Technology Selection and Comparative Performance of Source-Separating Wastewater Management Systems in Sweden and The Netherlands

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Abstract
Throughout the EU a large number of demonstration projects with source-separating sanitation systems have been realized in the past 15 years. In order to assess the potential of source-separating sanitation systems for wide-scale application, it is important to learn from these practical experiences. This research evaluates two systems with local grey water treatment in the Netherlands and three sites with urine separation in Sweden. The study has focussed on i) the technology selection (the drivers and barriers that led to establishment of a non-conventional system in a neighbourhood) by interviewing the stakeholders that were responsible for project implementation and ii) the comparative performance of the source separation systems after they have been established. For the Swedish cases the main drivers of the involved actors were nutrient recycling, reductions of emissions and an active policy of the local government. In the Netherlands the main drivers were the reduction of water use, reduction of sewer overflows and reduction of emissions. The main barriers in all cases were high investment costs and the low experience with new sanitation approaches systems compared to the conventional system. Three of the sites showed a lower performance with respect to public health because effluent monitoring protocols for the grey water treatment systems were not in place or people could have direct contact with feces. Lack of operation and maintenance is a cause of occasional failure for the grey water treatment systems. The dominant failure reason for the urine separation systems was pipe clogging. This can be controlled by extra maintenance activities of the tenants / house owners or improved pipe constructions. All sites had an appropriate rain water management system in place. The inventory also showed that source-separating sanitation systems have a high potential to save or recover resources (water and nutrients).

Keywords
drivers and barriers, black water, decentralised sanitation and reuse, DESAR, ecological sanitation, grey water, performance assessment, technology selection, urine

INTRODUCTION

In last 10-15 years various new systems for municipal wastewater management based on separation at source have been developed or are under development. The basic approach of these systems is to separate black water (toilet water), urine and grey water (shower-, washing-, and bath water) at household level and treat these flows separately. The treatment can eighter be done on decentralised (i.e. neighbourhood) scale or off-site. The potential advantages of source-separation systems over the traditional wastewater system are a.o. i) reduced use and/or recovery of resources (water, nutrients, organic material, energy), ii) reduction of emissions to the environment and iii) more efficient handling of flows due to less dilution (Otterpohl et al, 1997; Otterpohl et al, 1999; Lens et al, 2001; Johansson et al, 2001).

The practical implementation of source-separating sanitation systems in urban settings has shown to be rather complex due to the involvement of many actors, such as project developers or housing cooperations, future inhabitants, the local municipality, water authorities and water utility companies. Another important barrier in implementing new sanitation systems is that in most European cities, sewer systems already exist, viz. investments in assets have already been made. Development of new sanitation option in most western countries therefore requires a long-term vision. Despite the complexity, throughout the European Union some tens of demonstration projects based on source-separation have been realized in the past 15 years. In order to assess the potential of source-separating sanitation systems for wide-scale application in the long run, it is important to learn from these practical experiences. In The Netherlands e.g., about 5 projects with local grey water treatment are in operation (Mels and Zeeman, 2003), while in Sweden approximately 10 projects in urban neighborhoods with urine separation have been implemented (Aarsrud, 2003).

The study that is described in this paper has investigated a number of sites in The Netherlands and Sweden in order to gain more insight into the technology selection process and to collect data on the practical performance of these systems. More specifically the research has focussed on:

- Technology selection - the drivers and barriers that led to establishment of a non-conventional system in a neighbourhood. For this purpose interviews were made with the important stakeholders in these projects in order to gain insight into their main drivers and barriers.
- Performance - the comparative performance of the source separation systems after they have been established. A field performance assessment was made based on five criteria: compliance with primary functions and sub functions, user-perspective and environment. Each criterion had several verifiable indicators.

MATERIALS AND METHODS

Study sites

Within the framework of this investigation 5 sites were studied that were established in the 1990s:

- In the Netherlands: ‘Het Groene Dak’ situated in Utrecht (1993) and ‘Polderdrift’ in Arnhem (1997), both with local grey water treatment and reuse. The black water is discharged to the municipal sewerage;
- In Sweden: ‘Ekoporten’ situated in Norrköping (1995), ‘Understenshöjden’ in Stockholm (1995) and ‘Gebers’ in Stockholm (1998), all three with urine separation. In Ekoporten and Understenshöjden grey and brown water is discharged to the municipal sewerage. In ‘Gebers’ the feces are collected in a dry toilet and composted locally, while the grey water is discharged to the municipal sewerage.

Technology selection proces

To gain insight in the technology selection process interviews were made with the stakeholders that were involved during the design and implementation phase of the various projects. The various interviewees were approached by letter or phonecall.

Performance assessment

In order to evaluate the performance of the systems, five performance indicators (PIs) were formulated. These PIs and their means of verification are presented in Table 1. Some of the PIs make a comparison with the conventional sanitation system, i.e. transport of wastewater and rain water by sewers to off-site treatment facilities. The information necessary for the PIs was gathered by interviews with system operators and current inhabitants, by review of literature and internet sources, and by site-inspections. Per case 5 randomly selected households were interviewed to find answers for the user perspective questions.

Table 1 Indicators to evaluate the performance of the investigated source-separating systems

Performance indicator	Means of verification
1.Public health protection	• Is there a chance for the house owners / tenants to get in contact with excreta or untreated wastewater? • Is the effluent quality of wastewater flows that are treated in the neighborhood monitored? • If so, does the effluent quality comply with local standards?
2.Sub functions	• Is there a system for rainwater/stormwater management?
3.User perspective	• Are the yearly costs for water supply and wastewater disposal for the house owners/tentants equal/higher/lower compared to the conventional system?[1] • Does the system cause nuisance (vermin, noise, odours)? • What are the operation & maintenance inputs of house owners/tentants?
4. Robustness	• What is the nature and frequence of system failure?
5.Environmental aspects	• Are the emissions to surface water of nutrients and BOD equal/higher/lower compared to the conventional system? • Does the system save or recover resources (water, nutrients, energy, etc.) compared to the conventional system?

[1] The yearly costs were assessed based on the investment and operational costs, including the water and wastewater fees. Investment costs were expressed in yearly costs, by using the annuity method.

RESULTS

Het Groene Dak (1993, Netherlands)

In 1989 the tenants' association 'Het Groene Dak' initiated the design of an ecological neighborhood with a low environmental impact. They cooperated with a public housing company and a private developer. The neighborhood was established in 1993 and consists of 66 houses. The area has two clusters of five houses with a special sanitation system based on separation of grey, black, and rainwater. These two clusters (rental apartments) were subject of this study. Grey water is treated in a process train consisting of sedimentation and a trickling filter. A part of the treated grey water is led into a surface-flow constructed wetland from where it is led into a retention pond; another part is used as irrigation water in a small greenhouse. The black water was at first composted in Clivus Multrum composting toilet systems. However after many problems with smell, flies and a disturbed composting process, these systems were removed and replaced by (low) flush toilets. The black water is currently discharged into the municipal sewer. Rain water of the entire neighborhood is infiltrated. Rain water from the roofs is collected and used in a number of collective laundry machines.

The actors involved in the design and decision-making in the two clusters were the tenants' association and the housing company. Interviews with these actors showed that the drivers for implementing grey and rain water measures were water consumption reduction, reduction of storm water overflows, prevention of drying-out of soils and reduction of pollutant emissions by the conventional wastewater system. The main barrier was the higher investment cost.

The tenants are responsible for the in-house equipment (toilet, pipes, etc.) and take part in the maintenance of the pond system (yearly removal of the plants) and the small greenhouse. The housing company is responsible for the treatment and maintenance of the grey and rainwater system. The effluent quality of the grey water system is not monitored on a regular basis. The interviewed tenants appreciated the system and they indicated that it made them feel environmentally concerned. They managed to reduce their water consumption by approximately 40% compared to the average Dutch water consumption. They reported incidental smell coming from the constructed wetland and the greenhouse. The greenhouse was reported to have occasional flooding problems due to loss of infiltration capacity and the tenants were considering removing it at the time of the interviews (autumn 2005). There were no noise complaints and no vermin problems.

Polderdrift (1997, Netherlands)
Polderdrift, a neighbourhood with 40 houses, was initiated by a public housing company (‘Woningbouwvereniging Gelderland’, nowadays ‘Portaal’) in 1991 and constructed in 1997. Through a series of workshops new tenants could participate in the urban and architectural design and other aspects of their future neighborhood. Reduction of water consumption received a high priority in the final design. Polderdrift has its own local grey water treatment by means of fat removal, sedimentation and a surface-flow constructed wetland. The treated water is discharged into a pond system for storage and from there it is used for toilet flushing. The black water is discharged into the municipal sewer. Rain water of the entire neighborhood is infiltrated. Rain water from the roofs is collected, stored and used in the laundry machines. The resulting water consumption in Polderdrift is approximately 43 % lower compared to the average Dutch water consumption.

The main actors involved in the decision making were the tenants, the housing company and a green architect. The main drivers were to reduce water consumption, to reduce sewage overflows, and to create a nice neighborhood. The main barriers were the high investment cost and low experience with grey water systems.

The tenants are responsible for the in-house equipment (toilet, pipes, etc.) and for the operation and maintenance of the constructed wetland. Maintenance activities include cutting of the reed, regular inspection of the manholes and flushing of the drainage pipes once a year. Operation problems should be reported to the housing company. Two times a year a specialized company removes the settled sludge from the sedimentation tank. The effluent quality of the grey water system is not monitored on a regular basis. Site-inspections and an interview with one of the operating tenants showed that the status of the system at the time of the visit (autum 2005) was not good. The sedimentation tank was not emptied that year and the frequency of water discharge to the reedbed was too high.

The interviewed tenants appreciated the system and also the required maintenance work. Two people said it made them more environmentally aware. Three out of the 5 interviewed tentants sometimes experienced smell. There were no noise complaints and no vermin problems.

Understenhöjden (1995, Sweden)
The site ‘Understenshöjden’ in Stockholm includes 44 rental houses. A local tenants’ association was the main actor in the design and decision-making. The association cooperated with two project developers with experience in ‘tailor-made’ housing projects. The tenants implemented several ecological building measures of which one was a source-separating sanitation system. Urine is separated and transported once a year to a location near Lake Bornsjön. This location is owned by Stockholm Vatten and leased to a local farmer. After storage for six months (to remove pathogens)

the urine is used to fertilize cereal crops. Grey and brown water was locally treated, but because the effluent standards could not comply with local effluent standards these flows are nowaydays discharged into the municipal sewer system. Rain water from roofs and roads is infiltrated.

According to interviews with representatives of the tenants' association, the interviewed 5 tenants and one of the project developing companies, the main drivers for a source-separating sanitation system were nutrient reuse and the development of a innovative environmental technology. The role of the tenants in operation and maintentance is limited to the inhouse equipment (toilet and pipes). The main operational difficulties encountered so far were problems with clogging of the urine pipes (approximately 2 times per year). Maintenance activities to solve this include flushing the toilet with hot water and soda, and cleaning the pipes with a mechanical snake.

The interviewed tenants appreciated the system and also had no problems with the cloggings and the required maintenance work. Two persons indicated that the system could produce some smell during cloggings. There were no noise complaints and no vermin problems.Urine separation recovers nutrients for agricultural use and also potentially reduces nutrient emissions to surface water. According to Jönsson the emissions of N and P to water may decrease by 55 % and 33 %, respectively (Jönsson, 2002). The water saving capacity of the urine separation toilet is, depending on ones habits, approximately 5 – 40 L/p.d (Johansson et al, 2001). Urine transport from Understenshöjden over 33 km to Lake Bornsjön requires 44 MJ/p.y (Jönsson, 2002). However the energy savings for the conventional system and fertilizer production amount respectively 32 MJ/p.y and 75 MJ/p.y (Jönsson, 2002).

Ekoporten (1995, Sweden)

The site 'Ekoporten', consisting of 18 apartments, was an initiative of a local housing company to implement the latest technologies on sustainable building. Among other measures also a source-separating sanitation system was implemented. Urine is separated and, since 2002, transported to two local farmers and used on their land. The transport is paid by the housing company. The brown water undergoes a centrifugal liquid/solid separation in a so-called Aquatron system. The separated feces are mixed and composted with organic waste and wood chips. The flush water fraction and the grey water were treated in a three-chamber-sedimentation tank, UV-filter, and a horizontal-flow constructed wetland. In 1999 the UV-filter and the horizontal-flow constructed wetland were replaced by a vertical-flow constructed wetland. The reason was a poor functioning UV-filter due to the high suspended solids concentration, leading to high amounts of e-coli in the effluent of the wetland. Also exposure to greywater in the horizontal-flow wetland was an argument to do replace this system. Allthough the system is now performing well, it is considered to connect the flush water and the grey water to the sewer. The reason is that the constructed wetland discharges on a sensitive river.

The main actors involved in the design and decision making were the housing company and local government. The main drivers were nutrient reuse, the development of an innovative environmental technology and the application of sustainable building measures. The housing company also considered having a green label as a driver. The main barriers were the high investment costs.

The role of the tenants in operation and maintentance is limited to the inhouse equipment (toilet and pipes). There is a system manager for operation and maintentance of the constructed wetland. An important operational difficulty encountered in Ekoporten is clogging of the urine pipes. The applied pipe diameters are low and some pipes have angles of 90°. This occasionally leads to complete stoppages. The tenants flush the toilet relatively often in order to remove the sediments and also flush the toilet with soda. Based on the experiences in Ekoporten recommendations were made to use bigger pipes for urine transport (preferably 110 mm) and to use a slope of 1% for new applications.

Despite the cloggings the inhabitants were generally satisfied with the system. Occasional smell was reported during cloggings. There were no noise complaints and no vermin problems. Due to the installation of urine diverting toilets the water use in the area was lower than average. The urine needs a flush of 0.2 litres and the feces of 4 litres. With the same amount of flushes the toilet saves 25 % water compared to a conventional Swedish toilet (Vinnerås, 2001).

Gebers (1998, Sweden)
In January 1995 the tenant's organization EKBO (Ecological Collective Housing in Orhem) was founded. The EKBO members initiated the idea to live in the empty building of Gebers. In cooperation with a housing company the building was renovated in 1998. It currently has 32 apartments in which between 60 and 80 people have been living over the years (Boverket, 1998). The appartments have dry toilets with urine separation. The feces are collected by a drop-hole and a 200 mm wide pipe into a plastic bag in a 140 litre (or smaller) bin (Krantz, 2005). The amount of separated feces and toilet paper is approximately 0.22 L/p.d (Palmquist and Jönsson, 2003). When the bin is filled the tenants carry it out of the basement to empty it at the compost site. The urine is collected and transported to the farmer at Lake Bornsjön. Grey water is discharged into the municipal sewer system.

The main drivers of the tentants of EKBO were nutrient reuse, reduction in water consumption and an environmental-friendly neighborhood. The tenants are responsible for all operation and maintenance activities with respect to the feces and urine. In the processing of the feces they can get in contact with the feces. They use protective measures (gloves) while empyting the bin. An important operational problem is the occurrence of flies that are attracted to the feces collection bin. According to Krantz (2005) all 26 respondents had experienced problems with flies at least once. Also clogging of urine pipes was encountered. The air from the feces bins in the basement is ventilated in order to avoid odors. The amount of nutrients recycled is for N, P, and K respectively 9, 1, and 2.2 kg/hh.y (Palmquist and Jönsson, 2003).

TECHNOLOGY SELECTION PROCESS

Table 1summarizes the drivers and barriers for implementation of source-separating sanitation systems that were mentioned by the local stakeholders in Sweden and The Netherlands. The study showed that a number of the important drivers and barriers of the stakeholders to select certain technologies were different in the Netherlands compared to Sweden. In The Netherlands the interest in reuse of reclaimed wastewater as a measure to reduce the tap water consumption was a relatively important driver. This driver was – on average – rated lower in Sweden. Another noticeable difference was the higher interest in the recycling of nutrients in Sweden due to an active stimulation policy of the Swedish government to recover phosphorous. This formed an important driver for all Swedish actors in contrast with The Netherlands where nutrient recycling was generally not considered important at all. In Sweden also local governments such as Stockholm Vatten stimulated and facilitated the implementation of the studied urine separation systems. The water authorities in The Netherlands only played a passive role. In Sweden the protection of sensitive surface waters also rated higher than for The Netherlands. All actors address both in Sweden and in The Netherlands, rated higher investment costs as an important barrier. The last barriers is that in most urban areas already a conventional sanitation is present, and several actors value the system on its reliability and cost effectiveness.

Table 2 The drivers and barriers that were mentioned by the local stakeholders for implementation of non-conventional sanitation systems and their average score

Drivers	**Sweden**	**The Netherlands**
Reduction in water consumption	No	Yes
Reduction of pollutants' emissions to the environment	Yes	Yes
Recycling of nutrients	Yes	No
Development of innovative technology	Yes	Yes
Active governmental involvement	Yes	No
Discount on (waste)water fees	Yes	No
Barriers		
High costs	Yes	Yes
New technology	Yes	Yes
Presence of a conventional sanitation system	Yes	Yes

PERFORMANCE ASSESSMENT

Table 3 presents the performance evaluation of the various cases based on the assessment protocol that was developed for this project. The performance was assessed in comparison with conventional off-site wastewater transport and treatment.

- PI 1: An important conclusion with respect to PI 1 (public health) is that the two Dutch cases with local grey water treatment had no effluent monitoring systems in place. For the Swedish case Gebers the direct responsibility of inhabitants for emptying feces bins can be considered as a health risk according to our assessment protocol, although the involved people are well instructed and aware how to avoid risks.
- PI 2: All the investigated cases used local rain water infiltration system and sometimes had a rain water use system. This can be considered an improvement compared to the conventional system, because it reduces emission of pollutants through sewer overflows.
- PI 3: The total yearly costs for water supply and wastewater disposal compared to the conventional system were more or less similar for Groene Dak and Understenhöjden. The yearly costs for the inhabitants in Gebers were approximately 30% lower. Due to relatively high investments in equipment, the yearly costs for Polderdrift and Ekoporten were significantly higher. Gebers has a high level of nuisance due to frequent problems with flies. Moreover, this site also has a high O&M requirement by the tenants.
- PI 4: The two Dutch cases with local grey water treatment experienced (partial) system failures due to lack of operation and maintenance. The dominant failure reason for the urine separation systems in Sweden was pipe clogging. Pipe clogging can be controlled by extra maintenance activities of the tenants / house owners. For future cases recommendations for improvement have been made by Swedish experts.
- PI 5: The grey water treatment systems have the potential to significantly reduce water consumption (40%). The urine separation systems have a high potential in reducing emissions and in recovering resources (nutrients).

Table 3 Performance evaluation of the various cases (in comparison with the conventional sanitation system) based on the pre-defined performance indicators

Performance indicator		Groene Dak	Polderdrift	Understens-höjden	Ekoporten	Gebers
1. Public health protection		-	-	0	0	-
2. Sub functions		+	+	+	+	+
3. User perspective	Costs	0	-	0	-	+
	Nuisances	0	0	0	0	--
	O&M	0-	-	0	0	-
4. Robustness		-	-	-	-	-
5. Environmental aspects	Emission reduction	+	+	+	+	+
	Resource use / recovery	+	+	+	+	+

CONCLUSIONS

- This investigation showed that there were different drivers for the establishment of source-separating sanitation systems in three Swedish and two Dutch cases. For the Swedish cases the main drivers of the involved actors were nutrient recycling, reductions of emissions and an active policy of the local government. In the Netherlands the main drivers were the reduction of water use, reduction of sewer overflows and reduction of emissions. The main barriers in all cases were high investment costs and the small experience with new sanitation approaches systems compared to the conventional system (sewers and off-site treatment).
- With respect to public health the two Dutch cases with local grey water treatment had a lower score compared to the conventional system because no effluent monitoring systems are in place. All the investigated cases used local rain water infiltration system. This can be considered an improvement compared to the conventional system. All cases were characterised by relatively high investment costs, however the yearly costs of two cases in Sweden were lower than the conventional system. One of these sites had frequent problems with flies and a high O&M requirement by the tenants.
- The two Dutch cases with local grey water treatment experienced (partial) system failures due to lack of operation and maintenance. The dominant failure reason for the urine separation systems in Sweden was pipe clogging. Pipe clogging can be controlled by extra maintenance activities of the tenants / house owners. For future cases recommendations for improvement have been made by Swedish experts.
- The grey water treatment systems have the potential to significantly reduce water consumption (40%). The urine separation systems have a high potential in reducing emissions and in recovering resources (nutrients).

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