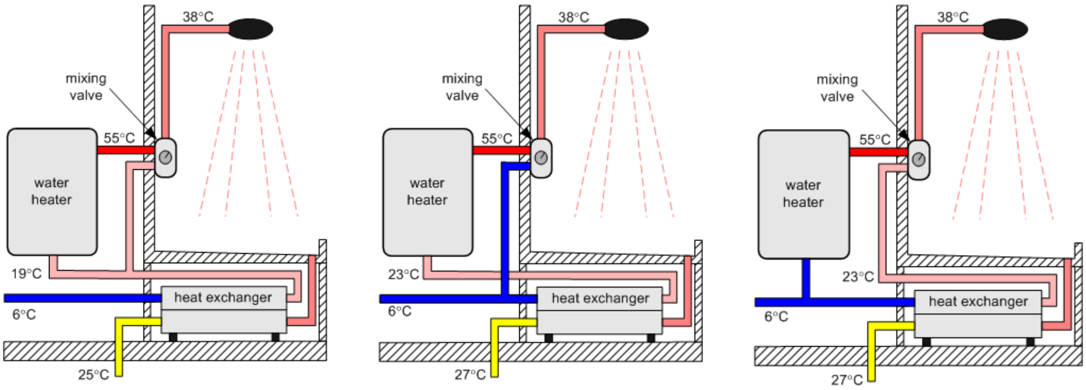


Figure 39 Tank based DWHR system (Source: http://www.heatsnagger.com)

The fourth type of DWHR uses an insulated tank where the drain water is stored temporarily, and through which the cold water is guided in a heat exchanger. This allows heat recovery also from other household appliances as clothes washer, and dish washer because it doesn't depend on water draining at the same time as cold water being used (Meander, 2011).

Depending on how the preheated cold water is used there are three ways of installing a DWHR system (Figure 40):

- Balanced flow;
- Water heater only;
- Shower only.



a. Balanced flow b. Water heater only c. Shower mixing valve only

Figure 40 Types of installation of DWHR system (Meander, 2011)

In **balanced flow installation**, preheated water is plumbed into both the mixing valve of the shower and into the cold water supply of the water heater. In this case the flow of the drain water is equal to the flow of the cold water through the DWHR system. This is called a balanced-flow setup and gives the best performance in terms of energy savings. It also requires most plumbing and installation effort and cost. (Meander, 2011)

In the second installation option**,** the preheated water is fed into the cold water supply of the **water heater only** (Figure 40 b). The energy savings are due to the preheated water requiring less energy to get up to the temperature setting of the water heater. The flow is unbalanced, because the cold water flow is smaller than the drain water flow, and this reduces the performance of the DWHR to some extent as compared to a balanced flow setup, because the temperature of the preheated cold water could actually be higher but due to its lower flow the total power transferred is less as compared to the balanced flow setup.

Feeding the preheated water into the mixing valve of the **shower only** allows the simplest installation: only shower drain and cold water input to the shower mixing valve need to be diverted locally (Figure 40 c). For this case, the flow is also unbalanced (cold water flow is 30-60% of drain flow, depending cold and hot water temperatures), which again reduces DWHR performance somewhat. Meander (2011) reports for 15% for a particular DWHR unit.

C. Economic data

The **investment cost** depends a lot on the type of the system as well as whether there will be a connection to the heating system or to hot tap water. This would probably be the main difference in the investment cost for the different systems.

The **variable costs** of such a system are minimal and consist of electricity to run pumps and regulation systems (Kleven, 2012).

A qualified plumbing and heating contractor is needed to install the system. Installation will usually be less expensive in new home construction. Paybacks range from 2.5 to 7 years, depending on how often the system is used (Energy.gov, 2012).

Some prices are given in Table 22 below.

D. Environmental performance

Performance of the DWHR vertical system with different waste water flow rates at 40 degrees are shown in Table 21.

Table 21 Performance of a vertical DWHR (Meander, 2011)

Flow rate (at 40 °C)	Shower DWHR unit efficiency and power delivered (at a cold water temperature of 10 ˚C).	Pressure drop
5.5 l/min,	62.7 % (7.2 kW)	< 20 kPa
7.5 l/min,	59.3 % (9.3 kW)	40 kPa
9.2 l/min,	57.6 % (11.1 kW)	55 kPa
12.5 l/min,	56.0 % (14.6 kW)	100 kPa

The efficiency of a drain water heat recovery unit is measured by a value called the Heat Recovery Efficiency, which is expressed as a ratio between the actual heat transfer and the theoretical maximum possible heat transfer.

According to Shower-Save, DWHR systems can save between 300 kg and 1000 kg of carbon dioxide emissions per year, depending on how often the shower is used and on what fuel the water is heated with (Shower-Save, 2013).

E. Maturity and availability

The principle of DWHR is well known, and commercial units for home owners are available. With the introduction of units at lower prices, and the increasing focus on energy saving and the environment, it is about time to put the DWHR concept to use everywhere possible (Meander, 2011).

The vertical type is produced by a number of manufacturers, both in USA, Canada as well as in Europe (Meander, 2011). Examples for applications are given in Table 22.

Table 22 Examples of applications of DWHR systems (Meander, 2011)

Product name	DWHR category	Efficiency	Price
Recoh-vert V3	Vertical (pipe-in-pipe)	65.4% at 9,2l/min 62.2% at 12.5l/min	€600 - €800
Recoh-tray RT2	Shower tray with integrated heat exchanger	39.6% at 9.2l/min 34.2% at 12.5l/min	€855
Douchebak WTW ver. 2	Shower tray with integrated heat exchanger	44% at 9.2l/min 40.7% at 12.5l/min	€990
Douchegoot WTW	Horizontal Unit	49.1% at 9.2l/min (9.4kW) 47.7% at 12.5l/min (12.5kW)	N.A.
Douchepijp WTW	Vertical (pipe-in-pipe)	57.6% at 9.2l/min (11.1kW) 56.0% at 12.5l/min (14.6kW)	€390

3 Innovative Technologies for urban water systems in the Canton Zurich, Switzerland

3.1 Technology Implementation Objectives

In this report technology implementation is taken into account for the two main parts of the system:

- **Water supply and discharge chain**
- **Water use stage**

Innovative technologies are presented with the objective to increase the eco-efficiency of the entire system which means the combination of water supply and discharge chain and water use stage. In the following, concrete objectives are discussed for the different sub-sections of the system.

Water supply and discharge chain:

The water supply system provides the water consumed by the domestic and non-domestic users. The freshwater ecosystem impact is generally caused by the users and not be the supply system. The water losses in the Case study area of Wädenswil account to about 9 % of the water abstracted (Steiger et al., 2012). The economic costs and the negative environmental impacts - e.g. energy consumption except freshwater ecosystem – connected with the volume of water lost do not produce any benefit in form of usage of this water. Hence the leakage reduction in the distribution network is an objective in order to improve the eco-efficiency.

Other negative environmental impacts are caused according to the energy consumption by the drinking water supply system. The major part of energy consumption is caused by the pumping for abstraction and distribution (about 90% - Mayr et al., 2012). Hence the reduction of energy consumption for pumping is an important objective.

The wastewater treatment plant in the case study area is fulfilling in a reliable way high standards regarding effluent concentrations of organic content and nutrients. Nevertheless, presently the nutrients are transferred into the sewage sludge and hence incinerated. Energy recovery is applied but the nutrients which are in principle valuable compounds remain unused. Hence innovative technologies for nutrient recovery are presented in this report.

Despite the functioning treatment steps for main pollutants, compounds like pharmaceutics, pesticides or endocrine disruptive compounds of low concentration are still contained in the wastewater treatment plant effluent. Several of these compounds are strongly supposed to have a negative impact on aquatic ecosystem and the human health. An important objective for new technologies is an effective prevention of the potential risk from also those contaminations existing in low concentrations.

The objectives regarding the **water supply and discharge chain** are summarized in the following list

1.1. Reduction of water leakage in the distribution network

1.2. Reduction of energy consumption for pumping in the water supply

1.3. Recovery of nutrients from the waste water treatment plant

1.4. Effective reduction of risk caused by micropollutants

Water use stage:

Households in Wädenswil consume on average 162 litres/person/day. According to the information given by Bello-Dambatta et al. (2012) and Grant (2006) the application of more efficient technologies could lead to a reduction of water consumption down to around 65 litres/person/day without reducing the service level (Bello-Dambatta et al., 2012).

The domestic water use is a relatively large part (74%, Steiger et al., (2012)) of the water consumption in Wädenswil and it is clearly shown that there exists a significant potential of savings. The water consumption itself causes indirectly the environmental impacts connected with the supply of drinking water. Hence an important objective is the application of technologies for reducing the water consumption by domestic users.

Another aspect emphasizing the importance of the objective of reducing water consumption in households is the energy consumption connected with water use. As shown in Table 23 the energy consumption connected with water applications (water heating, cooking, washing and drying) play an important role since they sum up together to 16.7%. Therefore water saving implicates also an additional reduction of environmental impact by reduction of energy consumption.

Table 23 Energy consumption in Switzerland 2010 according to using categories (Prognos, 2011)

Category	Percentage of total energy consumption [%]
Heating	72.3
Water heating	11.8
Cooking	3.5
Other electronic installations	3.2
Entertainment	2.1
Freezing and Cooling	2.6
Lighting	2.1
Washing and Drying	1.4
Climate	1

It was shown by Steiger et al. (2012) that around 26% of the water used in the case study area of Wädenswil is consumed in the non-domestic sector, which represents a significant amount. Therefore also the reduction of water consumption in the non-domesic sector is an important objective.

The objectives regarding the **water use stage** are summarized in the following list

2.1. Reduction of water and the related energy consumption by domestic users

2.2. Reduction of water and the related energy consumption by non-domestic users

3.2 Water Supply and Discharge Chain Technologies

In the following chapters several innovative technologies are presented to increase the eco-efficiency of the urban water value chain.

3.2.1 Technology 1. Pressure reducing valves for the water supply system

A. Justification of the necessity

As mentioned in the Ecowater deliverable 3.2 9% (Stadtrat Waedenwswil, 2012) of the total water which enters the drinking water distribution network is lost which corresponds to 157,030 m^3/year.

B. Description

Pressure reducing valves are important components for the pressure management in drinking water distribution systems. These valves can be applied for district metering areas (DMA) in the distribution network or for single buildings. The function of this technology is to maintain a constant optimal pressure in the pipes. This can be achieved by pilot operated valves which are connected with a pressure measurement device and controlled in order to achieve the pressure set by the operator. Another possible mechanism to operate at a fixed pressure is provided by the so called direct acting valves. These types of valves contain a spring connected with an adjustable orifice, with an adjustable screw and with a diaphragm which is in contact with the output water flow. If the output pressure increases the pre-set pressure, the diaphragm is pulled upwards and the spring is compressed. Compression of the spring leads to more closing of the orifice which throttles the water flow and hence reduces the output pressure as depicted in Figure 41 (Cleaning Technology Group, 2012; Clarke, 2013; Watts, 2013).

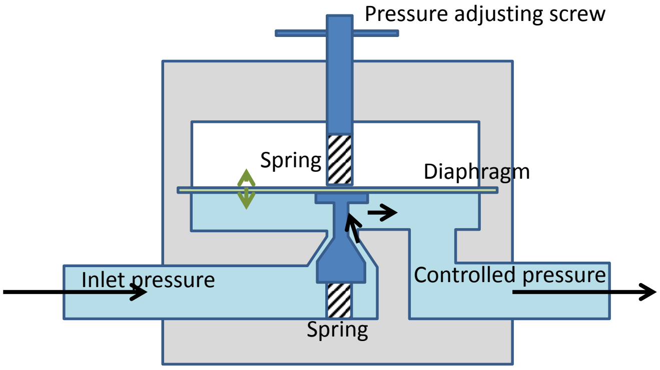


Figure 41 Scheme of direct acting valve (Cleaning Technology Group, 2012)

C. Economic data

Investment costs are in the range of 100 – 2,500 € per installation (RWC, 2013).

D. Environmental performance

Pressure reducing valves can reduce water losses since leakage from pipes is increasing as a function of the pressure addressing objective 1.1 mentioned in chapter 3.1.

E. Maturity and availability

This technology has been available for a number of years hence it can be assumed to be very mature.

3.2.2 Technology 2. Smart pumping for the water supply system

A. Justification of the necessity

The electricity consumption for distribution and pumping of raw water from the lake Zurich are 1,244 MWh/y which is almost three times the remaining electricity demand of the drinking water treatment plants (340 MWh/y) (Ecowater Deliverable 3.2).

B. Description

Smart pumping systems are centrifugal pumps equipped with special instrumentation and a microprocessor. The pump can be operated at variable speed. Several parameters such as suction pressure, suction temperature, discharge pressure and pump flow are measured. Analog 4-20 mA signals are transferred to the controller and processed by the smart pump control system. The operation of the pump can therefore be adjusted to the presently existing conditions and the operational settings required by the system (Stavale, 2001).

The smart pumping systems reveal advantages regarding the failure frequency of pumps and hence the maintenance costs and the pump efficiency.

The sensitivity of the pump against failures is significantly reduced since the control system is able to measure and recognise failure constellations as e.g. a dry running caused by closed suction valves can be detected as the suction pressure decreases below a pre-set value. The pump can react with e.g. a decrease of operation performance, an alarm or automatic shutdown in order to prevent damage of the pump. Additionally smart systems are able to recognize after failure reparation and maintain the normal operation again (Stavale, 2001).

The smart pump can be controlled to maintain constant values of e.g. speed, pressure or volume flow. A conventional pump operates at fixed speed and the adjustment to the required volume flow can be only done with the help of control valves increasing the friction head. This leads to a reduction of the pump efficiency. Conventional pumps operating at fixed speed are usually dimensioned with a safety margin which further decreases the energy efficiency of the pump. The smart pump with variable speed control can operate at a constant volume flow without the application of any control valve and without any requirement for over-dimensioning (Stavale, 2001).

C. Economic data

Regarding the lifetime of a pumping system of 15 years, the substitution of a conventional pump by a smart pump is cost-effective according to Stavale (2001). The investment costs were estimated to be 14,600 € (19,800 $, USA, 2001) for a system requiring 639 m^3/h volume flow. Nevertheless it was estimated that part of the measurement devices installed in conventional systems in the pipes are not needed using the smart pump system. Therefore the smart system is less expensive regarding the total installation costs than a conventional system. Taking into account operational costs significant cost savings (35% during the lifetime of the pump system of 15 years) are achieved due to lower maintenance and energy costs. The total operating costs for the system requiring 639 m^3/h volume flow are estimated to be 20,200 €/year (27,380 $/year, USA, 2001) (Stavale, 2001).

For the implementation of a smart pump system in a drinking water supply system a detailed analysis of the pump efficiencies should be performed. Costs for such a measurement programme of pump efficiency including 5 pumps and 3 measurement at different time per pump are estimated to be 1,500 € and require 7 hours (Mayr et al., 2012).

D. Environmental performance

Regarding an application with a requirement of 639 m^3/h volume flow the energy consumption can be reduced from 707,700 kWh/year with the conventional system down to 456,400 kWh/year with a smart pumping system. Hence the environmental impact in form of energy consumption can be decreased significantly (30-40%) by implementation of this technology (Stavale, 2001). This technology is addressing the objective 1.2 mentioned in chapter 3.1.

3.2.3 Technology 3. Micropollutants removal technologies

A. Justification of the necessity

For the whole Canton Zurich – and also for the municipality of Waedenswil – the lake Zurich is the most important source of raw water for drinking water production. According to the high population density there is a high number of wastewater treatment plants around the lake. 14 wastewater treatment plants are located next to the lake Zurich and additional 16 plants are in the catchment area. Therefore the emission of chemical compounds into the lake, which has an impact on the ecosystem and humans even in low concentration, is problematic especially since many of these chemicals are hardly biodegradable. Table 24 shows the concentration range of several micropollutants measured in the effluent of several wastewater treatment plants around the lake Zurich. Several of them (in bold letters) were detected also in the raw water influent to the drinking water treatment plants [Kaiser, 2006].

Table 24 Concentrations of selected micropollutants in effluents of wastewater treatment plants around the lake Zurich (Kaiser, 2006)

Name	Concentration range [μg/L]
Dichlormethane	<0.1-1.2
MTBE	0.1-5.3
Benzotriazole	7-14
Methylbenzotriazole	0.4-2.5
NTA	1.6-60.2
EDTA	12.7-239
Diclofenac	0.38-1.7
Carbamazepine	0.12-1.6
Atenolol	0.4-1.3
Iopamidol	<0.1-4.2
Iopromide	<0.1-38
Ioxitalamic acid	<0.1-3.8
Ioxaglinic acid	<0.1-4
Bisphenol A	<0.05-1
4-nonylphenol	<0.5-2.1

B. Description

Some relevant technologies regarding their potential for concentration reduction of micropollutants will be described in the following sections.

It was observed that some micropollutants are eliminated during the common biological wastewater treatment. Possible mechanisms which lead to the concentration reduction are biological degradation, adsorption to sludge flocs and volatilisation. It has to be taken into account, that a degradation of organic micropollutants is often not a complete mineralisation. The result of the degradation can be transformation products (TPs) which are sometimes also problematic or even more problematic than the original organic pollutant. Since the degradation processes are still not completely known for many micropollutants the characterisation and quantification of the formation of transformation products is incomplete.

It was observed that the elimination effectiveness of biological wastewater treatment increases as a function of the sludge age. Therefore the elimination effectiveness of membrane bioreactors is higher in comparison to conventional biological treatment processes (Hunziker, 2008).

Innovative technologies which are applicable as additional advanced treatment of wastewater treatment plant effluents are described in the following sub-sections.

Ozonation is an advanced oxidation process which used the high oxidation potential of ozone. Ozone is usually produced onsite from cleaned air or from oxygen using ozone generators containing narrowly-spaced electrodes subjected to high voltage. Since ozone is not stable, the production has to take place continuously. Ozone is dosed and mixed with the water to be treated in a special reaction tank. After contacting the water, ozone builds hydroxyl radicals. These radicals have a strong tendency to react with organic compounds and decompose the molecules down to complete mineralisation or by formation of transformation products. It was shown that the decomposing reactions have a kinetic of first order, which means that the elimination ratio is independent of the concentration of the pollutants (Hunziker, 2008).

The oxidation by ozonation can lead to an increase of biological degradable compounds. Hence the installation of a bioreactor and sandfilter as post-treatment can be beneficial (Haltmeier and Pazhepurackel, 2012).

Activated carbon adsorption: Micropollutants can also be removed from the water phase by activated carbon adsorption. Adsorption means an accumulation of compounds on the surface of particles due to surface complexation reactions, electrostatic interactions or hydrophobic expulsion. Activated carbon is a suitable adsorbent due to the high specific surface and due to functional groups existing on the surface. The effectiveness depends on the available surface and the load of adsorbing substances in the water. For the elimination of micropollutants from wastewater treatment plant effluents granulated activated carbon can be applied in form of filter beds or powdered activated carbon in combination with a solid-liquid separation post-treatment process. Powdered activated carbon is more economic and has a higher weight-specific effectiveness. Figure 42 shows an example scheme of an activated carbon adsorption process using powdered activated carbon. The removal of the activated carbon is achieved by sedimentation and filtration. Part of the activated carbon is recycled into the biological reactor (Hunziker, 2008). This technology removes a wide range of micropollutants effectively and without causing additional formation of transformation products. But the pollutants themselves are not decomposed. The loaded activated carbon has to be regenerated or burnt.

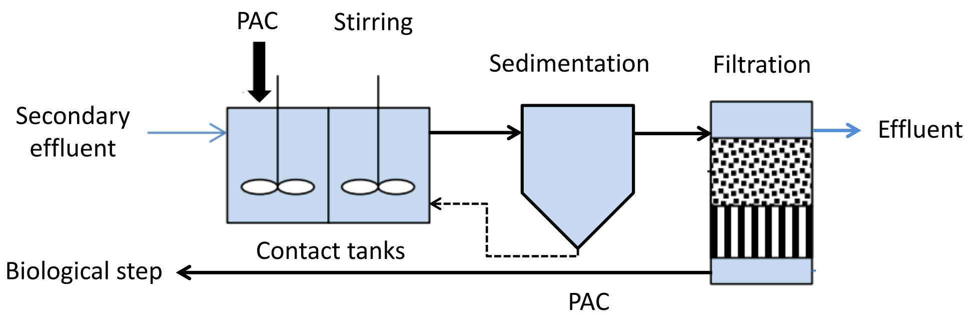


Figure 42 Example of process scheme for activated carbon adsorption with powdered activated carbon.

Dense membrane filtration processes can also remove micropollutants effectively. Suitable types of membrane filtration are dense nanofiltration membranes and reverse osmosis membranes. Reverse osmosis membranes do not contain any pores in the active filtration material. Water can permeate though the membrane by diffusion while salts and molecules are rejected by the membrane almost entirely. The materials of the active layers of nanofiltration membranes have a less dense structure than in the case of reverse osmosis membranes. Hence the spaces in the polymeric structure are sometimes referred to as pores with a diameter smaller than 1 nm, sometimes the transport is characterised as solution-diffusion transport as for reverse osmosis membranes. According to these differences, the retention effectiveness of nanofiltration membranes is lower than of reverse osmosis membrane, but also the pressure required to achieve a certain permeate flow is lower. Hence the nanofiltration process is less energy-intensive and hence more economic regarding energy costs. Nevertheless, the costs for membrane material is usually at the moment lower for reverse osmosis membranes since these membranes are produced worldwide in larger charges due to the more abundant applications, especially for seawater desalination.

Nanofiltration and reverse osmosis membranes produce a permeate which contains strongly reduced concentrations of micropollutants without any formation of transformation products. However, these membrane processes never work with a permeate yield of 100% but always produce a retentate (or brine) stream which contains the rejected compounds in elevated concentrations. The retentate has to be further treated – e.g. by incineration or advanced oxidation processes – to substantially decompose the harmful substances.

C. Economic data

Table 25 shows an estimation of investment and operating costs for the technologies ozonation and powdered activated carbon adsorption done in 2012 in Switzerland

(Haltmeier and Pazhepurackel, 2012). Table 26 shows the same results but calculated in €.

Table 25 Cost estimation according to Haltmeier and Pazhepurackel (2012) done in 2012 in Switzerland. The costs are presented as function of the plant size x in person equivalents

	Powdered activated carbon		Ozonation	
WWTP-size [person equivalents]	>80,000*	<80,000**	>80,000*	<80,000**
Investment costs [CHF]	$48,235.0*x^{-0.48}$	$36,176.2*x^{-0.48}+$ $+7,033.9*x^{-0.49}$	$26,889.5*x^{-0.51}$ $+21,424.5*x^{-0.57}$	$36,176.2*x^{-0.48}+$ $+6,932.1*x^{-0.49}$
Operating costs [CHF]	$179.4*x^{-0.22}$	$134.6*x^{-0.22}+$ $+34.4*x^{-0.22}$	$367.6*x^{-0.35}$	$275.7*x^{-0.35}+$ $+69.9*x^{-0.36}$

* The wwtp in Wädenswil has no sandfilter, hence the costs include a new sandfiltration For ozonation is was assumed that an economic fixed bed reactor would be installed.
** It was assumed that 25% of the plants already have a sandfiltration

Table 26 Cost estimation according to Haltmeier and Pazhepurackel (2012) done in 2012 in Switzerland. The costs are presented as function of the plant size x in person equivalents and calculated in €

	Powdered activated carbon		Ozonation	
WWTP-size [person equivalents]	>80,000*	<80,000**	>80,000*	<80,000**
Investment costs [€]	$39,031.7*x^{-0.48}$	$29,282*x^{-0.48}+$ $+5,693.4*x^{-0.49}$	$21,759.0*x^{-0.51}$ $+17,336.7*x^{-0.57}$	$29,282*x^{-0.48}+$ $+5,611*x^{-0.49}$
Operating costs [€]	$145.2*x^{-0.22}$	$108.9*x^{-0.22}+$ $+27.8*x^{-0.22}$	$297.5*x^{-0.36}$	$223.2*x^{-0.35}+$ $+56.6*x^{-0.36}$

* The WWTP in Wädenswil has no sandfilter, hence the costs include a new sandfiltration. For ozonation is was assumed that an economic fixed bed reactor would be installed.
** It was assumed that 25% of the plants already have already a sandfiltration

D. Environmental performance

The technologies presented in this section reduce the environmental impact of the water value chain by removing micropollutants from the effluent which impose a potential risk for aquatic ecosystems and the health of humans. Hence this technology referred to the objective 1.4 from chapter 3.1. On the other hand all of these additional innovative technologies are also connected to additional environmental impacts in form of energy consumption (especially reverse osmosis, nanofiltration and ozone) and consumption of materials and chemicals (especially activated carbon adsorption).

3.2.4 Technology 4. Advanced phosphorus recovery technologies

A. Justification of the necessity

The total theoretical potential for phosphorus recovery from the wastewater in Wädenswil is 18,200 kg_P per year. An amount of 17,950 kg_P per year is available in Wädenswil if it is assumed that only the phosphorus which is removed in the WWTP from the wastewater into the sludge is available for a recovery.

B. Description

In the last decades more and more innovative technologies for the recovery of phosphorus from different streams of the wastewater treatment plants have been under investigation.

Some technologies which have been demonstrated to be effective in full scale are presented in the following sections.

The Pearl technology developed and patented by the company Ostara produces struvite (magnesium ammonium phosphate (MAP)) as crystallisation product. This process uses the centrates of the centrifuges which are used for thickening of the digested sewage sludge. The crystallisation process is operated using struvite prills as seeding crystals and by dosing of magnesium chloride and eventually sodium hydroxide for pH adjustment. The crystallisation reactors are designed in a way that relatively large struvite particles in the range of 1 to 3.5 mm can be obtained and marketed as Crystal Green®, a slow release fertiliser for special applications. The process is applicable on waste water treatment plants using enhanced biological phosphorus removal for phosphate elimination. The ratio of phosphorus which can be recovered with this technology is limited by the dissolution of phosphorus after the digester since only the part of the phosphorus from the centrate of the centrifuge enters the crystallisation reactor (Baur, 2009; Ostara, 2013).

Also the **Airprex** process is only applicable for waste water treatment plants with enhanced biological phosphorus removal. This process uses digested sludge as input stream. The Airprex reactor is designed as an airlift reactor. The air injection leads to mixing and stripping out of CO_2. The latter effect causes a rise of pH. Additionally, magnesium chloride is dosed to the reactor. At these conditions struvite crystallisation takes place which sediments in the same reactor. The Airprex process prevents the risk of struvite encrustations in the centrifuge and hence reduces the demand of anti-incrustation agents to be dosed to the digested sludge (Heinzmann and Lengemann, 2012). The phosphorus recovery rate of this process is between 20 and 50% of the phosphorus contained in the waste water intake according to Heinzmann and Lengemann (2012). Since the phosphorus elimination in the WWTP Wädenswil is done by chemical precipitation the Airprex process is only applicable if the phosphorus elimination is changed into enhanced biological elimination.

The **Stuttgarter Process** can be applied for sewage sludge from wastewater treatment plants with chemical or biological phosphorus elimination. The digested sewage sludge is leached with sulphuric acid at reduced pH (approximately 4). A liquid- solid separation can be performed using centrifuge, belt filtration or chamber pressure filtration. After this, citric acid is dosed to the liquid phase as complexating agent for heavy metals. Finally, the pH is adjusted to around 8.5 with caustic soda and magnesium oxide is added. As a result, a struvite product is achieved by precipitation and sedimentation. A total recovery rate in the range of 26-83 % of the total phosphorus contained in the sewage sludge can be achieved (Meyer and Steinmetz, 2013).

The main part of the sewage sludge is currently incinerated in many countries due to hygienic reasons. The phosphorus contained in the sludge remains completely in the remaining ash. The **Ash-Dec technology** is a thermal process for the production of a fertiliser product out of sewage sludge ash. The ash is treated in a rotary kiln at 850-1,000°C. During the process magnesium and calcium chloride is dosed into the rotary kiln. Under these conditions heavy metals which are contained in the ash will form volatile heavy metal chlorides. The phosphorus product contains different types of phosphorus containing minerals. Investigations showed that the solubility in citric acid increases as function of the temperature during the thermal treatment (between 450 and 1,000°C) (Adam, 2008). Solubility in citric acid is often used as approximation for the plant availability.

C. Economic data

The costs for phosphorus recovery with the Ash-Dec process are estimated to be around 2.2 €/kg_P by Sartorius (2011). The phosphorus price and hence the benefit achievable with this process are 2 €/kg_P according to Dockhorn (2012).

Heinzmann and Lengemann (2012) mentioned that the process is cost efficient only due to reducing the consumption of anti-encrustation agents. The cost saving are estimated to be in the range of 450,000 to 500,000 € per year for the wastewater treatment plant of Wassmannsdorf, Berlin which has a capacity of 230,000 m^3/day at dry weather (Heinzmann and Engel, 2005).

D. Environmental performance

The positive impact on eco-efficiency of the phosphorus recovery processes is a significant reduction of primary resource depletion. The recovered phosphorus substitutes mineral fertilisers which are applied in agriculture and obtained from phosphorus rock, hence mineral phosphorus resources. Therefore these technologies address the Objective 1.3 from Chapter 3.1.

On the other hand, all presented processes imply also consumption of energy and materials for the installation of the technologies, pumping, consumption of chemicals and partly obtaining elevated process temperature leading to environmental impacts.

E. Maturity and availability

All technologies were demonstrated in full scale.

3.3 Water Use Technologies

3.3.1 Technology 5. Water reuse for domestic water users

A. Justification of the necessity

Households are the main user of drinking water and producer of waste water. The environmental impacts connected with the production of drinking water and with the treatment of wastewater are hence caused to an important part by these users. Water reuse would decrease the amount of freshwater consumed.

B. Description

Water reuse systems for households are suitable to recycle the so-called greywater from domestic water users. Greywater means the wastewater from washing machines, showers, baths and washbasins. Wastewater from the toilet is referred to as black water and contains a significantly higher organic content than greywater (Bello-Dambatta et al., 2012). The categorization of wastewater from the kitchen sink and dish washers differs between different authors between greywater and black water (Li et al., 2009). The suitability of this stream to be included in a domestic water reuse system depends on the complexity of the treatment technology applied. If a biological treatment should be applied in the water reuse system including the kitchen greywater is beneficial for meeting the microbial nutrient requirements (Li et al., 2009). Typical characteristics of several types of greywater are shown in Table 27.

The water included in the water reuse system is applied for non-potable purposes as toilet flush, washing machines or showers. The reuse for toilet flushing is most often applied since here the quality requirements are lowest and quantity requirements have been highest of all domestic types of usage.

Table 27 Properties of different types of greywater (Li et a., 2009)

Parameter	Bathroom	Laundry	Kitchen	Mixed
pH [-]	6.4-8.1	7.1-10	5.9-7.4	6.3-8.1
TSS [mg/L]	7-505	68-465	134-1,300	25-183
Turbidity [NTU]	44-375	50-444	298	29-375
COD [mg/L]	100-633	231-2,950	26-2,050	100-700
BOD [mg/L]	50-300	48-472	536-1460	47-466
TN [mg/L]	3.6-19.4	1.1-40.3	11.4-74	1.7-34.3
TP [mg/L]	0.11- >48.8	ND- >171	2.9- >74	0.11-22.8
Total coliforms [CFU/100mL]	$10\text{-}2.4*10^7$	$200.5\text{-}7*10^5$	$>2.4*10^8$	$56\text{-}8.03*10^7$
Faecal coliforms [CFU/100mL]	$0\text{-}3.4*10^5$	$50\text{-}1.4*10^3$	-	$0.1\text{-}1.5*10^8$

C. Economic data

The domestic reuse system consists of components for storage of the treated water, for pumping, for distributing the treated water and for treatment. The choice of treatment processes and combinations of processes depends on the type of use intended to fulfil with the treated water and the type and properties of greywater. Some typical process configurations are shown together with the estimated capital costs in Table 28. The lifetime of a greywater reuse system is estimated to be 20 years (Nazer et al., 2010).

Table 28 Typical process combinations for the treatment of greywater rom households and related capital costs (Domènech & Saurí, 2010)

Technology	Capital costs [€/household]
Filtration with nylon filter + sedimentation + disinfection with hypochlorite	195
Sedimentation + silex anthracite filter + cartridge filter + sedimentation + disinfection with hypochlorite	428
Filtration with cylindrical sieve + oxygenation + disinfection with UV light	1,018
Oxygenation + Filtration with 20-µm-filter + disinfection with hypochlorite or UV light	691

It was mentioned by Bello-Dambatta et al. (2012) that the energy and cost efficiency depend strongly on the type of greywater reuse system and the number of users. In general it is estimated that a more complex greywater system with several treatment steps causes more carbon emissions than the production of a corresponding amount of drinking water. Generally the water reuse systems require more energy and chemical consumption than water saving appliances (Bello-Dambatta et al., 2012).

It is estimated that the water saving appliances are more economic than complex water reuse systems due to the investment and operational costs. Payback times for single households are more than 50 years (Bello-Dambatta et al., 2012; Warner 2006).

In Wädenswil still almost half of the buildings used for living are single-household buildings as shown in Figure 43, which is slightly under the average for the whole Canton Zurich of 53.4% (Canton Zurich, 2011a). Figure 44 shows that less than 40% of the houses used for living in the Canton Zurich contain more than one flat. The majority of the houses nowadays have three levels or less (Canton Zurich, 2011b). This situation indicates a relatively long payback time for domestic reuse installations. Nevertheless it is observed that there is the tendency towards a denser building structure with increasing the use of additional levels on areas which contain already buildings (see Figure 45). More than half of the living area constructed in 1993-2005 in the Canton Zurich was built in areas which contain already buildings so that the density of constructed living area increase by 10% from 1993 to 2005 up to 5m100 m^2/ha (Baudirektion Kanton Zürich, 2007). This observation shows the tendency of more persons living in smaller areas, more households per building. This could lead in the future to more possibilities of using water reuse technologies for more than one household.

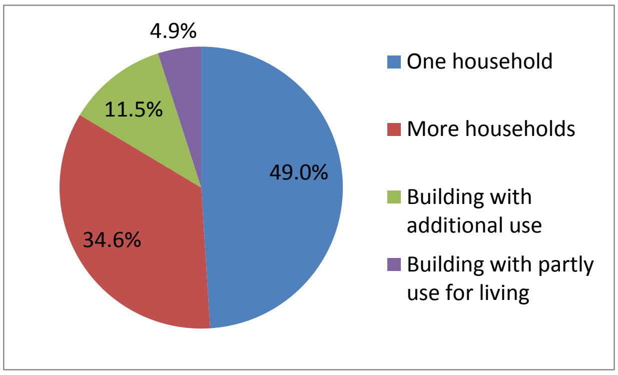


Figure 43 Overview of categories of buildings used for living (Canton Zurich, 2011a)

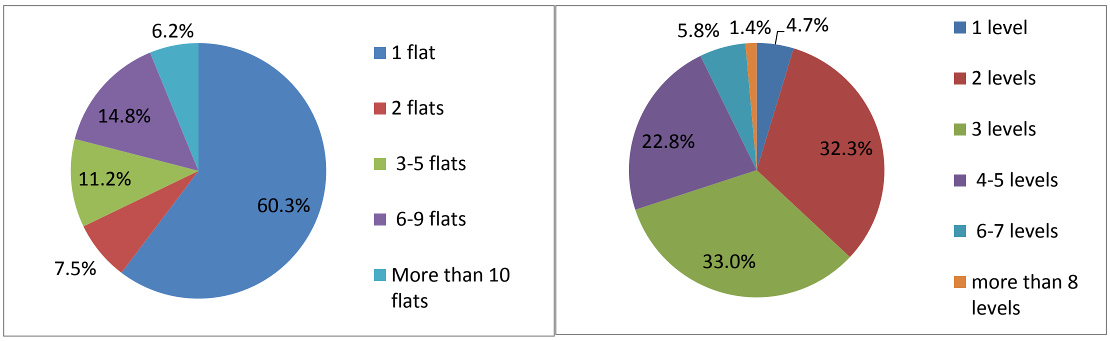


Figure 44 Distribution of numbers of flats per building and levels per building in the Canton Zurich (Canton Zurich, 2011b)

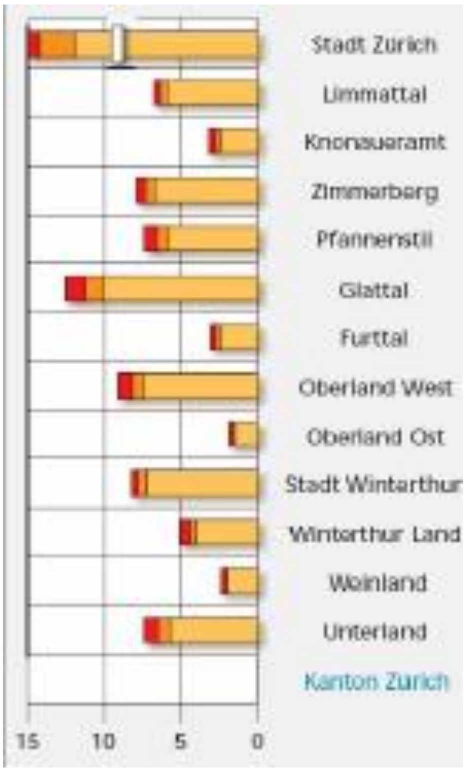


Figure 45 Area [million m^2] built for households. Yellow indicate existing area by 1993, orange indicate the increase in the area built until 1993, red indicate the increase in the area built between 1993 and 2005. Wädenswil is located in the region Zimmerberg (Baudirektion Kanton Zürich, 2007).

D. Environmental performance

The aim of water reuse systems is to reduce the consumption of drinking water by households (see Objective 2.1 from Chapter 3.1).

Table 29 Different configurations of greywater reuse systems and their potential to reduce water contamination load (Li et al., 2009)

	Screening + sedimentation + disinfection [March et al., 2004]		Coagulation with aluminium salt [Pidou et al., 2008]		Membrane bioreactor [Merz et al., 2007]	
	In	Out	In	Out	In	Out
TSS [mg/L]	44	19				
Turbidity [NTU]	20	17	46.6	4.28	29	0.5
COD [mg/L]	171	78	791	287	109	15
BOD [mg/L]			205	23	59	4
TN [mg/L]	11.4	7.1	18	15.7	15.2	5.7
TP [mg/L]			1.66	0.09	1.6	1.3
Total coliforms [CFU/100mL]				<1		
Faecal coliforms [CFU/100mL]					$1.4*10^5$	68

Greywater reuse systems are offering the potential of saving up to 30-40% of drinking water additionally to possibly used water saving appliances (Bello-Dambatta et al., 2012).

Table 29 shows the load of water contaminants which can be removed with some typical configurations for greywater treatment.

3.3.2 Technology 6. Water reuse for non-domestic water users

A. Justification of the necessity

Companies are the second user of drinking water and producer of waste water. The environmental impacts connected with the production of drinking water and with the treatment of wastewater are hence caused to a part by these users. Water reuse would decrease the amount of freshwater consumed.

B. Description

The selection of suitable technologies for water reuse depends strongly on the characteristics of the wastewater to be reused and on the intended purpose. Some sectors as food production and beverage production will require the same quality standards as for usage as potable water. If water reuse is intended for these sectors, a comprehensive combination of treatment technologies has to be applied to achieve the criteria for unrestricted use. Other applications like cooling water, pulp and paper industry or rinsing water for commercial laundries require lower quality requirements. Furthermore there are applications for which the quality requirements are very high but different than for drinking water like boiler feed water (Bixio et al., 2006).

The possible unit processes applied for water reuse are similar as treatment processes in drinking water and wastewater systems. Possible processes are shown in the following list:

- Conventional biological wastewater treatment
- Membrane bioreactors
- Nanofiltration and reverse osmosis membrane processes
- Electro dialysis (reverse)
- Disinfection processes (with chlorine compounds, ultraviolet light irradiation (UV), ozone)
- Granulated activated carbon adsorption
- Coagulation, flocculation, filtration, sedimentation, flocculation
- Phosphorus elimination

C. Economic data

Some specific cases of implementation of technologies or combinations of technologies are described in the following:

Giurco et al. (2011) estimated the effectiveness and costs for reusing wastewater from a food production plant after treatment as freshwater for a plasterboard production company. The treatment train assumed consists of

1. Upflow anaerobic sludge blanket
2. Aerobic activated sludge process
3. Anoxic stage
4. Membrane bioreactor
5. UV disinfection stage

It was estimated that this technology is suitable to produce a water quality which is sufficient for urban use with public access but not for drinking water. According to the assumptions it was concluded that 250,000 m^3/day of water could be reused. The required investment costs were estimated to be 1,750,000 € (2,500,000 AUD, Australia, 2011) with operational costs of 290,000 € (420,000 AUD, Australia, 2011) leading to specific costs of 6.3 €/m^3 (9 AUD/m^3, Australia, 2011). The energy consumption is expected to be 15.4 kWh/m^3 (Giurco et al., 2011).

Bixio et al. [2006] estimated costs for several disinfection options:

- Ozonation:
    - Investment costs: 75,000 € for 380 m^3/day and 1,600,000 € for 38,000 m^3/day
    - Operating costs: 0.02-0.035 €/m^3 for 10-15 g/m^3 ozone dosing
- UV
    - Capital costs for low pressure open channel vertical lamp arrangement: 1,898,000 for 174,000 m^3/day average flow
    - Capital costs for low pressure open channel horizontal lamp arrangement: 2,067,500 for 174,000 m^3/day average flow
    - The operating costs for UV were generally estimated to be in the range of 0.017-0.035 €/m^3

Iglesias et al. (2010) defined a matrix of qualities for several applications and treatment trains which are suitable to reach these qualities. Regarding applications for non-domestic use the following categories were mentioned:

- Application type 1:
    - Applications:
        - Water reuse for recreational uses as ponds, water bodies or running waters without public access
    - Process and cleaning water except in food industry
    - The suggested treatment train contains: filtration and disinfection
    - The investment costs are estimated to be in the range of 9-22 €/(m^3/day) and the operation costs in the range of 0.04-0.07 €/m^3
- Application type 2:
    - Applications:
        - Water reuse for recreational uses as irrigation of golf fields
    - The suggested treatment train contains: physical-chemical treatment with a lamella settling system, depth filtration and disinfection
    - The investment costs are estimated to be in the range of 28-48 €/(m^3/day) and the operation costs in the range of 0.06-0.09 €/m^3
- Application type 3:
    - Applications:
        - Refrigeration towers and evaporation condensers
        - Bathroom appliances (non-potable)

- The suggested treatment train contains: physical-chemical treatment with a lamella settling system, depth filtration, ultrafiltration and disinfection
- The investment costs are estimated to be in the range of 185-398 €/(m^3/day) and the operation costs in the range of 0.14-0.2 €/m^3

Hoinkis et al. (2012) presented a study about the effectiveness of a MBR technology for water reuse in a commercial laundry. He showed that a part of the permeate of the MBR had to be additionally filtered by reverse osmosis in order to achieve the required concentrations of salts.

D. Environmental performance

The aim of water reuse systems is to reduce the consumption of drinking water by non-domestic water users and to reduce the hydraulic load to be treated by the wastewater treatment plant (see Objective 2.2 from Chapter 3.1).

3.3.3 Technology 7. Water saving appliances for domestic water users

A. Justification of the necessity

Households are the main user of drinking water and producer of waste water. The environmental impacts connected with the production of drinking water and with the treatment of wastewater are hence caused to an important part by these users. Water saving would decrease the amount of freshwater consumed.

B. Description

This chapter gives an overview of several technologies which are suitable to reduce the water consumption in households. Two of these technologies are selected and described more in detail in the subsequent sub-sections – the 4-litre-toilet flush and water saving shower heads.

Table 30 shows that the categories toilet and bath and shower have the highest share of the total domestic water consumption. The water saving potential estimated for the category toilet flush is also the category with the highest reducing potential relative to the total consumption in the baseline situation.

Regarding bath and shower, it can be observed that the water saving technologies were developed more recently. The reduction potential using the best available technologies which are not causing excessive costs estimated in 2001 is zero compared to the baseline. But the application of the best available technologies which are not causing excessive costs estimated in 2006 lead to a reduction of already around 6.1% of the total consumption in the baseline situation.

The water saving appliances are intended to reduce the amount of water required for the different categories of domestic use which are toilet flush; bath and shower; washing machine; kitchen sink – cooking, drinking, dish washing by hand; wash basin - hygiene, washing by hand of cloths and housing cleaning; dishwasher and others. Table 30 shows the estimated distribution of the total water consumption for these purposes. The water saving appliances should accomplish fully the intended service – like e.g. cleaning dishes or flushing the toilet without causing blockage or unhygienic status – with at the same time less water consumption. Otherwise, with a reduced effectiveness the consequence would be in many cases the multiple usage of a service and therefore in total higher water consumption – e.g. extensive pre-cleaning of dishes or double flushing of the toilet – or/and an insufficient acceptance by the users and hence reduced market penetration of the product.

Table 30 Overview of water reduction potential for household water appliances (Grant, 2006; Bello-Dambatta et al., 2012)

Category	Baseline		Reduction potential I*		Reduction potential II**	
	Liter/ person/day	%	Liter/ person/day after reduction	Delta to baseline [%]	Liter/ person/day after reduction	Delta to baseline [%]
Toilet	47.8	29.5	15.0	20.2	11.3	22.6
Bath and shower	31.8	19.6	31.8	0	21.8	6.1
Washing mashine	30.1	18.6	11.8	11.3	9.2	12.9
Kitchen sink	24.3	15	13.0	7	6.8	10.8
Wash basin	20.7	12.8	11.7	5.6	8.6	7.5
Others	3.7	2.3	3.7	0	1.8	0
Dish washing	3.6	2.2	2.3	0.8	3.7	1.1
Baseline total	162	100				

* Reduction potential estimated for an application of the best available technologies which are not causing excessive costs estimated in 2001

** Reduction potential estimated for an application of the best available technologies which are not causing excessive costs estimated in 2006

B1. Description

The simplest technologies reducing the water consumption caused by toilet flush means the installation of toilets with smaller cistern or the installation of cistern displacements. For old toilets with a very high flushing volume these measures seem to be suitable since it is mentioned in the literature that for a flushing volume in the range of 8 to 12 litres the correlation between flush volume and cleaning effectiveness is not significant (Bello-Dambatta et al., 2012).

Further options for water saving include improvement of the flexibility, i.e. the possibility of applying different flushing intensities and designs improving the fluid mechanics of the toilet in order to achieve a fully effective result with ultra-low volume of water.

In the following concrete options are listed:

- Cistern displacement
- Interruptible flush device
- Variable flush device
- Dual flush
- Ultra low flush toilets
- Vacuum and compressed air toilets (*here additional other environmental impacts: energy to produce vacuum/compressed air)

- Macerating toilets
- Dry toilets (*here additional other environmental impacts: chemical or materials for cleaning or containment)
- Valve flush/siphon flush
- Composting toilets

C1. Economic data

Millock and Nauges (2010) mention that dual flush toilets have investment costs of 100-140 € (150-200 AUD, Australia, 2010) and lead to 35,000 L water savings per year and 17 € (25 AUD, Australia) economic savings per year.

D1. Environmental performance

All these options reduce the environmental impacts by reducing the water consumption and the amount of water disposed as wastewater. Additional environmental impacts are caused due to the production and disposal processes of the technologies. If a retrofitting is taken into consideration before the normal lifetime of the device is expired it has to be analysed carefully if the reduction of water consumption justifies the additional environmental load due to production (Shimizu, 2013). (Objective 2.1, Chapter 3.1)

For the vacuum, compressed air and dry toilets additional environmental partly impacts in form of energy consumption and/or chemical consumption is caused.

B2. Description

The water saving options regarding the action of bathing are limited since the nature of this action involves the entirely immersion of the human body into the water and hence filling of the bathtub until a certain level. Possible optimization of the bathtub geometry includes the lowering of the overflow, reduction of the total depth, designing corner baths. Nevertheless it has to be taken into account that these measures could lead to reduced satisfaction of part of the users hence not fulfilling the requirements/services.

Reducing the water consumption connected with showers can either reduce the shower duration or volume flow per time flowing out of the shower head. The first options can be achieved by increasing the awareness of the user by measurements like egg timers or alerts installed in the shower or by improving the effectiveness of the showering devices (Bello-Dambatta et al., 2012).

Technological options to reduce the volume used include:

- Mixer valve
- Flow regulators
- Aerated shower heads
- Egg timers and alerts

C2. Economic data

Some information about costs and environmental impacts were concluded by Millock and Nauges (2010):

- Low flow shower head with investment costs of 35 € (50 AUD, Australia, 2010) leads to 15,000 L water savings per year and 8 € (11 AUD, Australia, 2010) economic savings per year

D2. Environmental performance

All options regarding the category bath and shower cause with the reduction of water consumption also the amount of energy consumed in form of gas, oil or electricity since the showers or baths are mainly taken hot and hence the water has to be heated. (Objective 2.1, Chapter 3.1)

B3. Description

Appliances for the reduction of water consumption from water taps are partly using similar principles as shower heads, i.e. reduction of pressure and/or increase of effectiveness at constant pressure. Water savings from tap water means partly also energy saving since the water is partly used at elevated temperature. Examples for available appliances are:

- Tap inserts (aerators, laminar flow devices -> reduce splashing giving sensation of higher volume flow)
- Flow restrictors
- Spray taps
- Variable flow rate taps with brake
- Self-closing tap
- Automatic (sensor) taps (high investment costs)
- Electronic tap

B4. Description

Innovative features which are available for washing machines and which can improve the eco-efficiency are (Quack, 2010):

- 20°C programme for energy saving
- Automatic detergent dosing system for the reduction of chemical consumption
- Feedback-function: showing consumption of water and energy during the washing programme to increase the awareness and allow consumers to adapt their way of using
- In general it is a matter of fact that vertical axis washing machines are less water efficient than horizontal axis washing machines (see Figure 46).
- Yang and Yang (2011) mention another innovative technology with ultra-low water consumption (around 0.2 L/cycle) by the application of plastic chips as adsorbents. But this system was not proven to be available and information about the environmental impact due to disposal and treatment of plastic chips was not yet available (Yang and Yang, 2011).

C4. Economic data

Millock and Nauges (2010) describe that a water-efficient washing machine with investment costs of 559 € (800 AUD, Australia, 2010) leads to 21,000 L water savings per year and 10 € (14 AUD, Australia, 2010) economic savings per year

D4. Environmental performance

With the development of more modern washing machine the efficiency in terms of water and energy consumption increased nowadays machines with 0.9-1.02 kWh/cycle of 6 kg and 37-45 litres/cycle of 6 kg are available (Quack, 2010) while older models require around 100 litres per use (Bello-Dambatta et al., 2012). It was mentioned that further decrease of water volume used in washing machines per cycles is problematic since it is expected that the rinsing effectiveness will decrease and that the rinsing effect is also in nowadays used washing machines not always satisfactory. Nevertheless, the rinsing effectiveness is difficult to evaluate for the users [Quack, 2010]. (Objective 2.1, Chapter 3.1)

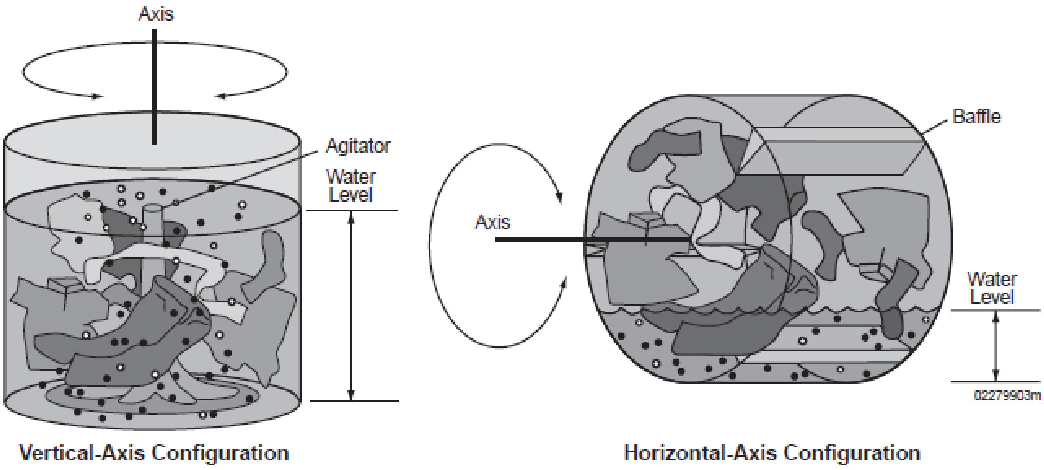


Figure 46 Schematic illustration of vertical and horizontal washing systems [Collins et al., 2002 and EPRI 1995]

B5. Description

In the following several options for increase of eco-efficiency of dishwasher are presented (Jones et al., 2002, Karwowski et al., 2012):

- More variable wash programmes
- Automatic scaling detection
- Improved rack and basket design
- Alternating arm movement
- Improved spray arm
- Automatic detergent supply
- Reuse water within cycle by applying filters, centrifugal separator, hydrocyclone
- Heat exchanger for heat recovery from used water
- Combination sink and dishwasher

C5. Economic data

In general it is estimated that the presented water saving appliances could have probably the same investment costs as conventional products if the innovative technologies would reach a stronger market penetration (Bello-Dambatta et al., 2012).

D5. Environmental performance

Innovative technologies for dish washing machines lead to a reduction in water and energy consumption mainly in the domestic sector. (Objective 2.1, Chapter 3.1)

E. Maturity and availability

All technologies presented here are commercially available.

3.3.4 Example for technology 7: Toilet flush 4 litre

A. Justification of the necessity

See technology 7.

B. Description

Until around 1990s most conventional toilets worked with a water consumption of around 13 litres per flush. It was mentioned by Bello-Dambatta (2012) that down to a volume per flush of 8 litres there was no clear correlation between performance and volume per flush. This offers a certain potential of water savings without effectively changing the toilet flushing technology. A significant water consumption reduction could be achieved by using dual flush or variable flush devices. With this technology, the intensity of flushing is adjustable by the user in a flexible way depending on the requirement.

Nevertheless, for achieving a further reduction of water volume required per flush with at the same time equally effective performance, innovative technologies had to be developed. There are basically three different working mechanisms of conventional toilets:

- The tank type siphoning toilets are installed together with a storage tank of water for flushing. The flush itself is gravity driven and the flow of water from the tank is controlled either by a siphon valve or a flapper valve while the latter is more sensitive for leakage but allows at the same time a faster and more water-efficient flush. This type of toilet includes another siphon for the evacuation of the bowl which leads to an increased pull force from the bowl to the sewage line.
- Blowout toilets do not use siphoning effect to evacuate the bowl and hence require a significant higher volume of water to transport the waste. Nevertheless, this technology is more robust against clogging than other options.
- Valve-type toilets work without a tank using the water pressure from the drinking water line. During opening of the valve water enters at high pressure and high volume flow. These toilets apply usually also the siphon effect to evacuate the bowl. These toilets are useful for medium to high usage but a disadvantage is a relatively high degree of noise (Hauenstein et al., 2013).

New types of toilet of the principle of tank type siphoning toilet were further developed with the purpose to reduce the required water volume per flush below 4 litres. One possible mechanism is the vacuum-assist toilets using under-pressure to suck the water out of the bowl. This increases the velocity of the water flush and hence the shear forces for the transportation of waste leading to better cleaning results. One example for such a system using a connection between filling tank and exit-siphon to achieve the vacuum is shown in Figure 47 (Niagara Conservations, 2013).

Pressure-assist toilets use an elevated pressure of the flushing water to increase the cleaning force of the toilet flush. The higher pressure can be reached by using valve-type toilets and hence using the pressure of the drinking water line directly, by using a pressurized tank and hence using the pressure of the drinking water line indirectly and electromechanically (Hauenstein et al., 2013).

A disadvantage of the pressurize assist toilets is, that it is more difficult to connect the water tank to water reuse systems at least requiring additional pumping energy.

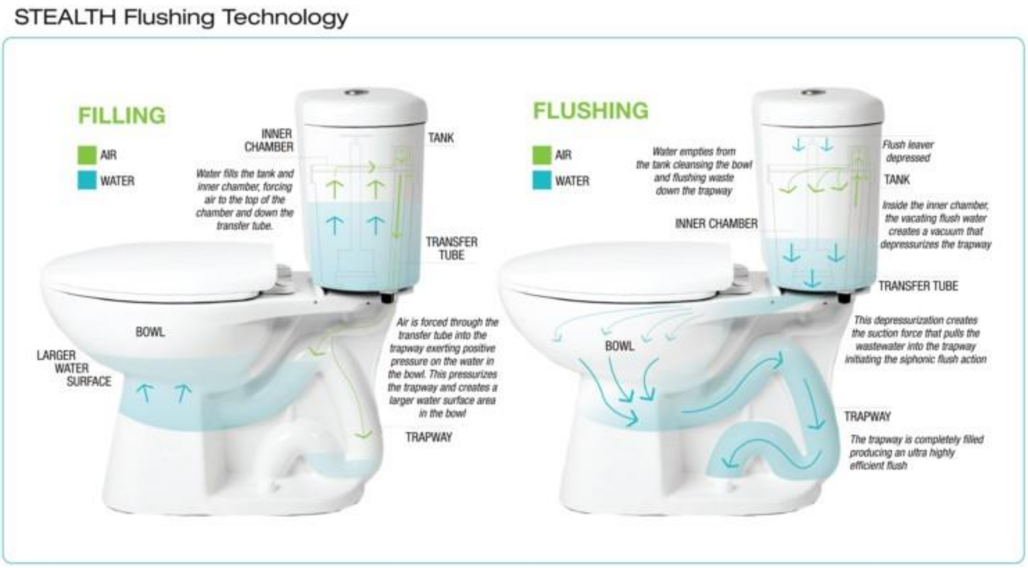


Figure 47 Principle of the Stealth Flushing technology – a vacuum assist toilet flushing system (Niagara conservations, 2013)

C. Economic data

The required investment for domestic use would have to be done by the user, hence the persons living in the household themselves.

According to a web-research the investment costs for a 4-litre toilet are recently in the range from 110-340 € (150-460 $, USA, 2013).

The information is obtained from the following websites:

http://www.itseasybeinggreen.com/catalog/category/view/id/8/?limit=all

http://www.itseasybeinggreen.com/stealthtm-0-8-gpf-ultra-high-efficiency-toilet.html

http://www.conservationwarehouse.com/zurn-toilet-z5576.html

http://www.conservationwarehouse.com/zurn-toilet-z5561.html

http://www.conservationwarehouse.com/zurn-toilet-z5571.html

The investment costs for dual flush toilets were estimated to be 200$ and the investment costs for dry toilets to be 660 € (900$, Palestine, 2010) (Nazer et al. 2010). Hence it can be assumed that the investment costs for extremely low-flush toilets are the range or slightly above the costs for a dual flush toilet but probably below the costs for dry toilets.

D. Environmental performance

From an environmental point of view, toilets with ultra-low flushing volume are beneficial by saving drinking water. Nevertheless, it has to be taken into account that the production and transportation of a new toilet installation also cause environmental impacts. Therefore very often substitutions of toilets with more modern versions before the end of life of the old one could also increase the total environmental impact. E.g. it was estimated by Shimizu (2013) that more than one exchange of a toilet during its estimated lifetime of 30 years would lead to an increase of environmental impacts. (Objective 2.1, Chapter 3.1)

E. Maturity and availability

Availability of this technology is given.

3.3.5 Example for technology 7: Water saving showerhead

A. Justification of the necessity

See technology 7.

B. Description

Conventional shower heads can consume up to 10 - 12 litres per minute. The water consumption is especially high for so-called power showers which use electric pumps allowing an adjustment of pressure and temperature. Such high water consumption leads to the situation that using the shower for around 5 minutes requires a water volume in the range of a bath.

Some models of innovative shower heads reduce the volume flow required for effective showering by including a flow regulator and a proper design with small openings to maintain a sufficiently high velocity.

Other innovative shower head models use air to improve the shower performance at lower water consumption. An example for such a design is shown in Figure 48. This patented technology includes an air intake on the upper part of the shower head. Due to the volume flow of water entering the shower head, the water is pressurized and dispersed. The water-air-mixture exits the shower head at high velocity leading to a satisfactory sensation and effect of the shower at flow rate lower than 4.8 litres per minute (Bricor, 2013).

C. Economic data

Investment costs for water saving shower heads differ significantly according to brand, technology and design. Investment costs were estimated by Nazer et al. (2012) to be 11 € (15$, Palestine, 2010) at 10 years lifetime and similar prices are given by shops specialised in water-saving solutions for households.

D. Environmental performance

The environmental benefit connected with this innovative technology is clearly the saving of drinking water. Assuming that the volume flow during showering can be reduced by around 50% the estimated water saving is around 15-30 litres per person and day. Additionally it has to be taken into account that the shower is one of the household water applications with the highest energy demand per volume water consumed. According to Beal et al. (2012) showering requires around 35-70 kWh/m^3.

Figure 48 Aerated shower head – patented VACUUM flow „booster" [bricor, 2013]

Hence in this case the water saving is directly connected with a reduction of the energy consumption. (Objective 2.1, Chapter 3.1)

As mentioned already regarding the retrofitting with innovative toilets, the production and transport of new shower heads are connected with environmental impacts as well. Too short retrofitting times would lead to the situation that these negative environmental influences would decrease the benefits from water and energy savings. Nevertheless, Shimizu (2013) shows that for shower heads a significantly shorter retrofitting interval of around 3 years is environmentally beneficial. Shimizu (2013) assumed for the calculations that the new developed models of shower heads will have decreasing shower flow rate [litres/min]. Shimizu assumed a decrease of 1 % per year.

E. Maturity and availability

The availability of this technology is high.

3.3.6 Technology 8. Water saving appliances for non-domestic water users

A. Justification of the necessity

Companies are the second user of drinking water and producer of waste water. The environmental impacts connected with the production of drinking water and with the treatment of wastewater are hence caused to a part by these users. Water saving would decrease the amount of freshwater consumed.

B. Description

The water saving appliances for non-domestic water users differ strongly between the sectors due to the very different type of usage. The two main classifications of consumers are small and medium companies and the public service sector.

Water consumption in the public service sector and in the tourism sector contains the processes which are included in a similar way in household usage. Nevertheless, the proportion of consumption differs, e.g. in office buildings water is used by taps and toilets but less often by washing machines and bathtubs. Also the usage rate can differ significantly, e.g. the number of dishes cleaned per day by dishwashers will be significantly higher in canteens and restaurants than in normal households.

In general the technologies for water appliances in the public service sector are the same as explain for household appliances. Nevertheless, the prioritisation can be different and the payback times. E.g. shorter retrofitting intervals might be environmental and economic beneficial in case of high rate usage as for dishwashers in canteens. This means, that it might be beneficial to exchange technologies in the public sector by an option with higher water saving potential more readily than in the household sector.

Also it has to be taken into account, that the awareness of the importance of water saving is often higher in the domestic use than at the work place, in hotels or in schools. Therefore useful appliances are information campaigns or signs installed close to the water installations (Bello-Dambatta et al., 2012).

Exceptional users in the public sectors are those who utilize water for recreational purposes, which is in the area of Wädenswil mainly the public swimming pool. In the case of the swimming pool a significantly different type of usage is applied in comparison to domestic users. Water saving appliances in this application would mean to ensure a suitable disinfection and treatment process in order to be able to maintain a certain hydraulic retention time. Additionally, detection and prevention of leakage as well as water saving appliances regarding toilets and showers are applicable.

In the sector of small and medium companies the water saving appliances mentioned for domestic use are relevant to a certain extent since the company buildings usually contain water installations for the employees – always toilets and taps, partly also kitchen tap, dishwasher, shower and more seldom washing machine and bathtubs. For this part of the water consumption the water saving appliances mentioned above for the public sector are applicable.

In several companies water is used for additional purposes which can be usually attributed to one of the categories cooling, heating, transport, washing, wet (electro-) chemical processes and being finally part of the final product (Dworak et al., 2007).

Examples for water saving appliances in the industry are shown in the following list (Dworak et al., 2007; Alkaya et al., 2012; Bello-Dambatta et al., 2012):

- Developing a water audit regarding quantity and quality
- Changes in the production processes
- Reduction of leakages (e.g. by reducing the pressure with pressure reducing valves)
- Changes in cooling technology (close-loop cooling)
- Automatic shut-off
- Counter current rinsing
- Spray/jet upgrades
- High pressure cleaners

- Scrapers
- Cleaning in place (CiP) (explanation is given in the next chapter)

C. Economic data

Some examples for water saving appliances together with estimations of water reduction and costs are given in Table 31. In general the investment costs and the water saving benefits differ strongly between different sectors and sizes of companies.

Table 31 Examples for applications of water saving appliances by non-domestic users and estimations of costs and benefits. (Dworak et al., 2007)

Sector	Appliance	Estimation of water saving [%]	Estimation of costs	Reference
Chemicals	Overall savings	53%	-	[ICAEN, 1999]
Food	Leaks repairs, new defroster, improved cleaning, dry filleting	58%	No costs given (estimation of benefit: 112,400 € per year (95,500 £ per year, UK))	*
Food	Water audit and different water saving measures	60%	66,100 €/year (89,500 $/year, USA, 2006) (estimation of benefit: 95’900 €/year (130,000$/year))	**
Manufacturing	Close-circuit water system, rainwater harvesting	90% (around 180,000 m^3/year)	700,000 € (estimation of benefit: 27,000 €/year)	***

* http://www.envirowise.gov.uk/
** http://www/grist/org/biz/tp/2006/04/25/makower/
*** http://www.jeconomiseleau.org/

D. Environmental performance

The main environmental benefit from these technologies is the reduction of water consumption. Additionally some appliances reduce at the same time the energy consumption mainly in cases in which water is applied at elevated temperature. (Objective 2.2 from Chapter 3.1)

3.3.7 Example for technology 8: Clean-in-place (CiP)

A. Justification of the necessity

See technology 7.

B. Description

Clean-in-place technologies are automated and usually programmable cleaning processes which are suitable to clean production plants without deconstruction or dismantling.

Clean-in-place systems can differ significantly regarding to the complexity and generally consist of the following components (Valigra, 2010):

- Tanks for water and/or detergents and/or disinfection agents
- Steam heat exchanger
- Pumps
- Sensors (e.g. pH, conductivity, turbidity, pressure, flow rate)
- Microprocessors
- Programmable logic controllers
- Pipes and lines

An example for a clean-in-place system for a pilot plant is shown by Canut and Pascual (2007) (see Figure 49).

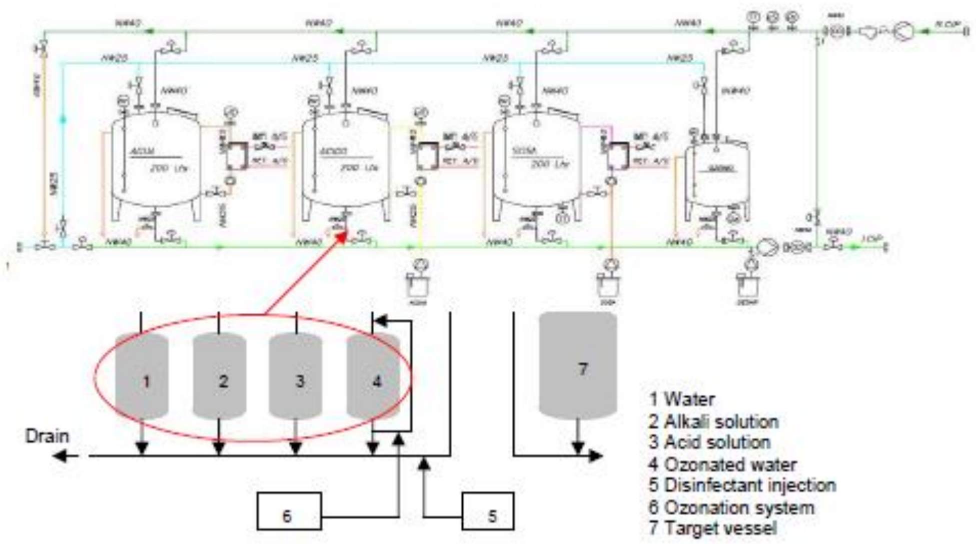


Figure 49 Example for a clean-in-place system for a pilot plant (Canut and Pascual, 2007)

This technology can use higher temperatures and stronger chemicals in comparison with manual cleaning procedures. This reduces the amount of water required to achieve the same effectiveness of cleaning. Due to the automation the process is in general more efficient and the reuse of water, detergents and disinfection agents is facilitated. Intelligent clean-in-place systems include functions for analysis and evaluation of cleaning results and efficiency (Valigra, 2010).

A typical routine of a clean-in-place system consists of the following working phases (Valigra, 2010):

- Pre-rinsing
- Detergent dosing
- Rinsing
- Sanitizer
- Final rinse

A possible optimization of this procedure is the application of specific combinations of chemicals which allow performing the cleaning and disinfection in one cleaning step.

Recently there are technological innovations increasing the efficiency in clean-in-place system. Canut and Pasual (2007) mention the application of ozone in order to enhance the cleaning procedure. Valigra (2010) presents an innovative technology using a turbulent air flow in order to optimize the cleaning efficiency especially for the clearing and cleaning of pipes. In the latter case the following cleaning phases substitute the conventional procedure:

1. laminar flow for pre-cleaning
2. turbulent air flow
3. small amount of water or/and chemicals is used together with the turbulent air flow for rinsing
4. drying with heated air

C. Economic data

According to the results of Muster-Slawitsch et al. (2011) it can be estimated that the application of a clean-in-place system in a brewery with a production in the range of 100,000 m^3 per year results in around 20,100 € investment costs and energy saving in the magnitude of around 8,300 kWh/week (Muster-Slawitsch et al., 2011).

D. Environmental performance

The environmental benefit of this technology is the saving of water and energy. (Objective 2.2 from Chapter 3.1)

Canut and Pascual (2007) reviewed different food production sectors and came to the conclusion that around 80% of the water consumption is used for cleaning processes so that there is still a relatively high potential for water savings.

4 Concluding remarks

This report includes technological and economic information about innovative technologies with the potential to increase the eco-efficiency of the urban water value chains. Table 32 gives an overview of the selection of these technologies.

Table 32 Overview of innovative technologies for the case study site Sofia and Waedenswil, Zurich

No	Technology name	Unit of implementation
Case study Sofia		
Water supply and discharge chain technologies		
T1	Pressure reduction valve, which acts as hydropower generator	Distribution network
T2	Solar drying of the sludge	WWTP
Water use technologies		
T3	Water saving appliances (low flushing toilets, shower heads, dishwashers)	Households
T4	Solar water heating (SWH)	Households
T5	Drain water heat recovery (DWHR)	Households
Case Study Waedenswil, Zurich		
Water supply and discharge chain technologies		
T1	Pressure reduction valves	Distribution network
T2	Smart pumping	Distribution network
T3	Micropollutants removal	WWTP
T4	Advanced phosphorus recovery	WWTP
Water use technologies		
T5/6	Water reuse technologies for domestic/ non-domestic users	Households/ Companies
T7/8	Water saving appliances for domestic/ non-domestic users	Households/ Companies

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