Research

The implementation of DESAR concepts in two projects in Germany

This research encompasses an inventory of the practical applications of two selected projects in Germany where DESAR systems are applied in order to provide better information for technology selection in the future for interested parties.

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Preface

This minor thesis on Decentralized Sanitation and Reuse (DESAR) was performed within the MSc. Environmental Sciences. This research is done for the Urban Environment Group (UE) of the University of Wageningen. The UE-group, together with Lettinga Associates Foundation (LeAF), are currently building a database on DESAR projects in Europe with the idea of comparing and mapping practical experiences. This includes an assessment on operational performance, user acceptance and costs. For this report two projects are investigated:

"Arbeiten & Wohnen" a model housing project in Freiburg im Breisgau

"Östarkade" an office building of KfW Bankengruppe in Frankfurt am Main

During this research many actors where willing to help me gathering all the knowledge that was needed for this research. Not only for this reason I would like to thank them all but also for the pleasant time that I experienced during my stay in Germany. A special thanks for Arne Panesar for his hospitality. He made it possible to stay within the complex so that I could use the applied systems by myself.

Finally I would like to thank my supervisors, Adriaan Mels and Okke Braadbaart, for given me the opportunity to do this research and for their assistance during my research.

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Summary

Nowadays there is a lot of interest in new types of sanitation systems that are designed to be improvement of the current sanitation system that is based on large-scale sewer systems and centralised wastewater treatment. A general name for this kind of systems is DESAR, DEcentralized Sanitation And Reuse These non-conventional sanitation systems are developed to avoid the reduce the volume of water used, to reduce emissions into the environment and to enable the reuse of nutrients and treated wastewater.

A wide range of technologies can be applied in these non-conventional systems. Decentralised systems, waste separation at source and minimization of dilution are the main features of many DESAR systems but mixtures of decentralised and centralised systems are also possible.

On different places all around the world demonstration projects of DESAR systems are applied. For this research two selected sites in Germany are investigated where DESAR systems are implemented.

The selected research sites in Germany were:

1. **"Arbeiten & Wohnen" a model housing project in Freiburg im Breisgau**
2. **"Östarkade" an office building of KfW Bankengruppe in Frankfurt am Main**

The information that was collected within the framework of this thesis includes a technical study of the implemented technologies, an inventory of the involved actors, an inventory of the drivers and barriers that were the reason for the implementation of these DESAR systems, the operational performance, the costs and the maintenance requirements and the user acceptance in order to provide better information and knowledge about the implemented systems. The research objective was to investigate the practical application of two selected DESAR projects in Germany in order to evaluate the potential in this approach for other new housing projects in Germany (and The Netherlands).

Main research questions:

1 What are the key-features of the implemented ecosan systems of the selected sites in Germany based on the technical description, drivers and barriers for the implementation, performance, maintenance, costs and the user perception of the two selected sites in Germany?
2 What are the main features of the conventional sanitation system in Germany?
3 Could the investigated DESAR concepts be an innovative approach to the current conventional domestic wastewater treatment system in Germany (and / or The Netherlands)? In other words, does it offer advantages compared to the current system.

In order to investigate the second research question the wastewater treatment of Frankfurt am Main is selected as research site for the conventional way of domestic wastewater treatment.

The idea of implementing alternative sanitation concepts in a passive energy house or office building can be accomplished by collaboration between different actors. First of all the project owner has an idea that needs to be designed by several actors like, technology suppliers, architects and technical bureaus to give an clear overview what the possibilities are and the best way of implementation.

Both projects show some similarities concerning the role of the actors. For the project “Arbeiten & Wohnen” other actors are involved because of the scale and intensions of the project. For instance it is financed from private and government funding as for the KfW by their own resources. At the project “Arbeiten &* Wohnen” an association is formed who was responsible for the management and juridical assistance.

By applying DESAR concepts within the project “Arbeiten & Wohnen” a water saving of approximately 52 litre per day is established, when assumed that 147 litre/day is normal. As for the personal at the “Östarkade” they use an average of 20 litre fresh water each day. When assumed that in normal situation 35 litre is used within is a office by an employee it saves 15 litre each day. The fees are depending on the amount of freshwater used (as explained before) so less fees has to be paid, respectively € 55,- and € 16 for the residents of “Arbeiten & Wohnen” and the KfW per employee per year.
The investment costs of the project “Arbeiten & Wohnen” are higher when DESAR concepts are implemented on this scale in comparison with the conventional wastewater treatment plant (regarding the amount of p.e.). The investment cost for the grey- and blackwater treatment is approximately € 6300,- with an service life of 30 years is € 210,- per year in comparison with the conventional treatment that costs € 117 each year (useful service life 30 years). As for the operational/maintenance costs the DESAR sites are cheaper than the conventional wastewater treatment plant.

The residents of the project “Arbeiten & Wohnen” are satisfied with the current situation, although there are some who think that the system is not running on it full potential as it was designed for. With this they mean that there is no intensive reuse of the treated greywater for flushing of the toilets and the fact that the biogas installation is not in operation. Despite the fact that these parts are not in operation the resident are pleased with the fact that they own and use an ecological sanitation concept that contributes to a better environment. Not only the ecological aspects are important but also the social contacts between the residents and the economical advantages (water saving) they experience.

The investigated DESAR concepts can be an alternative approach to the current conventional domestic wastewater treatment system in Germany (and / or The Netherlands). In other words, it offers advantages compared to the current system. Advantages are based on, social, economical and performance of the DESAR systems compared to the conventional way of domestic wastewater treatment. By incorporating DESAR concepts in a building like “Arbeiten & Wohnen” the residents feel like they are responsible for treating their own wastewater, ecological thinking is improved. A closer contact between the residents is established. Not only on social level but also on the economical level advantages are achieved for both projects in the form of water savings and maybe in the future the use of biogas within the project “Arbeiten & Wohnen”.

Overall it can be stated that both projects are showcase projects of innovative technologies that are contributing in the closed-loop concepts of wastewater management. They are an example for further implementations not only in Germany but also worldwide

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1 Introduction

1.1 Background

The first conventional sanitation systems in the Netherlands were introduced in the 1870s. They consist of a network of sewerage pipes that transport wastewater out of the city towards centralised wastewater treatment plants. The primary goals of the systems are:

- Protection of public health by safe removal and treatment of human waste products.
- Protection of surface water quality and environment by the prevention of discharging oxygen binding substances and nutrients. (Stowa, 2005-12).

The wastewater system in The Netherlands functions well with respect to its main function, the protection of the public health. Also the protection of surface water and environment by the prevention of untreated discharges is generally well, with exception of sewer overflows during rain events.

However, despite of its merits, the conventional wastewater management system is coming under increasing criticism for being economically and environmentally unsustainable. Some problems that the wastewater plants are coping with are:

- Relatively high energy consumption at the wastewater treatment plant (aeration)
- High sludge production (chemical waste);
- Nutrients are destroyed and not recovered;
- Emissions of CO_2 into the atmosphere;
- Wastewater treatment plants have to cope with increasingly stricter effluent standards. To cope with these stricter standards the energy consumption of the conventional system will increase and a larger sludge production will occur;
- The cost for the treatment/disposal of the produced sludge and the treatment of larger amounts of wastewater are financially increasing.

The sewerage is needed to transport wastes off-side towards to conventional wastewater treatment plants where it can be treated and disposed. These conventional sewerage systems require an elaborate infrastructure and large amounts of water to transport the wastes. Some other problems that the sewerage are coping with are:

- Pollution of soil, by leakage of sewer;
- High maintenance/construction costs;
- Within combined sewage system, a dilution of wastewater by added rainwater occurs;
- Rainwater is transported out of the area. Which can lead to drying out of the soil.

Nowadays there is a lot of interest in new types of sanitation systems that are designed to deal with the problems of the wastewater treatment plants. A general name for this kind of systems is DESAR, DEcentralized Sanitation And Reuse and/or ECOSAN (ECOlogical SANitation). These non-conventional sanitation systems are developed to avoid the discharge of domestic wastewater into the environment and to enable the reuse of nutrients (like phosphorus, which has limited global supplies), organics, water and energy, that are present in the waste streams and end products. A presentation in poster form of these advantages is given in appendix 1.

A wide range of technologies can be applied in these non-conventional systems. Decentralised systems, waste separation and minimization of dilution are the main features of many DESAR systems but mixtures of decentralised and centralised systems are also possible.

On different places all around the world these DESAR systems are applied. For this research two selected sites in Germany are investigated where DESAR systems are implemented. The information that was collected within the framework of this thesis includes a technical study of the implemented technologies, an inventory of the involved actors, an inventory of the drivers and barriers concerning implementation of these DESAR systems, the operational performance, the costs and the maintenance requirements and the user acceptance. As a start a general overview of the conventional way of wastewater treatment in Germany is given in chapter 3, and also for the selected site Frankfurt am Main. For Freiburg only the cost are taken into account.

The ultimate aim of the research is to provide better information and knowledge that can be used for technology selection.

1.2 Research objective

The research objective is to investigate the practical application of two selected DESAR projects in Germany in order to evaluate the potential in this approach for other new housing projects in Germany (and The Netherlands).

To do so, we will investigate technical features, drivers and barriers for the implementation, performances, maintenance, costs and the user perceptions.

1.3 Research questions

Main research questions:

What are the key-features of the implemented DESAR systems of the selected sites in Germany based on the technical description, drivers and barriers for the implementation, performance, maintenance, costs and the user perception of the two selected sites in Germany?

What are the main features of conventional domestic wastewater treatment in Germany?

Could the investigated DESAR concept be an alternative approach to the current conventional domestic wastewater treatment system in Germany (and / or The Netherlands)? In other words, does it offer advantages compared to the current system.

Sub questions:

1. What is the conventional domestic wastewater management system for Germany in general and more specifically for Frankfurt am Main where a DESAR concept is applied in the office building of the KfW Bankengruppe?

2. Which actors were / are involved in the decision making process (technology choice) of the two selected projects?

3. What are the drivers for applying certain ecological sanitation systems for the selected sites according to the actors?

4. What are the barriers for applying certain ecological sanitation systems for the selected sites according to the actors?

5. What are the differences between the drivers and barriers between the involved actors per selected site?

6. What are the technical features of the implemented ecological sanitation systems per selected site?

7. What is the performance of the selected ecological sanitation systems per selected site?

8. What were and are the financial aspects for the applied ecological sanitation systems?

9. How do users perceive the applied ecological sanitation systems per selected site?

1.4 Interviewees

The stakeholders that were interviewed for the purpose of this research are:

- Actors who are and were actively involved in the decision making and realization of the selected sites
- Households / employees using the systems at the selected sites in Freiburg and Frankfurt am Main
- Employees of the selected wastewater treatment plant of Frankfurt am Main.

1.5 Outline of the report

In chapter 2 the research design of this research is presented. The next chapter presents the wastewater management system of Germany, followed by the conventional way of domestic wastewater treatment in Frankfurt am Main. Thereafter, in chapter 4 and 5, the research sites “Arbeiten & Wohnen” in Freiburg and the office building “Östarkade” in Frankfurt am Main are described. In chapter 6 the conclusions and in the last chapter the recommendations are given for further research.

2 Research design

2.1 Introduction

In this chapter the design of the research is described, including the selected sites and methods that are used in order to retrieve the information needed for this research. The division is made between: drivers and barriers, system performance and costs.

2.2 Selected research sites

The selected research sites in Germany were:

3. **"Arbeiten & Wohnen" a model housing project in Freiburg im Breisgau**
4. **"Östarkade" an office building of KfW Bankengruppe in Frankfurt am Main**

In the map below (figure 1) the selected sites are pointed out with a red arrow.

Figure 1: Locations of the selected sites in Germany[1] www.stadtplandienst.de

[1] Source: www.bugbog.com/maps/ europe/germany_map.html

In order to get an insight in the conventional way of wastewater treatment, the local wastewater treatment of Frankfurt is visited and a general literature research has been done for the conventional wastewater management system in Germany .
The conventional wastewater treatment plant where the wastewater of Freiburg is treated has not been visited. The reason for this is that it would not fit in the available research time.

2.3 Drivers and barriers

To gain insight in the decision-making of the design and implementation phase of the system several actors involved are interviewed according to a questionnaire. The used questionnaire is presented in appendix 2. The aspects that are covered by these questionnaires are standing below:

- environmental
- public health
- legal & regulatory
- financial
- social & managerial

2.4 Performance

To gain insight in the performance of the implemented technologies several actors involved were interviewed by means of three questionnaires. The three questionnaires are related to the actors that where responsible for maintenance, system expert and system owner. The used questionnaires are presented in appendixes 3, 4 and 5. The implemented technologies are described in chapters 4 and 5 for each selected research site.

For the performance of the wastewater treatment plant an employee of the selected wastewater treatment plant has been interviewed.

For both the studied projects a literature study (review of internet sources, available literature, etc) was performed, in order to get detailed information about the implemented technologies.

2.5 Costs

For the costs of the implemented technologies and the conventional way of wastewater treatment the involved actors were interviewed. The questions are given in the questionnaires that were already mentioned under paragraph 2.4 Performance.

To also obtain this information for the conventional way of wastewater treatment in the project site Frankfurt, an employee was interviewed and literature study was conducted (review of internet sources, available literature, etc).

2.6 Household acceptance assessment

The households were interviewed according to a questionnaire (appendix 6). The number of households that where interviewed was depending on the willingness of interviewees to contribute to research. The number of households that where willing to cooperate differed among the two selected sites. For Freiburg, 11 households were interviewed and for Frankfurt only 1. To make it statistically representative the interview of the household in Frankfurt is

not taken into account. The results of this interviews hold in Freiburg are presented in appendix 7

The interviews focused on the following aspects:

- household descriptors (composition, age, etc.)
- sanitation system description
- performance, invisibility and user comfort
- system robustness
- (risks for) public health
- questions on the user perspective ?

The collected data were worked out in two ways:

1. overview of the given answers
2. the relations between the various answers.

The obtained data from the households are strict confidentially, for this reason no names are mentioned of those who participated this research.

3 The conventional wastewater management system in Germany

3.1 Introduction

The conventional way of sewage treatment in Germany is presented in this chapter. Included is in this chapter some background information in paragraph 3.2. Paragraph 3.3 highlights the organisation and paragraph 3.4 describes the laws and regulations. The costs are discussed in paragraph 3.5. In the final two paragraphs the visited wastewater treatment plant of Frankfurt am Main and the wastewater treatment management system of Freiburg is discussed .

3.2 Background

Germany is divided into 16 counties: Baden-Württemberg, Bayern, Berlin, Brandenburg, Bremen, Hamburg, Hessen, Mecklenburg-Vorpommern, Niedersachsen, Nordrhein-Westfalen, Rheinland-Pfalz, Saarland, Sachsen, Sachsen-Anhalt, Schleswig-Holstein, Thüringen. Within these 16 counties approximately 95% of the population are connected on the sewage system. The capacity of the wastewater treatment plants, together with the number and total capacity is presented in table 1. Wastewater is treated in 10,188 wastewater treatment plants all over Germany. The length of the used sewage net is approximately 450.000 km, which is equal of travelling round the earth 11 times. The total amount of wastewater that is treated within the waste treatment plants is approximately 9.6 billion m^3 on yearly basis.

Table 1: Capacity and number of wastewater treatment plant in Germany

Capacity (p.e)*	Number WWTP	Total capacity (million p.e)
< 1000	4305	2
1000 - 5000	2742	7
5000 – 20000	1744	19
20000 – 100000	1129	43
> 1000000	268	82
Total	***10188***	***153***

* p.e. biologically organic degradable load with a biochemical oxygen requirement of 60 g oxygen per day in 5 days (BSB5).

Three types of domestic wastewater treatment are applied in Germany:

- mechanical
- biological without post treatment
- biological with post treatment

There has been a shift in applied technologies during the time. In 2001 95 % of the wastewater is treated biological with post treatment. In 2005 96 % of the wastewater treatment plants are treating the wastewater biological with post treatment(BMU,2005). The biological treatment of wastewater without post treatment is 5 % and the mechanical treatment is reduced till 0.1 %. In 2001 a total amount of 10.5 billion m^3 of wastewater is treated in the wastewater treatment plants and has been discharged on surface water. 5.3 billion m^3 was polluted water from households, industries etc. and 5.2 billion was rainwater

and undefined water. As a result of applying treatment on a biological way the oxygen level in the surface water has increased, this has lead to an improved living surroundings of the water organism.

In figure 2 the total amount of treated wastewater is presented during the time with the treatment technology applied.

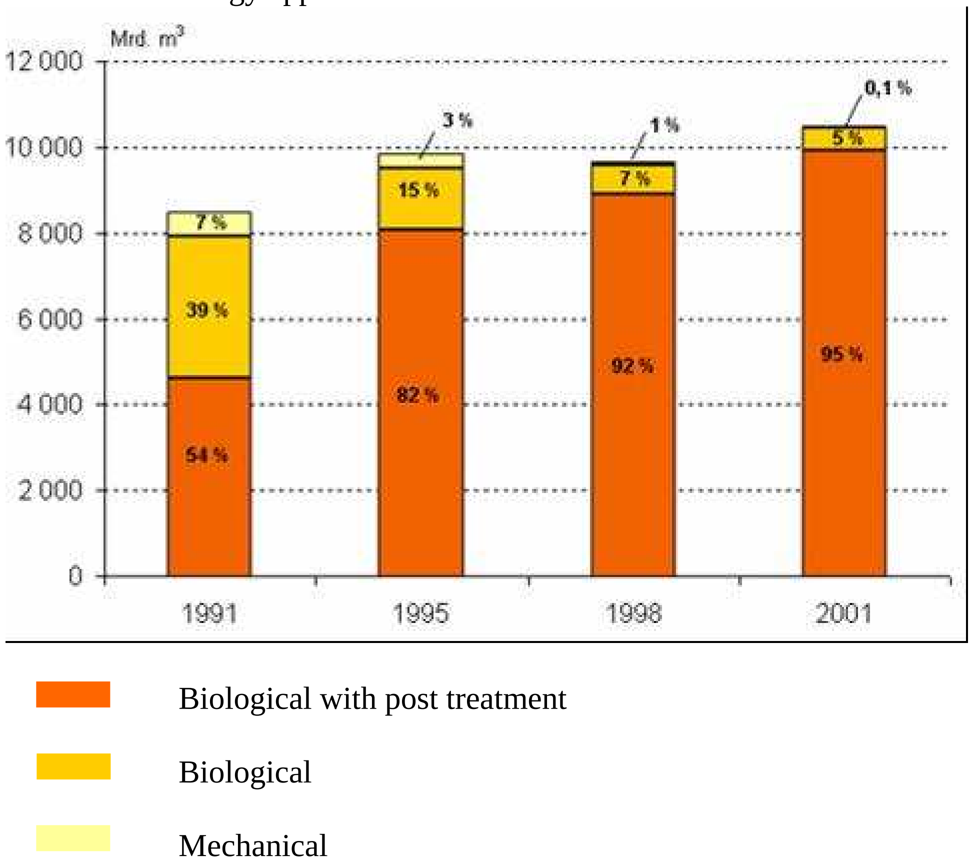


Figure 2: Total amount treated wastewater by applied technology in percentages (Source: BMU,2005)

3.3 Organisation

Germany has different administrative levels that are involved in the wastewater treatment. A scheme of the different levels is presented in figure 3. The municipality is responsible for the collection and purification of the collected wastewater. Sometimes, for economical reasons, cooperatives between municipalities can be formed to set up a new wastewater treatment plants. Several forms of cooperatives are listed below (Tritten,2002):

Municipal department:	Enterprise by the municipality in the context of the general local administration
Municipal utility:	Enterprise by the municipality as special estates with independent record keeping.
Municipal company:	Enterprise in private legal form controlled by the municipality.
Joint company:	Local enterprise under participation of a private business.

The larger counties of Germany have a structure of government agencies on three levels:

Level 1: “Oberste Wasserbehörde“

Level 2: "Obere Wasserbehörde"
Level 3: "Untere Wasserbehörde"

The smaller counties en the counties in former East-Germany have a structure based on two levels.

The so called "Wasserbehörde" are responsible for the implementation of the relevant laws, these laws are the Wasserhaushaltgesetz (WHG) and the Landeswassergesetz (LWG). The "Oberen Wasserbehörde" are responsible for the wastewater treatment plants > 5000 p.e. and the "Unter Wasserbehörde" are responsible for the wastewater treatment plants < 5000 p.e.
The municipality or the cooperative are responsible for the operational aspects of the wastewater treatment plant.

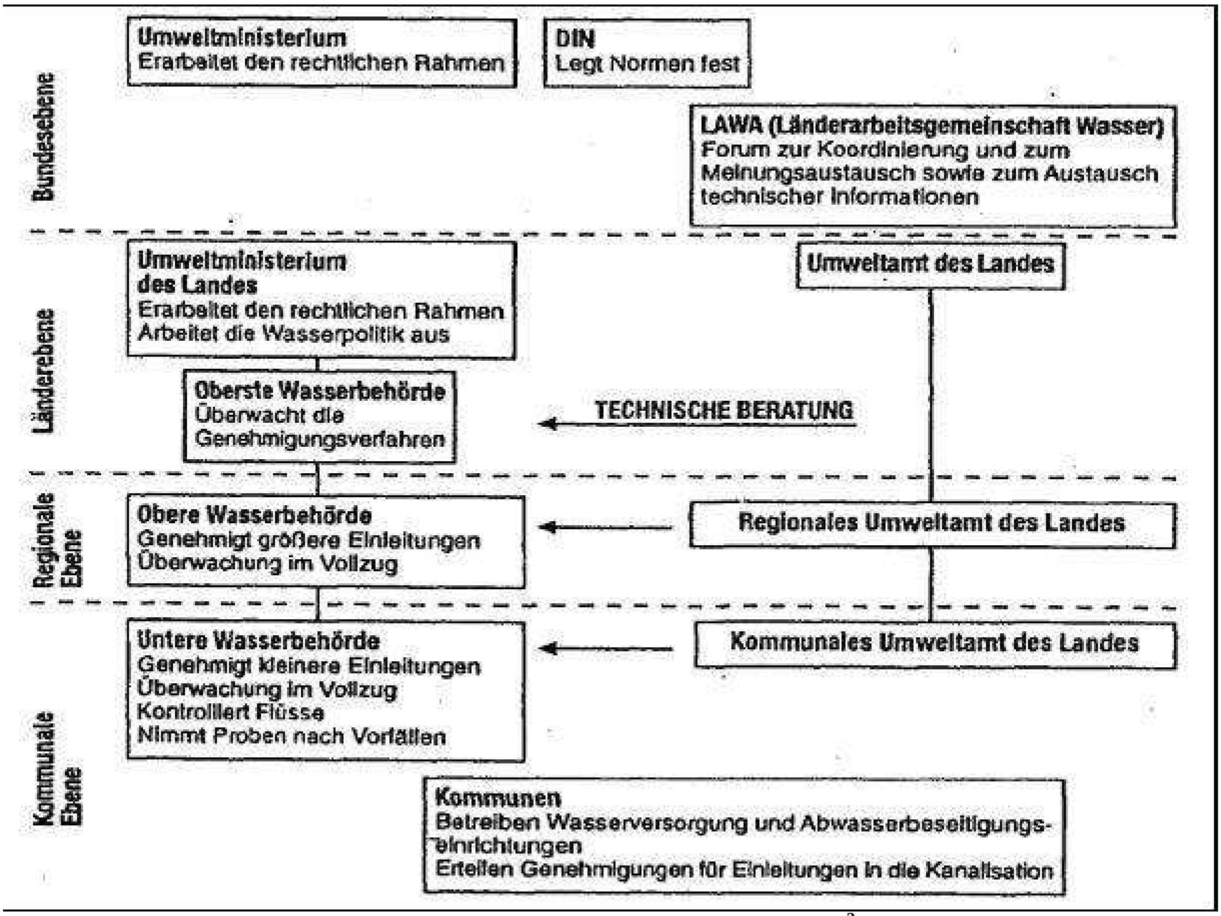


Figure 3: Different administrative levels involved in wastewater treatment[2]

The function/organisation fulfilment is accomplished by public enterprises and private enterprises in the municipalities. The percentual portions of these organization forms are shown in table 2, according to sewage disposal and waste water treatment.

[2] Source: STOWA buitenlandse technieken

Table 2: Function/organisation fulfilment wastewater treatment[3]

Function / organisation	Share in total (%)
Water federation	28
institute of public right	17
self-company AG/GMBH	4
operator/co-operation company AG/GMBH	2
company under private law	4
public utility	17
own establishment	28

3.4 Laws and regulations

The laws and regulations at the various levels are shown in figure 4. The law, which applies to all counties, is the WHG, which has been effective since 1957. This law has been adapted since then a number of times, particularly in the field of reinforcement of effluent requirements. The legislation at state level (LWG) is a derivative of the WHG with the possibility to reinforce the requirements.

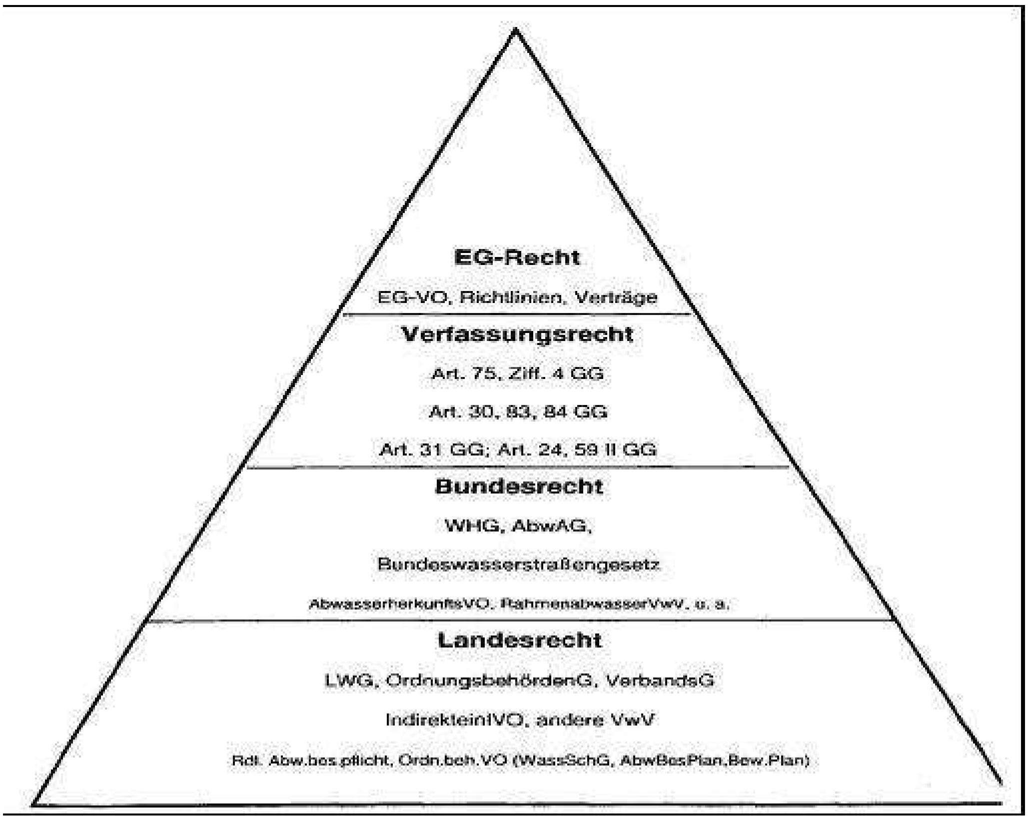


Figure 4: Laws and regulations at various levels.

The minimum effluent requirements (standards) are fixed within the sewage regulation (Abwasser Verordnung). In table 3 the present effluent requirements are presented per wastewater treatment plant capacity and parameters.

[3] Source: http://www.bmu.de/gewaesserschutz/doc/2833.php

Table 3: Effluent requirements per wastewater treatment plant capacity (source: Lange et al.,2000)

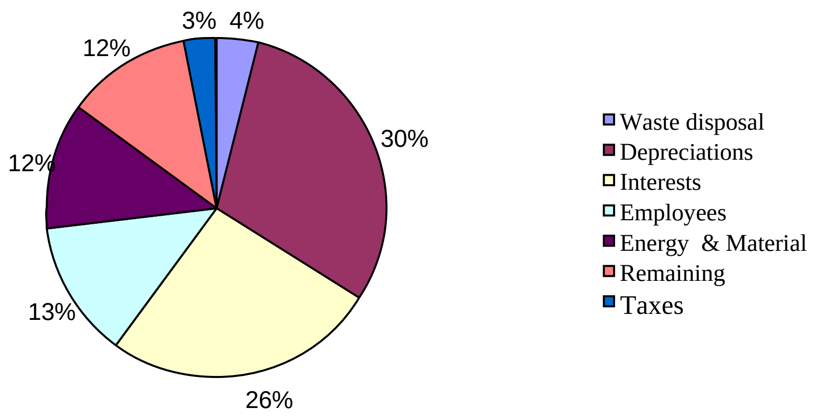
p.e.	mg/l	mg/l	mg/l	mg/l	mg/l
< 1000	40	150	-	-	-
1000 - 5000	25	110	-	-	-
5000 - 20000	20	90	10	18	-
20000 -100000	20	90	10	18	2
> 1000000	15	75	10	18	1

The rules to evaluate compliance with the requirements are also represented in the LWG. Samples of the effluent are taken as quantified sampling (5 samples every two hours, with an intermittency of at least 2 minutes) or as two-hours volume-proportional sampling. Of the 5 samples, 4 of these must comply with the effluent standards (presented in table 3) and under no circumstances the concentration is allowed to exceed these standards by 100 %. The control frequency depends on the capacity size of the wastewater treatment plant.
When the effluent is not complying with the requirements of the standards the criminal law is infringed. The person who is responsible for the plant can be accused personally by this law (STOWA).

3.5 Costs

The costs for sewage disposal have almost been constant since 2001. The investment costs are estimated by ATV (der Vereinigung Abwasser, Abfall und Gewässerschutz e.V.) and BGW (Federal association of the German gas and water management) on 6.85 Billion Euro per year (per inhabitant 117 Euro each year) (Statistisches Bundesamt, 2003).
Approximately 2.18 Euro per m3 is paid for the general fees which is included in the fresh water price. The realization of the fees (Gebühre) is presented in appendix 8. These taxes are included in the fresh water price
In general it can be said that about 68 percent of the investment in the municipal wastewater sector is for the sewerage networks (realisation of new connections and maintenance). In table 4 the cost in percentages of a general wastewater treatment plant are presented.
The investment for the sewer amounts 150,000 – 250,000 Euro per kilometre, depending on the situation (height difference, soil structure number of connections etc.). (Source http://www.ifat.de)

Table 4: Costs structure wastewater treatment plant, 2000[4]



3.6 *Site Frankfurt am Main*

3.6.1 Background

The sewerage of Frankfurt is approximately 1600 kilometres long and is leading to two wastewater treatment plants: ARA Niederrad/Griesheim and ARA Sindlingen. The ages of the sewer system is given in table 5.

Table 5: Ages sewer system[5]

Age of sewer system in years	Amount in percentages
< 26	31
26 – 50	23
51 – 75	19
76 – 100	16
> 100	11

The ARA Niederrad/Griesheim plant has two locations that are separated by the river Main. However, the system is working as one plant, due to the connection pipe that is running under the river with a diameter of 3 metre. The plant has a maximum capacity of 1.350.000 p.e (population equivalent) while ARA Sindlingen has a maximum capacity of 470.000 p.e. The maximum flow that can be treated is ca. 585.000 m^3/day.

For this research the wastewater treatment plant ARA Niederrad/Griesheim (figure 4) is taken as a reference site and is investigated.

[4] Source http://www.bmu.de/gewaesserschutz/doc/2833.php
5 Source: Umweltbericht Nr. 3/II (2000)

Figure 5: Wastewater treatment plant ARA Niederrad/Griesheim

3.6.2 Implemented technology

The first step in the treatment process is the separation of particles that are present in the wastewater (screening). These particles are filtered out with an automatically cleaned screening installation (figure 6) . The screened waste is dewatered and collected in containers for transport (figure 7).

Figure 6: Screening installation (partly)

Figure 7: Collected waste in transport containers

The next treatment step is in the separation of sand and other mineralised particles that are present in the wastewater. This takes place in the sedimentation basin. The collected sediment (mainly sand) is dewatered and collected in containers for transport. The total amount of sand that is separated is ca. 1208 ton/year. By mild aeration of the sedimentation tank the fat and other light particles are driven towards the water surface. With the help of a circular scraper

the floating particles are transported towards the screening installation where they are removed together with the other larger particles.

A pumping station is used to transport the wastewater 8 meter upwards into the pre-treatment phase of the plant. In this pre-treatment phase the retention time is 1.5 hours resulting in sedimentation of the particles that are still present in the wastewater. The pre-treatment step is the final mechanical treatment of the plant. Rainwater collection basins are situated under the pre-treatment basin, because of the limited available space of the total plant. The water level inside the rainwater collection basins can be controlled. There are two scenarios for this water:

1. To pump the water back into the mechanical treatment phase at the beginning of the plant;
2. When the rain intensity is so high, that the rainwater basins can not handle the flow of rainwater, the water is directly pumped towards the river Main where it is discharged (untreated).

The wastewater from the pre-treatment flows towards the first biological treatment step of the plant. The bacteria that are present in the wastewater are aerated in order to increase the growth rate. The organic contamination is used by the bacteria for the growth. By means of an overflow the wastewater from this first biological treatment phase is led into a basin where the remaining sludge is separated from the wastewater. The separated sludge is transported towards the sludge treatment facility at the same location.

The wastewater is subsequently led into a basin where the second biological treatment step takes place. With the help of autotrophic bacteria the nitrogen, that is present as ammonium, is transformed in two steps:

1. Nitrosomonas bacteria transform the ammonium to nitrite (NO_2)
2. Nitrobacter bacteria transform this nitrite into nitrate (NO_3)

During this process nitrogen (N_2 gas) is produced that escapes to the atmosphere.

Nitrogen compounds are converted into nitrate and removed in the denitrification step by bacteria. The present phosphate is flocculated from the wastewater. On yearly basis a total of 5350 ton of sodium-aluminates solution is used to remove the phosphate.
After this second biological treatment step the water flows into the post treatment step.
The sludge from the second biological treatment step can sedimentate on the bottom of this post treatment basin. A part of this sedimentated sludge can be reused in the second biological treatment step.

The amount of sludge that can not be re-used (when to much is present) is also transported towards the sludge treatment facility on location (figure 8).

Before the sludge is incinerated on site it the first step is the dewatering of the sludge. For this process 431 ton of cationic polyelectrolyte solution per year is used (Heidemann and Holzhausen, 2004)

The sludge incineration process is given in figure 9.

Figure 8: Sludge treatment facility on location.

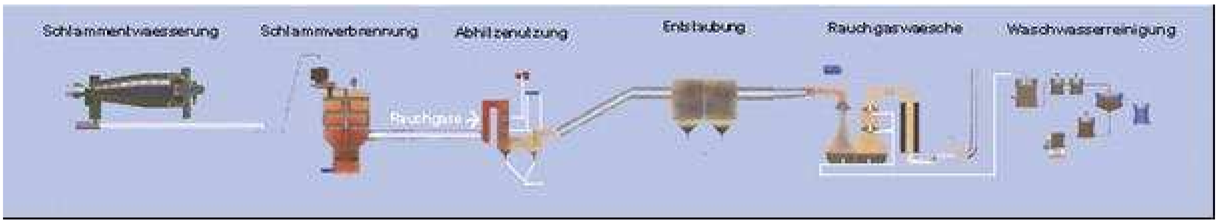


Figure 9: Incineration process sludge

The water still contains small amounts of nitrate. This nitrate is removed by a final treatment step. The water flows through a filter bed (sand, figure 10) to remove sludge particles. At the top of the filter (figure 11) bacteria are present that transform the nitrate into nitrogen gas (N_2).

Figure 10: Filter material

Figure 11: Denitrification tanks

From here the water is discharged on the river Main.

3.6.3 Legislation

An overview of the discharge standards of the wastewater treatment plant is given in table 6 These do not differ per county, however additional, special arrangements could be present within other counties. For various discharge points (lake, river, etc) the legislation may differ. E.g., the effluent rates to a river are depending on the volumes discharged per day, the functional use and the pollution load. The normal effluent standard for e.g. the Bodensee for phosphor was 1 mg/litre. This effluent standard has been recently reduced to 0.5 mg/litre. The main reason is because the sea is also used as swimming water (Lange et al, 2000r, *pers. com.*)

Table 6: Physical and chemical discharge standards

Number	Parameter	Value
1	Temperature	35 ° C
2	pH	6,0 - 10.0
3	Removable material in no domestic wastewater	1,0 ml/l
4.1	Cyanide (CN) easily set freable	0,2 mg/l
4.2	Cyanide (CN) total	5,0 mg/l
5	Solvent organic hydrocarbons (calculates as organically bound chlorine)	10,0 mg/l 1,0 mg/l
6.1	Mineral oils and greases (hydrocarbons)	20,0 mg/l
6.2	Heavy volatile lipophilic materials	100,0 mg/l
7	Phenol index	20,0 mg/l
8	Sulphate	400,0 mg/l
9	Arsine (As)	0,1 mg/l
10	lead (Pb)	2,0 mg/l
11	Cadmium	0,5 mg/l
12	Chrome (Cr)	2,0 mg/l
13	Iron Fe)	20,0 mg/l
14	Cupper (Cu)	2,0 mg/l
15	Nickel (Ni)	2,0 mg/l
16	Quicksilver (Hg)	0,05 mg/l
17	Silver (Ag)	0,5 mg/l
18	Zink (Zn)	5,0 mg/l
19	Tin (Sn)	3,0 mg/l

For surface waters, that function as shipping routes and cover several counties (Rhine, Main, Elbe, etc.), the Federation is responsible. For other regional surface waters the counties or municipalities are responsible.

3.6.4 Performance

The performance of the wastewater treatment plant is based on operating figures from the year 2004 (Langer et al, 2005, *pers. com*).

Table 7: Total wastewater treated (m^3/year)

WTP Griesheim	WTP Niederrad	WTPs Griesheim + Niederrad
52.268.600	35.887.900	88.156.500

59.3 % of the total wastewater flow is treated at the Griesheim side
40.7 % of the total wastewater flow is treated at the Niederrad side

Table 8: Pollution loads and concentrations

WTPs Griesheim/Niederrad	
15.163 ton BOD_5/year	172 mg BOD_5/litre
39.406 ton COD/year	447 mg COD/litre
3.050 ton NH_4-N/year	34.6 mg NH_4-N/litre
696 ton $P_{tot.}$-P/year	7.9 mg $P_{tot.}$-P/litre

Table 9: Effluent concentration and legal standards

Parameter	Griesheim/Niederrad	Legal standard
BOD_5	4.6 mg/litre	15 mg/litre
COD	30.0 mg/litre	50 mg/litre
NH_4-N	0.6 mg/litre	8 mg/litre
$N_{tot,anorg.}$	10.0 mg/litre	14 mg/litre
$P_{tot.}$	0.75 mg/litre	1 mg/litre
AOX	27 µg/litre	-
Hg	<0.2 µg/litre	-
Cd	<0.3 µg/litre	-

The BOD_5 removal is 97.3 %.

Table 10: Sludge treatment (incineration)

Sludge amount	Percentage dry weight	Total dry weight
1,052,380 m^3/year	2.5 %	25,812 ton

The emissions to air are not available for the investigated sludge incineration plant.

Table 11: . Energy consumption (kWh/year)

Griesheim/Niederrad	Sludge incin.used	Sludge incin. Produced
30,639,920 kWh/year	11,325,911 kWh/year	15,774,900 kWh/year

The amount of energy that is produced by the incineration of the sludge is completely re-used for operating the wastewater treatment plant.

3.6.5 Cost

The cost structure of the wastewater treatment plant is presented in figure 12. The taxes are part of the fresh water price. For Frankfurt these taxes are 1.76 Euro per m^3 fresh water that is used for treatment costs and has not changed since 1994.

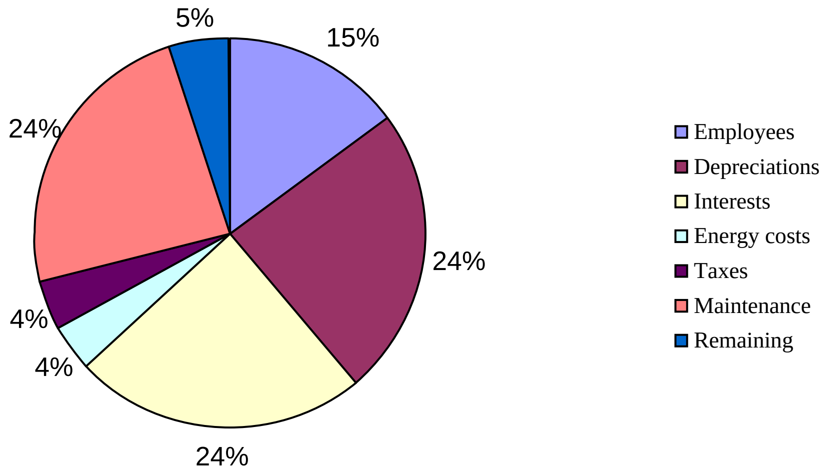


Figure 12: Cost structure wastewater treatment plant Frankfurt

The cost for discharging the ash that is produced when the dewatered sludge is incinerated is 28 Euro/ton + 16 % tax (Langer et al,2005, *pers. com*.).

The operating costs of the sewage system in Frankfurt are 25 million Euro per year (Umweltbericht Nr. 3/II ,2000)

3.6.6 Cost municipal wastewater treatment in Freiburg

The sewerage net in Freiburg is approximately 710 kilometre long, 52 % of these sewerage net is a combined sewer (rainwater and domestic wastewater) and 48 % consists of a separate sewer net (rainwater is transported separately from the domestic wastewater).

The total costs for sewage disposal in Freiburg were 27.2 million Euro in the year 2004. Of these total costs, 8,9 million Euro was needed for treating the wastewater at the wastewater treatment plant. An investment of 5.33 million Euro was made during this year. In order to protect the groundwater, 4.2 million Euro was invested for the replacement of 3.2 km sewer net. The sewer net was also extended by 1.5 kilometre during this year against a cost of 0.6 million Euro.

The total fee amounts1.57 Euro per m^3 water. Part of this fee is used for the treatment of the wastewater and a part is used for treatment of the rainwater. The water price in Freiburg is at this moment 1.72 Euro per m^3 which includes the cost for treatment of the produced waste water (source: website Badenova).

4 Project “Arbeiten & Wohnen”, Freiburg im Breisgau

4.1 Introduction

The model housing project “Arbeiten & Wohnen” is situated in Freiburg im Breisgau, Walter-Gropius-strasse 22, 79100 in Germany (figure 13) It contains 14 apartments and 4 offices. Blackwater is evacuated by 24 vacuum toilets and greywater is treated in a membrane filter module. Rainwater is infiltrated in ditches near the building.

Figure 13: Project complex "Arbeiten & Wohnen

4.2 Background

In 1995 new buildings were to be constructed at the Freiburger Vauban district.
On the site were French barracks situated. Citizens where encouraged to form groups and implement ideas based on innovative energy, waste and sanitation concepts. Resident Jörg Lange et al,2000 (biologist)of the project “Arbeiten & Wohnen”, and Micheal Gies (architect) had some ideas[6]:

Jörg Lange et al,2000: “I would like to implement an alternative sanitation concept in a house.”

Michael Gies: “I would like to build a multifamily passivehouse”

The idea was born to construct a building where working places are combined with living places with ecological aspects. This idea formed the project name “Arbeiten & Wohnen”.

[6] Source: http://www.passivhaus-vauban.de

These working places can be used by the residents of the building. With the help of the association "Forum-Vauban e.V, Freiburg" a new group was formed by people who were also interested in this project. The new group was called the "Okobauverein e.V, Freiburg" This society was able to raise funds and deal with other financial aspects. In addition cooperation opportunities with other research partners could be formed (Panesar, *pers. com.*)

The objectives of the project were threefold:

- The realisation of a model house with innovative energy, waste and sanitary concepts to improve the social environment.
- Reduction of operation and maintenance costs of the building through water saving measures and recycling and reduction of the energy consumption through the application of solar technology.
- Demonstration of innovative closed loop systems for wastewater management.

In June 1998 the constructions of the building started. By May 1999 the following concepts were implemented in the apartment block: a passive energy concept, solar panels together with a gas-operated co-generation unit (biogas installation) and the alternative sanitation concept. The sanitation concepts consist of vacuum toilets that are connected to a biogas installation while the greywater is treated in a membrane filter module. The applied sanitation techniques are described in paragraph 4.5 implemented technology. The biogas installation is not yet running. The energy concept (solar panels) is not investigated within this research.

4.3 Actors and their roles & responsibilities

The role of the actors are presented in the table 12. These actors were responsible for the decision making and designing process technology suppliers and the person responsible for maintenance . During the research it became clear that the municipality and the water board had in the project. The only regulations that are the blackwater discharge the sewer. Due to the not yet operating biogas installation the blackwater is discharged the sewage system.

Table 12: Actors involved in project

Nr.	Description	Company name	Contact person(s)	Role(s)
1	Project owner	Aturus	Mr. J. Lange et al,2000 Mr A. Panesar	Initiator and project manager
2	Association	Ökobauverein e.V, Freiburg	Residents	Management and juridical assistance
3	Water supplier	Badenova	Mr. M. Toens	Drink water supply treatment wastewater (in wastewater treatment plant Freiburg)
4	Architect	Common & Gies Architecten	Mr. M.Gies	Building design; also one of the initiators
5	Funding assistance	Deutsche Bundesstiftung Umwelt	Not known	Funding assistance

6	Technology supplier	Mall Umweltsysteme	Mr. S. Klemens	Supplier of the greywater system and parts of biogas installation and maintenance
7	Technology supplier	Roediger Vakuum- und Haustechnik GmbH	Mr. C. Rüster	Supplier of the vacuum toilet systems and maintenance
8	Technology supplier	TBW	Bankrupted	Supplier of the biogas installation
9	Technical design	Krebser & Freyler	Mr. Krebser	Planning of the project
10	Maintenance	Hombach Bausupervision	Mr. Hombach	Maintenance of total system.

* not involved

As mentioned earlier, the idea of implementing an alternative sanitation concept in a passive energy house came from Jörg Lange et al,2000, together with the architect Micheal Gies.
To realize these plans an association was formed that was able to cooperate with the involved research partners. Therefore, the “Ökobauverein e.V., Freiburg (Association For Sustainable Buildings)” was founded. This association was able to apply for funding and to handle the financial aspect as well as to run the experimental project phase. The members of this association are nowadays residents of the passive house.
The Deutsche Bundesstiftung Umwelt (DBU) supplied funding for the development and implementation of the alternative sanitation concepts (vacuum technology, biogas installation and the greywater treatment installation) for the project. The installations were also partially funded by price reductions of the suppliers: naturgerechte Technologien, Bau- und Wirtschaftsberatung GmbH (TBW) (Frankfurt am Main), Mall-Umweltsysteme (Donaueschingen) and Roediger Vakuum- und Haustechnik GmbH (Hanau).

Planning bureau Krebser & Freyler was responsible for the project planning and had took care of the contact the other involved actors. The waterboard Badenova is responsible for the wastewater treatment plant and is the supplier of tap water in Freiburg. Hombach Bauspervision is the local maintenance expert. Residents can call him when small malfunctioning of the installations occurs.

4.4 Drivers and barriers

An analysis of the drivers and barriers was performed by interviewing the actors who where involved in the decision making process. The actors that were interviewed are shown in table 13:

Table 13: Interviewed actors project:”Arbeiten & Wohnen”

Description	Company name	Contact person(s)	Role(s)
Project owner	Aturus	Mr. J. Lange et al,2000 Mr A. Panesar	Initiator and project management
Architect	Common & Gies Architecten	Mr. M.Gies	Building design and partially initiator

Technology supplier	Mall Umweltsysteme	Mr. S. Klemens	Supplier of the greywater system and parts of biogas installation and maintenance

The drivers and barriers are divided in several aspects:

-	environmental	drivers and barriers
-	public health	barriers
-	legal & regulatory	barriers
-	financial	drivers and barriers
-	social & managerial	drivers and barriers

Because of the fact that the answers of each actor differ, the answers are described for each actor separately. This in order to keep a good overview of the results from the questionnaires.

The complete list of the drivers and barriers are presented in appendix 9. The aspects, as mentioned above, within the drivers and barriers questionnaire were rated on a rating scale from 0 to 4. On the scale of importance: 0 represents “unimportant” and 4 represents “important”.

4.4.1 Environmental drivers and barriers

Project Owner: Mr. J. Lange et al,2000 (one of the initiators)

When selecting the system the following environmental drivers important to the project initiator, Mr. J. Lange et al,2000: reduction of water emissions, recycling of water, protection of surface water, protection of groundwater and recycling of nutrients. The aspects of the sanitation system realised according to Mr. J. Lange et al,2000 are: positive feeling about environmental behaviour, water saving, protection of surface water, protection of ground water and recycling of nutrients. Recycling of water is partly realised. The greywater system is not yet operating at full capacity. The treated water was (December 2005) used for irrigation of the garden at the moment of this investigation.

No environmental barriers hampered incorporating non-conventional elements in the design and implementation of the sanitation system.

Project Owner: Mr. A. Panesar (management)

According to Mr. A. Panesar, different environmental aspects where drivers during the selection phase of the systems. These drivers where: positive feeling about environmental behaviour, reduction of water emissions, recycling of water, protection of surface water, protection of ground water and recycling of nutrients. During the selection phase it became clear that other drivers where also important, the project should be seen as a “showcase project” where researchers and other visitors can gain data and knowledge about the implemented systems. Practical performance data are important to implement these kind of systems in the future within other projects. The described drivers are also realised within the project.

No environmental barriers hampered incorporating non-conventional elements in the design.

Architect: Mr. M. Gies (building design and one of the initiators)

As architect and one of the co-initiators of the project Mr. M. Gies had a different view on the environmental drivers, when the system was selected and when the building was designed. Important drivers related to environmental issues where: positive feeling about environmental behaviour, water saving, prevention of drying out of soil, reduction of water emissions, recycling of water, recycling of nutrients and the reduction of energy use.
The environmental aspects that are realised within the project are: water saving, prevention of drying out of soil, reduction of water-related emissions and the reduction of energy use. Recycling of nutrients is neutral on the scale of unimportant till very important, this according to the fact the installation of the biogas plant is not operating yet and the greywater is only partly reused. On what scale the positive feeling about the environmental behaviour and the quality of neighbourhood landscaping has been realised is not known by the architect.

No environmental barriers hampered incorporating non-conventional elements in the design

Technology supplier: Mr. S. Klemens (Supplier of the greywater system and parts of biogas installation and maintenance)

A positive feeling about the environmental behaviour, prevention of drying out of soil, reduction of water emissions recycling of water and protection of ground water were important environmental aspects to Mr. S. Klemens when he was selecting the systems (together with the other involved actors). The environmental aspect of water saving was of neutral importance. During the selection of the system the protection of surface water and the quality of neighbourhood landscaping were taken into account, but had no relative importance.
The realised environmental aspects were, positive feeling about the environmental behaviour, reduction of water emissions and recycling of water.

A barrier, which was encountered during the incorporation of non-conventional elements in the design, was the potential flood risk of the system. This risk is minimized by using overflow systems.

4.4.2 Public health barriers

Project Owner: Mr. J. Lange et al,2000 (initiator)

No public health barriers hampered incorporating non-conventional elements in the design.

Project Owner: Mr. A. Panesar (management)

When the biogas installation becomes operational, it produces biogas which is stored in storage tank (situated in the basement). This stored biogas can form an explosion hazard, if safety measures are neglected.

Architect: Mr. M. Gies (building design and partially initiator)

According to the architect the public health barriers were: health risk, chemical hazards and noise disturbances.

Technology supplier: Mr. S. Klemens (Supplier of the greywater system and parts of biogas installation and maintenance)

Physical injury from householders who can access the installation was a barrier. To prevent physical injury, all the tanks are situated below ground level and are closed by lids.

4.4.3 Legal and regulatory barriers

No legal and regulatory barriers hampered incorporating non-conventional elements in the design. This statement is verified by all the interviewed actors. When the project started no laws or regulations hampered the implementation of these kind of techniques. Nowadays monitoring activity on regular basis is necessary for the greywater system, because the treated greywater can be reused for flushing the toilets and has to be clean enough for this purpose

4.4.4 Financial drivers and barriers

Project Owner: Mr. J. Lange et al,2000 (initiator)

The financial consideration "reduced drinking water consumption (and lower bills)" was a driver of deciding to incorporate non-conventional elements in the design. The most important financial barrier was the bankruptcy of TBW, by this bankruptcy a large amount of the investments where never used for the project "Arbeiten & Wohnen". Nowadays these problems still have the side-effect that the biogas plant is not yet operating. Other financial barriers were the higher design costs (compared to conventional system) and application vacuum toilets. Application of vacuum toilets within a apartment block was a rather new technique, which have led to cost that are higher than the costs of a conventional system. The operating cost and energy cost (compared to conventional system) also formed a barrier, but were less influential than the barriers mentioned before.
The extent to which these barriers played a role in the system choice were low, according to the Mr. Lange, since the DBU financed a large part of the implemented systems.

Project Owner: Mr. A. Panesar (management)

The following considerations were neither a driver nor a barrier: design cost, operating cost, applying vacuum toilets and reduced drinking water consumption (and lower bills). They were categorised as neutral. Neutral means that the considerations played a role in the system choice, but had no overhand in the selection. The bankruptcy of TBW had a large effect on the project was and was a barrier for the implementation of the selected systems.

Architect: Mr. M. Gies (building design and partially initiator)

Energy cost and reduced drinking water consumption (and lower bills) were drivers to incorporate non-conventional elements in the design. The energy costs have been reduced by designing the building in such a way that the sunlight is heating the rooms, especially in the winter times (building is situated on the south). Warmth bridges are hardly present and the building is isolated well. Aspects about the energy concepts are not further discussed.
The implementation of vacuum toilets was considered a barrier, which has to do with the fact that the residents were afraid that the toilets would produce a disturbing noise.
The drivers and barrier, as mentioned above, were important to the architect.

Technology supplier: Mr. S. Klemens (Supplier of the greywater system and parts of biogas installation and maintenance)

As supplier of the greywater system and parts of the biogas installation various drivers and barrier were considered important. The main driver was the reduced drinking water consumption (and consequent lower bills). The possibility to reuse the treated greywater for rinsing the garden and flushing the vacuum toilets was a related financial driver.
Barriers were the higher design, operating and energy costs (compared to connection to a conventional system). These driver and barriers were all important according to the supplier.

4.4.5 Social and managerial drivers and barriers

Project Owner: Mr. J. Lange (initiator)

The aspect of implementing an eco-sanitation concept was an important factor for the initiator. An important managerial consideration, which hampered incorporation of non-conventional elements in the design, was the bankruptcy of TBW.

Project Owner: Mr. A. Panesar (management)

Improvement of the quality of living - ecologically and more sustainable - was an important social aspect to realise a non-conventional design. The difficult technology was a factor that hampered the process, but had no overhand. The importance of the following aspects: ownership unclear, maintenance responsibilities and maintenance burden on householders were considered neutral.

Architect: Mr. M. Gies (building design and partially initiator)

Involvement in sanitation / taking responsibilities for your household water management system (water saving, reducing emissions) were an important social aspect. Intensive contact and collaboration with neighbours was also considered important, but to a lower extent than involvement in sanitation / taking responsibilities for your household water management system (water saving, reducing emissions).
The implementation of a difficult technology was an important aspect hampering the incorporation of non-conventional elements in the design.

Technology supplier: Mr. S. Klemens (Supplier of the greywater system and parts of biogas installation and maintenance)

To the supplier of the system no social and managerial drivers were present when the system was realised. The difficult technology behind the design was experienced as an important barrier. The maintenance responsibilities were considered of neutral importance.

4.5 Implemented technology

The project “Arbeiten & Wohnen” is one of two pilot projects(7) in Germany where ecological sanitation concepts are used and tested. These concepts can be diverted in five categories:

7 The second project is the project “Flintenbreite” in Lubeck

- vacuum toilets
- vacuum station
- biogas installation
- greywater treatment installation
- rainwater reuse

The various system components are described in the following paragraphs.

4.5.1 Vacuum toilets

Within the project “Arbeiten & Wohnen” 24 vacuum toilets are installed. These vacuum toilets are fabricated out of porcelain by the company Evac and are mounted on the wall (figure 14).

Figure 14: Top- and side view of an installed vacuum toilet

The needed vacuum of 0.5 bar for flushing the toilets is produced by the central vacuum station (type PE30, Roediger) in the basement of the building. By pressing the flush button a membrane valve opens for two seconds resulting in an under pressure. In these seconds 15-20 litre of air and 1 litre water is used to flush the toilet. The waste stream is than transported towards a reservoir (“selbstenleerenden Sammelbehälter”) behind the toilet. This reservoir is a development of Roediger and has a capacity of circa 9 litre of wastewater. Up to 5-6 flushes are stalled inside this reservoir and when this reservoir is full it automatically empties itself with the help of 60-70 litre of air. The wastewater is subsequently transported to the collecting tank in the basement.

The different parts of this reservoir can be summed up as follows:

1. reservoir
2. suck off valve
3. compact steering
4. air valve

5. sound silencer
6. connecting support (toilet)
7. connecting support (back pressure)
8. connecting support (under pressure)
9. adjusting screw

By using these kinds of reservoirs (that are connected straight after the vacuum toilet) the possibilities of clogging the vacuum pipes towards the collecting tank is reduced. This because of the fact that a larger amount of blackwater is flushed towards the collecting tank in one time.

The reservoir is connected with the vacuum toilet by connecting point number 6. The steering of the reservoir (1) is connected by connecting point 8 (steering pipe and a backflow stop) to the vacuum pipeline. With the suck valve (2) the reservoir (1) is connected to the pipeline that leads the blackwater towards the collecting tank. Through connection point 6 the blackwater flows from the toilet into the reservoir (1). The blackwater is stored in this reservoir (1) until the back pressure opens the valve of the pipeline that leads towards the collecting tank. The backpressure is transferred by connection point 7 over the steering pipe to the compact steering (3). The suck valve and air valve are opened by the backpressure that is created in the reservoir. The air valve (4) is leading air from the atmosphere inside the reservoir (1) and is pushing the collected blackwater into the vacuum pipeline towards the collecting tank. During the time that the collected blackwater is running out of the reservoir the back pressure also drops which closes the suck valve and air valve. The time that these valves are open can be adjusted by the adjustment screw (9) on the compact steering. This is necessary because the length of the piping towards the collecting tank is not everywhere the same in the building (Roediger, 1999)

4.5.2 Vacuum station

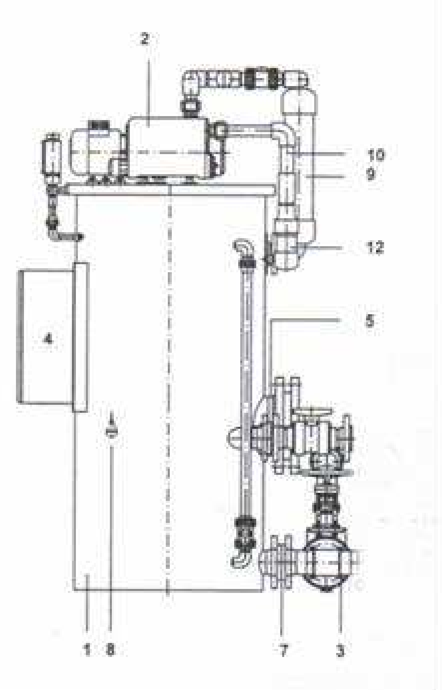
The used vacuum station (type PE30) of Roediger is standing in the basement of the building, and has the following main components (the numbers used in the text below are corresponding with figure 15):

- vacuum tank
- vacuum pump (2 pc)
- discharge pump
- control unit (2)
- water separator
- level control
- pressure control

The incoming vacuum pipe, coming from the interface units of the toilets in the complex, is connected on the station by a flange DN 50 (5). This flange is extended with a slider (6) in order to enable blocking of the entering. At the bottom of the tank (1) is equipped with an outlet nozzle (DN 50) (7) which is connected to the municipal sewerage system by a discharge pump. *The blackwater stream is connected on this municipal sewerage system because the biogas installation in not operating.*

Blackwater that flows into the vacuum tank is temporally stored in the tank (1). By means of a float shut-off (8) the discharge pumps are automatically triggered to discharge the blackwater

on the sewage system. The pump is stopped after a certain time when there is no signal coming from the float shut-off. The vacuum pumps (2) are getting air from suction pipes (9) with a vent line (11) and are connected on the vacuum tank which is pressurized. Condense water which build up in the vent line is evacuated via the interface unit (12). When the pressure in the tank falls to 0.5 bar the main pump is triggered automatically by a pressure switch (13). After the pressure in the tank is 0.6 bar the vacuum pump switches off. In case the pressure drops to 0.45 bar, despite of the running vacuum pump, a second vacuum pump is triggered by a second pressure switch (14). Both pumps switch off when the pressure inside the tanks is 0.6 bar (Roediger, 1999).



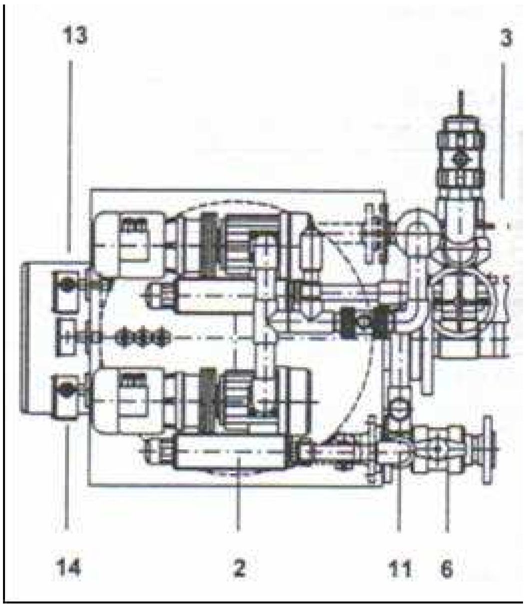


Figure 15: Technical overview vacuum station (source: Roediger, 2004)

As described above the vacuum station is situated in the basement of the building (figure 16), the room that used for this installation has a ground surface of 11.3 m^2. The total surface area of the basement is 510 m^2, so 2.22 % is used (vacuum station and part of biogas installation).

The dimensions and operations data of the vacuum station are as follows:

- suction performance — 2 * 16.0 m^3/h at 0.5 bar
- discharge pump flow rate — 12 m^3/h
- tank volume — 600 litre
- length — 710 mm
- breadth — 710 mm
- height — 2000 mm
- electrical connection performance — 4.1 KW

Figure 16: Vacuum station as situated in the basement

4.5.3 Biogas installation

The biogas installation is not yet operational, because of problems with the coordination of the research work and the financing of the biogas gas plant. Due to these problems, some components are not yet installed (conditions May 2005). The parts that are already installed are described below. The biogas installation is an important part of the ecological sanitation concept of the project. A lay-out of the system is given in figure 17

The installation was a totally new development and was the first biogas plant for an apartment building in Germany. The separated tanks are constructed out of concrete by Mall Umweltsysteme and are situated below ground level. The blackwater can be transported through a pipeline from the vacuum station towards the biogas reactor by the discharge pump. Not only the blackwater can be used for the biogas plant but also organic household waste. This waste can be shredded to small pieces and leaded towards the biogas reactor. To get a homogeneous substrate (blackwater & organic household waste) in the plant an integrated gas stirrer is installed in the first compartment (biogas reactor). Biogas and substrate that is formed can be stored in the next tank (biogas storage and postfermentation) where a post treatment takes place and the biogas is separated by a membrane. A part of the produced biogas can be reused to run the gas stirrer in the biogas reactor. After cleaning and drying the gas through an active carbon filter it can be used for the gas cooker in the kitchen.
The substrate is pumped by a pumping station towards a storage tank where it can be reused as fertilizer in agriculture. (Steeger-Ballbach, 2001)

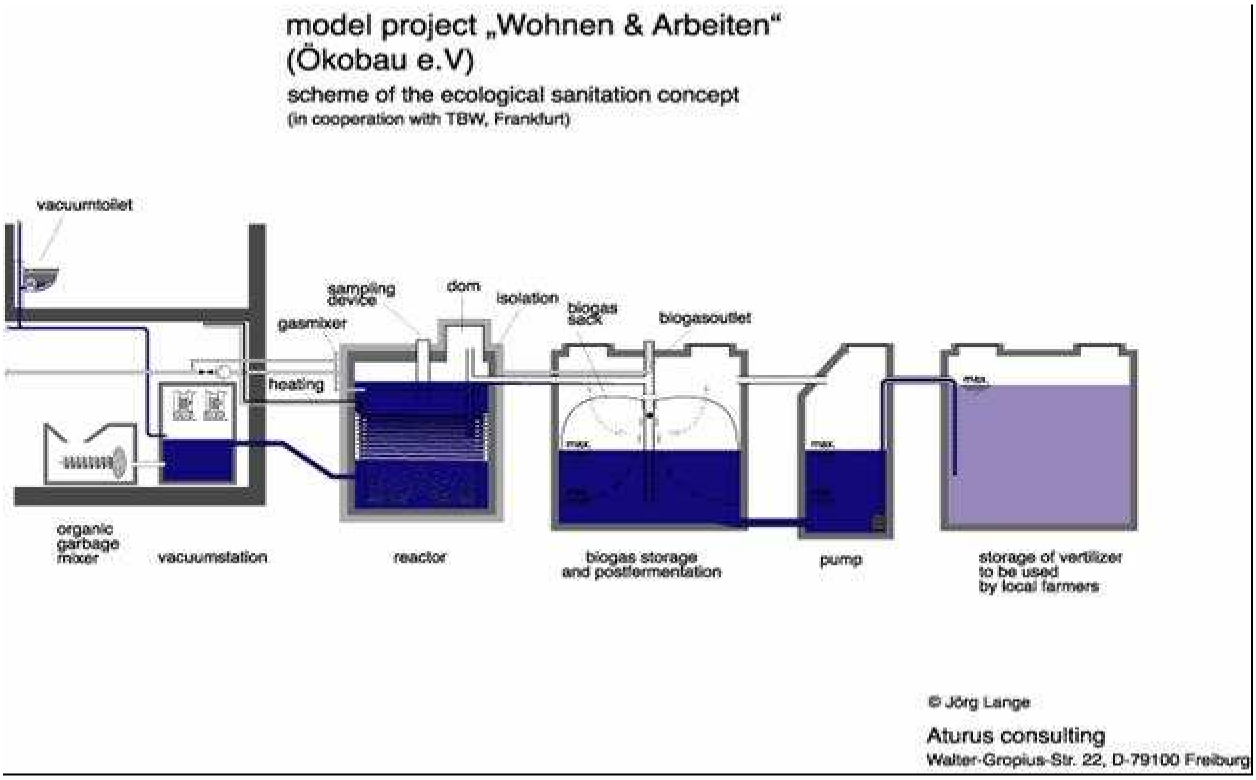


Figure 17: Overview biogas installation (source: http://www.passivhaus-vauban.de)

The dimensions and operations data of the biogas plant are as follows:

- biogas reactor	6 m^3
- biogas storage and postfermentation	9 m^3
- pump station	3 m^3
- storage of fertilizer	14 m^3

4.5.4 Greywater treatment installation

When the project started in 1999 the greywater was treated with a so called NEUTRAClear 2000 (figure 18). This installation was installed underground and treated the greywater as a mechanical biological treatment system. With the help of filter material (gravel 8/16 and lava 40/80), biofilm techniques, filtration, adsorption and flotation the greywater was treated (Mall Umweltsysteme). The system was aerated to prevent unpleasant odour production. Without the help of chemicals a reduction of COD, BOD, phosphate, nitrate, suspended matters lipophilic matters, hydrocarbons and was accomplished. Due to technical problems with this installation (clogging), it has been replaced by a membrane filter unit (Mall Ultra-Sept) by Mall Umweltsysteme in 2003.

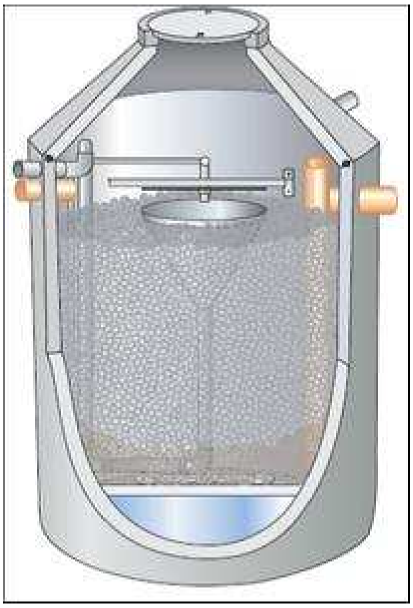


Figure 18: NEUTRA-Clear 2000 (source: Mall Umweltsysteme)

Within the new installation (figure 19) the polluted water is cleaned with the help of micro-organism, which form CO_2 and mineralised particles. This treatment occurs under aerobic conditions. New sludge is produced within the system that has to be reused within the system, therefore a returning cycle of the sludge is installed inside the installation. Within the water there are some floating particles and sludge present that are not separated by flotation. To avoid the presence of particles in the treated wastewater a membrane-module (figure 20) is installed, this membrane is forming a barrier where no sludge or other particles can flow through. The membrane has a pore diameter of 0.4 µm. (0.0004 mm) and is supplied by Weise Water Systems. To avoid clogging of the membrane surface a so called crossflow-filtration technique is used. On the membrane surface a turbulence is created in the wastewater so a continuous filtration can take place. This turbulence is enforced by the air that is flowing next to the surface of the membrane.

**Figure 19: Greywater system (Ultra-Sept)
(source: Mall Umweltsysteme)**

Figure 20: Membrane module

The dimensions and operations data of the greywater treatment system are as follows:

- membrane surface 16 m2
- pre-treatment 6 m3
- aeration basin 5.5 m3
- energy use blower 500 Watt

The treated water can be reused for flushing the toilets and for watering the garden. When the amount of treated water is exceeding the amount that can be reused it will be discharged on to the sewerage. (Peters, 2002)

The technical overview of the greywater installation is presented in figure 21.

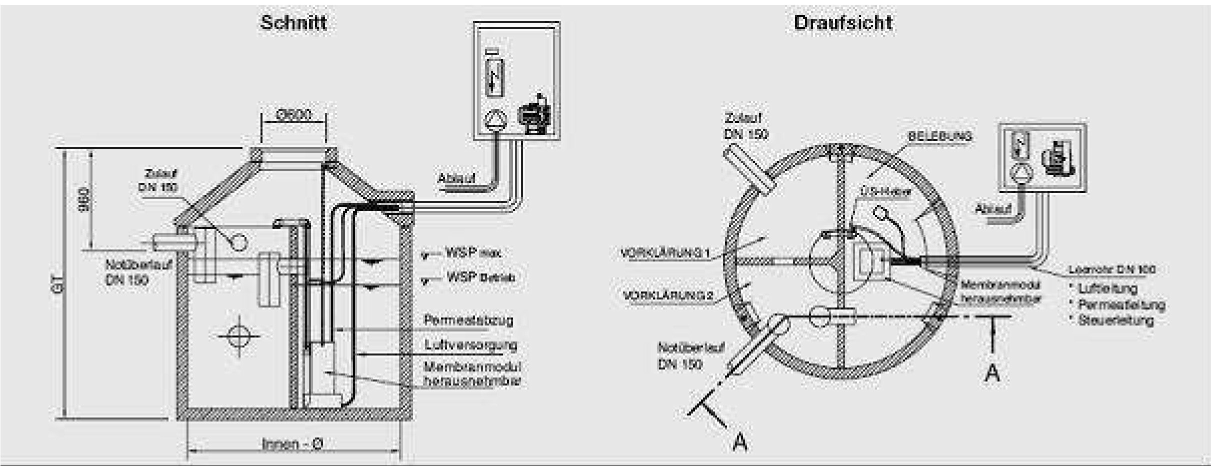


Figure 21: Technical overview (Source: Mall Umweltsysteme)

4.5.5 Rainwater reuse

For the total Vauban district a plan is realised that the rainwater can be irrigated in the surrounding soil. This means that for the project “Arbeiten & Wohnen” the rainwater is leaded over open gutters into two ditches near the complex, see figures 22 and 23.

Figure 22: Rainwater infiltration system

Figure 23: Open rainwater pipe system

The yearly rainfall in Freiburg is 956 mm per year [8].

4.6 Performance and evaluation

4.6.1 Water consumption

The total amount of fresh water used in within the complex by the residents is about 1103 m^3/year. This according to the research done by Jörg Lange (year 2000). In table 14 the values are presented by the number of residents per apartment and the total water consumption by the people who work in the offices.

Table 14: Water consumption by residents, year 2000

Number of residents	Amount of water consumption m^3/year
4	125
3	88
3	34
4	60
3	137
4	96
1	57
2	120
1	70
3	110
1	51
1	20
2	35
Offices	100

[8] Source: www.klimadiagramme.de/

Total	1103

According to M. Steeger-Ballbach (2001), the amount of greywater produced in total for the complex lies between 1220 litre/day (minimum) and 3158 litre/day (maximum) This gives an average of 1991 litre/day. These values are measured over a time period of 41 days (07 December 2000 till 16 January 2001) and are presented in figure 24.

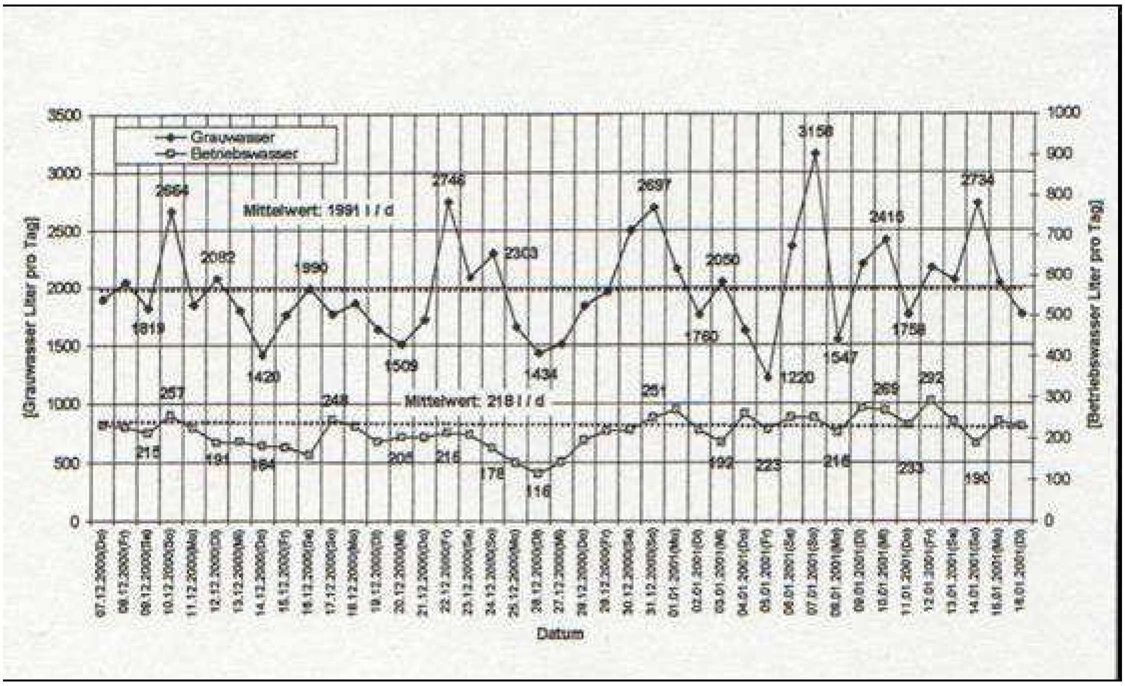


Figure 24: Amount of greywater produced in the period 07 December 2000 till 16 January 2001 (source: Steeger-Ballbach, 2001)

4.6.2 Blackwater

Blackwater is transported by vacuum toilets that use +/- 1 litre for flushing. Conventional toilets need 6-9 litre water per flush. This saves 5-8 litre each time the toilet are flushed.
A development of Roediger is the part behind the vacuum toilet: the reservoir ("selbstenleerenden Sammelbehälter"), see paragraph 5.4.1 .
By using these kind of reservoirs some advantages can be summed up:

- These reservoirs help to reduce to amount of air needed to flush the toilets, normally the toilets use circa 60 litre of air for each flush to transport the waste stream directly towards the large collecting tank in the basement where all the black water is collected
- Reduction of energy consumption (less energy used by vacuum pumps)
- Reduction of noise produced by the toilets
- The change that clogging of the pipe system occurs is reduced, this because of the fact that a larger amount of collected blackwater from this reservoir is transported through the pipe system in one time towards the collecting tank in the basement. (5-6 flushes).

The maximum noise level produced by the vacuum toilets is +/- 83 decibel. The locations of the toilets within the complex are not "back to back". The "back to back" method means that the toilet of the neighbours sits direct behind the wall of the own toilet. Each floor is designed differently. This in order to reduce to amount of noise that can be heard. An example of the design one floor is given in appendix 10 and a side view is given of the complex in appendix 11.

The maximal particle size that the system can handle is 46 mm, this is the opening inside the toilet. The valve behind the toilet has a diameter of 50 mm. The valve has a larger diameter than the opening inside the toilet. What is going through this opening ends in the vacuum station. (Roediger, 1999)

Public health

The vacuum system in total (vacuum toilets and vacuum station) does not represent a chemical hazard and the change of health problems and physical injuries is 0 %, this according to all the interviewed actors (Roediger, Lange, Panesar *Pers. com.*)

4.6.3 Biogas installation

The biogas plant is connected to the internal gas system of the complex. It is suspected that the biogas plant does not produce enough biogas for heating purposes of the complex. Instead the produced biogas can provide cooking gas for the households.
The plant is almost ready only the automatic regulation of the gas pressure and the feeding device for organic household waste need modification and adjustments.

No current performance data is available, because the biogas installation is not yet operating

4.6.4 Greywater

The greywater was treated with the NEUTRAClear 2000, with the help of filter material (gravel 8/16 and lava 40/80), biofilm techniques, filtration, adsorption and flotation the greywater was treated. (Mall Umweltsysteme). During operation of this system measurements where taken of the influent and effluent. These values of the performance are presented in table 15.

Table 15: Performance of the greywater system (original installed)

	Influent		**Effluent**	
Parameter	Unit	Average Concentration*	Average Concentration*	Treatment removal %
pH	-	7.1	7.2	-
Cond.**	µS/cm	505	612	-
COD	mg/l	350	111	68
BOD_5	mg/l	129	56.0	57
N_{tot}	mg/l	15.6	16.0	-
P_{tot}	mg/l	5.8	5.8	-
PO_4-P	mg/l	3.1	4.6	-
K	mg/l	8.0	9.3	-
Cd	µg/l	<0.5	<0.5	-
Cr	µg/l	38.3	41.6	-
Ni	µg/l	43.6	42.1	3
Hg	µg/l	<1	<1	-
Pb	µg/l	14.8	14.2	4
Cu	µg/l	38.4	12.8	67
Zn	µg/l	250	200	20
AOX	µg/l	159	62	61

Ds	mg/l	742	648	13

* 18 samples are taken
** Conductivity

The retention time of this system was +/- 78 hours. A biological reduction of carbon, phosphate and nitrogen is possible when such a system is used. The concentrations of nitrogen and phosphor in the influent are due to the washing powder and detergents used. Heavy metals concentration where below the expected values, because of the fact that the pluming in the complex are fabricated out of polyethylene. Only concentrations of Cr and Ni in the influent are higher than normal, this because there is a art gallery situated in the complex. (Steeger-Ballbach, 2001)

Since 2003 a new system is installed (ULTRA-Sept), this system is treating the greywater with membranes, see paragraph 4.5.4. In the table 16 the effluent values (performance) of the greywater treatment system are presented. The monitoring of the greywater system is done by “Mall Umweltsysteme”.

Table 16: Performance greywater system [9]

Parameter	Unit	Effluent concentration	Treatment performance (%)
COD	mg/l	25	-
BOD_5	mg/l	3.9	98.4
N_{tot}	mg/l	5.0*	-
$P_{tot.}$	mg/l	< 2.0*	-
Pathogens	Ppm	4	99.88
E.coli bact.	mg/100ml	< 3.0	-
Nutrients	mg/l	3.0	-

* general values for these kind of systems

The probability that a batch of final treated greywater failing to comply with official wastewater quality standards is 0 %. For the sludge there are no monitoring data available, but there are no expectations that the sludge will exceed official quality standards.
The used membrane has a pore diameter of 0.4 µm. This means that particles that are larger can not pass this membrane, figure 20. As can been seen in figure 25 a part of the colloidal particles can penetrate the membrane, this can lead to clogging of the membrane. Before the greywater is treated it flows through a pre-treatment step where the large particles can settle.

[9] source: Klemens pers. com.

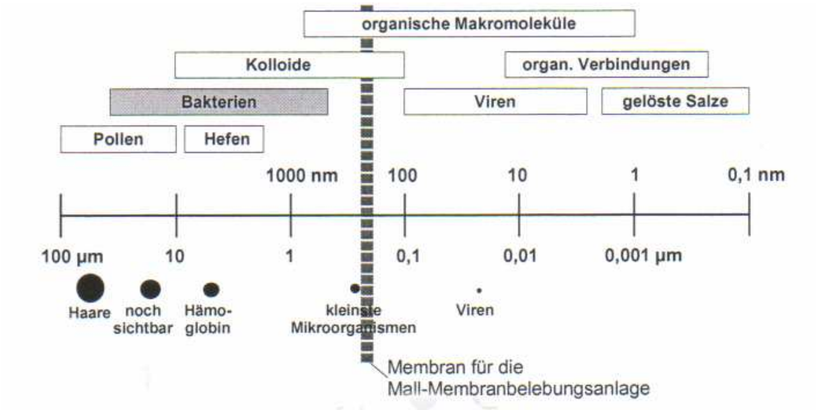


Figure 25: Penetration properties of membrane (source: Mall Umweltsysteme)

Figure 26 shows on the left side a glass filled with influent water (greywater untreated) and on the right side a glass filled with effluent water (treated greywater).

Figure 26: Influent and effluent sample greywater system [10]

In table 17 the different effects of fluctuations in concentrations of components in the greywater are described. The effects are categorised by numbers. The number run from 0 till 4. The number 0 means no effect on the performance of the system and the number 4 means a lot of effect on the performance. So the higher the number the more effect it has.

Table 17: Effects of fluctuations in concentrations of components

Component	Effect	Description
Heavy metals	2-4*	The effect is larger when the concentration becomes toxic for biology
Pathogens	0	No effect on the system
Fatty substances	4	The change of clogging the membrane
Medicines and hormones	2-4*	The effect could be lager when concentration is high. It can result in damage of biology, but is not known yet.

[10] source: www.passivhaus-vauban.de

Phosphorus / nitrogen	0	For the project in Freiburg it does not matter under normal circumstances
Organic materials	0-4*	The change of clogging the membrane and the retention time should be adjusted, so bacteria can brake done the extra organic material

* Means that the effect increases when the concentration is increasing.

When the outdoor temperature is colder than 5 degrees Celsius two effects occur within the system:

- flow speed of the greywater is hampered slightly
- bacteria are degrading the contaminations slower

Further research has to be done to make sure that the treated water can be used for flushing the vacuum toilets. The treated water can be used again for toilets flushing if the effluent values are below the legal quality standards for one year operating time. Nowadays the treated greywater is reused for watering the garden.

Public health

The greywater system forms no direct hazard for public health and injuries. The inhabitants of the neighbourhood can not get into direct contact with untreated water and the underground installation is covered with a concrete lit. It is not likely at all that householders, who use the system, fall ill or get physical injuries due to system failure or other causes.

Chemical hazards are not used within the system itself. After a period of time the membranes are taken out of the system and replaced by cleaned membranes (see maintenance).

4.7 Costs and maintenance

The project “Arbeiten & Wohnen” is a pilot project where the new implemented ecological system where tested. The Deutsche Bundesstiftung Umwelt (DBU) supplied funding for the development and implementation of the alternative sanitation concepts (vacuum technology, biogas installation and the greywater treatment installation) for the project. The installations were also financially supported by the suppliers of the implemented systems: TBW GmbH (Frankfurt), Mall-Umweltsysteme (Donaueschingen) and Roediger Vakuum- und Haustechnik GmbH (Hanau).

The building cost where ca. 3.3 million Euro. In general the building has cost 7 % more than an usual low-energy building. This is because more techniques are implemented than a normal low-energy building.

An overview of the costs are given below for the separate installations.

Vacuum system

The investment cost for the vacuum system are presented in table 18 and are given in the Euros.

Table 18: Costs Vacuum system

Part	Number	Price per part (DM)	Price total (DM)
Vacuum station	1	------------------	13119.34
Installation vacuum station	1	------------------	3499.28
Vacuum toilets	24	1404.46	33706.98
Installation Vacuum toilets	24	465.58	11173.98
Vacuum pipelines incl. installation	1	------------------	12017.25
Total cost vacuum system: 73516.82			

The estimated annual operating cost of the process train per household is ca. 30,- Euro per year and has an estimated useful service life of approximately 30 years. (Rüster, *pers. com.*)

When the system experience a failure that cannot be solved by the residents or Hombach Bausupervision than Roediger is sending a maintenance expert. The time needed from failure till operating again of the system depends on the kind of failure and the location of the maintenance expert. Mostly the failures are solved within 8 hours by Roediger. When the problem can be solved by the residents or Hombach Bausupervision it will take 1-4 hours. According to Mr. H-C Rüster (2005) the time needed per household unit per year of operations and maintenance activity for the process train that is required from its users is 12 hours per year.

<u>Greywater system</u>

The investment cost for the greywater system are presented in table 19 and are given in the Euros.

Table 19: Costs Greywater system

Part	Number	Price per part (Euro)	Price total (Euro)
NEUTRA-Clear incl installation	1	9203.25	9203.25
Ultra sept. Membrane module	1	********	********
System parts incl. installation	1	------------------	1687.26
Grauwasser recycling pipelines (24 toilets)	1	------------------	2556.46
Pressure station	1	1278.23	1278.23
Steering	1	255.65	255.65
Total cost greywater system: 14980.85			

* not known

For the greywater system is for the first year a cost calculation made for monitoring activities. These cost are 4652.76 Euro, ca. 2 hours per week. The activities where:

- Flow meter greywater control
- Sludge level control

- Water level control
- Toilet flush control

The estimated useful service life of the greywater system is different for the components used:

Concrete tank where the process takes place	30-50 year
Electrical steering components	10-15 year
Membranes (depending on the loading rate)	5-8 year

The maintenance is done by several people. Small maintenance is done by Hombach Bausupervision and Mr J. Lange or Mr A. Panesar. Larger maintenance is done by Mall Umweltsysteme. When there is a system failure it takes less then 48 hours to repair the system and make it operational again. The time period depends on the kind of failure. (Klemens, *pers. com*)

The cleaning of the membranes, after a certain time period of operating, takes place at the company of Mall Umweltsysteme. The membrane modules are flushed with chemicals and afterwards cleaned in a fresh water bath, see figures 27 and 28.

Figure 27: Cleaning installation of membrane modules

Figure 28: Fresh water bath

Biogas system

For the biogas system no data are available about the total cost and maintenance activities.

5 Research site KfW Bankengruppe, “Östarkade”, office building (Frankfurt am Main)

5.1 Introduction

Within the office building “Östarkade”, of the KfW Bankengruppe, a vacuum sewer system and greywater recycling installation are applied. The office is situated in Frankfurt am Main, Palmgartenstrasse 5-9, 60325 in Germany (figure 29). The office has 7 floors and offers space for approximately 300 workplaces and 13 appartments on the two top floors. It contains 60 vacuum toilets and 20 vacuum urinals. Greywater is treated with a compact activated sludge reactor combined with membrane filtration system.

Figure 29: KfW Bankengruppe building

5.2 Background

The mission of the Kreditanstalt für Wiederaufbau (KfW Bankengruppe) is to give impulse to economic, social and ecological development on a global scale. Among other activities, the KfW is financing investments and is offering consultancy services in developing countries on behalf of the German Ministry for Economics Cooperation and Development (BMZ). In addition, the bank stimulates innovations and the equity capital market, advances environmental protection and encourages the expansion of municipal infrastructure.

The KfW Bankengruppe is one of the ten biggest banks in Germany with a balance sheet total of EUR 329 billion (as per 31.12.2004). It is owned by the government for 80 % and 20 % by private owners.(www.kfw.de)

The offices in Frankfurt are divided over 9 office buildings in the centre of Frankfurt. In 1976 the KfW moved into the first office building at the Palmengarten. The Östarkade is the most recent building and was opened in November 2002. This building has a capacity of approximately 300 working places and contains several innovative sustainable building features that combine economical and ecological demands.

The innovative facilities are: a passive ventilation system, a vacuum sewer system, a greywater treatment system, the use of a photovoltaic and photo thermal electricity (?) system and greenery on the roofs of the apartments. In the framework of this research the vacuum sewer system and the greywater system are investigated.

The main objectives for KfW of the project were:

- Improvement of the in-house environmental balance at KfW
- Reduction of operating and maintenance cost by water saving and recycling
- A showcase project of innovative technologies who are contributing in the closed-loop concepts of wastewater management. (Klingel et al., 2004 and Selig, *pers. com.*)

In total 60 vacuum toilets and 20 vacuum urinals are transporting the blackwater within the office building towards the vacuum pumping station that is situated, together with the greywater treatment system, in the basement. Greywater from sinks, showers/baths, cleaning and kitchen is collected with a gravity pipe system and is treated in a compact activated sludge reactor combined with membrane filtration. The installations implemented are described in paragraph 5.5. A system for rainwater collection and reuse was taken into consideration, but has not been implemented, because the greywater treatment system is providing enough water for reuse. Therefore collection of the rainwater was not considered necessary. (Selig and Schwarb, *pers. com*)

5.3 Actors and their roles & responsibilities

The roles and names of the main actors are presented in the table 20. These actors are responsible for the decision making and designing process, the technology supply and the maintenance of the vacuum sewage system and the greywater treatment installation.

Table 20: Actors involved in the project

Nr.	Description	Company name	Contact person(s)	Role(s)
1	Project owner	KfW Bankengruppe	Mr. K. Helms	Investor, project management and user
2	Technical design	Ip5 ingenieurpartnerschaft	Mr. W. Selig	Water concept calculation and design
5	Architect	RKW	Mr. J.Papenhagen	Building design
8	Technology supplier	Roediger Vakuum- und Haustechnik GmbH	Mr. C. Rüster	Supplier of the vacuum sewage system and maintenance

9	Technology supplier	ACO-Passavant – Roediger	-----------------	Supplier of the greywater treatment installation and maintenance
10	Technology supplier	Wiese Water Systems	Mr. U. Weise	Supplier of the membrane filtration unit for greywater treatment installation
11	Maintenance	Hochtief Facility Management	Mr. Bonfert	Maintenance of total system.

------- = unknown

KfW has incorporated separate treatment of the greywater and blackwater within their new office building "Östarkade" with the intention to reduce the consumption of fresh water significantly. To accomplish these goals the KfW invested in these technologies which made this a showcase project of innovative technologies who are contributing in the closed-loop concepts of wastewater management.
One time per month, Mr. K. Helms of the KfW had a meeting with the other actors during the selection of the systems. KfW was responsible for the final decisions on the system selection/technology choice, these decisions where based on authority.
Ip5 ingenieurpartnerschaft had an active role concerning the development and technical design of the energy- and water concepts (vacuum sewage system and the greywater treatment system).
As technology supplier Roediger Vakuum- und Haustechnik GmbH supplied the vacuum sewage system and is performing maintenance if required. ACO-Passavant – Roediger supplied the greywater treatment installation and also performing maintenance if required from the KfW. The membrane filtration unit, which is part of the greywater treatment installation, is supplied by Weise Water Systems.
General maintenance is done by the Hochtief Facility Management.

5.4 Drivers and barriers

An analysis of the drivers and barriers was performed by interviewing the actors that were involved in the decision making process. The actors that were interviewed are shown in table 21:

Table 21: Interviewed actors

Description	Company name	Contact person(s)	Role(s)
Project owner	KfW Bankengruppe	Mr. K. Helms	Project management/initiator and owner
Technical design	Ip5 ingenieurpartnerschaft	Mr. W. Selig	Water concept calculation and design

The drivers and barriers are divided in several groups:

-	environmental	drivers and barriers
-	public health	barriers
-	legal & regulatory	barriers

- financial drivers and barriers
- social & managerial drivers and barriers

Because of the fact that the answers of each actor differ, the answers are described for each actor separately. This in order to keep a good overview of the results of the questionnaires.

The complete list of the drivers and barriers is presented in appendix 12. The aspects, as mentioned above, within the drivers and barriers questionnaire were rated on a scale from 0 to 4. On the scale of importance: 0 represents “unimportant” and 4 represents “important”.

5.4.1 Environmental drivers and barriers

Project manager: Mr. K. Helms

When selecting the system the following environmental drivers were important to the project management/initiator and owner: water saving and protection of groundwater were rated on importance scale 4. The positive feeling about environmental behaviour, reduction of water emissions, recycling of water and reduction of energy use were rated on importance scale 3. The recycling of nutrients was considered as neutral. The aspects of the sanitation system realised according to Mr. K. Helms are: water saving and recycling of water rated on importance scale 4 and positive feeling about environmental behaviour and reduction of water emissions on importance scale 3. The protection of groundwater was rated as neutral. Prevention of drying out of soil, protection surface water, quality of neighbourhood landscaping, reduction of energy use and recycling of nutrients were rated on importance scale 0. The quality of neighbourhood landscaping was unimportant, because the office building itself is not built with any ecological aspects that are clearly can been seen on the outside.

Technical design: Mr. W. Selig

When the system was selected the following environmental aspects of the wastewater management system were important for the technical design: water saving (scale 4) and positive feeling about environmental behaviour (scale 3). Water saving was one of the objectives for the KfW to implemented non-conventional sanitation concepts in the office building. Reduction of water emissions, recycling of water and recycling of nutrients were rated as neutral. Recycling of nutrients was rated as neutral. The other remaining environmental aspects that influenced the technical design when the system was selected were: protection of surface water, groundwater and reduction of energy. These influences were scaled on number 1. The environmental aspects that were unimportant and had a number 0 on the rating scale were: prevention of drying out of soil and the quality of neighbourhood landscaping.
The importance of the aspects realised are exactly the same as the ones when the sanitation system was selected.

The risk that the system could overflow hampered incorporating non-conventional elements in the design and implementation of the sanitation system. For these risk safety measurement are taken in the design. In case of an overload of the system the extra wastewater is directly discharged on the municipal sewerage net. When the importance is scaled is became a number 4.

5.4.2 Public health barriers

Project manager: Mr. K. Helms

No public health barriers hampered incorporating non-conventional elements in the design.

Technical design: Mr. W. Selig

The public health barriers: health risks, chemical hazards and physical injury for employees and householders who have access to the system where a barrier with the rating scale 4 of importance. The vacuum station and greywater treatment system are located in the basement of the office building and is not accessible by unauthorised personal.

5.4.3 Legal and regulatory barriers

Project manager: Mr. K. Helms / Technical design: Mr. W. Selig

The administration of Frankfurt had discussions with the KfW in order to get the permission for applying the sanitation techniques. The reduction of the wastewater flow could cause blockage in the municipal sewerage system.

Nowadays monitoring activity on regular basis is done for the greywater system, because the treated greywater is reused for flushing the toilets and has to be clean enough for this purpose.

5.4.4 Financial drivers and barriers

Project manager: Mr. J. Lange (initiator)

The financial consideration “operating costs (compared to conventional system)” was a barrier of deciding to incorporate non-conventional elements in the design and was rated on the importance scale 3. The budget for the project was known from the beginning and was rated on the same scale of importance as the operating costs. The KfW financed the project in total. Reduced drinking water consumption (lower bills) was an important driver for the KfW (rating scale 3). The other financial considerations as design and energy cost (compared to conventional system) where neither a driver or barrier, but were taken into account and were rated on the importance scale with a number 3.

Technical design: Mr. W. Selig

All the financial considerations were neither a driver or a barrier according to Mr. Selig. The financial considerations were neutral. The budget was known from the begining, so the technical design was based on the budget. When the costs became higher than the budget allowed, adjustments were made to make it within the budget.

5.4.5 Social and managerial drivers and barriers

Project manager: Mr. K. Helms

Involvement in sanitation / taking responsibilities for your household water management system (water saving, reducing emissions) were important social aspects to realise a non-

conventional design and was rated with scale number 3. Intensive contact and collaboration with neighbours was considered as unimportant, because the building has as main function an office building. Improvement of the quality of living was neutral.

The implementation of a difficult technology was an important aspect hampering the incorporation of non-conventional elements in the design. There was no references available for applying vacuum toilets on this scale. The aspects of ownership - , maintenance unclearness and the maintenance burden on householders/employees was unimportant.

Technical design: Mr. W. Selig

The involvement in sanitation / taking responsibilities for your household water management system (water saving, reducing emissions) were important social aspects to realise a non-conventional design and was rated with scale number 4. A showcase project of innovative technologies who are contributing in the closed-loop concepts of wastewater management was an objective of the KfW. To achieve this objective, people must take responsibility for their wastewater. Otherwise these kind of project have no future. Intensive contact / collaboration with neighbours and improvement of the quality of living were considered as unimportant.

The social and managerial considerations that hampered the incorporation of non-conventional elements in the design was the same as that for the KfW, see social and managerial barriers of Mr. K. Helms.

5.5 Implemented technology

Within the office building “Östarkade” two main ecosan techniques are applied, vacuum sewage system and a greywater treatment installation. A division is made for the sewage system in:

- vacuum toilets
- vacuum station

For the greywater treatment installation the overall treatment process is described, technical treatment with sedimentation/fat separation, biological degradation, membrane filtration unit and UV disinfection (the membrane filtration unit is highlighted separately).

5.5.1 Vacuum toilets

Within the office building “Östarkade” 60 vacuum toilets and 20 vacuum urinals are installed and fabricated out of porcelain. These toilets are mounted on the wall, figure 30 and 31. The needed vacuum for flushing the toilet is 0.35 bar-0.6 bar and is produced by the vacuum station that is situated in the basement of the building. The user pushes the push-button, the interface valve is opened and the blackwater is evacuated. Air is also sucked into the system. At the same time the clean water valve is opened and rinsing water is sprayed into the bowl. For each flush 0.7 – 1.2 litre of water is needed. The vacuum valve is closed but the water valve remains open. A small amount of fresh water is sprayed into the bowl. The water valve is closed, a small volume of clean water is retained in the bowl and the toilet is ready for use. When the toilet is flushed 60 litre of air volume is transporting the blackwater towards a self-discharging batch vessel. This vessel is included into the vacuum pipeline system directly after the vacuum toilet or urinal and can store multiple flushes. When the vessel is filled with 5-7 litre of black water a trigger mechanism starts which automatically empties the vessel.

From here the blackwater is transported trough the vacuum pipelines towards the vacuum station, the needed vacuum for this process is 0.2-0.6 bar. (60-70 litres air).


Figure 30: Top- and front view of installed vacuum toilet

Figure 31: Front view of installed vacuum urinal

5.5.2 Vacuum station

The vacuum station (figure 32) is situated in the basement of the office building and is connected on the municipal sewerage system. In this vacuum station the blackwater from the vacuum toilets is temporally stored in the vacuum station receiver tank. The tank has a volume of 600 litre. When a certain level of blackwater in this tank has reached, it is discharged into the municipal sewage system in batches by one of the two discharge pumps. The discharge pump is automatically triggered by means of a float shut-off and stopped after a running time of 25 seconds after the float shut-off has gone. The two vacuum pumps are connected via suction pipes with the vacuum tank and pressurized by means of pipelines with a vent line. This vent line is drawn over the roof of the office building. Condense water which build up in this vent line is evacuated via the interface unit. The vacuum pumps suck in the air which has entered the vacuum system via the interface units or the vacuum toilets.
If the pressure of the vacuum tank falls under 0.5 bar, the main vacuum pump is triggered automatically by means of a pressure switch. Having re-established the necessary vacuum 0.6 bar and passed an after-run of 1 minute, the main vacuum pump is switched off again. A second vacuum pump is present if the pressure is falls under 0.45 bar and the main pump is already running. Both pumps shut down when the pressure has reached the final vacuum of 0.6 bar. When the final vacuum of 0.6 bar is not reached after a period of 60 minutes, both pumps shut down and an alarm malfunctioning signal is given. In case the discharge of the blackwater is not triggered by the float shut-off and the vacuum tank is overloaded a second float shut-off is triggering an alarm after 10 seconds.

The vacuum station has a suction performance of 2 × 63.000 litre/hour at 0.5 bar and a discharge capacity of 20.000 litre/hour against 14 meters (water pressure).

Energy connection performance of 6.0 kW.

Diameter: 800 mm
Height : 1950 mm (with fundament)
Volume: 600 litre

Figure 32: Vacuum station

5.5.3 Greywater treatment installation

The total greywater treatment installation (figure 33) is divided in several treatment steps, for each step a description is given below. The numbers between the brackets refer to the total scheme given in appendix 13.

The volume that is required for the installed greywater treatment installations is approximately 60 m^3.

Figure 33: Greywater treatment system

<u>Grease separator (8):</u>

The grease separator is functioning using the gravity principle. Wastewater containing grease and cooking oils enters the separator through a inlet calming device so as not to interfere with the separations process. Inside the chamber, heavier sludge's settle to the bottom while lighter oils and grease rise to the surface of the separator. The cleaned wastewater then exits the

separator and flows into the biological treatment unit. The collected sludge and grease should be disposed within 2-4 weeks by a licensed disposal company. During disposal, the entire contents of the separator are pumped into a waiting disposal truck and finally the empty grease separator is refilled with fresh water and placed back into operation.

Filter unit (1):

The filter unit (figure 34) is filtering the solid materials that are present in the greywater (hair, textile, etc.). It has an overflow towards the municipal sewerage system, in case of an overload. From this filter the water is transported towards a collecting tank (2).

Figure 34: Filter unit

Biological treatment:

The first step of the biological treatment is the collecting tank. This tank is aerated is order to prevent the development of bad odours. From the collecting tank the greywater is pumped towards tank 3, were micro-organism are breaking down the organic pollutants that are present in the greywater.

Ultrafiltration unit (5):

When the greywater has passed the biological treatment step the water is transported to a collecting tank (4). In this tank coarse dirt particles are removed with a screen and sedimentation. In order to prevent the development of odours when the plant is not in operation, the collecting tank is aerated from time to time.

In tank (5) the actual filtration process takes place with membranes, Micro Clear filters (MCO2). These filters are developed and produced by Weise Water Systems. In total 8 membrane filters packs are installed within the ultrafiltration unit. Figure 35 is representing a membrane filter pack with the technical specifications.

- Number of active plates: 38
- Plate distance: 2.5 mm
- Packing density: 250 m^2/m^3
- Membrane area: 5.5 m^2
- Average flux: 20-60 l/m^2hour
- Membrane material: polymer
- Pore size: 0.01 -0.1 µm

Figure 35: Membrane filter pack

Bacteria with the addition of oxygen decompose the organic substances in the greywater. The membranes, which are directly submerged into the greywater not only holds back all bacteria inside the system, but also prevents germs from coming through. Solvents can go through the membranes.

Figure 36: Ultrafiltration unit

A blower, which is mounted to the tank provides the air supply for the biology and cleans the filter at the same time. The blower is continues in operation, this in order to prevent clogging of the membranes. In order to prevent bio-fouling on the membranes, regular back-flushing's with permeate together with a disinfection chemical (e.g. hydrogen peroxide) are required. The back-flushing's and also the chemical dosage take place fully automatic

The filtrate is withdrawn with a filtrate pump at a suction pressure of 0.1 – 0.3 bar. The filtrate is pumped over a permeate back-flush tank towards the clean water collection tank (6). The permeate back-flush tank is situated on top of the unit. The ultrafiltration unit is presented in figure 36 , bellow the technical features are described.

- Maximum output: 1 m^3/hour
- Design flux: 22 l/m^2hour
- Total membrane area: 45 m^2
- Length: 1.5 metre
- Breadth: 1.2 metre
- Height 2.2 metre

Fresh water collection tank (6):

The clean water collecting tank is a reservoir for the treated greywater. The water is circulated over a Ultra-violet (UV) treatment module that is performing the last step of the greywater treatment process. UV treatment is the disinfection process of passing water by a special light source. The special light source emits UV waves that can inactivate harmful micro-organisms that are present in the water flow. The ultra-violet rays, similar to the sun's UV but stronger, alters the nucleic acid (DNA) of viruses, bacteria or parasites, so that they can not reproduce and are considered inactivated.

From the fresh water collecting tank the water is pumped towards the needed reuse points within the office building by a pumping station.

5.6 Performance and evaluation

<u>Water consumption</u>

During the construction of the office building care was taken to use innovative and resource-saving technologies, in particular to save on fresh water. The aim for this building was a water consumption of approximately 22 litres per person per day. Nowadays the water consumption is approximately 20 litre per person per day.

<u>Blackwater treatment</u>

Blackwater is transported by vacuum toilets and vacuum urinals. The vacuum toilets use +/- 1 litre for flushing and 60 litre air and the vacuum urinals +/- 0.5 litre. Conventional toilets need 6-9 litre water per flush. This saves 5-8 litre each time the toilets are flushed.

The maximum noise level produced by the vacuum toilets is +/- 83 decibel. A research about the noise production of the installed vacuum toilets and normal gravity toilets is performed by Roediger Vakuum- und Haustechnik GmbH. Sound measurements are taken on several floors (ground floor, 1 st. floor and second floor). The results of these measurements are presented in appendix 14. As can be seen in this figure the maximum noise level of the vacuum toilets is almost similar to the normal gravity toilets. The difference lies in the time that the noise is heard. The time for the vacuum toilets is 15 seconds as for the normal gravity toilets 29 seconds.

The maximal particle size that the system can handle is 46 mm, this is the same diameter of the opening inside the vacuum toilet. The valve behind the toilet has a diameter of 50 mm. which is larger than the diameter the opening inside the toilet. What is going through this opening inside the toilet ends up in the vacuum station collecting tank.

Problems that occurred when the system was operating where:

- leakage in the vacuum pipeline, resulted in pressure loss of system
- blockage inside the pipeline, especially in the beginning (Nowadays these problems occur instantaneously, because the people are familiar with the system. If blockage occur in the main vacuum pipeline than the complete vacuum system is out of order.)

Advantages of the vacuum system:

- pipelines with small diameters
- flexible installation of pipelines, also ascending (independent of slope)
- small space required for pipelines
- easy reconstruction in case of additional connections or modification of connection places
- no lifting machines or pumping station required
- no leakages of wastewater in case of pipe damages
- no odour annoyance thanks to tight and odourless system
- occurring leakages are immediately recognized due to increasing pressure loss
- water saving
- improvement efficiency of connected sewage treatment plants thank to lower dilution of wastewater.

Greywater treatment:

The performance and evaluation of the greywater treatment installation is divided in the greywater treatment installation in total (1) and for the ultrafiltration unit (2).

1. *Greywater treatment installation (total)*

The greywater treatment installation operates at a capacity of approximately 500 litre/hour and it produces bathing quality water. The water is used for reuse as toilet flushing or cleaning water.

The treatment efficiency for BOD removal is 98.8 %, (influent 400 mg/l, effluent 5 mg/l). The treatment efficiency for pathogens removal is 99.99999 %. The probability that a batch of final treated greywater failing to comply with official wastewater quality standards is 0 %. The final effluent water does not exceed the official quality standards. For the sludge there are no monitoring data available, sludge is directly discharged on the municipal sewage system. The monitoring activity is performed by the University of Karlsruhe (http://www.kfw-monitoring.de) and Hochtief Facility Management.

In table 22 the different effects of fluctuations in concentrations of components in the greywater are described for the greywater treatment installation. The effects are categorised by numbers. The numbers run from 0 till 4. The number 0 means no effect on the performance of the system and the number 4 means a lot of effect on the performance. So the higher the number the more effect it has.

Table 22: Effects of fluctuations in concentrations of components

Component	Effect	Description
Heavy metals	0	Influent water does not contain heavy metals in such concentrations that it has effect on the process.
Pathogens	0	No effect on the system.
Fatty substances	0-4*	Interfere with the separations process, originally no grease separator was installed. Kitchen water was added to process which formed problems. (clogging the system)
Medicines and hormones	0	The effect could be lager when concentration is high. It can result in damage of biology, but is not known yet.
Phosphorus /	0	No effect on the system.

nitrogen		
Organic materials	2	Bacteria are able to brake done the extra organic material. More time needed for breakdown.

* Means that the effect increases when the concentration is increasing

There are no effects on the process to fluctuations in particle diameter and temperature. Large particles are filtered out by the filtration unit. (figure 34).

The greywater treatment installation was originally designed to treat only greywater, now it also receives wastewater from the kitchen of the office building. Due to this connection several problems with the system performance occurred. The ultrafiltration unit in particular has had problems and needed to be adapted to treat higher loading rates. A second problem that influenced the system performance negatively is that the wastewater, contained fatty substances that caused clogging of the membranes and pipelines. These problems were solved by installing a grease separator. (Selig and Weise, *pers. com.*). Approximately 5 failures occur per year, when the system fails it takes around 5 hours maximum to get it operating again (depending on the type of failure). (Helms, *pers. com.*)

Public health

The greywater installations forms no direct hazard for public health and injuries. The employees and householders can not get into direct contact with untreated water. The installations are situated in the basement of the office and is only accessible by authorised personal.. It is not likely at all that householders, who use the system, fall ill or get physical injuries due to system failure or other causes.
The membranes are cleaned with hydrogen peroxide, this is the only chemical used for the process, under normal circumstances it is not forming a hazard for the employees and households. (Helms, Selig and Weise, *pers. com.*).

2. *Ultrafiltration unit:*

In table 23 the different effects of fluctuations in concentrations of components in the greywater are described for the ultrafiltration unit (Weise, *pers. com.*). The effects are categorised by scale numbering. The numbers on the scale run from 0 till 4. The number 0 means no effect on the performance of the system and the number 4 means a lot of effect on the performance (the higher the number the more effect it has).

Table 23: Effects of fluctuations in concentrations of components

Component	Effect	Description
Heavy metals	0	Influent water does not contain heavy metals in such concentrations that it has effect on the membranes
Pathogens	0	No effect on the system
Fatty substances	0	The change of clogging the membrane, crease separator is included in process. If not there is a change of clogging.
Medicines and hormones	0	The effect could be lager when concentration is high. It can result in damage of biology, but is not known yet.
Phosphorus / nitrogen	0	No effect on the system
Organic materials	0-4*	The effect could be lager when concentration is high. It can result in damage of biology

* Means that the effect increases when the concentration is increasing.

The used membranes have a pore diameter of 0.01-0.1 µm. This means that particles that are larger can not pass this membrane, for the total particle and filtration range see figure 37. The maximum particle size that the unit can handle is 2 mm.

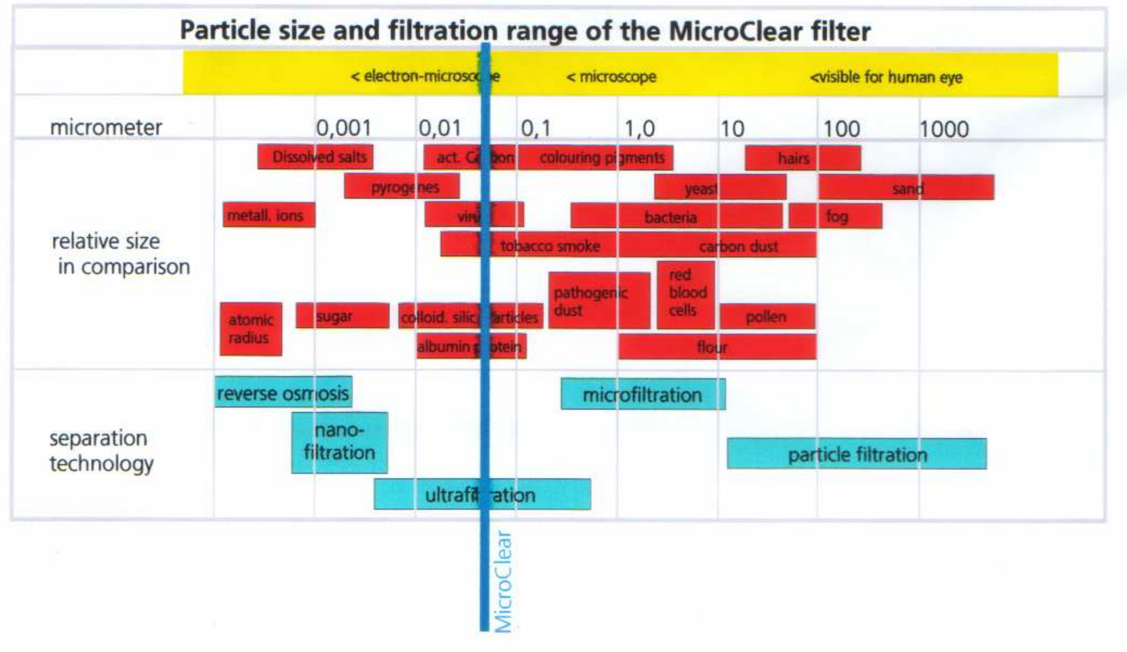


Figure 37: Particle and filtration range MicroClear[11]

Filtration occurs through a membrane, with a pore size so small, that all particles, bacteria and even viruses are retained.

The maximum noise level produced by the unit is +/- 55 decibel, produced by the blower.

In order to prevent bio-fouling on the membranes, regular back-flushing's with permeate together with a disinfection chemical (e.g. hydrogen peroxide) are required. The amount of hydrogen peroxide used is 60 kilograms per year.

Advantages of the ultrafiltration unit:

- high water quality
- safe treatment and disinfection of rainwater, greywater and sewage
- saves water
- easy, reliable operation
- compact
- quickly put into operation
- minimum maintenance requirements
- upgrade for larger buildings possible due to the modular design
- high cost savings due to low invest and minimum energy consumption

[11] source: Brochure Water with Security, Weise

5.7 *Costs and maintenance*

The KfW financed to complete system (vacuum sewage system and greywater installation).

Vacuum sewage system

Total investment costs for the vacuum sewage system were 80.000,- Euro. The estimated annual operating cost of the process train for the vacuum sewage system are ca. 1550 € per year for maintenance and 500,- Euro electricity costs per year. The system has an estimated useful service life of approximately 30 years. A test has shown that the vacuum toilets can handle at least 2.8 million flushes (pers. comm. Mr. C-H Rüster, Roediger).

Maintenance is performed by Roediger and HTM, Roediger performs +/- 20 hours per year on (general) maintenance and operating activities. (pers. comm. Mr. C-H Rüster, Roediger). The time needed for maintenance and operating activities by HTM is +/- 70 hours (pers. comm. Mr. K. Helms, KfW).

When there is a system failure it takes less then 0.5 hours to repair the system and make it operational again. The time period depends on the kind of failure (pers. comm. Mr. Selig, Ip5).

Greywater system

Total investment costs for the greywater treatment system were 50.000,- Euro. The estimated annual operating cost of the process train for the total greywater treatment system are not available.

Maintenance is performed by ACO-Passavant and HTM and takes +/- 30 hours per year on (general) maintenance and operating activities. (pers. comm. Mr. K. Helms, KfW).

When there is a system failure it takes less then 0.5 hours to repair the system and make it operational again. The time period depends on the kind of failure (pers. comm. Mr. Selig, Ip5).

The estimated life time of the total greywater system is 20 years, for the membranes that are used within the ultrafiltration unit the estimated lifetime is +/- 5 years.

Initial cost estimates that the return on the additional cost of KfW`s wastewater management system is about 2 - 5 % per year depending on the future rise in water price. (GTZ, datasheet)

6 Conclusions

6.1 Introduction

This chapter is divided in several paragraphs based on the research questions. Comparisons are made between the projects and the conventional domestic wastewater treatment according to the obtained and available information, for the cost, performance and user acceptances.

6.2 Conventional wastewater treatment Germany

For this research the conventional treatment methods of domestic wastewater in Germany were investigated. Germany is divided into 16 counties: Baden-Württemberg, Bayern, Berlin, Brandenburg, Bremen, Hamburg, Hessen, Mecklenburg-Vorpommern, Niedersachsen, Nordrhein-Westfalen, Rheinland-Pfalz, Saarland, Sachsen, Sachsen-Anhalt, Schleswig-Holstein, Thüringen. According to the data that was available 95 percent of the population are connected on a sewerage system. In total 10,188 wastewater treatment plants are in operation with a total sewage network of 450.000 kilometres. The total wastewater treatment plants are responsible for treating 9.6 billion m^3 of sewage on a yearly basis.

Three types of domestic wastewater treatment are applied in Germany:

- Mechanical
- Biological without post treatment
- Biological with post treatment

According to the latest numbers (2001) 95 percent of the wastewater is treated biologically with post treatment, 5 percent only biologically and the rest (equals 0.1 percent) mechanically.

The following tables presents an overview of the performance of wastewater treatment plants in Frankfurt am Main.

Table 24: Total wastewater treated (m^3/year)

WTP Griesheim	WTP Niederrad	WTPs Griesheim + Niederrad
52.268.600	35.887.900	88.156.500

Table 25: Pollution loads and concentrations

WTPs Griesheim/Niederrad	
15.163 ton BOD_5/year	172 mg BOD_5/litre
39.406 ton COD/year	447 mg COD/litre
3.050 ton NH_4-N/year	34.6 mg NH_4-N/litre
696 ton $P_{tot.}$-P/year	7.9 mg $P_{tot.}$-P/litre

Table 26: Effluent concentration and legal standards

Parameter	Griesheim/Niederrad	Legal standard
BOD_5	4.6 mg/litre	15 mg/litre

COD	30.0 mg/litre	50 mg/litre
NH_4-N	0.6 mg/litre	8 mg/litre
$N_{tot,anorg.}$	10.0 mg/litre	14 mg/litre
$P_{tot.}$	0.75 mg/litre	1 mg/litre
AOX	27 µg/litre	-
Hg	<0.2 µg/litre	-
Cd	<0.3 µg/litre	-

Table 27: Sludge treatment (incineration)

Sludge amount	Percentage dry weight	Total dry weight
1,052,380 m^3/year	2.5 %	25,812 ton

Table 28: . Energy consumption (kWh/year)

Griesheim/Niederrad	Sludge incin.used	Sludge incin. Produced
30,639,920 kWh/year	11,325,911 kWh/year	15,774,900 kWh/year

6.3 Involved actors

The idea of implementing non-conventional sanitation concepts in a passive energy house or office building was accomplished by collaboration of different actors. Both projects have a project owner that had an idea that needed to be designed by several other actors like, technology suppliers, architects and technical bureaus.

Both projects show some similarities concerning the role of the actors. For the project "Arbeiten & Wohnen" other actors are involved because of the scale and intentions of the project. For instance it is financed from private and government funding as for the KfW by their own resources. At the project "Arbeiten & Wohnen" an association is formed that was responsible for the management and juridical assistance.

6.4 Drivers and barriers

The actors as mentioned above are interviewed for the drivers and barriers concerning implementation of DESAR concepts within the investigated projects. The results are re-presented in table 28. In the table the available data concerning drivers and barriers from a previous research done by van Betuw (2005) in which 2 Dutch DESAR sites were investigated is presented in the same table.

Table 28: Drivers and Barriers invetigated sites

Drivers	**Arbeiten & Wohnen**	**KfW Bankengruppe**	**Dutch sites (Van Betuw, 2005)**
Environmental and public health			
Reduction of water emissions	Yes	Yes	Yes
Recycling water	Yes	Yes	Yes
Protection of surface water	Yes	Yes	Yes
Protection of groundwater	Yes	Yes/No*	Yes
Prevention of drying out of soil	Yes	No	-

Reduction of energy use	Yes	Yes	Yes
Emissions reduction	Yes	Yes	Yes
Recycling nutrients	Yes	Yes/No	No
Quality of neighbourhood landscaping	No	No	Yes/No
Financial			
Operating cost (compared to conventional system)	No	Yes/No	-
Energy costs (compared to conventional system)	Yes	Yes/No	-
Reduced drinking water consumption (lower bills)	Yes	Yes	-
Design costs (compared to conventional system)	No	Yes/No	-
Applying vacuum toilets	No	Yes/No	-
Social			
Positive feeling about environmental behaviour	Yes	Yes	Yes/No
Implementation of eco-sanitation	Yes	Yes	-
Intensive contact with neighbours / collaboration	Yes	No	-
Involvement in sanitation	Yes	Yes	-
Improvement quality of living	Yes	Yes/No	-
Barriers	**Arbeiten & Wohnen**	**KfW Bankengruppe**	
Environmental and public health			
Health	Yes	Yes	Yes
Flood risks	Yes	Yes	-
Chemical hazard	Yes	Yes	-
Physical injury	Yes	Yes	-
Noise production	Yes	No	-
Use of biogas installation	Yes	No	-
Law and regulatory			
Site depending	No	Yes	-
Financial			
Operating cost (compared to conventional system)	No	Yes/No	Yes
Bankruptcy involved actors	Yes	-	-
Energy costs (compared to conventional system)	No	Yes/No	-
Design costs (compared to conventional system)	Yes	Yes/No	Yes
Applying vacuum toilets	Yes	Yes/No	-
Social			
Difficult technology	Yes	Yes	No
Ownership unclear	Yes	No	-
Maintenance responsibilities unclear	Yes	No	-
Maintenance burden on householders	Yes	No	-

Use of biogas installation	Yes	-	-
chemical hazards	Yes	No	-
Noise disturbances	Yes	No	-
Management and maintenance problems	Yes	Yes	Yes

* stated as neutral importance or as neither driver or barrier

The differences in drivers and barriers between both projects can be explained by the non-similarity of the projects. Within the environmental and public health drivers a large similarity can be seen. They only differ in the drivers: protection of groundwater, prevention of drying out of soil and the recycling of nutrients. The first two are due to the location of the projects. In Freiburg there are no problems with the groundwater level as for Frankfurt am Main they face low groundwater levels so this on the agenda. For the financial part of the drivers and barriers some similarities can be seen. The difference lies in the fact that the KfW financed the project by them self so they had a clear view on the costs. As for “Arbeiten & Wohnen” a large part is financed by DBU, which in this case is a driver. A clear difference that can be seen in the social drivers and barriers is that within the project “Arbeiten & Wohnen” it was unclear who is/was responsible for the installations in case of breakdown.

As can be seen is that the recycling of nutrients is not a driver in the Netherlands, while in both German cases it is, and that the applied technologies are not considered difficult while in Germany they are. It should be mentioned that the Dutch cases only have grey water treatment systems (constructed wetlands) in place.

6.5 Implemented technologies

The model housing project “Arbeiten & Wohnen” is situated in Freiburg im Breisgau and includes 14 apartments and 4 offices. Blackwater is evacuated by vacuum toilets and greywater is treated in a membrane filter module. Rainwater is infiltrated in ditches near the building. A biogas installation is installed but is not operating yet.

Within the office building “Östarkade”, of the KfW Bankengruppe, a vacuum sewer system and greywater recycling installation are applied. The office is situated in Frankfurt am Main, The office has 7 floors and offers space for approximately 300 workplaces and 13 apartments on the two top floors. It contains vacuum toilets and vacuum urinals. Greywater is treated with a compact activated sludge reactor combined with membrane filtration system. What about rain water (do you have information?) – since you mention it with A & W.

<u>Vacuum toilets</u>

Within the project “Arbeiten & Wohnen” 24 porcelain vacuum toilets are installed. The needed vacuum of 0.5 bar (15-20 litre of air and 1 litre water) for flushing the toilets is produced by the central vacuum station in the basement of the building. The waste stream is than transported towards a reservoir (“selbstenleerenden Sammelbehälter”) behind the toilet. This reservoir has a capacity of circa 9 litre of wastewater. Up to 5-6 flushes are stalled inside this reservoir and when this reservoir is full it automatically empties itself with the help of 60-70 litre of air. The wastewater is subsequently transported to the collecting tank in the basement.

As for the office building “Östarkade” 60 vacuum toilets and 20 vacuum urinals are installed and fabricated also out of porcelain. The needed vacuum for flushing the toilet is ranging

between 0.35 bar-0.6 bar and is produced by the vacuum station that is situated in the basement of the building. For each flush 0.7 – 1.2 litre of water is needed. When the toilet is flushed 60 litre of air volume is transporting the blackwater towards a self-discharging batch vessel. This vessel is included into the vacuum pipeline system directly after the vacuum toilet or urinal and can store multiple flushes. When the vessel is filled with 5-7 litre of black water a trigger mechanism starts which automatically empties the vessel. From here the blackwater is transported trough the vacuum pipelines towards the vacuum station, the needed vacuum for this process is 0.2-0.6 bar (60-70 litres air per flush). The vacuum station is situated in the basement of the office building and is connected on the municipal sewerage system. When a certain level of blackwater in this tank has reached, it is discharged into the municipal sewage system.

Vacuum stations

The used vacuum stations, for generating the needed vacuum is standing in the basements of the buildings and are connected to the municipal sewerage system. The vacuum station within the project "Arbeiten & Wohnen" is connected on to the municipal sewerage system because the biogas installation is not operating.

Biogas installation "Arbeiten & Wohnen"

The biogas installation is not yet operational, because of problems with the coordination of the research work and the financing of the biogas gas plant. Due to these problems, some components are not yet installed (conditions December 2005). The biogas installation is an important part of the ecological sanitation concept of the project. The installation was a totally new development and was the first biogas plant for an apartment building in Germany. Not only the blackwater can be used for the biogas plant but also organic household waste. It is expected that the biogas plant does not produce enough biogas for heating purposes of the complex. Instead the produced biogas can provide cooking gas for the households. The substrate what is left over from the process is pumped by a pumping station towards a storage tank where it can be reused as fertilizer in agriculture.

Greywater treatment installations

The greywater treatment installations of both researched projects show a clear similarity with respect to the applied treatment processes :

Within the greywater treatment installations the polluted water is cleaned with the help of aerobic micro-organisms, which form H_2O, CO_2 and mineralised particles. This treatment occurs under aerobic conditions. New sludge is produced within the system that has to be reused within the system or discharged; therefore a returning cycle of the sludge is installed inside the installation. Within the water there are some floating particles and sludge present that are not separated by sedimentation. To avoid the presence of particles in the treated wastewater a membrane-module is installed, this membrane is forming a barrier where no sludge or other particles can flow through. The treated water can be reused for flushing the toilets and/or watering the garden. When the amount of treated water is exceeding the amount that can be reused it will be discharged on to the sewerage.
The difference between both projects regarding the greywater treatment installations is first of all in the dimensions of the treatment facility. For the office building "Östarkade" the amount of wastewater is larger requiring larger treatment installations. At the office building

"Östarkade" two additional treatment steps are applied, i.e a grease separator and an Ultra-Violet (UV) treatment module

Rainwater reuse

For the total Vauban district where the project "Arbeiten & Wohnen" is situated a plan is realised that the rainwater can be irrigated in the surrounding soil. This means that the rainwater is led over open gutters into two ditches near the complex to not dilute the wastewater streams. No rainwater reuse is applied within the office building "Östarkade" of the KfW.

6.6 *Performance of the installed installations "Arbeiten & Wohnen" and KfW Bankengruppe "Östarkade"*

Table 29 presents a comparison between the performance of the installed treatment installations for both research sites and compares it to the conventional wastewater system.

Table 224: Performance installed installations and conventional system

Parameter	**Arbeiten & Wohnen**	**KfW Bankengruppe**	**Conventional wastewater system in Germany**
Estimated useful service live blackw. system	30 years	30 years	30 years (sewer)
Estimated useful service live greyw. syst	5-50 years	5-20 years	-
Water consumption p.p.	94.4 litre/day[oo]	20 litre/day*	147 litre/day
Water needed for flushing	+/- 1 litre	+/- 1 litre	5-9 litre
Energy	66 Wh/resident/day	-	-
Air needed for flushing	15-20 litre	60 litre	-
Noise level	+/- 83 decibel	+/- 86 decibel	+/- 83-86 decibel
Max particle size (vacuum syst.)	46 mm	46 mm	80 mm
Capacity greywater system	140 litre/hour	500 litre/hour**	-
BOD removal efficiency in greywater system	+/- 98.4 %[ooo]	+/- 98.8 %***	+/- 97 % [+]
Pathogens removal efficiency greywater	+/- 99.8 %	+/- 99.9	-
Failures greywater system	+/- 5 times/year	+/- 5 times/year	-
Failures blackwater system	+/- 3 times/year	Seldom (only in beginning)	-

[0] Concrete tank where the process takes place 30-50 year
Electrical steering components 10-15 year
Membranes (depending on the loading rate) 5-8 year

[00] The water consumption is based on 34.5 m3 per year/per resident

[000] influent 129 mg/l, effluent +/- 3.9 mg/l
* The aim for this building was a water consumption of approximately 22 litres per person per day. So it can be concluded that a low water consumption is established.
** maximal capacity
*** influent +/- 400 mg/l, effluent +/- 5 mg/l
+ mixed wastewater (black and grey)

Between the two selected DESAR sites a large simularity can be seen in the table presented above. The differences that are not due to the size of the treatment system are discussed below. As can be seen from table 29 the amount of air needed for flushing is higher within the “Östarkade” and the amount of failures with the blackwater system are less than the project “Arbeiten & Wohnen”, because of the fact that the project “Arbeiten & Wohnen” was one of the first projects with a vacuum sewerage system applied on this scale. So it was a case of trial and error when the system was installed. Later the system has overcome the problems and is now functioning in the right way. Another fact is the chance of clogging of the system in the office building is lower than in a living complex, because in a project like “Arbeiten & Wohnen” children are present that frequently try too flush objects which are not meant for discharge through the toilets (toys,etc).

<u>KfW Bankengruppe, project “Östarkade”</u>

The probability that a batch of final treated greywater fails to comply with official wastewater quality standards is 0 %. The final effluent water does not exceed the official quality standards. For the sludge there are no monitoring data available, sludge is directly discharged on the municipal sewage system.

Problems that occurred to blackwater system at KfW Bankengruppe:

- Leakage in the vacuum pipeline, resulted in pressure loss of system
- Blockage inside the pipeline, especially in the beginning (Nowadays these problems occur seldom, because the people are familiar with the system. If blockages occur in the main vacuum pipeline than the complete vacuum system is out of order.)

Problems that occurred to greywater treatment system at KfW Bankengruppe:

- Fatty substances in the influent caused problems (in the beginning) because the system was not adapted to receive grease containing wastewater from the temporary kitchen. These problems are solved by the implementation of a grease separator.

Influent water does not contain heavy metals in such concentrations that it has effect on the treatment process. Phosphorous and nitrogen concentrations have no effect on the treatment system. Organic material is broken down in normal order, when more organic matter is present in the wastewater the system needs more time for breaking down these components. There are no effects on the process to fluctuations in particle diameter and temperature. Large particles are filtered out by the filtration unit.

<u>Public health</u>

The greywater installation forms no direct risk for public health and injuries. The employees and householders can not get into direct contact with untreated water and/or used chemicals.

Project "Arbeiten & Wohnen"

Problems that occurred to blackwater system at "Arbeiten & Wohnen":

- Reservoir (selbstentleerenden Sammelbehälter) behind the toilet which holds 5-6 flushes malfunctioned and is removed within certain apartments.
- Blockage inside the pipeline.
- Loss of vacuum

Problems that occurred to greywater treatment system at KfW Bankengruppe:

- The greywater system is upgraded from a mechanical biological treatment system with gravel as filter material to an installation (also with biological treatment) but with a membrane as filter. Because technical problems related with clogging of the system.

When the outdoor temperature is colder than 5 degrees Celsius two effects occur within the system:

- Flow speed of the greywater is hampered slightly
- Bacteria are degrading the contaminations slower

Public health

The vacuum system in total (vacuum toilets and vacuum station) does not represent a chemical hazard and the change of health problems and physical injuries is 0 %, this according to all the interviewed actors (Roediger, Lange, Panesar; pers. com.)
The greywater system forms no direct hazard for public health and injuries. The inhabitants of the neighbourhood can not get into direct contact with untreated water and the underground installation is covered with a concrete lit. It is not likely at all that householders, who use the system, fall ill or get physical injuries due to system failure or other causes. Chemical hazards are not used within the system itself. After a period of time the membranes are taken out of the system and replaced by cleaned membranes (by supplier of membranes)

By the data that is available it can be concluded that the systems are performing well and are contributing to an ecological way of sanitation.

6.7 Costs

Table 30 presents a overview of the cost from the conventional wastewater treatment in general and specifically for the treatment plant in Frankfurt am Main. A distinction is made between total investment cost, investment cost per person, cost for the sewage, ash discharging and fees. Part of this fee is used for the treatment of the wastewater and a part is used for treatment of the rainwater

Table 25: Overview costs conventional treatment in general and from selected site

Cost item	General	Frankfurt
Total investment costs	6.85 billion /year	25 million/year
Investment costs per person	117 Euro/year*	117 Euro/year
Operation costs	61,4 Euro/inhabitant/year	-

Sewage	150000-250000/per kilometre	150000-250000/per kilometre
Ash discharging	-	28 Euro/ton
Fees for water (including wastewater treatment)	2,90 Euro / m^3	2,18 Euro / m^3
Expected lifetime sewage	25 years	25 years

* based on costs for treating domestic wastewater, without sewage costs
- not known

Table 31 presents an overview of the available costs for realizing and operating the implemented DESAR technologies per site.

Table 31: Costs per investigated project

Cost item	Arbeiten & Wohnen	KfWBankengruppe
Vacuum system (total)	€ 73,517 (€ 5250 per household)*	€ 40,903
Maintenance/operation**	€ 15.34 (per household/year)	€ 792 per year
Energy	-	€ 256
Greywater system (total)	€ 14,981 (€ 1070 per Household)*	€ 25,565

* based on 14 household within the building. Excluded are the 4 offices
** Maintenance is performed by Roediger and HTM, Roediger performs +/- 20 hours per year on (general) maintenance and operating activities. The time needed for maintenance and operating activities by HTM is +/- 70 hours. For the first year a total cost calculation was made for the monitoring activities of the greywater system, in total it costs € 4650,-.
- not known data

It is not easy to compare the costs of the two selected DESAR sites because of the dissimilarity of implementation and use of the buildings. But for the aspects water consumption a comparison is made. Not only between the two selected DESAR sites but also the conventional way of wastewater treatment.

By applying DESAR concepts within the project "Arbeiten & Wohnen" a water saving of approximately 52 litre per day is established, when assumed that 147 litre/day is normal. As for the personal at the "Östarkade" they use an average of 20 litre fresh water each day. When assumed that in normal situation 35 litre is used within is a office by an employee it saves 15 litre each day. The fees are depending on the amount of freshwater used (as explained before) so less fees has to be paid, respectively € 55 per person and € 16 per person for the residents of "Arbeiten & Wohnen" and the KfW per employee per year, respectively.

From the tables above it can be concluded that the investment costs of the project "Arbeiten & Wohnen" are higher when DESAR concepts are implemented on this scale in comparison with the conventional wastewater treatment plant (regarding the amount of p.e.). The investment cost for the grey- and blackwater treatment is approximately € 6300,- with an service life of 30 years is € 210,- per year in comparison with the conventional treatment that costs € 117 each year (useful service life 30 years). As for the operational/maintenance costs the DESAR sites are cheaper than the conventional wastewater treatment plant. More specific economical data need to be gathered in order to give representative conclusions about which type of method is more economically feasible. As for the available data that is gathered from this research it can be noticed that when more households/offices using this kind of

techniques it might become more economical feasible to implement DESAR concepts. Nowadays both project are showcase projects.

6.8 User perception

For this research only the residents of the project “Arbeiten & Wohnen” are interviewed.
In general it can be concluded that the majority of residents of the project “Arbeiten & Wohnen” are satisfied with the current situation, although there are some who think that the system is not running on it full potential as it was designed for. With this they mean that there is no intensive reuse of the treated greywater for flushing of the toilets and the fact that the biogas installation is not in operation. Despite the fact that these parts are not in operation the resident are pleased with the fact that they own and use an ecological sanitation concept that contributes to a better environment. Not only the ecological aspects are important but also the social contacts between the residents and the economical advantages (water saving) they experience.

Overall conclusion:

The investigated DESAR concepts can be an alternative approach to the current conventional domestic wastewater treatment system in Germany (and / or The Netherlands). In other words, it offers advantages compared to the current system. Advantages are based on, social, economical and performance of the DESAR systems compared to the conventional way of domestic wastewater treatment. By incorporating DESAR concepts in a building like “Arbeiten & Wohnen” the residents feel like they are responsible for treating their own wastewater, ecological thinking is improved. A closer contact between the residents is established. Not only on social level but also on the economical level advantages are achieved for both projects in the form of water savings and maybe in the future the use of biogas within the project “Arbeiten & Wohnen”.

Overall it can be stated that both projects are showcase projects of innovative technologies that are contributing in the closed-loop concepts of wastewater management. They are an example for further implementations not only in Germany but also worldwide.

7 Recommendations

Project "Arbeiten & Wohnen"

- Further research has to be done to make sure that the treated greywater can be used for flushing the vacuum toilets at the project "Arbeiten & Wohnen". The treated water can be used again for toilets flushing if the effluent values are below the legal quality standards for one year operating time. Nowadays the treated greywater is reused for watering the garden.

- The possibilities for operating the biogas installation should be researched. In order to reuse to the nutrients more.

- It should be clear who is responsible for the installations and the laws that have to be fulfilled before implementing these kind of techniques.

- New and present residents should be well informed over the state and conditions of the implemented installations.

Project KfW Bankengruppe "Östarkade"

- More research has to be done on implementing reuse of rainwater within the building.

- The user acceptance of the employees and residents should be investigated. In oder to give a clear view on the user acceptance.

- The installed installations is operating satisfying, no further research is necessary.

General

- More research has to be done on the economical feasibility of these kind of projects. In order to give good predictions on the costs when larger sites are constructed.

- It is proven that the applied techniques are capable of fulfilling the needs of the users on small scale what happens if it is applied on large scale?

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Interviews

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Interviews with Mr. J. Lange, initiator and project manager, partly company owner ATARUS, on 08 December 2005, 13 December 2005.

Interviews with Mr A. Panesar, project management, partly company owner ATARUS, on 08 December 2005.

Interviews with Mr. M. Gies, architect of complex "Arbeiten & Wohnen" on 07 December 2005.
Interview with Mr. M. Toens, employee Badenova, supplier fresh water, on 13 December 2005.

Interview with Mr Hombach, Bausupervision, maintenance of system, on 12 December 2005.

Interview with Mr. S. Klemens, employee of Mall Umweltsysteme and so supplier of the greywater system and parts of biogas installation and maintenance, on 13 December 2005.

Interview with Mr C. Rüster, employee Roediger Vakuum- und Haustechnik GmbH, supplier of vacuum system, on 15 December 2005. (site Freiburg)

Interview with Mr C. Rüster, employee Roediger Vakuum- und Haustechnik GmbH, supplier of vacuum system, on 15 December 2005. (site Frankfurt am Main)

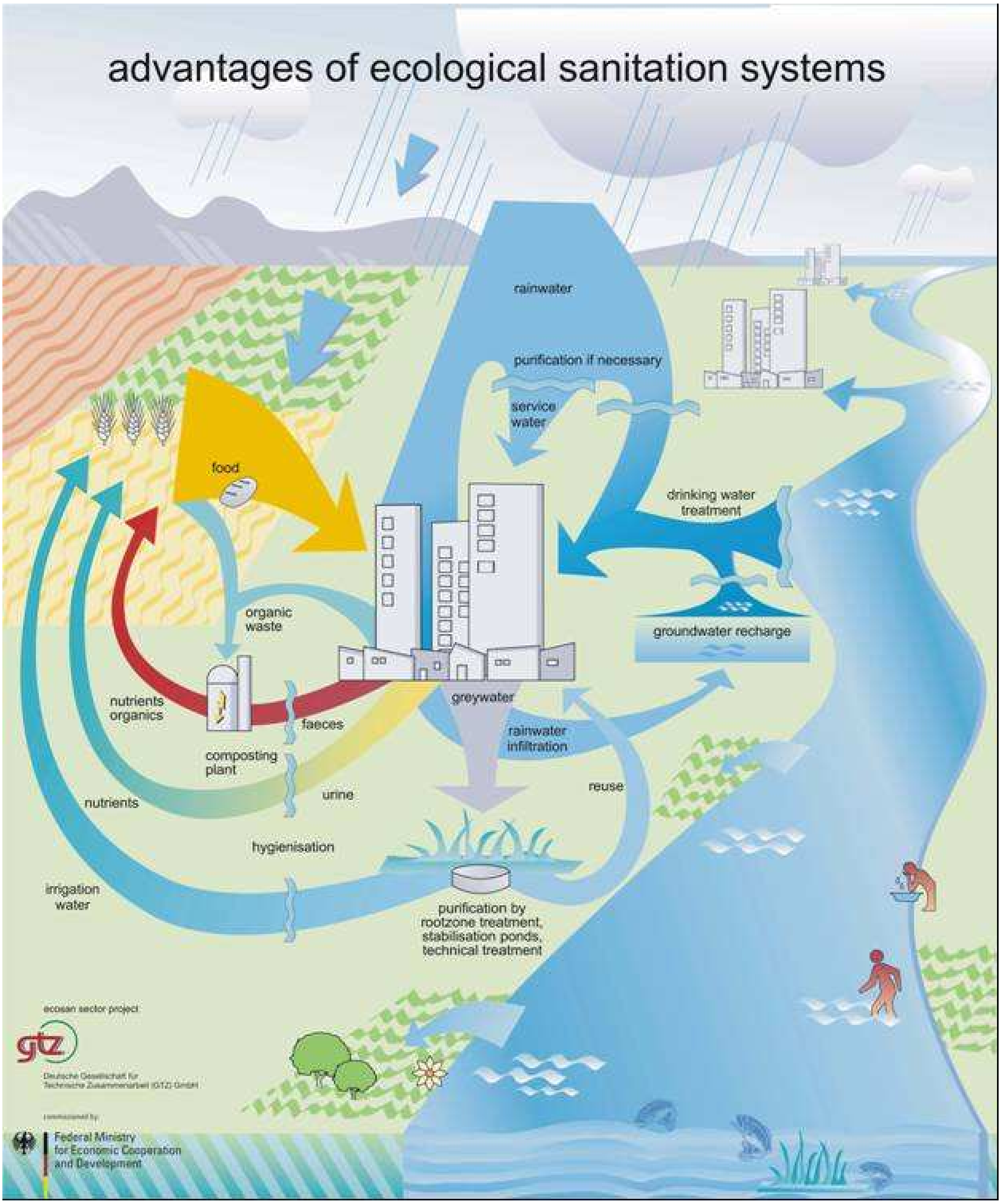
Interview with Mr. K. Helms, employee KfW, project management and user, trough post.

Interviews with MR. M. Selig, Employee Ip5 ingenieurpartnerschaft, water concept calculation and design, on 22 November 2005.

Interview with Mr U. Wiese, director Weise Water Systems, supplier of the membrane filtration unit for greywater treatment installation, on 23 November 2005.

Appendixes list

Appendix 1 Advantages ecological sanitation systems



Appendix 2 Drivers and barriers questionnaire

Analysis of Drivers and Barriers in Non-Conventional System Design Phase

I am Erwin Koetse of Wageningen University in the Netherlands. I am currently conducting a survey. The aim of this survey is to get an overview of the practical experiences of ecological projects. Your opinion about this is important to us for making this survey successful.
The interview will take us only around 30 minutes.
All the information you give will be treated confidentially and will not be shown to anyone else.

Questionnaire No:………………………………….Institution:……………………………………….
Date:…………………….Respondent name:…………………………………………Age:…………
Address: Street……………………………………………………………………….No:………….
District…………………………………………..Ward:…………………………………….

Questions on design

Sanitation system description

0. Can you describe the technical and managerial features of the sanitation system (ownership, process train, management, size, number of households connected to the system, and so on)?
…………………………………………………………………………………………………
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1. Did you participate in the technology choice of the sanitation system?

O Yes
O No

2. When was the system constructed and over what period?

………………….
………………….years

3. Which actors were involved in the technology choice? And what was their role?

	Actor	Role
1		
2		
3		
4		
5		
6		
7		
8		

4. How were decisions made? (consensus or authority)

   O consensus
   O authority

5. Did you agree with the decision-making process?

   O Yes
   O No, because…………………………………………………………………………………
   ………………………………………………………………………………………………
   ………………………………………………………………………………………………

6. Who was responsible for the final decision on the system selection / technology choice? (Which part?)

   ………………………………………………………………………………………………
   ………………………………………………………………………………………………

7. How often did you meet with other people involved in the system selection?

   ………………….times/month

Environmental drivers

8. What kind of environmental aspects of the waste water management system were important for you and other actors when you were **selecting** the system?

Environmental aspect	Unimportant Very important				
	0	1	2	3	4
Positive feeling about environmental behaviour					
Water saving					
Prevention of drying out of soil					
Reduction of water emissions					
Recycling of water					
Protection surface water					
Protection of ground water					
Recycling of nutrients					
Reduction of energy use					
Quality of neighbourhood landscaping					
Other………………					
Other …………………					
Other …………………					

9. What environmental aspects of the sanitation system were **realised** in the sanitation system as it was constructed?

Environmental aspect	Unimportant Very important				
	0	1	2	3	4
Positive feeling about environmental behaviour					
Water saving					
Prevention of drying out of soil					
Reduction of water emissions					
Recycling of water					
Protection surface water					
Protection of ground water					
Recycling of nutrients					
Reduction of energy use					
Quality of neighbourhood landscaping					
Other…………………					
Other …………………					

Other …………………					

Environmental and public health barriers

10. What barriers stood in the way of incorporating non-conventional elements in the design?

Environmental aspect	Unimportant Neutral Important				
	0	1	2	3	4
Health risks					
Chemical hazards					
Physical injury from users access to equipment					
Other …………………					
Other …………………					
Other …………………					

Legal and regulatory barriers

11. What laws and regulations hampered implementation of what non-conventional elements in the original design? (specify)

	Law or regulation	Impact on non-conventional design element(s)
1		
2		
3		
4		
5		

Financial drivers & barriers

12. What financial considerations were a driver or a barrier of decision to incorporate non-conventional elements in the design?

	Driver		Neutral		Barrier
	0	1	2	3	4
Design costs (compared to conventional system)					
Operating costs (compared to conventional system)					
E n e r					

	Unimportant		Neutral		Important
Other…………………					
Other …………………	0	1	2	3	4
Other…………………					
Design costs (compared to conventional system)					
Operating costs (compared to conventional system)					
E n e					

13. Was the budget for the system known from the beginning?

O Yes
O No

14. To what extent did the budget played a role in the system choice?

Unimportant		Neutral		Important
0	1	2	3	4

Social and managerial drivers and barriers

13. What social aspects of the sanitation system were important for you and other actor to realise a non-conventional design?

Aspects	Unimportant		Neutral		Important
	0	1	2	3	4
Involvement in sanitation / Taking responsibility for your waste water management system. E.g. water saving, reducing emissions					
Improves quality of living					
Other …………………					
Other …………………					
Other …………………					

14. What social and managerial considerations hampered incorporation of non-conventional elements in the design?

Aspects	Unimportant		Neutral		Important
	0	1	2	3	4
Difficult technology					
Ownership unclear					
Maintenance responsibilities unclear					
Other …………………					
Other …………………					
Other …………………					

Current and future status waste water management system

15. Did you participate in the period of building until now of the sanitation system?

    O Yes
    O No (skip next 2 questions)

16. Have there been any changes/modifications on the sanitation system from the start of using until now?

    O No
    O Yes, what and why?..
    ....
    ....
    ....
    ....
    ....
    ....

17. Are there any changes on the sanitation system that you think will happen in the future?

    ....
    ....
    ....
    ....
    ....
    ....

General

18. Which aspect(s) of the sanitation system do you think has a (good) future?

    ....
    ....
    ....
    ....
    ....

19. Who do you think is the most important actor in developing/initiating implementation of non-conventional systems? Why?

    ....
    ....
    ....
    ....
    ....

20. If you could do the project over again would you do it in the same way or would you deal with it differently?

    ....
    ....
    ....
    ....

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The interview is over now. Thank you for answering these questions

Are there any questions you missed or any question you thought was irrelevant?

Appendix 3 Maintenance and operation expert questionnaire

Interview operation and maintenance expert

I am Erwin Koetse of Wageningen University in the Netherlands. I am currently conducting a survey. The aim of this survey is to get an overview of the practical experiences of ecological projects. Your opinion about this is important to us for making this survey successful.
The interview will take us only around 50 minutes.
All the information you give will be treated confidentially and will not be shown to anyone else.

Questionnaire No:………………………………….Institution:……………………………………….
Date:……………………Respondent name:………………………………………Age:…………
Address: Street……………………………………………………………………….No:………….
District………………………………………..Ward:…………………………………….

Questions

Sanitation system description

0. Can you describe the technical and managerial features of the sanitation system (ownership, process train, management, size, number of households connected to the system, and so on)?
………………………………………………………………………………………
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………………………………………………………………………………………
………………………………………………………………………………………

Sanitation system description

1. What is the up-front investment per household in EURO of the process train?

   Total………….€/household

   Grey water ……………€/household

   Black water ……………€/household

   Rain water………………€/household

2. What is the estimated useful (service) life of the process train in years?

   …………years

3. What is the estimated annual operating cost in EURO of the process train per household?

   Total……………..€/household/year

Grey water ……………€/household

Black water ……………€/household

Rain water………………€/household

Performance dimension: invisibility and user comfort

4. Are householders satisfied with the sanitation system?

O Yes
O No, because………………………………………...
…………………………………………………………………………………………
…………………………………………………………………………………………

5. Have householders made adaptations to the sanitation system as originally installed?

O No
O Yes. What did they change and why?...
…………………………………………………………………………………………
…………………………………………………………………………………………
…………………………………………………………………………………………

6. How many hours per household unit per year of operations or maintenance activity does the process train require from its users?

Total………………….hours/household/year

Grey water …………… hours/household/year

Black water …………… hours/household/year

Rain water……………… hours/household/year

7. What area of the above-ground indoor space on household premises does the process train equipment require expressed in m^3 per households?

…………………..m^3/household

8. What area of the above-ground outdoor space on household premises does the process train equipment require expressed in m^3 per households?

…………………..m^3/household

9. What area of the above-ground space in the residential area (neighbourhood) does the process train equipment require expressed in m^2?
(what is the depth?……….)

…………………m^2/neighbourhood

10. What area of the under-ground space in the residential area (neighbourhood) does the process train equipment require expressed in m^3?

…………………..m^3/neigbourhood

11. How many official odour level complaints do users make per year (registered at for instance the municipality)?

    …………………number/year

12. How many non-official odour level complaints do users make per year (complaint at your address)?

    …………………number/year

Dimension: system robustness

13. Is the sanitation system being monitored? How?
    ……………………………………………………………………………………………
    ……………………………………………………………………………………………
    ……………………………………………………………………………………………
    ……………………………………………………………………………………………
    ……………………………………………………………………………………………
    ……………………………………………………………………………………………
    ……………………………………………………………………………………………

14. How many times per year does a system failure occur?

    Total………………….. failures/year

    Grey water …………… failures/year

    Black water …………… failures/year

    Rain water……………… failures/year

15. When the sanitation system fails, what is the average down time in hours?

    Total………………….. hours/failure

    Grey water …………… hours/failure

    Black water …………… hours/failure

    Rain water……………… hours/failure

16. What is the effect of the process to fluctuations in heavy metals in influent quality?

No effect		Effect		A lot of effect
0	1	2	3	4

17. What is the effect of the process to fluctuations in pathogens in influent quality?

No effect		Effect		A lot of effect
0	1	2	3	4

18. What is the effect of the process to fluctuations in oily or fatty substances in influent quality?

No effect		Effect		A lot of effect
0	1	2	3	4

19. What is the effect of the process to fluctuations in medicines and hormones in influent quality?

No effect		Effect		A lot of effect
0	1	2	3	4

20. What is the effect of the process to fluctuations in phosphorus or nitrogen in influent quality?

No effect		Effect		A lot of effect
0	1	2	3	4

21. What is the effect of the process to fluctuations in organic materials in influent quality?

No effect		Effect		A lot of effect
0	1	2	3	4

22. What is the effect of the process to fluctuations in particle size in influent quality?

No effect		Effect		A lot of effect
0	1	2	3	4

23. What is the maximum particle diameter the process can treat?

……………..mm particle size

24. What is the effect of the process to fluctuations in outdoor temperature?

No effect		Effect		A lot of effect
0	1	2	3	4

25. What is the effect of the process to fluctuations in rain intensity?

No effect		Effect		A lot of effect
0	1	2	3	4

Dimension: public health

26. What is the chance of inhabitants of the neighbourhood to come into direct contact with waste water in percentages?

……………….%

27. What is the probability of a batch of final treated waste water failing to comply with official waste water quality standards in percentages?

……………….%

28. Does the final effluent water exceed official quality standards?

O Yes (go to next question)
O No (skip next question)

29. In how far does the final effluent water exceed official quality standards in percentages?

……………….%

30. Does the final sludge exceed official quality standards?

O Yes (go to next question)
O No (skip next question)

31. In how far does the final sludge exceed official quality standards in percentages?

……………….%

32. How likely is it that householders using the system fall ill due to system failure or other causes?

Not likely at all				Very likely
0	1	2	3	4

33. How likely is it that householders sustain physical injury because they have access to sanitation system equipment?

Not likely at all				Very likely
0	1	2	3	4

34. Does the system or its components represent a chemical hazard to householders?

O No
O Yes, what is a chemical hazard?...
…………………………………………………………………………………………

35. What is the treatment efficiency for pathogens removal in percentages?

………………..%

36. What is the average effluent quality of water for pathogens?

………………..mg/kg

37. What is the average effluent quality of sludge for pathogens?

   ……………….mg/kg

Dimension: impact on eco-system

38. What is the volume of effluent water production per household per year, by effluent type?

   Grey water…………………m^3/household/year

   Black water………………… m^3/household/year

39. What is the amount of sludge production per household per year?

   ……………kg/household/year

40. How many kilograms of chemicals does the sanitation system use per household per year?

   …………….kg/household/year

41. What is the energy consumption per household per year for the sanitation system?

   …………….Kwh/household/year

42. What amount of energy is recovered from the treatment process per household per year?

   …………….Kwh/household/year

43. What is the volume of drinking water usage per household per year?

   ……………..m^3/household/year

44. What is the volume of water recycled from the sanitation system per household per year?

   ……………...m^3/household/year

Dimension: surface and groundwater management

45. Does the sanitation system evacuate rain water?

   O No
   O Yes

46. Does the sanitation system contribute to groundwater management?

   O No
   O Yes

47. What is the average rain water intensity per year?

   ……………mm rainfall/m^2/year

48. What is the maximum intensity rainstorm the system can handle?

……………mm rainfall/m^2

The interview is over now. Thank you for answering these questions

Are there any questions you missed or any question you thought was irrelevant?

Appendix 4 System expert questionnaire

Interview sanitation expert

I am Erwin Koetse of Wageningen University in the Netherlands. I am currently conducting a survey. The aim of this survey is to get an overview of the practical experiences of ecological projects. Your opinion about this is important to us for making this survey successful.
The interview will take us around 60 minutes.
All the information you give will be treated confidentially and will not be shown to anyone else.

Questionnaire No:………………………………….Institution:……………………………………….
Date:……………………Respondent name:…………………………………………Age:…………
Address: Street……………………………………………………………………….No:………….
District………………………………………..Ward:…………………………………….

Questions

Sanitation system description

0. Can you describe the technical and managerial features of the sanitation system (ownership, process train, management, size, number of households connected to the system, and so on)?
…………………………………………………………………………………………………
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Sanitation system description

1. What is the up-front investment per household in EURO of the process train?

   Total…………€/household

   Grey water ……………€/household

   Black water ……………€/household

   Rain water………………€/household

2. What is the estimated useful (service) life of the process train in years?

   …………years

3. What is the estimated annual operating cost in EURO of the process train per household?

   Total……………€/household/year

   Grey water ……………€/household

Black water ……………€/household

Rain water………………€/household

Performance dimension: invisibility and user comfort

4. Are householders satisfied with the sanitation system?

O Yes
O No, because………………………………………..
…………………………………………………………………………………………………
…………………………………………………………………………………………………

5. How many hours per household unit per year of operations or maintenance activity does the process train require from its users?

Total.………………….hours/household/year

Grey water …………… hours/household/year

Black water …………… hours/household/year

Rain water……………… hours/household/year

6. What area of the above-ground indoor space on household premises does the process train equipment require expressed in m^3 per households?

…………………..m^3/household

7. What area of the above-ground outdoor space on household premises does the process train equipment require expressed in m^3 per households?

…………………..m^3/household

8. What area of the above-ground space in the residential area (neighbourhood) does the process train equipment require expressed in m^2?
(What is the depth?..........................)

………………….m^2/neighbourhood

9. What area of the under-ground space in the residential area (neighbourhood) does the process train equipment require expressed in m^3?

………………….m^3/neighbourhood

10. What is the maximum noise level produced on the household premises by the process in dB when in operation?

………………….dB

11. How many official odour level complaints do users make per year (registered at for instance the municipality)?

    …………………number/year

12. How many non-official odour level complaints do users make per year (complaint at your address)?

    …………………number/year

Dimension: system robustness

13. Is the sanitation system being monitored? How?
    ………………………………………………………………………………………………
    ………………………………………………………………………………………………
    ………………………………………………………………………………………………
    ………………………………………………………………………………………………
    ………………………………………………………………………………………………
    ………………………………………………………………………………………………
    ………………………………………………………………………………………………

14. How many times per year does a system failure occur?

    Total.………………….. failures/year

    Grey water …………… failures/year

    Black water …………… failures/year

    Rain water……………… failures/year

15. When the sanitation system fails, what is the average down time in hours?

    Total.………………….. hours/failure

    Grey water …………… hours/failure

    Black water …………… hours/failure

    Rain water……………… hours/failure

16. What is the effect of the process to fluctuations in heavy metals in influent quality?

0	1	2	3	4

17. What is the effect of the process to fluctuations in pathogens in influent quality?

No effect		Effect		A lot of effect
0	1	2	3	4

18. What is the effect of the process to fluctuations in oily or fatty substances in influent quality?

No effect		Effect		A lot of effect
0	1	2	3	4

19. What is the effect of the process to fluctuations in medicines and hormones in influent quality?

No effect		Effect		A lot of effect
0	1	2	3	4

20. What is the effect of the process to fluctuations in phosphorus or nitrogen in influent quality?

No effect		Effect		A lot of effect
0	1	2	3	4

21. What is the effect of the process to fluctuations in organic materials in influent quality?

No effect		Effect		A lot of effect
0	1	2	3	4

22. What is the effect of the process to fluctuations in particle size in influent quality?

No effect		Effect		A lot of effect
0	1	2	3	4

23. What is the maximum particle diameter the process can treat?

    ……………..mm particle size

24. What is the effect of the process to fluctuations in outdoor temperature?

No effect		Effect		A lot of effect
0	1	2	3	4

25. What is the effect of the process to fluctuations in rain intensity?

No effect		Effect		A lot of effect
0	1	2	3	4

Dimension: public health

26. What is the chance of inhabitants of the neighbourhood to come into direct contact with waste water in percentages?

    ……………….%

27. What is the probability of a batch of final treated waste water failing to comply with official waste water quality standards in percentages?

……………….%

28. Does the final effluent water exceed official quality standards?

O Yes (go to next question)
O No (skip next question)

29. In how far does the final effluent water exceed official quality standards in percentages?

……………….%

30. Does the final sludge exceed official quality standards?

O Yes (go to next question)
O No (skip next question)

31. In how far does the final sludge exceed official quality standards in percentages?

……………….%

32. How likely is it that householders using the system fall ill due to system failure or other causes?

Not likely at all			Very likely	
0	1	2	3	4

33. How likely is it that householders sustain physical injury because they have access to sanitation system equipment?

Not likely at all			Very likely	
0	1	2	3	4

34. Does the system or its components represent a chemical hazard to householders?

O No
O Yes, what is a chemical hazard?...
………………………………………………………………………………………………

35. What is the treatment efficiency for pathogens removal in percentages?

………………..%

36. What is the average effluent quality of water for pathogens?

……………….mg/kg

37. What is the average effluent quality of sludge for pathogens?

……………….mg/kg

Dimension: impact on eco-system

38. What is the treatment efficiency for organic material (BOD) removal in percentages?

    ……………..%

39. What is the average effluent quality of water for BOD?

    …………….mg BOD/l

40. What is the average quality of sludge for BOD?

    ……………mg/kg dm

41. What is the average quality of water for heavy metals?

    ……………µg/l

42. What is the average effluent quality of sludge for heavy metals?

    ……………mg/kg dm

43. What is the volume of effluent water production per household per year, by effluent type?

    Total…………………. m^3/household/year

    Grey water……………m^3/household/year

    Black water……………m^3/household/year

44. What is the amount of nutrients in effluent water per household per year, by effluent type?

    ……………mg/m^3

45. What is the amount of sludge production per household per year?

    ……………kg/household/year

46. What is the amount of nutrients recovered from the waste water stream and recycled per household per year?

    …………….kg/household/year

47. How many kilograms of chemicals does the sanitation system use per household per year?

    …………….kg/household/year

48. What is the energy consumption per household per year for the sanitation system?

    …………….Kwh/household/year

49. What amount of energy is recovered from the treatment process per household per year?

……………..Kwh/household/year

50. What is the volume of drinking water usage per household per year?

……………..m^3/household/year

51. What is the volume of water recycled from the sanitation system per household per year?

……………...m^3/household/year

Dimension: surface and groundwater management

52. Does the sanitation system evacuate rain water?

O No
O Yes

53. Does the sanitation system contribute to groundwater management?

O No
O Yes

54. What is the average rain water intensity per year?

……………mm rainfall/m^2/year

55. What is the maximum intensity rainstorm the system can handle?

……………mm rainfall/m^2

The interview is over now. Thank you for answering these questions

Are there any questions you missed or any question you thought was irrelevant?

Appendix 5 System owner questionnaire

Interview system owner

I am Erwin Koetse of Wageningen University in the Netherlands. I am currently conducting a survey. The aim of this survey is to get an overview of the practical experiences of ecological projects. Your opinion about this is important to us for making this survey successful.
The interview will take us only around 30 minutes.
All the information you give will be treated confidentially and will not be shown to anyone else.

Questionnaire No:…………………………………Institution:……………………………………….
Date:……………………Respondent name:…………………………………………Age:…………
Address: Street………………………………………………………………………….No:………….
District………………………………………..Ward:…………………………………….

Questions

Sanitation system description

1. Can you describe the technical and managerial features of the sanitation system (ownership, process train, management, size, number of households connected to the system, and so on)?

…………………………………………………………………………………………
…………………………………………………………………………………………
…………………………………………………………………………………………
…………………………………………………………………………………………
…………………………………………………………………………………………
…………………………………………………………………………………………
…………………………………………………………………………………………
…………………………………………………………………………………………
…………………………………………………………………………………………
…………………………………………………………………………………………

Sanitation system description

2. What is the up-front investment per household in EURO of the process train?

Total………..€/household

Grey water ……………€/household

Black water ……………€/household

Rain water………………€/household

3. What is the estimated useful (service) life of the process train in years?

…………years

4. What is the estimated annual operating cost in EURO of the process train per household?

Total…………….€/household/year

Grey water ……………€/household

Black water ……………€/household

Rain water………………€/household

Performance dimension: invisibility and user comfort

5. Are householders satisfied with the sanitation system?

O Yes
O No, because………………………………………...
…………………………………………………………………………………………………
…………………………………………………………………………………………………

6. How many hours per household unit per year of operations or maintenance activity does the process train require from its users?

Total………………….hours/household/year

Grey water …………… hours/household/year

Black water …………… hours/household/year

Rain water……………… hours/household/year

7. What area of the above-ground indoor space on household premises does the process train equipment require expressed in m^3 per households?

…………………..m^3/household

8. What area of the above-ground outdoor space on household premises does the process train equipment require expressed in m^3 per households?

…………………..m^3/household

9. What area of the above-ground space in the residential area (neighbourhood) does the process train equipment require expressed in m^2?
(What is the depth?.............)

………………….m^2/neighbourhood

10. What area of the under-ground space in the residential area (neighbourhood) does the process train equipment require expressed in m^3?

………………….m^3/neigbourhood

Dimension: system robustness

11. Is the sanitation system being monitored? How?
……………………………………………………………………………………………
……………………………………………………………………………………………

…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………

12. How many times per year does a system failure occur?

Total………………….. failures/year

Grey water …………… failures/year

Black water …………… failures/year

Rain water……………… failures/year

13. When the sanitation system fails, what is the average down time in hours?

Total………………….. hours/failure

Grey water …………… hours/failure

Black water …………… hours/failure

Rain water……………… hours/failure

Dimension: impact on eco-system

14. What is the energy consumption per household per year for the sanitation system?

………………….kWh/household/year

15. What amount of energy is recovered from the treatment process per household per year?

………………….kWh/household/year

16. What is the volume of water recycled from the sanitation system per household per year?

………………….m^3/household/year

The interview is over now. Thank you for answering these questions

Are there any questions you missed or any question you thought was irrelevant?

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Appendix 6 Household questionnaire

HOUSEHOLD SURVEY including vacuum toilets

Your opinion about how you experience the system is important to us for making this survey successful.
The interview will take around 20 minutes.
All the information you give will be treated confidentially and will not be shown to anyone else.

Questionnaire No:……………….............Institution:…………………………………….

Date:……………………Respondent name: ……………………………………………Age:……

Gender:………………...Role in Household…………………………………………………………

Address: Street…………………………………………………….. No……………….

District:……………….…………… Ward:…………………………………..

Household information items:

1. How many people does your household have?

   …………..number

2. What is the composition of the household?

   O Single
   O One parent family
   O Two parent family
   O Married (no kids)
   O Living together (no kids)

3. How many members of the household spend the day outside home (school, work)?

   ………..persons

4. How many persons are spending the night at home at least 5 days per week?

   …………persons

5. For how long do you already live in the neighbourhood?

   …………years (O from the beginning)

6. Do you own or rent the house?

   O Own -0
   O Rent -1

7. Did you come to live here especially for the ecological aspects of the neighbourhood?

O Yes - 0
O No - 1
O Wasn't aware of it - 2

Sanitation system description:

8. Was there an up-front capital investment in EURO of your household for the sanitation system?
If yes, please fill in the amount of EURO. If no just skip this question

……….EURO

9. Did you pay money to realize/build the wastewater management system and what was included in this price?
If yes, please fill in the amount of EURO below. If no just skip this question

Total: ……………EURO

Elements included: Cost (if you know it)

Elements included	Cost (if you know it)
…………………………………..	………………EURO
…………………………………..	……………… EURO
…………………………………..	……………… EURO
…………………………………..	……………… EURO

10. What is the estimated annual operating cost in EURO per household for the sanitation system?
……………EURO

11. Did you receive any funding assistance for the ecological aspect?

O Yes, how much?..
O No

Performance dimension, invisibility and user comfort:

<u>*Black water system*</u>

12. Is your household satisfied with the **black water** system? (explain)
   - o Very satisfied - 0
   - o Satisfied - 1
   - o Neutral - 2
   - o Dissatisfied - 3
   - o Very dissatisfied - 4

because………………………………………………………………………………………
…………………………………………………………………………………………………

Is the vacuum toilet easily kept clean?

…………………………………………………………………………………………………

…………………………………………………………………………………………………

13. Does the vacuum toilet produce any annoying noise in your opinion?

…………………………………………………………………………………………………

…………………………………………………………………………………………………

14. Who is the owner of the vacuum toilet? *(Especially important for house owners)*

………………………………………………………………………………………………..

Next question only to be answered by house owners

15. Did you ever considered to replace the vacuum toilet with another toilet?

…………………………………………………………………………………………………

…………………………………………………………………………………………………

16. Are there any other comments in relation to the vacuum toilet that you would like to mention?

…………………………………………………………………………………………………

…………………………………………………………………………………………………

…………………………………………………………………………………………………

17. Can you recommend the **vacuum toilet** system to other households in other neighbourhoods?

O Yes I will actively recommend it – 0
O Yes I will – 1
O Do not know – 2
O Not without improvement – 3
O Not at all – 4

Comments…………………………………………………………………………………

………………………………..…………………………………………………………………

……………………………………………………………………………………………….

18. If you would move to another place/house would **you** like to have the vacuum toilet system or would you prefer the conventional way or another system?

O Same sanitation system

O Conventional way

O Another system, namely…………………………………………………………….

Other comments…………………………………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………………………

19. What mark would you give the **vacuum toilet** system as it is now?

O 10
O 9
O 8
O 7
O 6
O 5
O 4
O 3
O 2
O 1

Reason:…………………………………………………………………………………

…………………………………………………………………………………………

…………………………………………………………………………………………

Grey water system

20. Is your household satisfied with the **grey water** system? (explain)

- o Very satisfied - 0
- o Satisfied - 1
- o Neutral - 2
- o Dissatisfied - 3
- o Very dissatisfied - 4

because…………………………………………………………………………………

…………………………………………………………………………………………

…………………………………………………………………………………………

21. Does the **grey water** process produce unpleasant odours in your opinion?

- o Not at all - 0
- o A little bit - 1
- o Sometimes - 2
- o Very often - 3
- o Always - 4

22. If unpleasant odours occur, in which months?

Jan – Feb – March – April – May – June – July – Aug – Sept – Oct – Nov – Dec

23. Does the **grey water** system produce annoying noise level in your opinion?

O Not at all – 0
O A little bit – 1
O Sometimes – 2
O Very often – 3
O Always – 4

24. Can you recommend the **grey water** system to other households in other neighbourhoods?

O Yes I will actively recommend it – 0
O Yes I will – 1
O Do not know – 2
O Not without improvement – 3
O Not at all – 4

Comments……………………………………………………………………………………

…………………………………..……………………………………………………………

25. If you would move to another place/house would **you** like to have the **grey water** system or would you prefer the conventional way or another system?

O Same sanitation system

O Conventional way

O Another system, namely…………………………………………………………….

Other comments……………………………………………………………………………

……………………………………………………………………………………………

26. What mark would you give the **grey water** system as it is now?

O 10
O 9
O 8
O 7
O 6
O 5
O 4
O 3
O 2
O 1

Reason:……………………………………………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………………………

Complete system

27. Have you / your household made adaptations to the sanitation system as originally installed? (If yes, what and why)

O no

O yes

What……………………………………………………………………………………………

…………………………………………………………………………………………………

…………………………………………………………………………………………………

Why……………………………………………………………………………………………

…………………………………………………………………………………………………

…………………………………………………………………………………………………

28. Is there a visible part of the sanitation system near your house?

O yes (go to next question)
O no (skip next 2 questions)

29. What do you think of the visible part of the sanitation system in or near your house?

- o Beautiful - 0
- o Nice - 1
- o Not disturbing - 2
- o Annoying - 3
- o Really awful - 4

Comments…………………………………………………………………………………

……………………………………………………………………………………………………

30. Is the visible part of the sanitation system in or near your house vulnerable to damage/failure?

- o Not at all - 0
- o A little bit - 1
- o Sometimes - 2
- o Very often - 3
- o Always - 4

What is vulnerable? ……..……………………………………………………………………

…………………………………………………………………………………………………

31. How many hours per year per household does the wastewater management system prefers general maintenance? By who is it done?

Total system:………….hours/household/year. By…………………………………………

Activities:	Time
Rainwater	………. hours/year
Grey water	……… hours/year
Black water	……… hours/year
System inspection	……… hours/year
Other	……… hours/year

32. Are you involved in any monitoring activities regarding the system (such as visual inspections of effluent of treatment system, pump checks etc.) ?

O No (skip next question)

O yes (go to next question)

33. If yes, what are they and how many hours a month do you expect them to taken up?

What

…… ……………………………………………time…………………………….Hours/month

……………………………………….…….time……………………………Hours/month

…………………………………..……………time……………………………Hours/month

34. What area of the above-ground and / or underground **indoor space** does the sanitation system require expressed in m3 for your household (including the toilet itself) ?

Above-ground…………………..m3/household

Under-ground…………………..m3/household

(indicate which parts require the space. E.g. toilet requires a space / room of … m3. etc.)

35. What area of the above-ground and / or underground **outdoor** space does the sanitation system require expressed in m2 and m3 for your household?

Above-ground ……………………m2/household

Above-ground ……………………m3/household

Under-ground ……………………m2/household

Under-ground …………………...m3/household

36. What area of the under-ground space in the residential area (neighbourhood) does the process train equipment require expressed in m3?

    …………………m3/neighbourhood

Dimension system robustness:

37. Is the sanitation system being monitored? How?

………………………………………………………………………………………………
………………………………………………………………………………………………
…………………………………………………………………………...………………...……
………………………………………………………………………………..……………………

38. How many times per year does a system failure/blockage occur with your vacuum toilet?

    ……………………failures/year

39. How many times per year does the complete vacuum system fails?

    ……………………failures/year

40. How many times per year does the grey water system fails?

    ……………………failures/year

Only to be asked if one or two or all last 3 questions was/were higher than 0 failures per year

41. Which parts of the wastewater management system failed/was out of order? What was the problem? When and how often does it happen? How did you solve it and who did it?

Part of the system	Problem	When? (Date)	often? (t/m /y)	Solution	Solved

42. When the sanitation system fails, what is the average down time in hours?

…………hours/failure

Dimension public health:

43. What is the chance that you could come into direct contact with untreated or partially treated water (in percentages)?

   ……………….%

44. Have you suffered some kind of illness due to the wastewater management system?

   O No

   O Yes, explain.

   ....

   ....

   ....

45. Has anyone in your household ever been physically injured in using or maintaining the sanitation system? (If yes, how often, nature and cause or injury)

   O No
   O Yes,

   How often………………………………………………………………………………

   Nature

   …………………………………………………………………………………….

   ……..……………………………………………………………………………

   Cause

   ………………………………………………………………………………………

   ………………………………………………………………………………………

Questions on user perspective

Background questions

46. Did you do a higher education after high school/ youth school?

   O No
   O Yes, Yrkesfag (or similar education) – work subjects – for work (mechanic, electrician, healthcare etc)
   O Yes, Almennfag (or similar education) – common subjects- for bachelor/master

Involved questions

47. Do you feel environmentally concerned?

O Always –0
O Very often –1
O Sometimes –2
O A little bit –3
O Not at all –4

48. Did the sanitation system make you **more** environmentally concerned?

O Yes
O No

49. Which aspect(s) of the sanitation system do you think has/have a good future?

……………………………………………………………………………………………
……………………………………………………………………………………………
……………………………………………………………………………………………

50. What kind of benefits of the waste water management system do you experience?

……………………………………………………………………………………………
……………………………………………………………………………………………
……………………………………………………………………………………………
……………………………………………………………………………………………

51. What kind of drawbacks of the waste water management system do you experience?

……………………………………………………………………………………………
……………………………………………………………………………………………
……………………………………………………………………………………………
……………………………………………………………………………………………
……………………………………………………………………………………………

Appendix 7 Results household questionnaires “Arbeiten & Wohnen”

Household information items

- How many people does your household have? *(Answer: number of people)*

Interview number	Amount of people
1	4
2	3
3	4
4	3
5	2
6	3
7	3
8	2
9	3
10	1
11	2

The composition of the household differ from 1 person till 4 persons per household. The average composition is 2.7 persons per household.

- How many members of the household spend the day outside home (school, work)? *(Answer: number of people)*

Interview number	Amount of people spending the day outside home
1	4
2	3
3	2
4	3
5	1
6	2
7	3
8	2
9	3
10	1
11	2

The average amount of residents who are spending the day outside home is 2.36 persons. This is lower than the average amount of people per household, indicating that 87.4 % of the residents are spending the day outside home.

- How many persons are spending the night at home at least 5 days per week? *(Answer: number persons)*

All residents are spending the night at home for at least 5 days per week (see answer at question 1 for total numbers of residents)

- For how long do you already live in the neighbourhood. *(Answer: number of years)*

The years that the residents already live in the neighbourhood/complex differ from 1 till 6 years. The project started in 1999. 7 households are living in the complex for 6 years (from the beginning), 2 households are living for 4 years in the complex. 1 resident is living for 1 year in the complex.

- Do you own our rent the house? *(Answer: own/rent)*

3 out of the 11 residents are renting the apartment, the other are owners.

- Did you come here to live here especially for the ecological aspects of the neighbourhood?

73 % of the households (8) are living in the complex because of the ecological aspects. 18 % of the household are not living in the complex for the ecological aspects and one was not aware of the ecological aspects before they moved in.

- What is the estimated annual operating cost in Euro per household for the sanitation system?

The annual estimated operating cost in Euro per household is 50,-. 4 interviewed residents did not know the exact costs. According to the other residents it is supposed that the operating cost are all the same for each household.

- Did you receive any funding assistance for the ecological aspect? *(Answer: yes, how much, no)*

All the residents did not get funding assistance for the ecological aspects. This does not mean that the there was no funding assistance. The Deutsche Bundesstiftung Umwelt (DBU) supported the project financially. The funding was managed by the organisations who where responsible for the project.

Black water system

- Is your household satisfied with the blackwater system? *(Answer: 5 point rating scale)*

The answers are based on a rating scale from 0 till 4.

0 Very satisfied
1 Satisfied
2 Neutral
3 Dissatisfied
4 Very dissatisfied

From the interviewed residents are 2 very satisfied with the blackwater system, as reason of these residents was the water saving by using these kind of toilets. According to them the system is operating well. The overhand of residents (8) are satisfied with the system,

because of the fact that the system is contributing to lesser water cost (water saving), ecological principle, good functioning of the system, better for the environment. Despite the fact that the toilets are sometimes noisy 2 of these 8 resident have rated the system as satisfied. 1 resident was neutral about the system because there where some problems with the service and maintenance. It sometimes takes a long time for the system is operating again after a system failure.
As average the total satisfaction is 0.909, this indicates that the overall rate is satisfied with the blackwater system.

- Is the vacuum toilet easy kept clean? *(Answer: yes, no; because)*

81.8 % of the residents have no problems with cleaning the toilet. It is cleaned the same way as a conventional toilet. The other 17.2 % have two separated problems: cleaning the flush hole inside the toilet is not easy, because this hole is tighter than a conventional toilet. The cleaning brush can not go deep inside. The other problem is that the edge inside the toilet is corroded, causing unpleasant odours. The mentioned problems where according to two separated households.

- Does the vacuum toilet produce any annoying noise in your opinion? *(Answer: 5 point rating scale)*

The answers are based on a rating scale from 0 till 4.

0 Not at all
1 A little bit
2 Sometimes
3 Very often
4 Always

The vacuum toilets are producing a sound when they are flushed, what is not considered as disturbing according to four households. In the beginning the sound produced by the vacuum toilet was considered as unusual. After a certain period of time they get used to the sound and was no longer considered as disturbing. According to six households the sound is considered as sometimes disturbing. These residents hear the toilets of the neighbours when they are flushed, especially during the night. For this reason the toilets are as little as possible used during the night in order to prevent sound disturbance. For one resident the noise is considered as disturbing because of the fact that his bedroom is located next to the room where the toilet is situated standing.

- Do you ever considered to replace the vacuum toilet with another toilet? *(Answer: yes, no; because)*

One of the interviewed resident has considered to replace the vacuum toilet because they experienced some problems. So when a problem occurs the thought run through their mind to replace the toilet. The other residents did not consider to replace the vacuum toilet, despite some problems/failures of the system.

- Can you recommend the vacuum toilet system to other households in other neighbourhoods? *(Answer: 5 point rating scale)*

The answers are based on a rating scale from 0 till 4

0 Yes I will actively recommend it
1 Yes I will
2 Do not know
3 Not without improvement
4 Not at all

One of the residents answered: Yes, I will actively recommend it the vacuum toilet system to other households in other neighbourhoods because of three reasons: they had no problems with the system and for the ecological- and economic aspects. 72.7 % of the residents will recommend the system, but not actively. These residents had general related reasons: reduction of water use so better for the environment (ecological aspects) and by the reduction of water use the water bills are lowered (economical aspect). One off the residents is willing to recommend the system if the system is improved.

- If you would move to another place/house would you like to have the vacuum toilet system or would you prefer the conventional way or another system? *(Answer: three point rating scale)*

The answers are based on a rating scale from 0 till 2
0 Same sanitation system
1 Conventional way
2 Other system

Accept from one, almost all of the respondents (90.9 %) would have the same vacuum toilet when they would move to another place or house. The respondent that would not have the same vacuum toilet had problems with this vacuum toilet, concerning the reservoir behind the toilet. In this reservoir the wastewater is collected of 5-6 flushes. In case their will be a better solution for this reservoir the respondent was willing to have a vacuum toilet within the new accommodation.

- What mark would you give the vacuum toilet system as it is now ? *(Answer: ten point rating scale)*

10 Highest
--
1 Lowest mark

The grades that are given by the respondents are between a six and a nine. De grades are based on certain reasons. 18.2 % of the respondents gave a six for the vacuum toilet. They had in the past some problems with the system. One of these respondents is willing to give the vacuum toilet a higher grade when the problems are definitely solved. (reservoir problems and loss of vacuum pressure). Of the 11 respondents 45.5 % gave the vacuum toilet an eight, because of the new technology and that the system is working well. The noise that is produced when the vacuum toilet is flushed is a point where the people have to get used too. Three respondents (27.3 %) graded the vacuum toilet with a nine. They think it is a good idea for two main aspects. First of all the ecological aspects and second the economical aspects. They are well aware of the fact that they form an example of ecological techniques in Germany and are proud of what they have.

According to grades that are given by the respondents an average grade of 7.8 can be calculated.

Grey water system

- Is your household satisfied with the grey water system? *(Answer: 5 point rating scale)*

The answers are based on a rating scale from 0 till 4.

0 Very satisfied
1 Satisfied
2 Neutral
3 Dissatisfied
4 Very dissatisfied

Of the eleven respondents 45.5 % (five respondents) were very satisfied with the grey water system. According to them the system works well and it contributes to the water savings. The treated water is used for the irrigation of the garden and is not transported towards the large wastewater treatment plant. Despite some problems in the beginning with the system, two respondents (18.2 %) are feeling satisfied with the system. Three respondents (27.3 %) answered this question with a number two on the rating scale. This number corresponds to neutral. One of them found it an expensive system with high operating and maintenance costs. The idea was good, according to this respondent, because it contributed to the total ecological idea of the project. One respondent answered dissatisfied, because the treated water is only used for irrigation purposes. The plan was to use the treated water for flushing the vacuum toilets, but this is not operating yet. The respondent would like to see that the system is working where it was designed for. Treating greywater and reuse it for flushing the toilet and when there is abundant treated water available it can be used for irrigation purposes. But this way they do not have to use fresh water for flushing the toilet. The average score of this question was 1, indicating that the users are satisfied with the system.

- Does the grey water process produce unpleasant odours in your opinion? *(Answer: 5 point rating scale)*

The answers are based on a rating scale from 0 till 4.

0 Not at all
1 A little bit
2 Sometimes
3 Very often
4 Always

The grey water treatment system is situated outside the complex and the pipes that transport the greywater towards the treatment system are running through the cellar of the complex. Ten of the eleven respondents answered that the grey water treatment process does not at all produce any unpleasant odours. Only one respondent can sometimes smell a certain odour ,because this respondent lives near the cellar where the waste water is transported towards the treatment system in the garden.

- If unpleasant odours occur, in which month(s)? *(Answer: January - December)*

According to the previous question asked, the respondent who sometimes smells an unpleasant odour the answer was during the entire year, no distinguished month.

- Does the grey water system produce any annoying noise in your opinion? *(Answer: 5 point rating scale)*

The answers are based on a rating scale from 0 till 4.

0 Not at all
1 A little bit
2 Sometimes
3 Very often
4 Always

The grey water system does not produce any annoying noise, according to all of the respondents.

- Can you recommend the grey water system to other households in other neighbourhoods? *(Answer: 5 point rating scale)*

0 Yes I will actively recommend it
1 Yes I will
2 Do not know
3 Not without improvement
4 Not at all

81.8 % of the respondents is willing to recommend the grey water system to other households in other neighbourhoods. 81.8 % is 9 out of the 11 respondents. The reasons can be summarized as follows: the system is working well as far as they know. It has a high ecological factor in comparison to the complete system. The residents can treat a part of their waste water with the grey water treatment system in their own back garden. Five of these nine respondents would like to see that the treated water is reused more than nowadays is applied. The project started with the plan to use the treated water for flushing the vacuum toilets and that the abundant treated water should be used for irrigation of the garden. Nowadays the treated water is only used for irrigation of the plants that are standing in boxes near the complex. The other four of this group had no comments.
Two respondents did not know if they would recommend the system, the two respondents did not know if the system is operating as at should be and why it is not working on full scale (more reuse).

- If you would move to another place/house would you like to have the grey water system or would you prefer the conventional way or another system? *(Answer: three point rating scale)*

0 Same sanitation system
1 Conventional way
2 Other system

Same sanitation system is preferred by 81.8 % of the respondents, that is 9 out of the 11 respondents. They had no comment to this. The remaining 18.2 % would like to have the same grey water treatment system but they would like to see more reuse of the treated water.

Possibilities for reusing the treated water are rinsing the garden, flush the vacuum toilets and cleaning purposes (these possibilities are ideas of some of the respondents.

- What mark would you give the grey water system as it is now ? *(Answer: ten point rating scale)*

10 Highest
--
1 Lowest mark

When starting with the lowest grades, given by the respondents, the first one on the list was a six. This grade is given by three of the 11 respondents. Which is equivalent to ….%. The main reason for giving this grade was the type of reuse what is done nowadays with the treated grey water. There are more possibilities according to the respondents that the water can be reused, for instance for flushing the toilets. According to one of the respondents who gave a six it was better to let the other residents know what the condition and performance is of the greywater system. According to these information they can discus what can be done for the future. Then this respondent was willing to upgrade his six towards a higher grade.
Two respondents (18.2 %) gave the greywater system a seven. No comments where given for this grade. The majority of the respondents 45 % has given the system an eight. This grade was based on general en individual reasons. The general reason was that the system was operating without any major problems. For one of the respondent it was not clear if the system was working as should be working and that al the efficiencies where accomplished. But as good example of the ecological aspects of the building the respondent gave an eight as grade.
The other respondent had no comments for his given grade.
As last and highest grade given is by one of the eleven respondents. This respondent has given the grey water system a nine. Because according to him the system is working and is operating for some time without any big problems.

According to grades that are given by the respondents an average grade of 7.4 can be calculated.

Complete system

- Have you / your household made adaptations to the sanitation system as originally installed ? *(Answer: yes, no; (if yes what and why))*

Three of the eleven respondents (27 %) have made adaptations to the sanitation system. They removed the reservoir which is situated behind the vacuum toilet where a number of flushes are stored. The reason why these where removed is because they were broken. By removing these reservoir the wastewater from the toilet is directly transported towards the tank in the cellar of the building which leads to more sound production. Another adaptation was made by one of the respondents: the amount of water ,that was needed for flushing the toilet, has been changed, because too much water was used for flushing the toilet.
The other eight respondents (63 %) did not made adaptations to the sanitation system.

- Is there a visible part of the sanitation system near your house ? *(Answer: yes, no; (what))*

45 % of the respondents can see a part of the sanitation system near the house and the rest 55 % can not see a part of the sanitation system near the house. The main part that can be seen is the rainwater irrigation system (ditches).

- What do you think of the visible part of the sanitation in or near your house? *(Answer: 5 point rating scale)*

The answers are based on a rating scale from 0 till 4.

0 Beautiful
1 Nice
2 Not disturbing
3 Annoying
4 Really awful

Two respondents who can see a part of the rainwater irrigation system (ditches) found it nice to see. The ditches are part of the garden and is good for the surroundings. Three other respondents found it not disturbing to see. It is part of the building and one of them can only see it when he is leaving the building from the front side.

- Is the visible part of the sanitation system in or near your house vulnerable to damage or failure? *(Answer: 5 point rating scale (what is vulnerable))*

The answers are based on a rating scale from 0 till 4.

0 Not at all
1 A little bit
2 Sometimes
3 Very often
4 Always

According to one of the respondents, only a little bit, because children are playing sometimes in the ditches where the rain water is irrigated.

- Are you involved in any monitoring activities regarding the system (such as visual inspections of effluent of treatment system, pump checks etc.) ? *(Answer: yes, no)*

None of the respondents are involved in any monitoring activities regarding the system.

Dimension system robustness

- Is the sanitation system being monitored? How? *(answer: open question)*

From the eleven respondents only one knew that the greywater system is monitored by Mall Umweltsysteme. For the quality of the treated water. The other respondents had no idea if the sanitation system is being monitored.

- How many times per year does a system failure/blockage occur with your vacuum toilet? *(Answer: failures/year)*

Amount of failure	Amount of respondents	Percentage of total respondents (%)
0	2	18
1	6	54
2	2	18
3	1	9

The highest percentage of the number of failures/blockages occur with the vacuum toilet is 1 time per year. Eighteen percent had never experienced failures or blockages (they never noticed, during daytime they are not present in the complex). One respondent had 3 times a year a problem with blockages of the vacuum toilet. This was due to the presence of little children who tried to flush things that where not made for flushing through the toilet (toys, fabric, etc.)

- How many times per year does the complete vacuum system fails

Amount of failure	Amount of respondents	Percentage of total respondents(%)
0	1	9
1	9	82
2	0	0
3	1	9

Complete vacuum system failure in the frequency of one time per year happens for 82 % of the eleven respondents. The rest of the 18 percent is divided by zero failures and three failures per year, both have 9 percent of the total amount of respondents.

- How many times per year does the greywater system fails?

The greywater system, as it is now installed, has not failed to work during its time of operation. This according to all the respondents.

- Which part of the wastewater management system failed/was out of order? What was the problem? When and how often does it happen ? How did you solved it an who did it.

Part	Problem	When	Frequency	How solved	Solved by
Pipeline vacuum toilet	Blockage in pipeline	Not know	5	Remove blockage	Hombach / Roediger
Vacuum toilet/vacuum station	Loss of vacuum pressure	Not known	3	Not known	Hombach Roediger self
Reservoir behind the vacuum toilet	Was not working	Not known	2	Removed the reservoir	Hombach and self
Steering toilet	Water supply malfunctioned	Not known	3	Adjustment made on steering	Roediger / Hombach and self

- When the sanitation system fails, what is the average downtime in hours? *(Answer: hours/failure)*

The average downtime is depending on the time when a failure/problem to the system occurs. During weekends it takes longer time before it is repaired. The longest downtime was 72 hours. This happened in the beginning of the project. Nowadays the system can be repaired within three hours, depending on the kind of failure. When the system can not be repaired by Hombach or the residents the firm Roediger will sent a repairman. The time of arrival is depending on the location where this person is.

Dimension public health:

- What is the change that you could come into direct contact with untreated or partially treated water in percentages ? *(Answer: percentages)*

There is 0 % change that the residents could come into direct contact with untreated or partially untreated water. All the parts of the sanitation system and the belonging tanks are covered and are not accessible.

- Have you suffered some kind of illness due to the wastewater management system? *(Answer: yes; explain, no)*

Since the start of the project there where none kind of illnesses due to the wastewater management system by the residents of the building.

- Has anyone in your household ever been physically injured in using or maintaining the sanitation system? *(Answer: yes; (how often, nature and cause or injury), no)*

As for physical injuries due to using or maintaining the sanitation system are not known by the all the respondents.

Questions on user perspective

Background questions

- Did you do a higher education after high school / youth school ? *(Answer: three point rating scale)*

The answers are categorized by three typical forms of education levels in Germany.

0 Fachhochschule
1 Gymnasium
2 University

36 percent of the respondents has done an education at the Gymnasium and the other 64 percent followed an education on University level.

Involved questions

- Do you feel environmental concerned? *(Answer: 5 point rating scale)*

The answers are based on a rating scale from 0 till 4.

0 Always
1 Very often
2 Sometimes
3 A little bit
4 Not at all

From the eleven respondent felt 54.5 percent always environmentally concerned. Followed with 27 percent which feel very often environmentally concerned. The last group of the respondents equals 18 percent sometimes feel environmentally concerned. According to the answers given the average score is 1.5, that indicates that the respondents are environmentally concerned between different rating scales, namely very often and sometimes.

- Did the sanitation system make you more environmentally concerned? *(Answer: yes, no)*

The contribution of the sanitation system towards a more environmentally concern by the respondents was for almost 82 percent positive. The sanitation system made them more aware of the benefits and the possibilities to treat and reuse their own wastewater. The 18 percent who did not get a more environmentally concern was already well aware of the possibilities and benefits of the system.

- Which aspect(s) of the sanitation system do you think has/have a good future? *(Answer: open question)*

The total system (black, grey and rain water treatment) has a good future according to 73 percent of the respondents, they had further no comments according why they think that the system has a good future.
According to another respondent the separation of black and grey water has a good future. By this separation the flow of wastewater is set to a minimum and when the separated wastewater is treated water and reused it would not only contributes environmental profits but also economical benefits. Another respondent was not aware of the treatment cost when the waste water is treated on a conventional way, despite this fact he/she thought that the vacuum technology is heading for a good future. The good future is depending on the scale of appliance.

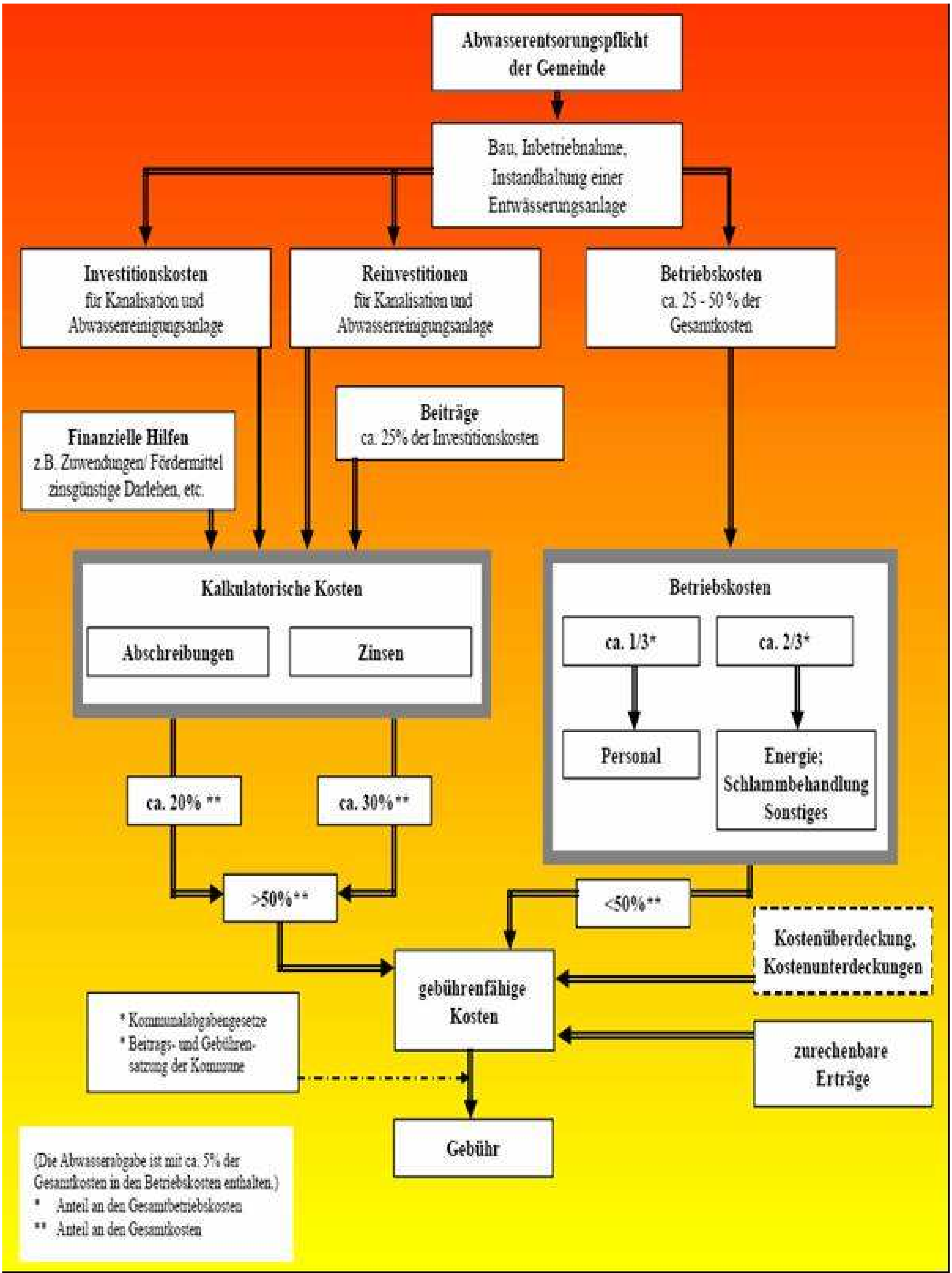
- What kind of benefits of the wastewater management system do you experience? *(Answer: open question)*

All the respondents experienced financial benefits from the wastewater management system. Lesser water is used that automatically lowers the water bills. 4 out of the 11 respondent experienced from the ecological and social aspects.

- What kind of drawbacks of the wastewater management system do you experience? *(Answer: open question)*

Three respondents experienced drawbacks from the wastewater treatment:
- higher maintenance costs than conventional system
- the construction time lasted longer
- biogas installation is not in operation yet

Appendix 8 Realization of the fees (Gebühre)



Appendix 9 Drivers and barriers, per actor, Freiburg im Breisgau

Aspects	Mr. J. Lange	Mr. A. Panesar	Mr. M. Gies	Mr. S. Klemens

Environmental drivers (selecting system)				
Positive feeling about environmental behaviour	**0**	**4**	**3**	**3**
Water saving	**0**	**2**	**4**	**2**
Prevention of drying out of soil	**-**	**0**	**3**	**4**
Reduction of water emissions	**4**	**4**	**4**	**4**
Recycling of water	**4**	**4**	**4**	**4**
Protection surface water	**4**	**4**	**-**	**2**
Protection of ground water	**4**	**4**	**-**	**3**
Recycling of nutrients	**4**	**4**	**4**	**0**
Reduction of energy use	**0**	**-**	**4**	**0**
Quality of neighbourhood landscaping	**0**	**0**	**-**	**1**
Showcase project	**-**	**4**	**-**	**-**
Research opportunities	**-**	**4**	**-**	**-**
Gain data	**-**	**4**	**-**	**-**
Environmental drivers (realised system)				
Positive feeling about environmental behaviour	**4**	**3**	**-**	**4**
Water saving	**4**	**2**	**3**	**0**
Prevention of drying out of soil	**-**	**-**	**3**	**4**
Reduction of water emissions	**0**	**2**	**3**	**4**
Recycling of water	**2**	**-**	**3**	**3**
Protection surface water	**4**	**-**	**0**	**1**
Protection of ground water	**4**	**-**	**0**	**1**
Recycling of nutrients	**4**	**-**	**2**	**0**
Reduction of energy use	**0**	**-**	**3**	**0**
Quality of neighbourhood landscaping	**0**	**-**	**-**	**1**
Showcase project	**-**	**4**	**-**	**-**
Research opportunities	**-**	**4**	**-**	**-**
Gain data	**-**	**4**	**-**	**-**
Environmental and public health barriers				
Health risk	**0**	**-**	**3**	**0**
Flood risk	**0**	**-**	**-**	**4**
Chemical hazard	**0**	**2**	**3**	**0**
Physical injury householders access to eqp.	**0**	**0**	**-**	**3**
Noise protection	**-**	**-**	**3**	**-**
Financial drivers & barriers				
Design costs (vs. to conventional system)	**4**	**2**	**-**	**4**
Operating costs (vs. to conventional system)	**3**	**2**	**-**	**4**
Energy costs (vs. to conventional system)	**3**	**-**	**2**	**4**
Applying vacuum toilets	**4**	**2**	**4**	**-**
Reduced drinking water consp. (lower bills)	**0**	**2**	**1**	**0**
Bankruptcy TBW	**4**	**4**	**-**	**-**
Extent of decision system choice				
Budget	**2**	**2**	**-**	**2**
Design costs (vs. to conventional system)	**0**	**2**	**2**	**4**
Operating costs (vs. to conventional system)	**0**	**2**	**2**	**4**
Energy costs (vs. to conventional system)	**0**	**-**	**4**	**4**
Applying vacuum toilets	**0**	**2**	**4**	
Reduced drinking water consumption (and lower	**0**	**2**	**4**	**4**

bills)				
Bankruptcy TBW	**4**	**4**	**-**	**-**
Social and managerial drivers and barriers				
Intensive contact with neighbours / Collaboration with neighbours	**0**	**0**	**3**	**0**
Involvement in sanitation / Taking responsibility for your household water management system. E.g. water saving, reducing emissions	**0**	**0**	**4**	**-**
Improves quality of living	**0**	**4**	**2**	**-**
Implementation eco-sanitation	**4**	**-**	**-**	
Difficult technology	**0**	**3**	**0**	**4**
Ownership unclear	**0**	**2**	**0**	**0**
Maintenance responsibilities unclear	**0**	**2**	**0**	**2**
Maintenance burden on householders	**0**	**2**	**-**	**-**
Bankruptcy TBW	**4**	**-**	**-**	**-**

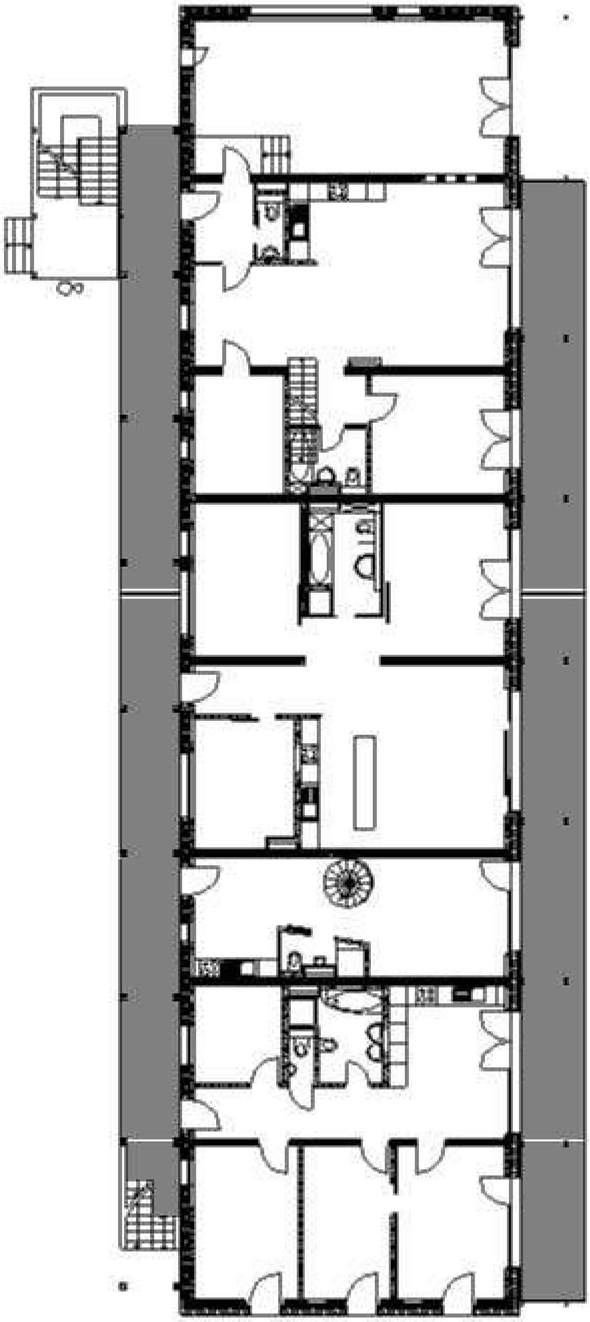
Project Owner: Mr. J. Lange (initiator)

Project Owner: Mr. A. Panesar (management)

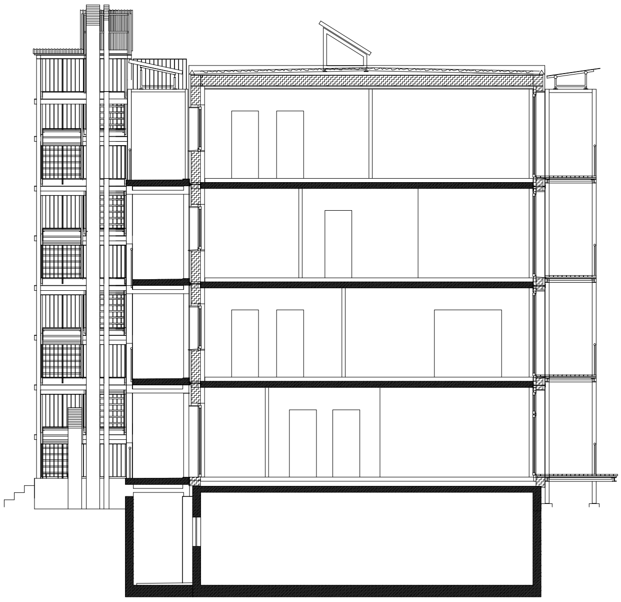
Architect: Mr. M. Gies (building design and partially initiator)

Technology supplier: Mr. S. Klemens (Supplier of the greywater system and parts of biogas installation and maintenance)

Appendix 10 Design 1st. floor project "Arbeiten & Wohnen"



Appendix 11 Design side view project "Arbeiten & Wohnen"



Appendix 12 Drivers and barriers, per actor, Frankfurt am Main

Aspects	**Mr. K. Helms**	**Mr. W. Selig**
Environmental drivers (selecting system)		
Positive feeling about environmental behaviour	**3**	**3**
Water saving	**4**	**4**
Prevention of drying out of soil	**0**	**0**
Reduction of water emissions	**3**	**2**
Recycling of water	**3**	**2**
Protection surface water	**1**	**1**
Protection of ground water	**4**	**1**
Recycling of nutrients	**2**	**2**
Reduction of energy use	**3**	**1**
Quality of neighbourhood landscaping	**1**	**0**
Environmental drivers (realised system)		
Positive feeling about environmental behaviour	**3**	**3**
Water saving	**4**	**4**
Prevention of drying out of soil	**0**	**0**
Reduction of water emissions	**3**	**2**
Recycling of water	**4**	**2**
Protection surface water	**0**	**1**
Protection of ground water	**2**	**1**
Recycling of nutrients	**0**	**2**
Reduction of energy use	**0**	**1**
Quality of neighbourhood landscaping	**0**	**0**
Environmental and public health barriers		
Health risk	**0**	**4**
Flood risk	**0**	**4**
Chemical hazard	**0**	**4**
Physical injury householders access to eqp.	**0**	**4**
Financial drivers & barriers		
Design costs (vs. to conventional system)	**2**	**2**
Operating costs (vs. to conventional system)	**3**	**2**
Energy costs (vs. to conventional system)	**2**	**2**
Applying vacuum toilets	**3**	**3**
Reduced drinking water consumption. (lower bills)	**0**	**2**
Extent of decision system choice		
Budget	**3**	**4**
Design costs (vs. to conventional system)	**3**	**2**
Operating costs (vs. to conventional system)	**3**	**2**
Energy costs (vs. to conventional system)	**3**	**2**
Reduced drinking water consumption (and lower bills)	**3**	**2**
Social and managerial drivers and barriers		

Intensive contact with neighbours / Collaboration with neighbours	**0**	**0**
Involvement in sanitation / Taking responsibility for your household water management system. E.g. water saving, reducing emissions	**3**	**4**
Improves quality of living	**2**	**0**
Difficult technology	**3**	**3**
Ownership unclear	**0**	**0**
Maintenance responsibilities unclear	**0**	**-**
Maintenance burden on householders	**0**	**3**

- not known

Project manager: Mr. K. Helms, KfW Bankengruppe

Technical design: Mr. W. Selig, Ip5 ingenieurpartnerschaft

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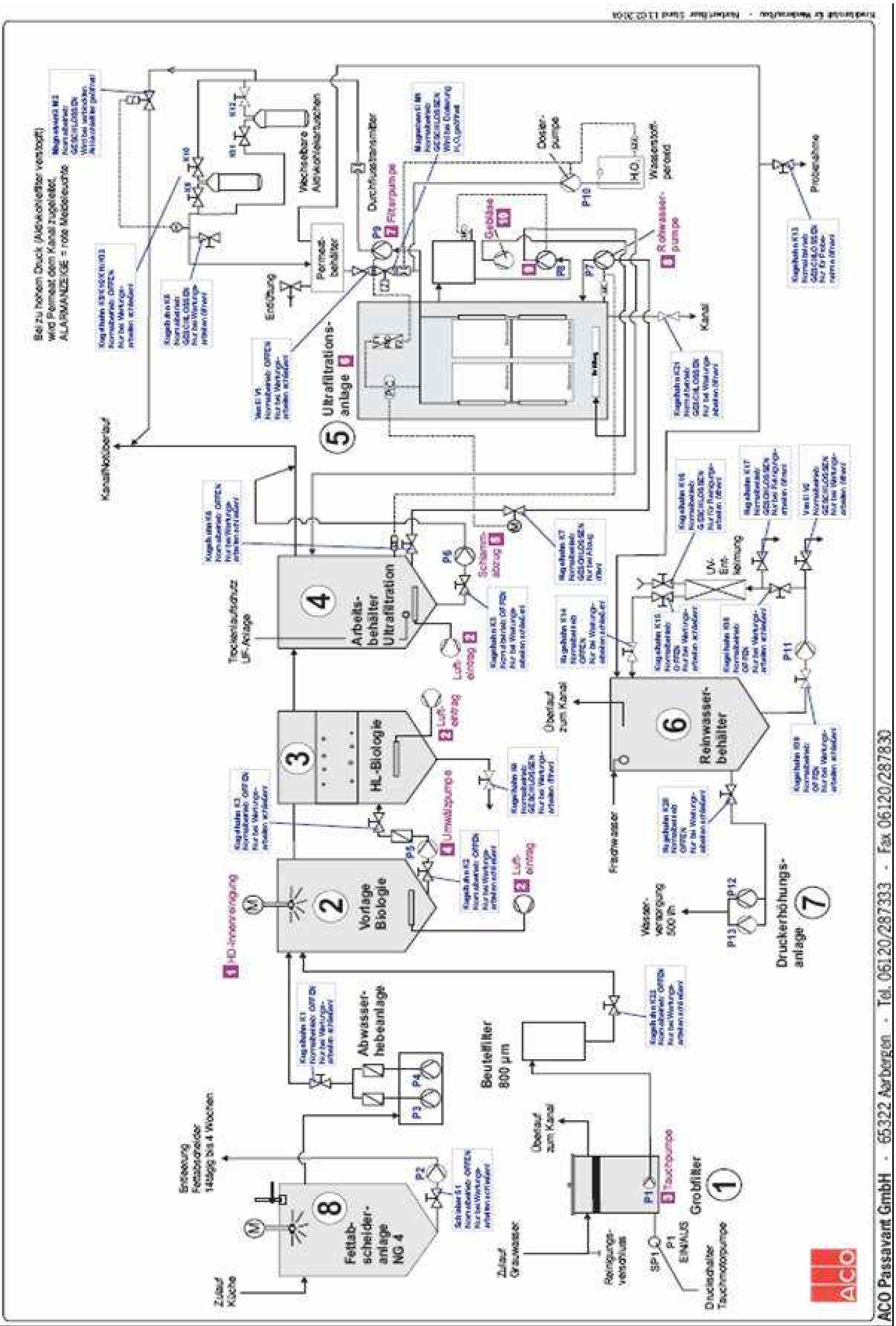
Appendix 13 Scheme greywater installation , KfW



Appendix 13 Sound measurements vacuum toilets by Roediger