Technology Review of Urine-diverting dry toilets (UDDTs)

Overview of design, operation, management and costs

Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

On behalf of

BMZ Federal Ministry for Economic Cooperation and Development

As a federally owned enterprise, we support the German Government in achieving its objectives in the field of international cooperation for sustainable development.

Published by:
Deutsche Gesellschaft für
Internationale Zusammenarbeit (GIZ) GmbH

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Name of sector project:
SV Nachhaltige Sanitärversorgung / Sustainable Sanitation Program

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Acknowledgements:
We thank all reviewers who have provided substantial inputs namely Chris Buckley, Paul Calvert, Chris Canaday, Linus Dagerskog, Madeleine Fogde, Robert Gensch, Florian Klingel, Elke Müllegger, Charles Niwagaba, Lukas Ulrich, Claudia Wendland and Martina Winker, Trevor Surridge and Anthony Guadagni.

We also received useful feedback from David Crosweller, Antoine Delepière, Abdoulaye Fall, Teddy Gounden, Richard Holden, Kamara Innocent, Peter Morgan, Andrea Pain, James Raude, Elmer Sayre, Dorothee Spuhler, Kim Andersson and Moses Wakala.

The SuSanA discussion forum was also a source of inspiration: http://forum.susana.org/forum/categories/34-urine-diversion-systems-includes-uddt-and-ud-flush-toilet

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Photo credits
Cover: Heike Hoffmann, Nadira Khawaja, Stefanie Lorenz, Christoph Platzer, Andreas Kanzler
Back: WECF, Abdoulaye Fall, Robert Gensch, Audrey Kameni, Enno Schröder

Printed on 100 % recycled paper, certified to FSC standards

Place and date of publication:
Eschborn, December 2012

Foreword

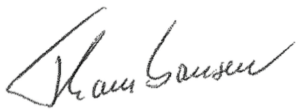
This publication provides guidance on urine-diverting dry toilets (UDDTs) for household and public sanitation in developing and countries in transition. It has been compiled by a team of international experts and the GIZ program “Sustainable sanitation”, a sector program commissioned by the German Federal Ministry for Economic Cooperation and Development (BMZ).

The sustainable sanitation approach is addressing the entire sanitation chain from the user interface (toilet) to disposal or reuse, in a functional system which aims at protecting and promoting human health as well as making use of valuable natural resources where feasible. This is in line with the five criteria for sustainable sanitation: economically viable, socially acceptable, technically and institutionally appropriate as well as protective to environment and natural resources.

Since the International Year of Sanitation in 2008, more and more users, stakeholders and decision makers have become aware of the worldwide sanitation crisis with more than 2.5 billion people having no or insufficient access to basic sanitation. The contamination of the environment with infectious faecal material causes health hazards which lead to the death of thousands of people, especially young children, on a daily basis, which could be prevented.

In the recent decade, urine-diverting dry toilets (UDDTs) have been recognised as a viable sanitation technology that is being accepted by users, from both a cost and user comfort perspective. Moreover the technology provides possibilities to develop value chains for recycling of excreta for agricultural purposes or to allow safe disposal.

I am sure this technology review will inspire people working on such sanitation solutions. Feedback about this publication is welcome and should be sent to sanitation@giz.de.



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Internationale Zusammenarbeit (GIZ) GmbH

Eschborn, December 2012

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1 Summary

This technology review deals with a type of toilet designed specifically for dry excreta management called the *urine-diverting dry toilet* (UDDT). The functional design elements of the UDDT are: source separation of urine and faeces; waterless operation; and ventilated vaults or containers for faeces storage and treatment. UDDTs may be constructed with two adjacent dehydration vaults or one single vault with interchangeable containers. This publication offers a complete overview of UDDT functions, design considerations, common operation and maintenance issues and generalised installation costs. Its focus is on applications in developing countries and countries in transition, although UDDTs are also applicable in developed countries.

The UDDT technology was originally promoted mainly in connection with safe reuse of excreta. However, the focus of UDDT implementation has gradually shifted from that of excreta reuse to the broader objective of creating an odourless, dry and versatile toilet that is applicable across a wide range of geographic and economic contexts. Many successful examples of large-scale UDDT programmes, such as those found in Lima, Peru and eThekwini (Durban), South Africa, dispose of treated excreta instead of reusing it, as it is considered more practical, convenient or acceptable to the users.

The primary advantage of UDDTs, as compared to conventional dry latrines like ventilated improved pits (VIP) latrines, is the conversion of faeces into a dry odourless material. This leads to an odour and insect free toilet which is appreciated by users and allows simple removal and less offensive and safer handling of the faecal material once the toilet has filled up. Moreover the risk of water pollution is minimised through the safe containment of faces in aboveground vaults and this allows the toilets to be constructed in locations where pit-based systems are not appropriate. The faeces are however not entirely sanitised when removed from the toilet, so careful handling is obligatory. In scenarios with reuse of excreta in agriculture, a post-treatment of faecal matter and storage of urine is advisable to ensure adequate sanitisation.

This publication provides comprehensive design guidelines for all UDDT components, including urine diversion (UD) pedestals, benches and squatting pans, dehydration vaults, single vaults with interchangeable containers, and urine piping and storage systems. Possible design modifications are discussed to ensure the toilet's suitability for small children, the elderly and persons with disabilities. Additionally, aspects of excreta management are described including treatment, disposal, reuse and maintaining a high level of hygiene.

Emphasis is placed on recent technical innovations that allow the UDDT to be integrated in a wide range of applications. The bench design, a sitting type of UD interface that minimises the need for stairs leading up to the toilet, is presented as a possible solution for indoor installations and barrier-free access. Other designs are presented for a variety of contexts, including indoor and outdoor installations, schools and public toilet blocks, flood prone areas and floating villages.

This technology review also describes common O&M problems, such as blockages in urine piping systems, wet conditions in the dehydration vaults and faulty construction. Possible solutions and preventative maintenance routines are emphasised to ensure the toilet's sustainability.

This publication challenges the common perception that UDDT installation costs are prohibitive for the poorest members of society. A number of low-cost UDDT designs are available that take advantage of locally available construction materials and can help tailor the toilet technology to available budgets.

2 Introduction

2.1 Target audience

The target audience for this publication are engineers, NGO staff, local government staff, consultants, trainers, lecturers and other persons possessing some basic technical background, wanting:

- Obtain an overview of the function, design and operational requirements of UDDTs
- Understand how a UDDT may provide a possible sanitation solution for a given context and
- Finance or implement sanitation systems and wish to discuss UDDT options with consultants and suppliers in an informed manner.

2.2 Scope of this document

This technology review discusses the function, design, operation and costs of *UDDTs with double dehydration vaults* and *UDDTs with single vaults using interchangeable containers*. It does not go into detail regarding UDDTs with shallow pits or composting vaults, UDDT construction procedures or post-treatment options for urine or faeces.

This document also does not provide information on 'software' for e.g. hygiene promotion and training activities for UDDT users.

For further information regarding the entire sanitation chain, from collection and treatment through reuse or disposal, consult the *Compendium of sanitation systems and technologies* (Tilley et al., 2008). A list of literature on related topics which are not comprehensively discussed in this document is provided in Section 11.2.

2.3 Definitions and terminology

The term *urine-diverting dry toilet* (UDDT) is, in essence, only descriptive of the toilet's user interface. This document further classifies UDDTs by the means in which they collect and store faecal material. We use the terms "UDDTs with double dehydration vaults" and "UDDTs with single vaults and interchangeable containers" to describe the toilet's faecal collection and storage mechanisms.

The term ‘urine-diverting’ is understood to be synonymous with ‘urine diversion’ and ‘urine separation’. The ‘faeces vault’ is alternatively referred to as a ‘faeces chamber’.

A variety of different names are currently used around the world to denote UDDTs:

- The term *ecosan toilet* is often used for UDDTs, largely because it provides a simple terminology for communication at the grass-roots level. This term implies that the user or community at large must reuse their treated excreta in accordance with the broader ecosan concept. However, we consider excreta reuse a matter of user preference that is not necessarily required for the sustainability of UDDTs. Furthermore, the range of possible ecosan solutions is not limited to UDDT technologies.
- In India and South America, UDDTs are often referred to as *composting latrines*. The term is misleading, however, as the treatment of faeces in UDDTs does not include a substantial composting process.
- Some researchers in the USA use the phrase *Double vault urine diversion latrine* (DVUD latrine) to describe UDDTs with double dehydration vaults.
- The term *Urine Diversion Toilet* (UD-Toilet) is used in the eThekwini Metropolitan Municipality in South Africa, which is home to the world’s highest number of UDDTs.
- In Spanish, the UDDT is widely known as *Baño Ecológical Seco*. The terms *Toilette sèche avec séparation d’urine* or *Toilette de déshydratation à separation d’urine are* used in French speaking countries.
- *Urine diversion dehydration toilet* is another term used by many people but strictly speaking it should only be used for double vault systems.

2.4 Background

According to the Joint Monitoring Program (JMP), approximately 2.5 billion people lack access to improved sanitation facilities, with 1.1 billion still practising open defecation (UNICEF and WHO, 2012). Knowledge and practice of critical hygiene behaviours, such as hand washing after toilet use, are also widely lacking. Consequently, the ingestion of faecal pathogens from contaminated food and water resources as well as faecal-oral transmission are a leading cause of disease and preventable death, especially in children under five years.

The effects of inadequate sanitation and hygiene and resulting diarrhoeal disease are dramatic: in 2010, the World Health Organization (WHO) reported that worldwide the impact of diarrhoeal disease on children is greater than the impacts of HIV / AIDS, tuberculosis and malaria combined.

Due to their relative affordability and simple and waterless operation, pit latrines are common in developing and transitional countries. However, pit latrines can spread faecal contamination to water resources, especially in urban areas and in flood prone and high water table areas. Moreover, pit latrines can have high life-cycle costs associated with faecal sludge removal or excavation of new pits when emptying is not feasible.

Increasingly, limited water supplies and the high cost of wastewater infrastructure make sewer-based waste management impractical in many regions. Water-based sanitation systems dilute excreta and create large wastewater streams that necessitate the construction of technologically complex and expensive sewer and treatment facilities. It is estimated that 90% of all wastewater in developing countries is discharged untreated directly into water bodies (Corcoran et al., 2010), a clear indication that sewer-based sanitation is not a viable solution for many parts of the world. Moreover, pharmaceutical residues in treated wastewater could have negative impacts on human health.

Expectations and attitudes surrounding sanitation are widely variable and influenced by both societal norms and personal preference. While improved hygienic standards, reduced contaminant impact and minimisation of water usage may be the goal of sanitation practitioners, toilet users generally strive to improve their current sanitation situation with regard to odour, insect infestations, privacy, comfort and ‘prestige’.

The UDDT is a dry excreta management system that since the late-1990s is seen as a viable alternative to pit latrines and flush toilets. However, significant barriers to more universal acceptance of this technology remain. To date, a general lack of awareness, a limited supply of prefabricated UDDT components and a low interest in financing sanitation services, have all acted as impediments to the construction of UDDTs.

2.5 Historical development

The earliest documented dry toilets with urine separation were installed in multi-storey houses in Yemeni towns and were, until recently, used continuously for hundreds of years. The UDDTs with double dehydration vaults that we know today were originally designed around 1950 in the Kanagawa Prefectural Public Health Laboratory in Japan and further developed in Vietnam in the 1960s as a means of increasing the hygienic safety of excreta reused in agriculture.[1]

Since the 1990s, modifications of this design have been promoted in countries like Mexico, Guatemala, El Salvador, India and Sweden. Ventilation pipes in the faeces vault were gradually integrated and allowed for the installation of UDDTs inside houses. More recently, prefabricated ceramic or plastic UD squatting pans and pedestals have become available on the market, generally increasing the durability and perceived prestige associated with the system. The design was further adapted in India and West Africa to accommodate anal cleansing with water, by including a separate anal cleansing pan with a drain to divert wash water into a dedicated disposal or treatment system.

As early as 2000, the bench UDDT, which is a design that allows the user to sit directly on the vault, began to be

[1] The first paragraph in this section is mainly taken from Winblad and Simpson-Hébert (2004).

promoted in Ecuador and Peru. This model is easily incorporated into existing housing structures and has emerged as a popular design for indoor installations (see Section 10.2).

UDDTs have also been commercially produced in Sweden since the mid-1990s. These commercial products are often installed in locations where piped sewerage is not available, such as remote summer cottages.

In 2001, the EcoSanRes Programme was initiated at the Stockholm Environment Institute (SEI). This was followed shortly thereafter by the establishment of the *ecosan program* at GIZ. Together these two government-funded programmes have helped to disseminate knowledge of UDDTs and have triggered the promotion of this technology in developing countries and countries in transition.

The exact number of UDDT users is impossible to determine, but a rough estimate by GIZ based on known projects in 84 countries puts the number at approximately 2 million users worldwide.[2]

2.6 UDDT technology

2.6.1 Overview

Urine-diverting dry toilets (UDDTs) allow for the source separation of urine and faeces through the use of a specially designed seat or squatting pan, generally referred to as the *user interface*. Urine diversion serves a number of important functions including reducing odour and simplifying the excreta management process (see Section 3.2). Dry or 'waterless' operation indicates that no water is used for flushing faecal material, though water must be present for hand washing and other hygiene practices following defecation and urination. A UDDT consists of eight basic functional elements:

1. A urine diversion toilet seat or squatting pan;
2. One or two vaults, usually above ground, or one shallow pit for faeces collection and storage;
3. A urine piping system leading from the user interface to an infiltration or collection system;
4. A ventilation pipe to exhaust moisture and odours from the vault or pit;
5. An anal cleansing area with mechanisms for the separate collection and drainage of anal wash water, if required;
6. A toilet super-structure, unless the toilet is installed inside an existing house;
7. A bucket with dry cover material; and
8. A hand washing facility with soap and water.

Urine is separated at the user interface, drained through a piping system and infiltrated into the soil for disposal, or collected, stored and sanitised in containers for use as a fertiliser.

Faecal matter and anal wiping material are collected into a ventilated vault directly below the user interface. Following defecation, the user covers the fresh faeces with a small volume of dry cover material in order to absorb moisture, control initial odour and prevent insect infestation (see Section 4.4). The faeces vaults may be located above or below ground, depending on the chosen faeces management method. UDDTs allow for distinct methods of faeces management (see Figure 1), namely:

Type 1) Faeces dehydration using double (two) dehydration vaults;

Type 2) Faeces collection using a single vault with interchangeable containers with external treatment;

Type 3) Faeces mineralisation in shallow pits; and

Type 4) Faeces composting using dedicated containers.

Most faeces management methods require the periodic removal of all faecal material from the toilet for disposal or reuse as an agricultural soil conditioner. This is a batch system. However, for shallow pit systems (Type 3) faecal matter can permanently remain in the soil and no emptying is required (one example is the *Arborloo*, see Section 2.6.4).

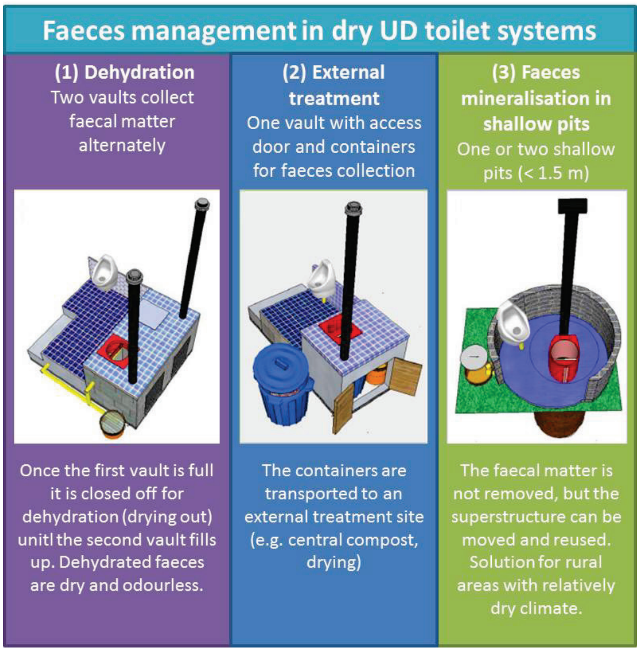


Figure 1. Overview of three different faeces management methods for UDDTs (Hoffmann, 2012).

The effectiveness of faeces management in most UDDTs relies on the faecal material remaining as dry as possible in the vault. This can only be achieved by proper and diligent use of the UD user interface; preventing rainwater entry into the faeces vault; the use of adequate dry cover material; the segregation of anal wash water and the appropriate design of vault ventilation systems (see Section 4.9). Composting systems (Type 4), however, are the sole exception to this rule and require a certain amount of

[2] Worldwide ecosan project list: http://www.susana.org/lang-en/library?view=ccbktypeitem&type=2&id=1423. This list does not include commercially sold units. For example: Approximately 200,000 UD units were sold by the Swedish company Separett worldwide between 1994 and 2010 (source: http://www.susana.org/lang-en/library?view=ccbktypeitem&type=2&id=1148).

moisture for faecal decomposition. A well-known example of composting toilets are Clivus Multrum.

The dehydration process taking place in the faeces vaults will substantially reduce the faecal pathogen load, allowing the treated matter to be more safely handled. Pathogens[3] are primarily concentrated in human faeces, and absent in the urine of healthy persons. When properly designed, built and maintained, UDDTs can effectively contain pathogens from human contact and reduce the pathogen content in the faeces to enable reasonably safe handling of the faecal matter once the vaults need to be emptied.

However, it should be noted that a complete pathogen removal, including inactivation of all helminth eggs, cannot be guaranteed under ordinary circumstances with any type of UDDT. While reduced pathogen content makes handling of faeces safer, it is paramount that safety protocols are met when emptying the faeces vaults due to the remaining health risks associated with the residual pathogen load. For agricultural applications and, in some cases, disposal, it is recommended to apply a post-treatment regimen to further reduce the faecal pathogen load and stabilise the material (see Section 7.5.2).

2.6.2 UDDTs with double dehydration vaults

The UDDT with double dehydration vaults, also called double vault UDDT, relies on the *in situ* dehydration of the faeces in two adjacent aboveground vaults that are used alternately. The faeces are stored in dry conditions in a vault for a minimum of six months without the addition of fresh faeces before removal.

Figure 2. Left: Outdoor UDDT with stairs in Ouagadougou, Burkina Faso (photo: A. Fall, 2009). Right: Rear view of a similar UDDT in Ouagadougou showing the dehydration vault access doors (photo: S. Tapsoba, 2009).

When the first vault is full, it is closed and allowed to rest. The user interface is then moved above the second vault, which is used for the collection of faeces until the vault is full. Alternatively, the toilet may be equipped with fixed UD seats or squatting pans above each vault. When the second vault is full, the first vault is emptied with a shovel through an access door located at the rear of the vault. The second full vault is then sealed and left to rest while the first vault refills. Proper operation mandates that there is always one *active* and one *inactive* vault. Correctly dimensioned faeces vaults (see Section 4.6) will fill in 6 to 12 months, and then rest for an equal period of time.

During storage, the faeces' natural moisture slowly evaporates and is exhausted through the vault's ventilation system, or is absorbed by the dry cover material. This process is called dehydration. The resulting dry and odourless material can be disposed of in burial pits or used as an agricultural soil conditioner (see Section 7).

2.6.3 UDDTs with single vaults and interchangeable containers

The UDDT with a single vault and interchangeable containers, also called single vault UDDT, is built with only one vault that houses one or more containers to collect the faecal material. As this UDDT configuration does not significantly reduce the pathogen content of the faecal material, a containerised collection system is necessary to help avoid direct contact with untreated faecal material and to allow for quick and convenient removal from the vault. The container system prevents the entry of water and moisture into the stored faeces, and therefore allows for the installation of the vault also below the ground surface.

Depending on the size of the vault and containers, two or more containers may be simultaneously stored in the vault. Once a container is full it can either be pushed into a corner for additional storage and dehydration, or immediately removed if storage space is not available in the vault. Though additional storage inside the vault will reduce the pathogen load, the limited ventilation of the container may slow the dehydration process. Therefore, UDDTs with single vaults *cannot reduce the faecal pathogen load* as effectively as UDDTs with double dehydration vaults. Consequently, most disposal scenarios and all agricultural applications of faeces collected in single vault UDDTs require post-treatment (See Section 7.5.2).

The interchangeable containers should be limited to a maximum volume of 50 litres and sized so that the full containers can still be moved manually (see Section 4.7). Care must be taken when removing containers from the vault, asfresh faeces lie at the top. In some special applications of mobile unventilated in-home UDDTs, emptying occurs as part of a daily routine (see Section 10.5).

2.6.4 UDDTs with shallow pits

In areas with low water table and with minimal threat of flooding, UDDTs can also be constructed with shallow ventilated pits for faeces collection. Often referred to as *Urine-diverting ventilated improved pit* (UD-VIP), this configuration presents the simplest form of UDDT systems. Urine is diverted at the user interface and the faeces are dropped directly into the pit where they undergo a natural mineralisation and composting process.

Diverting urine away from the faeces pit offers a number of advantages over conventional pit latrines. Urine separation reduces odours, provides the opportunity for using urine as fertiliser, slows down the filling rate of the pit and may also reduce the risk of contaminating groundwater resources by minimising the generation of pathogen contaminated leachate.

[3] Pathogens are germs or other infectious agents that cause diseases in humans, see Section 4.2.2

When the pit becomes full, the super-structure is razed or moved above a new pit. Following the examples of the *Arborloo* toilet (Morgan, 2004) and the *EcoLet* in Peru (Hoffmann, 2012), a tree may be planted on top of the decommissioned pit to allow the excreta's nutrient content to be utilised and the toilet's former location to be clearly demarcated. As the faeces are left in the ground permanently, it eliminates the need for handling. This model of operation, however, is limited to situations where adequate land is available for digging new pits regularly.

Alternatively, the pit can be emptied after one to two years of continuous composting, in accordance with the *Fossa Alterna* system described by Morgan (2004) and Tilley et al. (2008). The faecal pathogen content is reduced during the composting process.

As UDDTs with shallow pits are not widely used, they are not described further in this publication.

2.6.5 UDDTs with composting vaults

A UDDT with a composting vault receives faecal matter and wiping paper in a large, well-ventilated vault or container system installed directly under the toilet seat or squatting pan. While the use of a UD user interface will simplify the management of leachate, a composting toilet may be constructed also without urine separation. The composting process requires sufficient moisture content and a certain carbon-to-nitrogen ratio to stimulate the microbial activity that converts organic matter into compost. Consequently, organic materials, such as garden and kitchen waste, may also be discarded in the composting vault.

Only mature compost, which looks and smells like rich garden soil or leaf humus, should be removed from the vaults. The composting toilet is well documented for example by Berger (2011) and is not described further in this publication.

2.6.6 Comparison of UDDT types

A comparison of the advantages and disadvantages of single and double-vault UDDTs is provided in Table 1. Relevant issues regarding the suitability of UDDTs in various contexts are discussed in Section 2.7.

Each UDDT type has inherent advantages and disadvantages with respect to cost, user preference and environmental considerations. The long-term sustainability of the toilet is, to a large degree, dependent on the selection of the most appropriate technological option for a given context.

User preference must be taken seriously when selecting a UDDT design. Some users may prefer to empty the faeces vault themselves and use the content for agricultural purposes, making the double-vault model ideal. Others may find the idea of shovelling faeces, regardless of its dehydrated condition, repellent and opt for a single vault UDDT with a containerised collection system. It is therefore critical that users, decision-makers or planners understand the advantages and disadvantages of each UDDT design to allow for well-informed decision-making.

Table 1. Comparison of double dehydration vault and single vault systems.

UDDT with double dehydration vaults	UDDT with single vault and interchangeable containers
Advantages	*Advantages*
• Greater reduction of pathogen load after a longer period of dehydration. • Dry faecal matter is a crumbly, odourless material that is less offensive to handle. • Long storage durations lead to less frequent emptying. • No additional transport or treatment costs for situations where on-site disposal or reuse is possible. • Risk of spreading of untreated faecal material into the environment is greatly reduced. • Dependency on service providers is low.	• User interface can be permanently fixed, ensuring a watertight seal with the floor. • Containerised collection allows for greater flexibility with regard to the number of users. • Use of container makes emptying fast and convenient. • Toilet takes up less space, can be more easily fitted into existing houses and construction costs are considerably lower. • Toilet vault can be built underground, eliminating the need for stairs.
Disadvantages	*Disadvantages*
• May require the shifting of seats or squatting pans, unless twin drop-hole pans are used or two user interfaces are installed. • User capacity is not variable to guarantee sufficient storage time. • Use of shovel to empty vault may be repellent to owner • Misuse and overuse of toilets can lead to wet, malodorous faeces. • Higher construction costs and greater space requirements than single vault units. • Long emptying intervals may lead to emptying procedures being forgotten or neglected.	• No significant reduction of pathogen load occurs in the container. • Handling of fresh faeces by owners is not widely acceptable; service providers are advisable. • Frequent emptying requires a qualified service provider and adequate treatment centres for faeces. • Collection and treatment costs may be higher than in dehydration vaults. • Use for households without service providers is not recommended, as the untreated faecal matter can pose major health risks if not removed, disposed or treated properly.

The possibilities for on-site disposal of faecal material are also an important consideration. UDDTs with double dehydration vaults do create a stable product that can be safely removed, directly buried or reused by the owner (see Section 7), but such arrangements require adequate space and are not feasible in densely settled areas. On the other hand UDDTs with containerised collection and storage units have low space requirements, but require in general a post-treatment step for safe disposal. With regard to handling of faecal matter it has been found that service providers in urban and peri-urban areas are a good option, as the users do not have to handle faeces in that case.

Selecting the optimum UDDT type also requires a good understanding of local conditions with regard to weather patterns, flood events, subsurface characteristics, local water resources and water table fluctuations. While UDDTs with shallow pits are affordable and easily upgraded from pit latrines, they are only practical in certain environments. In flood prone areas and areas with high groundwater tables, UDDTs with above ground vaults are the most appropriate for preventing the wetting of faecal material.

Containerised systems are advisable for UDDTs with a high user frequency, such as in public toilets. Collection containers allow for more rapid action after misuse, by simply replacing the affected container rather than having to clean the entire faeces vault. Such designs also allow for a greater degree of flexibility with regard to the total volume of faeces collected over a given time period.

2.7 Suitability of technology

2.7.1 Competitive advantages of UDDTs

Dry excreta management systems are universally applicable and may be especially suitable in situations where water flushed toilets or sewer-based sanitation systems and their required infrastructure are not feasible.

UDDTs provide a number of benefits in a range of rural and urban environments being: (1) waterless operation; (2) no odour when correctly used and maintained; (3) treated faecal matter is dry, odourless and less offensive[4]; (4) does not attract flies or other vectors[5]; (5) treated faecal matter is partially sanitised and safer to handle; (6) aboveground design or use of containers in belowground vaults makes emptying simple; (7) minimal risk of contamination of ground and surface water resources; (8) possibility for aboveground design facilitates construction in challenging environments, such as rocky or unstable soils and high water table; and (9) possibility for construction in close proximity to or inside of the home which adds to security and convenience for users.

UDDTs also have a well-documented record of resilience during flood events. The sealed, aboveground vaults can be built above the established flood line and also returned to operation quickly when affected.

Therefore, *UDDTs are suitable in situations where*:

- *Water is scarce or costly*, such as in arid or semi-arid climates;
- *Sewerage infrastructure costs are prohibitive*, such as instances of unfavourable terrain, sprawling settlement patterns or poverty;
- *Frequent flooding* would impact pit latrines and septic tank systems, resulting in inoperable toilet systems and the contamination of water resources;
- *Unfavourable soil conditions*, such as unstable or rocky soil and high water table, make pit-based sanitation difficult and expensive (see Figure 3);
- *Groundwater is the primary source of drinking water* and is likely to be contaminated by pit-based sanitation;
- *Limited land space* restricts the excavation of new pits if full pit latrines are usually not emptied;
- *Indoor installations* are preferred as they provide greater comfort and security at night thus making them more accessible for all;
- *Local agriculture and diminishing soil fertility* create demand for affordable fertiliser and soil conditioner.

Furthermore, UDDT technology has recently gained attention as an adaptable sanitation solution for areas affected by *climate change*. UDDT technology addresses local water scarcity or flooding and may contribute to food security in areas with climate-induced migrations.

Figure 3. A collapsed pit latrine in Narok, Kenya, built on unstable sandy soil that could not withstand the rain events (photo: P. Mboya, 2009).

2.7.2 UDDTs in dense urban areas

Dense urban areas present a number of impediments for UDDT construction. Limited space and unclear land ownership structures, which may influence an individual's willingness to invest in sanitation or even compromise the legality of erecting permanent structures, are often barriers in urban environments. Consequently, UDDTs with single vaults and interchangeable containers, or even mobile UD solutions (see Section 10.5), may be a good option for such settlements, as these models are highly flexible.

[4] Applies to UDDTs with double dehydration vaults and in few circumstances also for UDDTs with single vaults.
[5] Vectors are organisms that transmit infections from one host to another. Most commonly known biological vectors are arthropods, such as mosquitoes, flies, sand flies, lice, fleas, ticks and mites, but many domestic animals too are important vectors or asymptomatic carriers of parasites and pathogens (source: http://en.wikipedia.org/wiki/Vector_(epidemiology)).

Land space for the safe management of urine and faeces tends to be quite limited in urban areas. Similar to other types of decentralised sanitation systems, excreta management in urban settings is largely dependent on third-party service providers who collect, transport, sanitise, and reuse or dispose of the excreta. Subsidies may be required to make service fees affordable for all UDDT users and to ensure that the entire chain of sanitation is followed through to completion.

Urban agriculture and landscaping could however absorb a certain quantity of treated excreta, potentially offsetting some of the transport costs. Urban and peri-urban agriculture plays a significant role in creating secure and fresh food supplies for cities and may be bolstered by an affordable source of fertiliser and soil conditioner. Sales of fertiliser could also offset the cost of vault emptying and transport services. However, safe handling protocols mandate that post-treatment of faecal matter and urine is required before the excreta can be distributed or sold on a larger scale (see Section 7).

UDDTs can in principle also be integrated in multi-storey houses, though this option has so far only been successfully carried out in Sweden[6] and showed difficulties in a project in China (McConville and Rosemarin, 2012).

2.7.3 Challenges of UDDTs

Many sanitation projects, both conventional and alternative systems, have been implemented through subsidised top-down programmes and ultimately resulted in high construction costs, a lack of ownership, neglect of facilities and poor scalability.

The UDDT is a relatively new concept for most users who are accustomed to conventional ‘drop-and-forget’ or ‘flush-and-forget’ systems. The difficulty of adjusting one’s toilet habits to a UDDT should not be underestimated, and may be best approached with intuitive toilet designs and comprehensive user training programmes. Many organisations have also hung illustrated instructional posters in the toilet’s interior for user guidance (see Section 11.2.5). Accidental misuse is inevitable when users are not aware of or accustomed to proper operational procedures, which can render the UDDT temporarily inoperable.

The foremost challenge with UDDTs is to make their use and maintenance simpler and thus more acceptable. The preferences of most users generally lie with convenient, rather than sustainable, sanitation systems. Additionally, users may have a strong aversion to managing excreta. Automated systems to mechanically enclose the faeces and to add cover material after each use might be future technological advances.

It is also critical that service providers begin to include ‘dry sanitation maintenance’ options in their list of available services. UDDT specific services may include the supply of cover material, the removal and sanitisation of excreta, and the sale of fertilisers from post-treatment procedures.

[6] Gebers housing project (2005): http://www.susana.org/lang-en/library?view=ccbktypeitem&type=2&id=1216

3 Design of the urine diversion toilet seat, squatting pan, urinal and the toilet cubicle

3.1 Who squats or sits, who wipes or washes?

People generally display strong preferences for either sitting or squatting when using a toilet based on what they are used to.

Sitting toilets, often referred to as ‘Western toilets’, have been established as the norm in most of Europe, North and South America, Russia, Australia etc. Conversely, squatting toilets are the norm in most Asian and African countries.

People accustomed to using sitting toilets may find squatting uncomfortable. On the other hand, others argue that squatting is the natural position used to evacuate the bowels and leads to a variety of health benefits related to more complete bowel emptying and the reduction of constipation and haemorrhoids[7].

The experience of the authors is that when given the choice, even people who are used to squatting often tend to opt for a sitting toilet, at least in their homes, because it has the feel of a more luxurious toilet. In public toilet settings, the same people may still prefer a squatting toilet as it is perceived to be more hygienic.

Anal cleansing behaviours also vary regionally, with two distinct practices: People who use toilet paper or other solid materials such as leaves to wipe away faecal residue following defecation are commonly referred to as ‘wipers’. Those using water to wash the anus are generally termed ‘washers’. Many washers also wash their genitals after urination. The water is splashed by hand, poured from a spout or applied using a hose or a jet, similar to a bidet. While anal washing is practised in the majority of Muslim, Buddhist and Hindu cultures, the behaviour cannot be exclusively linked to religious preference, as e.g. many Christians in India also practice anal washing.

3.2 How and why to keep urine separate?

The core element of a UDDT is the urine-diverting squatting pan and toilet seat– often referred to as the *user interface* – which separates urine from faecal material (see Figure 4).

[7] http://forum.susana.org/forum/categories/71-behaviour-change-psychology-user-engagement/746-squatting-vs-sitting#746

Figure 4. Overview of several models of UD user interfaces (adapted from Hoffmann, 2012; photos by various persons[8])

The importance of separating urine and faeces is to (1) reduce odour (a mix of urine and faeces causes substantial odour); (2) enable fast drying of faeces which makes handling of faeces more simple and hygienic; (3) reduce environmental impacts; and (4) allow for the recovery of urine, which can be reused as fertiliser. Therefore the aim is to not mix urine and faeces together.

Urine diversion takes advantage of the anatomy of the human body, which excretes urine and faeces separately. In a UDDT, the urine is drained via a basin with a small hole near the front of the user interface, while faeces fall through a larger drop-hole at the rear. This separate collection – or 'source separation' – does not require the user to change positions between urinating and defecating, although some care is needed to ensure the right position over the user interface.

UDDT designs generally require men to sit or squat while urinating in order to avoid unhygienic splashing of urine. In cultures where men prefer to stand for urination, urinals are a good complementary solution (see Section 3.5).

Female users may find that some urine may enter the vault during normal operation. This is typically a small amount and does not significantly affect the function of the toilet.

3.3 Urine-diverting seats

3.3.1 Pedestals

Urine-diverting pedestals look similar to standard flush toilet bowls and are installed on top of the vault. Most users find a sitting height of between 38 to 45 cm most comfortable.

Figure 5. Left: A painted concrete urine diverting pedestal in Bulgaria (photo: WECF, 2007). Right: Ceramic pedestal with an innovative urine diversion concept developed in South Africa and Namibia (photo: Clay House Project, 2011).

Most UD pedestals utilise a partitioned toilet bowl for separation of urine and faeces (see Figure 5, left). However, an innovative design developed in South Africa[9] and Namibia[10] offers an alternative UD interface. The pedestal is designed so that urine that comes in contact with the wall of the bowl is directed via wall adhesion to a trough at the bottom of the pedestal that leads to the outside (see Figure 5, right).

3.3.2 Benches with inserts

The bench design uses a UD insert that is fitted directly onto the slab of the vault (see Figure 6). The bench design may be an appropriate design for users accustomed to sitting toilets and may be a suitable option for people with disabilities (see Section 6.3).

Figure 6. Left: Bench UDDT with single access step for sitting in Peru. Right: UD insert from *Rotaria del Peru*[11] in Peru (photos: H. Hoffmann, 2010).

3.3.3 Options for anal washing

The integration of anal cleansing with water is achieved through the installation of a separate wash bowl or washing area on the floor adjacent to the toilet seat (see Figure 7). The foremost design objective for UDDTs that accommodate anal washing is to minimise the risk of wash

8 http://www.flickr.com/photos/gtzecosan/sets/72157628912448797/

9 http://www.amalooloo.com

10 For more information on these so-called 'Otji toilets', see www.susana.org/library?search=otji

11 http://www.rotaria.net/

water entering the faeces vault. This is commonly achieved by installing a separate anal washing device. The washing mechanism must be equipped with a drain and discharge piping system.

Figure 7. Left: Example in Kyrgyzstan with washing area in the centre of the photo, see arrow (photo: WECF, 2011). Right: Prototype of a ceramic urine-diverting pedestal in the Philippines with separate wash bowl for anal washing in a sitting position (photo: D. Lapid, 2007).

3.4 Urine-diverting squatting pans

3.4.1 Single drop-hole version

The simplest version of a UD squatting pan has only two holes: a small drain for urine and a larger drop-hole for faeces. For double vault UDDTs, two such user interfaces are placed in parallel over the two vaults or a single movable pan is placed above the active vault (see Figure 8, left). Alternatively, the squatting pan can be oriented perpendicular to the faeces vault partition, allowing the user to switch between the active and inactive vault by rotating the user interface by 180° (see Figure 10, bottom right).

Figure 8. Left: Plastic urine-diverting squatting pan from China installed in a school in Ukraine (photo: WECF, 2010). Right: A ceramic urine-diverting squatting pan from *Tabor Ceramics* in Ethopia (photo: GIZ, 2009).

3.4.2 Twin drop-hole version

Urine-diverting squatting pans can be designed with two faeces drop-holes that are symmetrically arranged at both ends of the pan with a single urine drain in the centre (see Figure 9). The squatting pan is oriented perpendicular to the faeces vault partition. The user faces the sidewalls, rather than the door, during use. This configuration allows for the installation of a single user interface that can be permanently fixed and sealed to prevent water from entering the faeces vaults through potential leakages between pan and toilet floor. Additionally, pans facing the sidewall may provide additional privacy, as the users' genitals are shielded from view if someone enters the toilet during use.

Figure 9. Left: Plastic twin drop-hole squatting pan manufactured by *eco-solutions* in India (photo: P. Calvert, 2005). Right: Similar plastic squatting pan with lids from *Kentainers* in Kenya and with concrete footrest (photo: C. Rieck, 2009).

3.4.3 Pan design for anal washing

The integration of an anal washing basin is typically achieved with the addition of a third outlet in the squatting pan or through the installation of a separate washbasin (see Figure 10). Following defecation, the user either shifts backwards to the third outlet of the pan or moves sideways to the separate washbasin. It is recommended to cover the faeces drop-hole before washing in order to minimise the risk of water entering the vaults.

Figure 10. Top left: Separate anal washing pan from *eco-solutions* in India (photo: P. Calvert, 2006). Top right: Ceramic squatting pan with attached anal washing basin manufactured by *Shital Ceramics* in India and installed in Afghanistan (photo: N. Khawaja, 2010). Bottom left: Anal washing area installed between single drop-hole pans in Burkina Faso (photo: S. Rued, 2008). Bottom right: Reversible pan manufactured by *N-Fibro Systems* on a single vault system in India (photo: D. Schäfer, 2008).

Off-setting the anal washing pans slightly from the user interface may be advantageous in schools and public settings. This arrangement reduces the risk of water entering the faeces drop-hole as they have to shift away for washing. It is also advisable for all installations where young children will be regularly using the toilet.

3.4.4 Footrests for squatting pans

The inclusion of footrests, installed adjacent to or as part of the squatting pan, can be an effective means of guiding the user to the correct squatting position over the faeces drop-hole. Footrest sizes should be sufficient to accommodate adults, but may be reduced in school settings. Footrests integrated as part of ceramic pans are typically ribbed to prevent slipping, though this is less practical for cleaning (see Figure 10, top right). The installation of a raised footrest adjacent to the faeces drop-hole may also act as an effective barrier to prevent water from entering the dehydration vault (see Figure 9).

Research conducted by Cai and You (1998) determined that users generally prefer a footrest with an approximately 10° slope towards the toe, as compared to 0°, 30° and 45° slopes.

3.5 Waterless urinals

The simplest means of urine diversion – at least for males – is through the use of a urinal. The incorporation of a waterless urinal in the toilet cubicle of a UDDT can help reduce the risk of misuse. Waterless urinals are preferable over flushing urinals but do require an adequate odour seal in poorly ventilated cubicles, especially for indoor installations (see Section 3.8.3). It is necessary to clean the urinal on a regular basis to avoid smell from contaminated surfaces.

Urinals are generally cheaper to install and requires less space than a full UD user interface. They may substantially increase the toilet's capacity with minimal additional capital investment, especially relevant for school facilities and public toilets. Urinals can be installed in the interior or exterior of the toilet cubicle and share effluent urine piping with the UDDT, or built as entirely separate facilities. Households usually prefer urinals for males integrated within the toilet cubicle, as it is more convenient (see Figure 52). Separate urinal facilities are generally advisable in schools and public toilets, as they can accommodate a greater number of users and their use is easier to understand than the use of UDDTs (see Figure 56).

Ceramic flushing urinals with u-bends can be easily modified for waterless operation. Water buckets and plastic funnels or bottles can be modified as the simplest and cheapest option for men's urinal construction (see Figure 51, right).

Squatting urinals may also be placed in women's facilities and are generally recommended for UDDT installations in schools and public toilets, since these toilets are often used mainly for urination only and not as much for defecation (see Figure 11, left).

Figure 11. Left: Tiled, waterless squatting urinal installed in a female toilet at a secondary school in Nakuru, Kenya. (photo: M. Wafler, 2010). Right: Wall-mounted male urinals made from plastic buckets and from standard ceramic bowls for different age groups in a church and pre-school in Nakuru, Kenya (photo: E. Müllegger, 2009).

3.6 Material options for toilet seats and pans

The user interface should be simple to use, easy to clean, durable, aesthetically pleasing and resistant to malfunction. Materials with smooth surfaces, such as ceramic, plastic, fibreglass, porcelain tiles and sealed concrete, tend to be durable and easy to clean. Experiences with plastic urine-diverting pedestals and pans have been very positive in South Africa, Kenya and a wide range of other countries. Plastic, ceramic and fibreglass units are generally preferred by users, and frequently linked to a sense of prestige. Manufactured and commercially marketed units are often available in a variety of colours, making them more attractive to consumers.

Figure 12. Left: Casting of concrete pedestals using professional moulds in the Philippines (photo: R. Gensch, 2010). Right: Moulding a concrete pedestal around a bucket, with a plastic urine separation fitting (photo: P. Morgan, 2008).

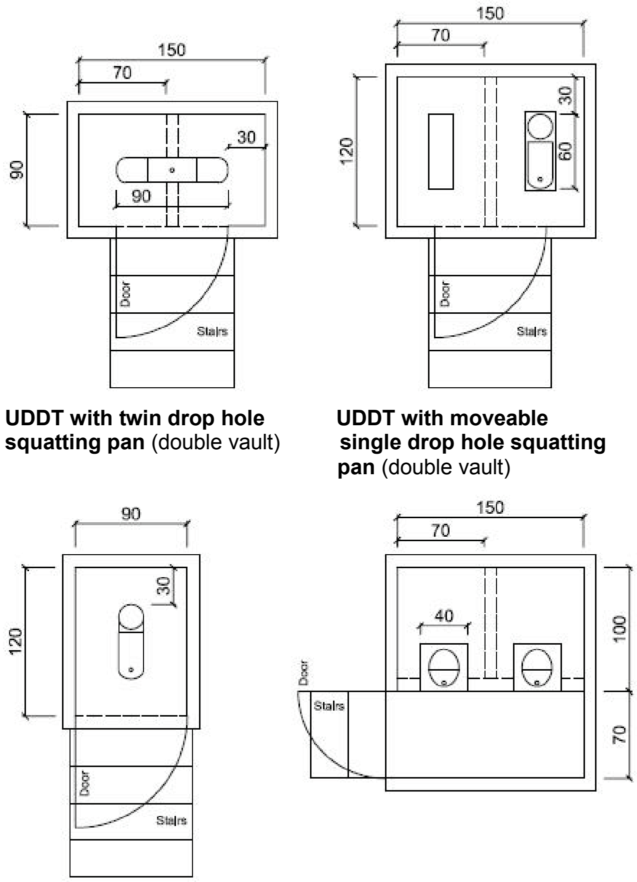
A detailed list of worldwide suppliers and prices of manufactured urine-diverting squatting pans and seats is maintained by GIZ[12].

While concrete UD seats and pans are a low-cost alternative that can be cast on-site, the concrete surface is easily abraded and is slightly porous making it prone to odour and the appearance of dirtiness. Concrete surfaces coated with wax or other commercial sealants may be easier to clean and less likely to emit odours. In order to ensure consistency and quality of the casting, concrete can be formed around a plastic bucket or other specifically designed mould[13] (see Figure 12).

3.7 Toilet cubicle design

The toilet super-structure should provide privacy and comfort for the users. Adherence to the following design guidelines can help achieve this, while ensuring the proper function of the UDDT:

- The floor should have sufficient slope to channel water towards a floor drain or other outlet, thus minimising the risk of water entering the faeces vault.
- The floor should have a smooth, durable, easily cleaned and attractive surface material, such as tile or polished concrete.
- The user interface should be oriented so the user faces the door or a side wall.
- The toilet cubicle should be well ventilated (see Section 4.9) and well lit through the use of openings, windows or translucent roofing and could be equipped with artificial lighting at night.
- The squatting pan should be placed at a minimum distance of 30 cm from walls and doors to avoid unintentional body contact when using the toilet.
- The minimum space requirement for a person to move freely in a toilet cubicle is around 90 cm wide by 120 cm long, and may be enlarged to accommodate wheelchairs.
- The installation of wall-mounted handles adjacent to a squatting pan may be beneficial for the elderly and for persons not accustomed to the squatting position.



UDDT with twin drop hole squatting pan (double vault)

UDDT with moveable single drop hole squatting pan (double vault)

UDDT with single drop hole pan (single vault)

UDDT for sitting in bench design (double vault)

Figure 13. Sketches of standard-sized UDDT cubicles, the stairs and outswinging doors with dimensions that enable sufficient space inside the cubicle and a sufficiently big vault size (depending on chosen height).

3.8 Installing the user interface

3.8.1 Fixing pedestals and pans to the floor

The pedestals or pans should be firmly attached or otherwise designed as to prevent liquids spilled during toilet cleaning or hygiene activities from entering the faeces vault. In cases where one user interface has to be shifted between the active and inactive vaults it does not allow for a watertight seal between the user interface and floor nor for the permanent attachment of these components. Rather, it requires either a prefabricated solution with a tight fitting socket, such as that provided by the South African *Envirosan* model (see Figure 14, bottom left), or a connection with screws and a removable sealant, such as a rubber grommet.

Alternatively, the area of the user interface can be elevated slightly above the slab with a raised lip and interlocking pan to minimise the risk of water entry into the vaults. This lip can be constructed with ceramic tiles or moulded concrete. A similar function can be achieved through the installation of footrests (see Figure 9).

[12] http://www.susana.org/lang-en/library?search=appendix

[13] Instructional photo series detailing the steps for on-site casting of concrete UDDT pans and pedestals: http://www.flickr.com/photos/gtzecosan/4216544801/in/set-72157623208424401/

The risk of water leakage into the vaults is significantly lower with *benches* than squatting pans and pedestals, as the former are cleaned with a wet cloth rather than a mop, and showering above the bench is not taking place.

The most appropriate method for fastening the pan or pedestal will depend on the construction materials of both the slab and user interface. With the exception of prefabricated plastic floors with integrated squatting pans, all designs require the separate fixing of the user interface to the slab or bench.

Figure 14. Top left: Placing a urine-diverting insert for a bench slab made of adobe in Peru (photo: H. Hoffmann, 2009). Top right: Precast concrete bench slab in Peru (photo: H. Hoffmann, 2011). Bottom left: Pedestals fixed with a socket system, manufactured by *Envirosan Ltd.* in South Africa (photo: B. Lewis, 2008). Bottom right: Placement of plastic twin drop-hole squatting pan prior to casting reinforced concrete slab in Kenya (photo: W. Osumba, 2010).

3.8.2 Minimising blockages in the urine collection section

Obstructions in the urine drainage funnel and subsequent discharge piping can pose serious risks to the overall function of the UDDT. Such blockages can cause pooling of the urine and generation of odours which may render the toilet temporarily inoperative. Obstructions in the urine drainage funnel are generally the result of accidental misuse of the toilet, usually from cover material, waste products or faeces mistakenly deposited in the urine-diverting section. Procedures for unblocking are described in the trouble shooting section (Section 8.6).

Adherence to design guidelines can help to minimise such obstructions at the point of urine outlet of the user interface. For example, the use of small diameter piping (1-2.5 cm) as the drainage outlet of the squatting pan or seat which is followed by larger discharge pipes will prevent larger objects from entering the urine piping system. The small diameter piping also visually differentiates the urine drainage area from the faeces drop-hole. Additional design criteria that may minimise blockages in the urine piping are discussed in Section 5.3.

It may also be useful to place a coarse plastic sieve or mesh in the urine funnel to prevent foreign objects from travelling from the drainage basin into the discharge piping (see Figure 9, left). Such a sieve may also encourage proper usage by creating a visual reminder that the urine drainage basin is ‘liquids only’. However, the sieve or mesh is prone to rapid clogging with body hair, cover material or misplaced wiping material, and may require daily cleaning. Regular and frequent cleaning of the sieve or mesh tends to be considerably easier than clearing obstructions in the effluent piping system.

3.8.3 Odour control at the toilet seat, squatting pan or urinal

In combination with the odour control measures described for the vault (see ventilation in Section 4.9 and use of cover material in Section 4.4) and for the urine collection system (see Section 5.4), mechanisms installed at the user interface can help maintain an odourless toilet.

Odour control measures at the user interface include:

- Use of smooth and non-absorbent construction materials (see Section 3.6);
- Use of lids to cover vault drop-holes; and
- Sufficient and consistent slope of the urine pipes to prevent any urine accumulation (see Section 5.3 for details).

In well-ventilated outdoor toilets, further odour control measures are usually not necessary. However, additional odour control mechanisms should be integrated into indoor and heavily used toilets.

A simple supplementary odour control measure has been used in Eastern Europe by the NGO WECF[14] on conventional flushing urinals that were retro-fitted for a waterless operation. All but one of the urinal’s drainage holes were sealed and a condom with a small hole cut into the tip was fitted over the outflow piping. This simple setup allows the gravity driven drainage of urine into the discharge piping, but prevents the migration of odours from the urine collection vessel and piping into the UDDT super-structure (see Figure 15). However, practitioners working in warm climates have reported that these condoms fail to work because they stick together within a short time, for example if the toilet is not used for a day.

A further option for odour control at the point of the user interface may involve the use of charcoal, which is supposed to have the ability to adsorb urine odours. Charcoal contained in a mesh bag and placed directly in the urine-diverting section of the user interface has been applied in the Philippines, and shown to be an effective means of odour reduction (Gensch et al., 2010). The adsorptive capacity of the charcoal will be gradually exhausted, and the charcoal thus requires regular replacement.

[14] http://www.wecf.eu/english/water-sanitation/

It has been suggested that another option to control odour could be a plastic ball (size of a table tennis ball) which is placed in the urine funnel of the urine diversion pan and could act as a one-way valve to prevent back-flow of odours (see Figure 51, right). When a sufficient volume of urine enters the funnel, the ball would float, allowing for the drainage of urine. When the urine has drained completely, the ball would return itself atop the drainage pipe, preventing odour from migrating into the toilet cubicle. The authors doubt that this system could work reliably, and no detailed experiences with this concept have been reported to our knowledge.

A one-way valve consisting of two silicon curtains or a flat rubber tube offers a more sophisticated odour control measure (von Münch and Winker, 2011).

Figure 15. Left: Flushing ceramic urinal retrofitted for waterless use by sealing all but a single drainage hole. Right: Condom with cut-off tip attached to the urinal outlet as an odour control measure at the user interface level (photos: C. Wendland, 2010).

3.8.4 Use of lids to cover faeces drop-holes

Generally, the faeces drop-hole should be fitted with a cover. Though dry faeces generally do not attract flies or other vectors, the use of a cover may prevent possible infestation. Furthermore, lids on squatting pans may serve as an additional measure to ensure water does not enter the faeces vault. The inclusion of faeces vault covers is critical for toilets with both a squatting pan and an anal washing basin, as such a design is especially prone to water splashing into the vault (see various lids in Figure 10, top right and bottom left).

However, such lids can be a source of confusion for users in toilets with twin drop-hole squatting pans. Such UDDTs have two lids, one for the active vault and another one for the inactive vault, thereby creating the possibility of misuse of the inactive faeces vault. In the case of schools and public toilets, it may prove beneficial to leave the faeces drop-hole of the active vault uncovered to avoid accidental misuse. Users of pit latrines are usually accustomed to uncovered drop holes, making the use of a UDDT with uncovered drop-hole more straight-forwarded.

The use of a semi-permanent lid may be considered for the purpose of covering the inactive dehydration vault. Such a lid is difficult to remove and provides a clear indication that the vault is not in use (see Figure 7 and Figure 45, left).

4 Faeces vault design and function

4.1 Vault functions

The UDDT vaults serve the basic function of collecting and storing the faecal material. The faeces need to be safely contained in the vaults so that they are hygienically separated from human contact. This requires a vault door or other means of blocking both direct and indirect human or animal contact, while allowing intermittent access to the vault for emptying and cleaning activities. In addition to faeces, the vault also stores toilet paper and cover material, collected directly in the vault (double dehydration vaults) or in interchangeable containers (single vault) as described in Section 2.6 of this publication.

The second important function of the faeces vault is to provide dry (low moisture) conditions to allow the faecal material to become and remain dry and odourless. This is primarily accomplished by installing the vaults above the ground surface and preventing rain and floodwater from entering the vaults. Moreover, the vaults should be adequately ventilated to exhaust moisture and odours.

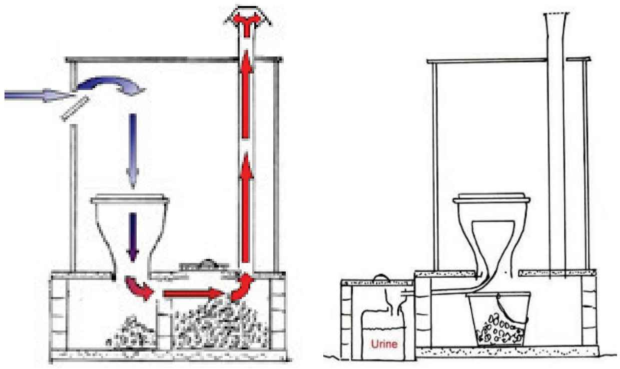


Figure 16. A double dehydration vault UDDT (left) with the indication of the air flow through the ventilation pipe, and a single vault with interchangeble containers (right) (source: M. Morgan, 2007). There can also be one ventilation pipe for each dehydration vault (see Section 4.9).

The dry conditions in the vaults facilitate the dehydration of faeces (loss of moisture) into a drier and less offensive material depending on the extent of storage. The dehydration process also results in the partial die-off of pathogens. Faeces treatment processes are further detailed in Section 4.5.

4.2 Quantity and quality of faeces

4.2.1 Quantity

On average, adults excrete between 0.12 to 0.4 kg of faeces per day or 44 to146 kg/person/year, depending on diet and quantity of food consumed (WHO, 1992 and Geurts, 2005). For example, the high fibre, vegetarian diet in Kenya results in an average of 0.53 kg/person/day, while the generally high protein diet commonplace in Sweden produces an average of only 0.14 kg/person/day (Geurts, 2005). In the absence of local information, the average figures presented in Table 2 can serve as an estimate of faeces production.

Faeces contain about 80% water. The storage and dehydration process taking place in the faeces vaults reduces the water content of faeces considerably. For example, the sampling of UDDT vaults in Kenya has shown a reduction of water content to 40% within a period of 3.5 months (Kraft, 2010). In general, it can be expected that the water contents reduces to < 25% after 6 months of storage in UDDTs as recommended by WHO (2006). Thus the approximate annual mass of faecal matter per person after six months of drying in UDDT vaults is between 20 to 66 kg/person/year depending on the diet (see Table 2).

Table 2. Average mass of excreted faeces and nutrients in faeces.

Parameter	Unit	Faeces	
		High protein diet	*High fibre diet*
Wet mass[a]	*kg/person/ day*	0.12	0.4
	kg/person/ year	44	146
Water content of wet mass[b]	*%*	80	80
Nitrogen[c]	*g/person/ year*	550	Not available
Phosphorus[c]	*g/person/ year*	183	Not available
Water content after 6 months of dehydration[d]	*%*	25	25
Dehydrated mass	*kg/person/ year*	20	66

[a] WHO (1992)
[b] Based on Jönsson et al. (2004)
[c] Swedish values, from Vinnerås (2002)
[d] Based on WHO (2006)

4.2.2 Hygienic quality

Faeces contain pathogens that can cause a variety of diseases, including diarrhoea, typhoid fever, cholera and parasitic infections. Pathogenic species are infectious microorganisms that can be divided into four categories – viruses, bacteria, protozoa and intestinal worms; the latter is often referred to as geohelminths or soil-transmitted parasitic nematodes. The presence of pathogens in faeces is dependent on whether the person is infected with or is a carrier of the pathogen in question. Many pathogens are easily transmitted via the faecal-oral route, either directly, through contact of contaminated hands, or indirectly, through faecal contamination of food and water. Faeces borne pathogens are often spread by flies and other vectors.

Protozoa and viruses are unable to grow outside of the host, thus their numbers will always decrease with time. Conversely, pathogenic bacteria, such as typhus or cholera, can survive indefinitely outside of the body under favourable environmental conditions. However, while non-pathogenic bacteria counts have been shown to increase under favourable conditions, their pathogenic counterparts will not multiply outside of the body (Schönning and Stenström, 2004).

Parasitic worms are typically transmitted through soil which is contaminated with untreated faecal material from open defecation or the agricultural application of untreated wastewater or faecal sludge. These soil-transmitted pathogens are called *geohelminths* and include: round worms (*Ascaris lumbricoides*, often referred to as simply '*Ascaris*'); whipworms (*Trichuris trichiura*); and hookworms (*Anclostoma duodenale* and *Necator americanus*). A large portion of the world's population suffers from parasitic worm infections, especially in regions with warm, moist climates with poor sanitation. Children are most at risk.

The eggs of helminths are contained in the faeces of infected persons. *Ascaris* and whipworm infection occurs primarily through faecal-oral transmission of these eggs. Hookworm eggs, on the other hand, will not cause infection when ingested; instead, the eggs hatch in the soil, releasing larvae that mature into a form that can penetrate the skin of humans.[15]

Their thick shells make helminth eggs more resistant to treatment and more persistent than other types of faecal pathogens. The eggs of *Ascaris* and whipworm, for example, can survive for several years in soil (Schönning and Stenström, 2004). The concentration of helminth eggs in dehydration vaults depends on the prevalence and severity of infection of the users.

4.3 Wiping material and waste in vaults

Soiled wiping materials, such as toilet paper, newspaper or leaves, should be discarded into the vault. Separate collection of wiping materials in bins is not advisable as the materials are contaminated with faecal pathogens from wiping. Their disposal in the faeces vaults can effectively contain them. Toilet paper may also act as an additional absorbent medium, benefitting the dehydration process, and will easily decompose when the treated faecal material is buried or applied to soil in agriculture.

The mass of toilet paper used is variable and was measured to be 8.9 kg/person/year measured in Sweden (Vinnerås, 2002). In settings where toilet paper is relatively expensive, its consumption will be lower. The anticipated mass of wiping materials is included in the proposed storage volume of dehydration vaults (see Section 4.6.3).

Some users may traditionally use stones, corncobs or sticks for anal wiping. Be aware that these materials may fill up the vault or container more quickly, thus reduce dehydration rates and pose difficulties during vault emptying and excreta reuse.

[15] http://www.cdc.gov/parasites/sth/

Hygiene items like sanitary pads or rags should generally be collected and disposed of separately, especially when the faecal matter is intended for agricultural reuse. However, if the faecal material is to be buried or incinerated, sanitary pads could also be disposed of in the faeces vault as a matter of convenience (see Section 6.6).

4.4 Use of cover materials

The use of cover materials such as wood ash, sand, dry soil, saw dust, lime, leaves, compost or rice husks, is critical to the overall function of the UDDT. A cup or scoopful of cover material atop fresh faeces will promote dry conditions within the faeces vault, control initial odour, prevent infestation of flies and other insects and create a visual barrier for the next user.

Information regarding recommended storage vessels for cover materials is provided in Section 6.4.

Figure 17. Left: Dried faeces with ash cover inside the vault of a UDDT in the Philippines (photo: E. Sayre, 2008). Right: Dehydration vault with soil and ash cover in Burkina Faso (photo: S. Tapsoba, 2009).

4.5 Treatment of faeces in vaults

4.5.1 Objectives of treatment in UDDTs

The objective of faeces treatment in UDDTs is to obtain a dry, odourless, inoffensive and partially sanitised product that can be more safely handled during vault emptying and disposal or reuse. It is not the objective to achieve a complete pathogen removal in the faecal material, including inactivation of all helminth eggs, as literature suggests that this *cannot be guaranteed* under ordinary circumstances with any type of UDDT.

Effective faeces treatment in UDDTs is dependent on the storage of faecal material for several months without the addition of fresh faeces. Thus a treatment of faeces in vaults is strictly spoken only taking place in UDDTs with double dehydration vaults with substantial storage time as compared to UDDTs with single vaults that have no or a too short storage period of faeces inside the vault.

4.5.2 Treatment processes during collection and storage

Treatment of the faeces begins upon collection and continues throughout the storage period. The four most important factors for treatment are: moisture content (dryness), duration, increased temperature and pH value. Of these, dryness and duration tend to be the most easily controllable and, therefore, most reliable methods of treatment in UDDTs. Increased temperature should not be relied upon as a primary treatment measure, as it is less reliable in practice. Additional information can be found in Schönning and Stenström (2004) and in Stenström et al. (2011). The post-treatment options of faeces outside of the vaults are described in Section 7.5.2.

Dehydration describes the loss of moisture in faeces over a certain period of time. The *moisture content* of fresh faeces is approximately 80% (see Table 2) and gradually decreases during collection and storage as water vapour is leaving through the ventilation pipes. The majority of pathogen die-off occurring during treatment is attributable to this dehydration process. Dehydration also leads to physical changes in the faeces, including textural changes and abatement of odour, which make it less offensive to handle. The addition of dry cover material further supports the dehydration process by absorbing moisture from the faeces. Faeces will, however, only dehydrate effectively when the vaults provide dry conditions and ample time.

Final moisture levels of less than 25%, as recommended by WHO (2006), can realistically be achieved in UDDTs with double dehydration vaults (see Section 4.2.1) and thus lead to a relevant treatment process. The extent of dehydration in containerised storage systems however is far lower, however, due to the much shorter collection and storage times, as well as the container's inferior ventilation capacity.

Moisture levels of below 5% have been shown to result in the complete sanitisation of faeces and die-off of helminth eggs (Feachem et al., 1983). However, these levels cannot typically be achieved in dehydration vaults without very warm, arid conditions and very long storage times.

Storage duration plays a crucial role in faeces treatment, as most pathogens die off naturally outside the human body over time, except for helminth eggs. After defecation, the faecal pathogen load is naturally reduced through antagonism, competition and consumption by other microorganisms, as well as by the action of antibiotics (Niwagaba, 2009). Furthermore, increased storage duration results in more pathogen die-off due to more effective dehydration, temperature and possibly pH increase (see below).

Alkaline treatment involves the increase in pH value in the vault. The addition of alkaline cover material like wood ash or lime can result in a *pH value* above 9, which significantly reduces the pathogen load during the collection and storage phase. However, practical experience has shown that the availability of alkaline cover material is often limited, and that pH levels above 9 are not reached reliably, at least not throughout the entire pile.

Increased temperature can have a treatment impact on pathogens. They have a limited temperature range in which they can survive. Most microorganisms die off rapidly at high temperatures (higher than 40-50°C). Pathogen die-off rates at ambient temperatures between 4-20°C are slower than in climates with 20-35°C ambient temperatures (Schönning and Stenström, 2004).

Many older UDDT designs call for the installation of sloped vault covers as a mechanism to transfer solar energy into the faeces vault and elevate the internal temperature. However, such designs generally cannot sustain temperatures exceeding 50°C for the duration necessary to effectively sanitise the faecal material (see Section 4.8.4).

A variety of *other treatment processes* may occur in the faeces vault. A certain amount of aerobic decomposition – or composting – of faeces does occur during collection and initial storage when the moisture content is sufficiently high. However, the contribution of composting to the overall pathogen destruction is generally negligible. The rate of organic decomposition in the dehydration vaults slows and ultimately stops as the moisture content of faeces in the vaults is decreased. It is possible to operate a UDDT as a composting toilet through the increase of moisture and addition of other organic matter into the vault, but the sanitising effect is not nearly as effective (see Section 2.6.5).

4.5.3 For how long should faeces be stored before emptying the vault?

Buckley et al. (2008) have analysed dehydrated faeces after a storage period of between 6 to 12 months and found a substantially higher number of viable intestinal worm eggs than the stipulated guideline value for safe reuse in agriculture (WHO, 2006). Other types of pathogens however are effectively killed in UDDTs with double dehydration vaults during such a storage period (Schönning and Stenström, 2004). The prevalence of worm eggs has a most critical for the disposal and reuse methodology described in Section 7.

We recommend for all climates a storage duration for faeces in double dehydration vaults of at least six months, as measured from the last addition of fresh faecal matter to the vault.

Six months of storage is usually sufficient to dehydrate the faecal matter and produce a dry, odourless, relatively inoffensive and partly sanitised product. Storage times of *12 months or more* might be used in cool, wet climates where sufficient dehydration may take longer. In fact, the minimal storage time may vary according to climatic conditions and the toilet's mode of operation. In general, longer storage periods deliver an end product with a lower pathogen and moisture content.

Figure 18. Emptying of dehydrated faecal material from a double vault UDDT after 6 months of storage at the university of Agraria de La Molina, Lima, Peru (photo: H. Hoffmann, 2011).

For UDDTs with interchangeable containers, the objective is not to treat faecal material inside of the vault, but rather to allow for simple removal and efficient transport to off-site treatment facilities. Short-term storage inside the faeces vault is advisable, as this will partially dehydrate the faeces and simplify collection and transport of the containers. While a minimum storage period of two weeks is recommended, the actual storage time will depend on available space and how quickly containers become full. In many cases, lack of space will not allow for any on-site storage.

Regardless of the on-site storage duration, containerised faeces from single vault UDDTs must be post-treated prior to disposal or reuse.

4.6 Design guidelines for double dehydration vaults

4.6.1 General requirements

The following basic design rules of double dehydration vaults should be followed to ensure the safe containment and effective treatment of faeces:

- The toilet is built with *double dehydration vaults* that allow the alternation between the active and inactive vault.
- The two vaults are each of *sufficient size to collect faecal matter over a period of at least six months*.
- The base of the vaults is elevated *at least 10 cm above the ground* to minimise the risk of water entry during heavy rains, maintain dry conditions and allow for easy emptying after the storage period. The vault doors can be further raised to above the height of an established flood line in flood prone areas (see Section 10.7).

- The UDDT *is not built in a depression* or at the topographic low point of a given area, as rainfall will typically collect in such areas and increase the likelihood of flooding the vault.
- The interior walls of the *vaults are plastered* when the vaults are installed partially below the ground (see Figure 19) or the UDDT is built in a flood prone area.
- The *vault doors are well closed* and keep the faecal matter safely contained, thus protecting the vault from rainwater, minimising potential routes of human contact and creating a dark interior in the vault which is of advantage for the users since the faeces are not or less visible (see Section 4.8).
- The *vaults are well-ventilated* via vertical ventilation pipes that remove moisture and odours above the level of the roof (see Section 4.9).

Figure 19. Left: Dehydration vaults under construction in Peru (photo: H. Hoffmann, 2011). Right: A dehydration vault on sloping terrain is built partially below the ground (photo: H. Hoffmann, 2011). Both toilets are still under construction here.

The physical structure of the vault needs to support the weight of the users and the toilet's super-structure. While bricks, concrete and adobe are the most common materials for vault construction, timber and bamboo may provide more lightweight and cost-effective options (see Section 6.10).

It may also be beneficial to install the vault with a sloped floor in order to drain away water that has accidentally entered the vault. The small volume of possible leachate in such an event will not impact groundwater quality. However, certain geographical and climatic conditions, such as susceptibility to flooding or heavy rainfall, may necessitate a concrete base of the vault floor.

The collection of faeces directly into the dehydration vault allows the entire volume of the vault to be utilised for storage. In contrast, the use of collection containers will significantly reduce the vault's storage volume, leading to a shorter storage period and less pathogen removal. However, container may be a suitable option also for double dehydration vaults if users prefer an additional barrier between themselves and their excreta, or for service providers that will transport the faeces off-site for treatment.

It should be noted that faeces tend to form a conical pile in the faeces vault, resulting in considerable unused space within the vault. Faeces may be evenly distributed throughout the vault using a stick or other tool, or an additional 20% can be added to the required volume to account for void space.

4.6.2 Dimensioning of double dehydration vaults

The volume and dimensions of the dehydration vaults are determined by two factors: the volume of faecal material deposited and the required storage time of the faeces (see Section 4.5.3). The dimensions should also match with the anticipated floor plan of the toilet cubicle above the vault (see Figure 13).

The expected volume of faecal matter per month depends on the number of users, their diet, the frequency of toilet use and the covering and wiping material used. In order to ensure adequate storage duration, it is critical that the faeces vault can support the anticipated number of users. Household UDDTs with double dehydration vaults can be designed to accommodate one to about ten users. UDDTs installed in public toilet blocks may be required to accommodate between 15 and 30 users daily, and may benefit from the flexibility of containerised collection systems (see Section 10.3).

For design purposes, it can be assumed that the average person will require approximately 50 litres of faecal matter storage space for a 6-month period. This corresponds to a vault volume of 500 litres for a 10-person household (see Box 1). Therefore, a **dehydration vault volume of 500 litres** (0.5 m^3) is common.

A typical 500-litre dehydration vault will have interior dimensions of 0.8 m long by 0.8 m wide and 0.8 m high, creating a total volume of 512 litres per vault (see Figure 20). The exact dimensions, however, may be adjusted to coincide with the dimensions of the toilet cubicle above, orientation of the toilet pan or to fit within available land space (see Figure 13). More drawings are available in the documents listed in Section 11.2.5.

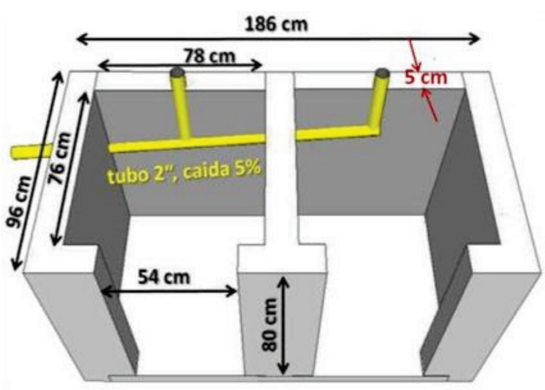


Figure 20. Sketch of double dehydration vaults with dimensions for a bench design like the one in Figure 19. The vault volume is about 500 litres each (source: Hoffmann, 2012). Tubo 2" is Spanish and means pipe with diametre of 2 inches and 'caida' means slope (%5).

4.6.3 Sample calculation of required storage volume

Box 1 below shows a detailed calculation example. In this example, a vault volume of 518 litres is required for a household of ten people. In practice, masons and implementers tend to use a standard design and size for a certain region e.g. 500 litres.

A household in a warm climate with 10 persons and a high fibre diet serves as the basis for this example. Adult members of this household defecate 0.4 kg/person/day, while children and elderly household members consume less food and produce only 0.15 kg/person/day. The household members deposit faeces, toilet paper and cover materials into the vaults, but additional hygiene articles and organic waste are not discarded in the vaults.

Not all members of the household use the toilet each time they have to defecate, as they are also at work, at school or travelling. This is assumed to reduce the total volume of faeces deposited by approximately 20%. During filling of the vault, the volumetric reduction due to faecal dehydration is assumed to be 25%.

A safety margin of 20% is included in the calculation to account for use by visitors, uneven distribution of faeces in the vault (conical pile of faeces) and a buffer zone between the top of faeces pile and the bottom of the floor slab.

Box 1: Calculation example for required dehydration vault volume for six month storage for a 10-person household with high fibre diet

Cover materials: assumed daily average 0.05 kg/p/day
Toilet paper: annual average of 8.9 kg/p/year*
Density of faeces assumed to be 1 kg/l
Storage duration: six months after last use

Faeces production:

5 Adults x 0.4 kg/day =	2.0 kg/day
5 Children/elderly x 0.15 kg/day =	0.75 kg/day
=	2.8 kg/day
faecal weight =	**83 kg/month**
accounting for absence -20% =	-17 kg/month
x 6 months =	396 kg/half year
moisture loss -25% =	-99 kg/half year
toilet paper =	45 kg/half year
cover material =	90 kg/half year
entire household per half year =	**432 kg/half year**
safety margin +20% =	86 litre/half year
required vault volume =	518 kg/half year
required vault volume =	**518 litre**

* according to Jönnson, 2004

4.7 Design guidelines for single vaults with exchangeable containers

Single vault UDDTs with interchangeable containers are usually designed with space for at least two containers at a time, in order to allow for short-term on-site storage of the faeces. Smaller vaults with space for only one container can also be built, though under such circumstances containers will contain fresh, wet faeces when removed from the vault.

Figure 21. Left: Single vault under construction in Zimbabwe that can easily fit two or more containers (photo: P. Morgan, 2007). Right: Interior of a UDDT with a single vault in Kampala, Uganda (photo: E. Schröder, 2010).

The following basic design rules should be followed to ensure the safe containment and effective treatment of faeces in single vault systems:

- The container can be a bin, barrel, bucket, sack or bag made from different materials, such as plastic, reed, wood or woven fabrics. Metal containers could be used as well but are prone to corrosion.
- The volume of the *containers should not exceed 50 litres*, as larger containers may be difficult to remove and transport. In order to allow for convenient operation, the container should be sized according to the anticipated number of users and the preferred emptying frequency (days, weeks to months).
- *The containers should be* watertight to prevent liquids from misuse or diarrhoea from leaking into or even out of the vault. If porous materials such as sacks or woven baskets are used for faeces collection, a watertight receptacle can be placed underneath to catch any liquids.
- *Single vaults can* be sized to accommodate two or more containers (see Figure 21) or only one container (see Figure 22 and Figure 61).
- The *height of the vault is flexible* and can be adjusted to match the height of the chosen container. A buffer between the user interface and collection container increases user comfort, especially for UDDTs with bench design.
- *Single vaults can easily be built below ground* as the containers will prevent moisture infiltration. Belowground vaults allow barrier-free access without the need for stairs (see Figure 53).
- *Single vaults should not to be located in depressions* and in topographical low points of an area since rainfall usually collects there and may flood the vault. Vaults belowground are very vulnerable to rainfall events or floods.
- The *vaults should be well ventilated* via vertical ventilation piping that directs moisture and odours above the level of the roof (see Section 4.9).
- *Vault doors should keep the faecal matter safely contained* and create a dark interior (see details in

Section 4.8). Vault doors must be easily opened and resealed, as single vault UDDTs require frequent vault access.

The selection of container materials depends on the anticipated fate of the faeces and the mode of transport. While impermeable materials like plastic may inhibit drying during collection and storage, they are often preferred by those responsible for transporting the faeces.

Figure 22. Left: Pre-fabricated plastic UDDT, called an EKO-LOO[16] with one interchangeable faeces container from *Kentainers* in Kenya (photo: C. Rieck, 2008). Right: Use of a plastic drum in a toilet for students at Adama University in Ethopia. The tight fitting lid is used for transport of the full drum (photo: K. M. Sintayehu, 2010).

4.8 Design guidelines for vault access doors

4.8.1 General requirements

Faeces vault doors are a possible point for rain or flood water to enter the faeces vault. These doors are particularly susceptible to poor design and craftsmanship, material fatigue, construction mistakes and insufficient maintenance. Adherence to the following guidelines can help prevent or reduce vault door failure:

- The vault doors provide *firm locking of the vault* using hinges, rails, locks, hooks or semi-permanent concrete sealant to avoid accidental opening by children or roaming animals.
- The vault doors can be *easily opened and closed* to remove the faecal matter.
- The vault doors *protect the vault from rainwater intrusion*. This is best achieved by shielding the doors from direct rainfall by installation of a roof overhang, using vertical rather than inclined vault doors and ensuring that the roof ideally slopes away from the vault doors.
- The vault doors are placed *above established flood lines* in flood prone areas.
- The vault doors are *not necessarily completely airtight*, although minimising airflow through the doors may help prevent the accumulation of odours inside of the toilet cubicle as the airflow should be moving from the cubicle into the vault and then into the ventilation pipe (see Section 4.9).
- The vault doors *act as a visual barrier* between the users or passers-by and the faeces. Transparent materials and large gaps should be avoided.

4.8.2 Materials for vault access doors

Faeces vault doors should be built using sturdy, weather resilient materials, such as galvanised and painted steel sheets, treated wood, concrete slabs, bricks and mortar or plastic panels (see Figure 23 and Figure 24). It is important that the doors are easy to maintain. Regular maintenance, such as repainting metal doors with rust-proofing paint and removing rot from wooden doors, should be performed as necessary to ensure proper operation.

Figure 23. Left: Wood frame doors with metal cover sheeting at a school in Ukraine (photo: WECF, 2010). Right: Semi-permanent brick and mortar doors for a household UDDT with double dehydration vaults in India (photo: L. Dengel, 2009).

4.8.3 Semi-permanent doors

Double dehydration vaults may be sealed with semi-permanent doors made from concrete, stone, brick, adobe or wood. These doors can be fixed with weak mortar, clay, soil or nails, which must be carefully broken and removed to gain access to the vaults. Resealing can be performed with the same materials. Semi-permanent doors are a good option when the doors are exposed to the public or roadsides and may be prone to vandalism. Before the decision to install semi-permanent doors is made, a regular supply of sealant must be secured, and the toilet's users or service providers must be adequately trained to ensure proper reinstallation.

UDDTs with single vaults need to be opened more frequently and therefore should *not* have semi-permanent but 'normal' doors.

[16] http://www.kentainers.com/kent/downloads/astpackages.pdf

4.8.4 Inclined compared to straight vault doors

Many UDDT designs used to require the installation of inclined vault doors (see Figure 24, left and Figure 25). Such a UDDT – often referred to as a ‘solar latrine’ – was supposed to be oriented towards the sun so that the vault door received the greatest possible amount of solar radiation, in order to heat up the air inside the faeces vault. This warming affect was thought to promote pathogen destruction via sustained high temperatures and to accelerate dehydration by improving the system’s natural ventilation. Inclined vault doors were generally built using painted black metal in order to absorb as much solar energy as possible.

Figure 24. Left: UDDT with slightly inclined metal vault doors in Kenya (photo: C. Rieck, 2010). Right: Toilet in eThekwini Municipality, South Africa with vertical sliding plastic doors (photo: eThekwini Water & Sanitation Unit, 2009).

While theoretically sound, the inclined vault door design has not performed particularly well in the field. The solar radiation with inclined doors is not sufficient to significantly increase the rate of dehydration nor to achieve sustained temperatures greater than 50°C, which is required for complete and reliable pathogen die-off[17] (see Section 4.5.2).

Practical experience has shown that a number of other factors, including improper UDDT orientation with respect to the sun’s path, trees and bushes casting shadows on the toilet, prevent the toilet from receiving the intended amount of solar radiation. The user’s preference for the location of the toilet is more important than the ‘correct’ positioning for the sun. Additionally, inclined vault doors tend to be more prone to failure than their vertical counterparts, usually as result of material fatigue or vandalism. A small hole or gap in an inclined vault door lets in more rainwater than the same size hole or gap in a vertical door.

[17] Example of this kind of research from rural El Salvador in 2006: http://www.mendeley.com/research/association-between-intestinal-parasitic-infections-type-sanitation-system-rural-el-salvador/

Figure 25. Left: Sketch of a UDDT with solar-heated processing vault (source: Winblad and Simpson-Hébert, 2004). Right: Solar heated UDDT installed in Bolivia (photo: R. Izurieta, 2011).

Vertical vault doors are not exposed as much to direct rainfall and consequently do not necessarily have to be watertight. Vertical vault doors simplify the design, implementation and thus also reduce costs. **Therefore, we strongly recommend building UDDTs with vertical vault doors.**

4.9 Design guidelines for ventilation systems

The ventilation system is the primary means of exhausting odours and moisture from the faeces vault. Ventilation should never be omitted from a UDDT design, even in very arid climates, in order to guarantee extraction of odours and ensure effective dehydration.

Ventilation systems can be natural or mechanical. While natural ventilation is usually sufficient for outdoor toilets, indoor installations, especially those in multi-storey buildings and with bends in the ventilation ducts, typically require mechanical support.

A natural ventilation system consists of a vertical pipe that leads from inside the collection vault to at least 50 cm above the roof. If the temperature in the faeces vault is warmer than the ambient air it creates a ventilation of air what is known as *stack effect*. This draws cooler air into the faeces vault through the user interface, windows or vault doors and exhausts warmer air through the ventilation pipes (see Figure 16). Wind also creates a draft that extracts air from the vault. Very windy conditions have been observed to force air down the vent pipe through the vault and into the toilet cubicle, resulting in mild odours (Groth, 2005). In areas where strong winds are to be expected, the prevailing wind direction should be considered when orienting the toilet thus placing the vault doors away from the wind direction.

The ventilation pipe should have at least 10 cm diameter and can be built using plasticised polyvinyl chloride (PVC), polyethylene (PE), metal or even locally cast concrete pipes (Morgan and Shangwa, 2010). For best performance, the pipe should be straight and without bends, which would increase friction and reduce the effect of drafts.

The ventilation pipe outlet should be covered with a cap, cowl or T-joint (see Figure 26) to prevent rainwater from entering the vault. This cover should not, however, significantly reduce the effective diameter of the ventilation outlet.

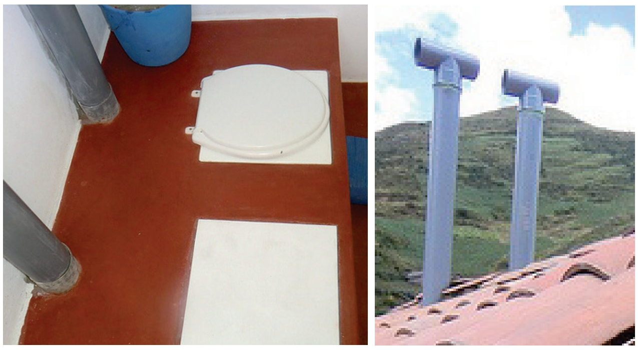


Figure 26. Ventilation piping in Peru with inside installation and a vent cover with T-joints (source: H. Hoffmann, 2010).

While it is possible to ventilate double dehydration vaults with a single pipe, it is generally recommended to provide each vault with its own ventilation system. In the case of a single pipe for double dehydration vaults, the interconnection of the vaults can be achieved through a penetration in the partition wall between the two vaults.

Protection against vandalism and accidental damage is an important consideration when designing UDDT ventilation systems. While vent pipes installed along the outside wall of the super-structure may have the advantage of increased stack effect, they may become brittle as a result of prolonged exposure to UV radiation and be susceptible to accidental damage or vandalism. In areas where the threat of vandalism is high, the vent pipes should be installed along the interior walls of the toilet cubicle and end above the roof. If vent pipes are to be placed outside of the super-structure, they should be firmly attached to the wall and coated with UV resistant paint to prevent material fatigue.

The air supply for ventilation enters through the user interface or through small openings in the vault doors. Air is drawn through the faeces drop-hole, into the vault and ultimately exits through the ventilation pipe. Additional air supply inlets are normally not necessary, unless the vault is equipped with semi-permanent doors sealed with grout or plaster and an airtight lid is placed over the faeces drop-hole.

The design of the toilet cubicle itself should provide a well-ventilated, adequately lit and odour free environment. Ventilation openings are often installed above the door and along the walls with vent blocks, latticework or gaps in the walling. An approximately 10 cm gap between the roof fitting and the walls may also be suitable in more temperate climates (see Figure 53, left), provided there is sufficient roof overhang to prevent rainwater intrusion. Privacy must be ensured, especially in schools and public toilets, by placing ventilation gaps above the height of a tall person. In colder climates, the UDDT cubicle may require windows to let in daylight, and more sophisticated mechanical ventilation systems for odour control measures.

4.10 Fly traps

Under normal circumstances, the separation of excreta and the use of adequate cover material added onto the faeces pile will prevent infestation of flies and other insects. However, in the case of persistent infestation, it is recommended to close the end of the ventilation piping with a mosquito proof mesh to seal off a possible route of entry.

Fly traps may also be beneficial in hot, humid climates with abundant insects. One low cost solution can be built using a modified 2-litre bottle (Hoffmann, 2012). The top one-third of the bottle is removed with scissors or a sharp knife, and fitted spout-side down into the bottom two-thirds of the bottle. This creates a narrow passage through which flies and other insects can fly into, but are unable to exit through. The trap is placed in the side wall of the vault, with the flat bottom of the bottle facing the outside, i.e. facing a source of light. Flies inside the faeces vault will be attracted to the light shining through the translucent bottle, and fly into the trap.

5 Urine collection system design and function

5.1 Functions of the urine collection system

The urine collection system is designed to drain the urine without the need for flushing water. Urine can be discharged into an on-site infiltration system, a sewer connection or into a storage vessel for reuse or for off-site disposal.

In the case of *disposal* it could make sense to mix urine with other wastewater streams from the toilet like hand washing or anal cleansing water since all can then be drained together into a soak pit or sewer. However the dilution of urine with water in the piping system (not the tank) can have negative effects on the piping system due to the formation of urine precipitates (urine stone) formed from dissolved salts in the urine, which can potentially cause blockages (Udert et al., 2003). Therefore an undiluted urine collection is of advantage.

A dilution of urine is also of disadvantage in a urine storage system since it would require a larger urine tank or more frequent emptying due to the higher quantity of effluent. Additionally, the increase in pH that occurs during the storage phase is less pronounced with diluted urine than undiluted urine, rendering the sanitisation process less effective (see Section 7.8.3).

However, it may be an option to mix urine with shower and hand washing water if the urine will be used in an on-site irrigation system which does not require storage (see Section 7.8.4).

In summary, the following three configurations for urine collection systems are feasible:

- Undiluted urine from UDDTs and urinals is drained directly into soak pits for disposal or infiltration trenches for reuse / disposal.
- Undiluted urine is collected from UDDTs and urinals in containers and tanks to be stored and reused in agriculture or transported for off-site disposal.
- Urine is mixed with other wastewater streams, such as hand washing or shower water and discharged into a: (1) sewer; (2) soak pit or infiltration trench; (3) subsurface irrigation system; or (4) constructed wetland or other form of treatment for subsequent use or disposal.

Foreign materials should not be introduced into the drainage system, because such objects will increase the likelihood of blockages (see Section 3.8.2).

5.2 Quantity and quality of urine

Adults excrete on average 0.8-1.5 litres of urine per day, depending on the volume of liquid consumed and extent of perspiration (WHO, 2006). This corresponds to 290-550 litres per person per year. Children excrete less urine per day, depending on their age and size.

As it leaves the *bladder*, urine from a healthy person is *sterile*. There are only a few diseases that can be transmitted through the urine of an infected person. Adherence to prescribed treatment and safe handling procedures can effectively eliminate the possibility of disease transmission during handling (Schönning and Stenström, 2004). Most bacterial pathogens encountered in urine – including *Salmonella typhi* and *paratyphi* and *Mycobacterium tuberculosis* – have survival times of less than one week in stored urine (Vinnerås et al., 2011).

Urine may also contain hormones and pharmaceutical residues. These micro-pollutants can be taken up by plants and potentially end up in the human food chain. However, the risk of health impacts as a result of ingestion of these micro-pollutants is negligible compared to other environmental health risks (von Münch and Winker, 2011).

The most significant quality concern with urine is possible cross-contamination with faecal pathogens. Handling and reuse of urine contaminated with faeces could cause transmission of diseases (see Section 7.8.2).

5.3 Design guidelines for urine piping

The urine piping system should ensure drainage with minimal odour and blockages.

The volume of urine collected in UDDTs is variable throughout the day, with lengthy stretches when no urine is collected for example at night. When urine has time to stand stagnant, it may produce offensive odours. Similarly, urine precipitates (urine stone) and slimy, viscous residues may form and can eventually lead to obstructions in the piping system. Such obstructions can be prevented by reducing the pipe length, using larger diameter piping, minimising the number of bends, ensuring sufficient slope and using no or minimal use of water for flushing.

A comprehensive description of the technical details for the design and construction of urine discharge and collection systems is available in Kvarnström et al. (2006) and Drangert et al. (2010). Their main recommendations are summarised below:

Materials: Either rigid piping or semi-rigid hoses are suitable for urine discharge systems. Plasticised PE, polypropylene (PP), polyvinyl chloride (PVC) and unplasticised PVC (uPVC) are ideal. Metal pipes are not suitable due to the corrosive properties of urine. Care must be taken when using semi-rigid hoses with a diameter less than 2.5 cm, as they can be prone to kinking. Therefore, *rigid pipes* or spiral-coiled tubes with a smooth inner surface are preferable.

Diameter: The minimum recommended diameter of the pipes is 5 cm.

Slope: A minimum slope of 5% – which corresponds to a 5 cm decrease in height for every one-metre run – is recommended in order to avoid pooling of urine in the piping system (see Figure 20). Steeper piping is, of course, even less prone to obstructions or pooling and should be incorporated into urine drainage designs when possible.

Length and bends: The total length of the piping system should be minimised in order to limit the residence time of the urine in the pipe and thus to reduce the odour generation. Bends and joints should be limited in number, as they are common points of blockage and leakage. It is best to avoid 90-degree ‘elbows’ and instead use two 45-degree bends that will create less friction and help maintain higher flow velocities. Couplings should be fitted with inspection ports to allow for inspection (see Figure 27) and for the insertion of cleaning tools.

Connections: It is crucial to make sure that all fittings and couplings are watertight to avoid leakages. Plastic pipes should be sealed with appropriate glue, or sealed using a rubber grommet.

Placement: It is important to minimise the exposure of plastic pipes to sunlight, as they become brittle with prolonged exposure to UV radiation. Exposed sections of plastic piping should be painted with UV resistant painting. Discharge pipes should be installed in a location that will prevent accidental damage or vandalism.

Figure 27. Left: Standard 45 degree coupling with inspection port (photo: internet source). Right: Two-inch plastic pipe inside a vault with sealed connections and slope exceeding 5%; the user interface with urine outlet pipe is placed from the top into the vertical pipe (photo: H. Hoffmann, 2010).

Alternatively, urine can be drained in open shallow trenches moulded into the toilet slab. This system functions similarly to a wall urinal, but may cause odour nuisances and would only be acceptable in well-ventilated outdoor toilets.

5.4 Odour control for piping and storage systems

Odours from urine collection systems can occur as a result of the urine's interaction with the atmosphere. When exposed to air, the urea in urine is gradually broken down into ammonia, which is the usual source of unpleasant odours from urine collection and storage units. The evaporation of ammonia will also lead to a loss of nitrogen, which would reduce the urine's effectiveness as a fertiliser.

Odour is emitted from stagnant urine that has pooled in a sagging hose or insufficiently sloped pipe. This has been observed in UDDTs with longer urine discharge pipes, like those common in the multi-seat installations in public toilet blocks and schools. Regardless of system length, pooling can be prevented by ensuring adequate slope, avoiding depressions at joints and couplings and minimising the number of bends.

Soak pits used for the infiltration of urine are generally not a source of odour. However, if the soak pit becomes waterlogged or clogged with particles or biomass, urine may pool at the surface and emit odours. An adequate assessment of subsurface conditions is necessary prior to the installation of a soak pit to ensure that the soil's hydraulic conductivity is suitable for infiltration.

If tanks are used for urine collection and storage, the inflowing urine displaces air in the tank (pressure equalisation), which may escape into the toilet cubicle and cause odours. The following design measures can help avoid this occurrence:

- The urine discharge outlet should be submerged near the bottom of the storage tank, creating a liquid seal inside the pipe.
- The area surrounding the tank should be well ventilated, and the tank and piping system itself should be tight, but not completely airtight in order to allow for pressure equalisation.
- The tank may be ventilated, with a ventilation pipe extending to above the roof. However, this solution is only appropriate in situations where the urine is not intended for agricultural application, as significant quantities of nitrogen will be lost to the atmosphere.

Conventional *water seals*, such as a p-trap, u-bend or 'bottle trap', are incorporated in some designs at the user interface. The urine itself acts as a seal between the toilet cubicle and the primary storage vessel, and emits minimal odour from the volume of urine contained in the trap. However, such traps can be sites for obstructions and are therefore not recommended.

The odour control strategies described in this section are most effective when combined with odour control measures at the point of the user interface, as described in Section 3.8.3.

5.5 Storage systems for urine

Urine storage tanks are required for the purpose of reuse of off-site disposal when local infiltration is not possible or desired. Storage containers and tanks serve one or more of the following four functions:

1. To sanitise the urine if urine is to be used as fertiliser in agriculture; and
2. To make urine easily transportable, in the case that small containers are used;
3. To accumulate fertiliser until the period when it is needed for agriculture, especially in areas with long gaps between planting cycles, such as cold climate areas or areas with pronounced rainy seasons;
4. To provide sufficient storage capacity for the anticipated frequency of urine tank emptying.

More information on urine treatment for the purpose of reuse as fertiliser is provided in Section 7.8.

5.5.1 Urine storage containers and tanks

Urine storage vessels should be completely watertight and equipped with a tight-fitting lid to prevent odour emissions and loss of nitrogen via ammonia evaporation. Urine storage vessels should be convenient to empty.

Urine storage systems typically employ one of the following three configurations:

- Two or more 20-litre plastic containers are alternately filled with the urine from a single household UDDT, stored for a short time, and applied to the user's crops (Figure 28). Alternatively, these containers could be collected by service providers and transported off-site for storage (examples given in Fall and Coulibaly, 2011; Suntura et al., 2012).
- Two medium-sized tanks (for example 1 m³) that are alternately filled with the urine from several UDDTs, and stored for a longer duration before use in agriculture.
- One large tank (for example 5 m³) shared between many UDDTs is emptied by a service provider and transported to an off-site storage facility.

Figure 28. Left: Urine discharge into 20L plastic container (photo: H. Hoffmann, 2009). Right: 20L collection container in an additional vault in Zambia; note the insufficient hose diameter (photo: R. Ingle, 2010).

Plastic 20-litre containers are currently the most common container for short-term urine storage, as they are widely available and can be easily transported and emptied by hand. The use of translucent containers allows the user to monitor the level of the urine and exchange the container when it becomes full (see Figure 28). Rainwater tanks (from other materials than metal) and plastic drums can be easily refashioned for urine collection and storage if larger storage volumes are required (see Figure 29).

The required storage volume is calculated by multiplying the daily urine production rate at the toilet with the number of desired storage days for either the purpose of sanitisation/reuse (see Section 7.8.3) or to achieve the desired emptying frequency.

For example, one person produces approximately 1.5 litres of urine per day, which corresponds to a total of 7.5 litres of urine produced daily by a household of five people. To account for the fact that people are not at home the entire day, this figure is reduced by one-third, resulting in 5 l/day per household. After 4 days one 20-litre container is filled up and should be stored for 14 days. Therefore a 5-person household would require approx. 5 containers of 20-litres each in order to achieve a storage time of 14 days.

For the purposes of collection, the urine containers should be placed in a dedicated chamber, a segregated section of the faeces vault or just outside of the super-structure. To allow for gravity driven drainage of the urine, the tanks must be placed on a level that provides for a sufficient slope of the pipes (see Section 5.3). In many instances, this may mean that storage vessels are installed belowground surface. Larger storage tanks are frequently installed underground. In this case, tanks should be rigid enough to support the overlying fill material without collapsing (see Figure 29). More information regarding various storage tank options and their merits is provided in von Münch and Winker (2011).

Figure 29. Left: Underground plastic urine storage tanks in Ukraine (photo: WECF, 2009). Right: Concrete urine storage tank in Sweden (photo: E. v. Münch, 2007).

Larger urine storage tanks do minimise the emptying frequency, but are considerably more costly. They may also require a urine overflow pipe that discharges into a soak pit in order to deal with unexpected overflow events. Overflow devices are not necessary for small collection vessels, as they can be more quickly and easily moved and emptied. Smaller containers should be placed on top of a soak area in order to allow for the infiltration of any overflow and avoid odours.

5.5.2 Emptying the urine tanks

Small, aboveground urine tanks can be emptied manually, while larger, underground tanks require the use of a pump e.g. with a vacuum truck. Short-term odour nuisance is to be expected during emptying activities, and should be considered during logistical planning together with users and service providers.

The manual withdrawal of urine from *aboveground tanks* requires one of several types of outlets:

Plastic water taps may be appropriate for larger aboveground tanks. Metal fittings cannot be used due to risk of corrosion. However, plastic taps are often poorly manufactured and can be at higher risk of breakage or material fatigue due to prolonged UV exposure. Therefore, these taps should be heavy-duty, sun-shaded and tightly attached to the tank to avoid leakage. Additional protection with brackets, cement mortar or other materials is also recommendable.

Figure 30. Left: Manual withdrawal of urine from an above-ground tank using a hose in Ethopia (photo: ROSA project, 2009).[18] Right: A piston pump used for urine withdrawal from an underground tank in India (photo: S. Navrekar, 2010).[19]

A simple solution can be to connect a flexible hose to the outlet at the bottom of the tank, bend up the hose and secure the end of the hose (outflow) at a higher elevation than the maximum level of urine in the tank. Urine can then be drained from the vessel by lowering the hose below the urine level (see Figure 30, left).

Urine can be withdrawn from *underground tanks* using plastic or metal hand pumps (see Figure 30, right; Morgan and Shangwa, 2010). Corrosion of metal pump components can be prevented by flushing the pump with water immediately after each use.

The cheapest but least safe method is to insert a bucket attached to a rope through a manhole opening or access port.

[18] Video about urine-diverting toilets in Ethiopia: http://www.youtube.com/user/susanavideos#p/f/44/RMqtqpdtNgo

[19] Navrekar, S. M. (2010). Collection, transportation, storage & utilization of human urine, available at http://www.susana.org/lang-en/library?view=ccbktypeitem&type=2&id=738

6 Additional design considerations

6.1 Anal cleansing water management

Anal cleansing water can be collected undiluted or mixed with urine and greywater for disposal. On average, people who practice anal washing use 1-2 litres of wash water per defecation event (Rosemarin et al., 2007). Due to the faecal content of anal cleansing water, it should be considered a waste stream and treated or disposed of safely.

In most cases, the anal washing water is drained into a soak pit for disposal. Other methods of wash water disposal include evapotranspiration in planted mulch beds (see Figure 31) and infiltration into trenches. In all circumstances, wash water should be discharged into coarse material below the ground, but well above the water table, to avoid groundwater pollution (see Section 7.6.1).

Faecal particles suspended in wash water may eventually clog soak pits. Consequently, coarse filter material, such as stone, crushed brick or gravel, should always be used to fill the soak pit. If mixed with other domestic greywater sources, a pre-treatment system may be required. Clogging is inevitable in most soak pits, thus requiring rehabilitation or relocation of the pit eventually. More information related to treatment, infiltration and reuse of domestic wastewater is provided by Morel and Diener (2006), Tilley et al. (2008) and Hoffmann et al. (2011).

Figure 31. Left: A planted soak pit for anal wash water with a container for urine collection in India (photo: L. Dengel, 2009). Right: An unplanted soak pit filled with crushed brick in Bangladesh (photo: M. Alam, 2011).

6.2 Indoor applications

Passive ventilation of the vault and toilet cubicle is less effective for indoor toilets, and therefore they may require more substantial ventilation systems to prevent odour in the house (see Section 4.9). If the location does not allow for adequate ventilation, the user should apply additional cover material to adsorb odours, and ventilate the home through windows (see Figure 32 and Figure 55).

Figure 32. Examples of indoor UDDTs with bench design being integrated houses and even existing bathrooms (photos: H. Hoffman, 2011).

There is some anecdotal evidence suggesting that the use of compost as cover material may adsorb odours very efficiently[20] (see Section 4.4 on cover materials). Covering the faeces drop-hole with a tight-fitting lid may also prevent transmission of odours into the toilet cubicle.

Wind propelled ventilation systems may be effective in relatively windy environments, but do not provide a significant airflow during calm conditions. The most effective, but more expensive, option is the installation of electrical fans to exhaust moisture and odour from the faeces vault, as exemplified by the 'Villa design' of the Swedish firm *Separett* (see Section 10.2).

6.3 Using bench designs to reduce the need for stairs

A bench design can provide barrier free access to a UDDT, as it can significantly reduce the need for stairs leading up to the toilet (see Figure 35 and Figure 57, left). A comfortable bench height of between 36 and 45 cm will usually require only two additional steps, as opposed to four, in order to provide e.g. a height of 80 cm of a dehydration vault. Certain indoor designs may eliminate the need for stairs entirely.

Steps can be built directly in front of the bench, in front of the super-structure, or in a combination of the preceding two options. Steps in front of the bench can provide a comfortable footrest for a user seated on the toilet. Most composting toilets also use such bench designs.

6.4 Buckets and scoops for cover materials

A bucket or other container must be provided to store dry cover material inside of the toilet cubicle (see Section 4.4). Scoops, cups or spades can be used to pour a consistent amount of dry material into the faeces drop-hole following defecation. The cover material should be stored in a heavy receptacle, as this type of container is less likely to slide or

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[20] http://inodoroseco.blogspot.com/

tip over when material is withdrawn, allowing for more hygienic one-handed removal of cover material.

6.5 Waste bins for hygiene articles

Sanitary pads and other sanitary products should be collected separately in bins, as they are usually not biodegradable and will not decompose in the faeces vault. These bins should be equipped with a tight-fitting cover. If the vault contents are to be disposed of via burial, menstrual hygiene articles may also be discarded in the vault, though the vaults will fill up faster in that case.

The guidelines for waste bins in schools and other public settings are the same for all types of toilets. Under ideal circumstances, waste containers should be fixed to a wall or similar to avoid toppling over. A disposable bag should be provided for the bin to enable easy and hygienic removal of the waste. If no bag is available, the bin should be removable so it can be easily emptied and cleaned. Bins should be emptied frequently to avoid odours.

6.6 Menstrual hygiene management and gender-specific issues

Toilet designs often neglect the specific needs of female users. It is crucial to account for gender-specific necessities like security, privacy, sanitary pad disposal and possibly washing of sanitary items and clothes in the design of UDDTs especially for schools and public settings. To ensure that women's needs are met, female users should have a high level of involvement in the planning and implementation of the UDDTs. More information regarding gender-specific requirements is provided in Wendland et al. (2011b).

Figure 33. Left: Example of a simple concrete hand washing basin inside a toilet cubicle. Right: A simple water dispenser made from a 5-litre plastic bottle (photos: A. Shangwa, 2010).

It is critical for menstrual hygiene management that female users are able to discard sanitary pads inside the toilet cubicle in privacy, ideally into covered waste bins. Plans for the final disposal of this waste must also be incorporated into the management plan of the toilet. Many public institutions and schools plan to incinerate sanitary pads, but often lack the required fuel or commitment to do so. In such situations, school grounds can become littered with hygiene waste, causing embarrassment to girls.

Female users may also need to wash themselves and certain sanitary items during the menstruation days. This should preferably take place inside the toilet cubicle, provided there is adequate space for a washbasin. In areas where anal washing is practiced, the anal washbasin may be suitable for menstrual hygiene activities. Care must be taken by the users not to spill any water into the vaults during washing. Water can be carried to the toilet in a small container (see Figure 33, right) if a piped water supply is not available.

Separate wash and change cubicles are also an option for school UDDTs. However, Shangwa (2011) has found that school girls often feel embarrassment when using separate facilities, as they believe it indicates that they are currently menstruating. Embarrassment surrounding menstruation is a risk factor for school dropout rates amongst girls in many developing countries.

If a UDDT is used during menses, blood may soil the toilet bowl or pan. Basic cleaning supplies should be available in the toilet to clean the UD basin. Menstrual blood does not pose a threat to the hygienic condition of urine, faeces or wash water, as the pathogen content and total volume of the blood are negligible (WECF, 2006).

6.7 Modifications for small children

Young children in primary schools may require a reduced seat size and lower sitting height for comfortable usage (see Figure 34). For squatting pans, the drop-hole diameter and the distance between the urine basin and faeces hole should be reduced. Footrests and urinals, if included, must be adjusted according to the users' height.

At the household level, it is not practical to provide different toilets for young family members. Here, moveable seat adapters may be the most appropriate solution (see Figure 34, left).

Figure 34. Left: A movable child seat adapter for a bench design in Peru (photo: H. Hoffmann, 2009). Right: Lowered UD pedestals for children at a school in Georgia (photo: WECF, 2010).

6.8 Hand washing facilities

All toilets should have a hand washing facility either attached to, adjacent to or inside of the toilet cubicle. If a water connection is available, piped hand wash stations are advisable. If not, then simple facilities can be constructed from cans, plastic bottles or modified tanks with a tap. More information on affordable hand washing stations can be found in Morgan and Shangwa (2010) and in Section 11.2.7.

6.9 Integration of showers

Most home owners like the idea of having a shower integrated into the UDDT structure, to provide a private washing facility while minimising construction costs. UDDTs with a bench design may provide the best and safest option for shower integration, as they can easily include a separate shower area next to the toilet. Designs from Peru (see Figure 35, left) and Bolivia (see Figure 54) have incorporated showers next to a toilet bench, and drain shower water separately from other waste streams into a constructed wetland or soak pit (Hoffmann, 2012).

In other UDDT designs with squatting pans or pedestals the addition of a watertight lid for the faeces drop-hole would be possible for the purpose of integrating a shower in the same area as the toilet itself. However the risk of shower water entering the vaults due to carelessness or design shortcomings is quite high.

For example, the 'Easy Shower' which was developed by *International Development Enterprises* (IDE)[21], uses a floor drain within the toilet's squatting area to collect and drain shower water. This design places tremendous importance on the proper operation of the watertight drop-hole lids, which are very susceptible to material fatigue and likely to be misplaced. There is currently no documentation proving the feasibility of this option and, therefore, the authors do not recommend it.

Figure 35. A bench UDDT with an attached shower for the security personnel at the university of Agraria de La Molina, Lima, Peru (photos: H. Hoffmann, 2011).

[21] http://blog.ideorg.org/2011/03/

6.10 Materials for construction

There is a wide range of possible materials suitable for UDDT construction, ranging from sand and concrete to pre-fabricated products like pre-cast slabs, sanitary fittings or pipes. Most materials can be sourced and manufactured locally or purchased at commercial hardware shops (see Table 3). Often, urine separation pans or seats are not locally available and must be sourced from a company or, alternatively, produced on-site.

UDDT construction costs can often be reduced by using locally available materials like clay, wooden poles, stones and thatch that are cheap, or even for free. For example, *adobe* – a traditional building material composed of sand, clay and fibrous matter – has been used successfully for UDDTs in Peru and has resulted in low construction costs (see Section 9.3). Some UDDT components must be purchased or manufactured, including the urine separating user interface, ventilation pipes, urine piping and roofing materials. If prefabricated parts are available, they are usually affordable and sometimes even less expensive than parts moulded on-site (see Section 9.1).

Cost breakdowns and lists of materials for UDDTs in many countries are provided in case studies (see Section 11.2.1). Construction guidelines are found in Section 11.2.4.

Table 3. Possible construction materials for UDDTs.

Item	Material options
Foundation	Concrete or gravel; compacted subsoil with no organic content
Vaults	Bricks; cement slabs; chiselled natural stone; wooden or plastic framing; adobe bricks; traditional wood-clay architecture
Toilet floor slab	Prefabricated or reinforced concrete slabs moulded on-site; plastic slabs; adobe; optional finishing with tiles or painting
Super-structure and stairs	Same as vaults
User interface and drainage piping	Prefabricated plastic, fibreglass, ceramic or concrete; concrete moulded on-site; plastic piping
Ventilation pipe	Plastic; concrete moulded onsite
Super-structure and vault doors	Prefabricated wooden or metal doors with metal fittings; wood or cloth fabricated on-site
Roof and carpentry (timber work)	Corrugated iron sheets; translucent fibreglass or plastic; thatching; roof tiles; timber for roof and doors
Urine containers or tanks	Plastic containers; cisterns; decommissioned rainwater tanks
Faeces containers	Plastic; metal; woven fabric
Hand wash facility	Piped water or tanks with tap; bucket with tap; modified can or bottle; *Tippy Taps*

7 Disposal, treatment and reuse of faecal matter and urine

7.1 Overview

The activities surrounding disposal or reuse of faecal matter and urine bring the handling persons in close contact with these substances. Since the treatment of human excreta in UDDTs cannot provide complete sanitisation of faeces and urine, there is a risk of disease transmission during handling especially with regard to intestinal worm eggs in faecal matter. Therefore, the handling person needs to take appropriate care and use precautionary measures which act as additional barriers to exposure to disease transmission. These include: wearing gloves, washing hands after handling, applying post-treatment processes where appropriate, following application guidelines, and minimising the spread of faecal material in the surrounding environment. Without these multiple-barriers to exposure (see Section 7.2) the handling of excreta from UDDTs cannot be considered safe for the handling person.

Urine can be infiltrated or reused in agriculture as fertiliser after treatment. The emptied faecal matter can be buried or reused on the household's property as well as transported off-site for disposal or reuse by a service provider. Post-treatment may be necessary, depending on the extent of treatment in the UDDT and the scale of the intended reuse.

In ***large-scale systems*** where third parties are involved in handling, applying faecal soil conditioner and consuming fertilised products, WHO (2006) has established guidelines for safe use of excreta in agriculture. This is because the involvement of third parties and simply the larger scale can result in a higher risk of disease transmission. Therefore, a post-treatment step is required for the production of faecal soil conditioner from large-scale systems.

In contrast there are no guiding values on the hygienic quality of reuse products for ***household systems***, which are situations where households handle and dispose or reuse the human excreta as well as consume all fertilised products themselves. This is because members of a single household are more likely to transmit communicable diseases through direct contact, such as hugging or hand shaking, than by consuming crops which were fertilised with the household members' excreta.

Disposal of human excreta may, in many instances, be more readily accepted, practical and safer than reuse. However, an understanding of the local physical environment is necessary to ensure that the disposal pathway does not impact water resources and threaten public health. It is advisable that a detailed risk assessment be conducted prior to finalising disposal plans.

Reuse of urine and faeces from UDDTs may contribute to increased crop production. The nitrogen (N), phosphorus (P) and potassium (K) naturally found in urine and faeces are essential for plant growth, and the organic carbon in treated faecal material can contribute to the sustained fertility of arable lands. On the other hand, there are several health risks associated with improper use of especially faeces in agriculture. Farmers often use excreta in an unsafe manner, as prominently witnessed by the widespread use of untreated wastewater and faecal sludge, thereby putting themselves, traders and consumers at risk.

Reuse should be considered an option for UDDTs, rather than a 'must'. The fertiliser produced can be a welcome benefit for crop production, if the costs of collection, treatment and transport are feasible in the local economic context, and if social norms within the community tolerate consuming products fertilised with excreta. In certain contexts, reuse may also require the support of legal frameworks.

Phosphorus is a limited mineral resource that has an important role in fertiliser production. The situation is similar for potassium. Known mineral phosphate rock reserves, in particular, are becoming scarce and increasingly costly to extract. One day, recycling of excreta will be required to meet future demands.[22]

In some cases, the advantages of the UDDTs with regard to the odourless operation and the possibility for installation within the home are the most desirable attributes from a user's perspective. In other cases, reuse may be the best point of entry to stimulate interest in UDDTs.

7.2 Multi-barrier approach

The World Health Organisation has issued in 2006 the "Guidelines for the safe use of wastewater, excreta and greywater in agriculture" containing guidelines for managing the health risks associated with the use of excreta in agriculture (WHO, 2006). These guidelines promote a flexible multi-barrier approach that comprises a series of measures and barriers from "toilet to table" that reduce health risks to a reasonable level for field workers, households and consumers (Richert et al., 2010). A ground of experts has developed a multi-barrier concept for the use of urine in agriculture according to WHO guidelines (see Figure 36).

For all types of treated excreta in reuse systems, various safety measures apply.

Important barriers in connection with UDDTs are:

Barrier 1. Source separation: Urine is not contaminated with faeces, and faeces are kept dry from liquids;

Barrier 2. Storage and Treatment: Dehydration of faeces during storage in the UDDT vaults and post-treatment of faecal matter after removal from vaults;

Barrier 3. Farming-related barriers: Application techniques, crop restriction, withholding period;

Barrier 4. Protective equipment (e.g. gloves, boots) and hand washing;

Barrier 5. Food handling and cooking;

Barrier 6. Health and hygiene promotion.

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[22] http://phosphorusfutures.net/index.php and UNEP (2011)

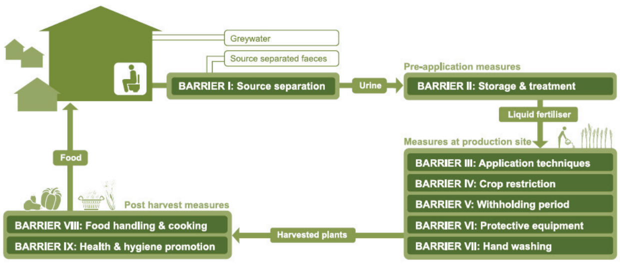

Figure 36. Multi-barrier concept for safe use of urine as a fertiliser (source: Richert et al., 2010)

7.3 Transportation of faeces

When on-site disposal or reuse of faecal matter from UDDTs is not possible, service providers are required to transport faecal matter to an off-site location. This is typically the case in urban and peri-urban areas where available land space is limited. Transport should take place in sealed containers in order to avoid spillage and to prevent contamination of the vehicles and environment, and to minimise routes of exposure to the involved persons. This may make the containerised solutions of single vault UDDTs more convenient if the faeces are to be taken off-site for disposal.

Generally service providers or local governments will provide for the collection, transport and further management of faecal matter (see Section 8.5).

Figure 37. Collection of faecal matter and urine from UDDTs with single vaults in covered barrels and yellow containers, respectively, by the NGO Sumaj Huasi in El Alto, Bolivia (photo: A. Kanzler, 2009).

7.4 Disposal of faecal matter

7.4.1 On-site burial of faeces

The simplest and most effective method for the disposal of faecal matter from UDDTs is on-site burial. This method is feasible in rural and peri-urban areas with sufficient space. Ideally, even disposal should be done 'productively' by burying faeces close to fruit trees, bushes or other plants that can make use of the nutrients and organic matter. An interesting research project on agro-forestry took place in South Africa where pit latrine sludge was buried in trenches (so called *deep row entrenchment*) and timber trees planted on top (Still et al., 2012).

Faecal matter from single vault UDDTs should receive post-treatment prior to burial. In general, on-site disposal of faecal material from UDDTs with containerised collection systems is not recommended, as it cannot be assumed that all users diligently and carefully bury the container's contents each time it becomes full. This is a critical aspect in an up-scaling context, and may necessitate the implementation of subsidies or other programmes to encourage third-party service providers to manage the excreta.

The treated faecal material should be buried under soil at a minimum depth of 25 cm to prevent resurfacing as a result of heavy rains, animal burrowing or human digging (EcoSanRes, 2005). Under ordinary circumstances, faecal material buried at sufficient depth does not pose a significant risk to human health. However, the health risks associated with the process of vault emptying and burying the contents can be increased for the involved persons and household members through contaminated surroundings (Buckley et al., 2008).

Over time, buried faeces will mineralise and ultimately become pathogen free. The complete die-off of worm eggs in the soil is, however, quite slow; *Ascaris* ova, for example, can be viable for more than 10 years in moist soils (O'Lorcain and Holland, 2000). Therefore, disposal sites should be clearly demarcated and be allowed to rest for sufficient time before the soil is disturbed again.

Faeces should be buried at least 1.5 m above the groundwater table and a minimum of 30 m from drinking water wells (Tilley et al., 2008). Heavy rains and highly conductive soils may cause upward and downward migration of matter (nutrients, COD, bacteria), possibly infiltrating drinking water aquifers (Guness et al., 2005). However, recent evidence from South Africa (see Section 7.6.2) suggests that the effects on human health from such processes are limited. Clearly, the lower pathogen loads in dehydrated faecal matter from *double vault* UDDTs reduce the risk of contamination of groundwater. In order to make the right decision about appropriateness of burial an assessment of groundwater pollution should be carried out (see Section 7.6.2).

7.4.2 Other disposal methods

There are few disposal options for dehydrated or treated faeces apart from burial. Incineration is another method. It requires that faeces have a moisture content of less than 10% in order for the material to burn at sufficiently high temperatures with acceptable odour. These low moisture levels can be difficult to achieve without post-treatment. Niwagaba (2009) suggested that low-cost, small-scale incinerators developed for the disposal of healthcare waste may be a practical solution for the disposal of dry faecal matter.

7.5 Use of faeces in agriculture

7.5.1 Recommended hygienic quality for safe use of treated faeces

The WHO (2006) 'Guidelines for safe use of excreta in agriculture' have defined health-based targets that help achieve an acceptable level of risk for the reuse of excreta. This methodology is known as the *flexible multi-barrier approach* and aims to prevent disease transmission by reducing the pathogen load and to minimise the likelihood of exposure to the remaining pathogens (see Section 7.2).

WHO also provides microbial concentration thresholds for quality monitoring (see Table 4), which can be used as a benchmark for the hygienic standard of excreta that is intended for use in agriculture. These guidelines are intended for *large-scale systems* where third parties, rather than the toilet's users, handle the excreta and consume the fertilised crop. In order to reach these values, post-treatment is usually necessary (see next Section 7.5.2). If these guiding values are not met with on-site storage and post-treatment, one must either ensure that other handling barriers and health protection measures are in place according to the multi-barrier approach, or change to disposal options.

There are no guiding values for safe use of excreta in *household systems*.

One decisive guideline value is the presence of *helminth eggs* which are found in the faecal matter of a large fraction of the world's population in tropical climates that is infected with intestinal worms (see Section 4.2.2). *Helminth* eggs are very resistant to treatment.

E. coli is used as a proxy for viral, bacterial and protozoan pathogen levels. According to the guideline values shown in Table 4, the treated faeces should contain very low levels of these indicator pathogens, but do not necessarily need to be completely pathogen-free.

Table 4. Guideline values for verification monitoring of excreta from large-scale treatment and reuse systems (Source: WHO, 2006, p. XVI).

	Helminth eggs (number per gram total solids)	***E. coli*** (number per 100 ml)
Treated faeces and faecal sludge	< 1 per gram of total solids	< 1,000 per gram of total solids

7.5.2 Post-treatment of faeces

Post-treatment, or 'secondary treatment', of faeces describes the process of treating faecal matter after it is removed from the toilet. It serves the objective of reducing pathogen content and producing a material that can be more easily and safely handled. Post-treatment may be required prior to disposal or reuse based on the level of sanitisation achieved during treatment in the UDDTs vaults and whether the excreta is intended for disposal or reuse on either a household or large-scale system.

Post-treatment of faeces from *double* dehydration vault systems for the purpose of disposal is not necessary due to its dry state after the long storage time in the vault. If the intention is to reuse the faecal material, then a post-treatment is optional but recommended for household systems and strictly required in large-scale systems.

Faecal matter from *single* vaults must always be post-treated, regardless of whether it is intended for disposal or reuse and regardless of the scale. This is because the extent of pathogen removal in single vault UDDTs is generally low. Furthermore, the faecal matter is likely to be still wet when it is removed, and therefore contain a substantial pathogen load. Moreover, as the small quantities of faeces in single vaults may not be practical for burial on a monthly or weekly basis, a post-treatment step may assist in accumulating sufficient quantities.

Post-treatment options include composting, vermi-composting, drying and storage, chemical, solar heat and heat treatment, each of which is briefly described below. It is also advisable to consider a combination of methods in order to reach good results, e.g. the combination of vermi-composting and solar drying in El Alto in Bolivia was applied for agricultural reuse purposes (Suntura et al., 2012). WHO provides a guideline on secondary treatment with treatment criteria for alkaline treatment, composting and incineration (WHO, 2006, Table 4.4) that shall be used for guidance on safe reuse of excreta.

Thermophilic composting of faeces is also called *high-temperature or heat composting* and has been widely studied to date. Results indicate that sufficiently high temperatures for pathogen destruction throughout the entire compost heap are difficult to achieve. Temperatures of greater than 50°C maintained in the faeces pile for more than one week, and temperatures exceeding 60°C maintained in the pile for a 24-hour period have been shown to result in complete pathogen die-off (Niwagaba, 2009 and Feachem et al., 1983).

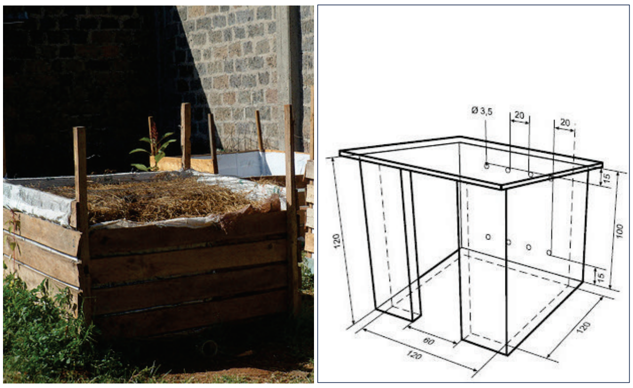

Figure 38. Left: A Co-composting of fresh human excreta and wood shavings (saw dust) in an actively aerated (with air blower) composting box of *Sanergy Inc*. in Nairobi, Kenya (photo: D. Mbalo, 2012). Right: Diagram of a compost chamber with removeable roof (source: Germer et al., 2010).

Temperatures within the faeces pile tend to be variable, leading to insufficient pathogen elimination and also allowing for the re-growth of microorganisms in cooler outer zones. Frequent turning of large-scale compost piles and insulation of small-scale compost piles can overcome such temperature distribution problems (Germer et al., 2010).

For example, confining faeces in separate concrete, brick or wooden vaults may help maintain temperatures exceeding 50°C for long enough to completely sanitise the entire batch (Niwagaba, 2009). Frequent turning is required to ensure homogeneous temperatures. Moist faeces from single vault systems may be readily composted, whereas dry faeces will need to be rehydrated for composting.

Mesophilic and low-temperature composting is the simplest method of producing good quality compost, but does not achieve a significant sanitising effect.

Figure 39. Left: Twin pit composter with two ringbeams used for low-temperature composting (photo: P. Morgan, 2007). Right: Earthworms used for vermi-composting (photo: E. Morin, 2010).

Faeces are placed in a heap or shallow pit with other organic matter and the material is gradually broken down into humus over a period of weeks or months (see Figure 39 left). As no thermophilic processes are aimed for, the material does not require turning. This methodology is not recommended as a viable post-treatment option in large-scale systems due to the negligible effect on the pathogen load, though it is viable on a household level with single vault systems.

Vermi-composting is a low-cost secondary treatment method that processes faeces through the activity of earthworms and other mesophilic microorganisms.

Figure 40. The Bolivian NGO Sumaj Huasi is vermi-composting faeces with subsequent solar drying in the same compartment in El Alto, Bolivia (photo: H. Hoffmann, 2012).

It is not yet proven that vermi-composting can provide for the complete sanitisation of faecal matter (see for example Buzie-Fru, 2010). Therefore, vermi-composting cannot be recommended as a viable post-treatment option until more conclusive results are available.

Prolonged storage can be an option in order to further reduce the pathogen load (see Figure 41). It can take place either inside a dehydration vault or external[23] to the UDDT. WHO (2006) suggests that relevant guideline values for safety (see Table 4) can be achieved with a storage duration of 1.5 to 2 years at temperatures between 2-20°C, and approximately one year at temperatures from 20-35°C.

Figure 41. Left: Prolonged storage of dry faeces from double dehydration vaults in Burkina Faso (photo: A. Fall, 2009). Right: Drying shed with faecal matter from single vaults in Kenya (photo: L. Kraft, 2011).

Stenström et al. (2011) have conducted research on storage times and resulting pathogen reduction results with regard to reuse. Their results indicate that in highland subtropical areas with average temperatures in the 17-20°C range, a prolonged storage time of 18 months will effectively reduce health risks if the product is to be applied directly from the vaults. The storage time can be reduced to 12 months if subsequent sun drying is carried out prior to reuse. Furthermore, in lowland tropical regions with average temperatures in the 28-30°C range, a storage time of 10-12 months is necessary for direct application; this can be reduced to 8-10 months if subsequent sun drying is carried out.

Chemical treatment of faecal matter has been successfully demonstrated with urea. The enzymatic degradation of the urea releases ammonia, which is toxic for pathogens (Fidjeland and Vinnerås, 2012; Nordin, 2010). This process is alternatively referred to as 'ammonia sanitisation' (see Figure 42). The treatment is quite easy to manage as it only requires an airtight storage facility to avoid ammonia losses by evaporation, and sufficient ammonia concentration and treatment time for pathogen inactivation. It has not yet been proved at a larger scale.

Solar sanitation is a similar method for treatment of faecal matter that uses solar radiation for either further drying or heat treatment. For example, in El Alto in Bolivia the faecal

[23] Extensive experience with prolonged storage in drying sheds has for example been documented during the ROSA research programme in East Africa: http://rosa.boku.ac.at/ and http://www.susana.org/library?search=ROSA

matter is initially vermi-composted and then dried in the same compartment with plastic covers (see Figure 40). Another way of using solar energy for post-treatment is through use of reflective parabolic panels to concentrate solar energy onto the surface of a black steel cylinder (see Figure 42, right). The start-up company *Sanivation* has tested this technology for faeces treatment in Chile, and measured temperatures up to 80°C inside the containers, allowing for the inactivation of greater than 99% of pathogens in less than one day. Scientific data is currently being made available.[24]

Figure 42. Left: Urea treatment of faecal sludge from pit latrines in Kampala, Uganda (photo: E. v. Münch, 2012). Right: Solar concentrator by *Sanivation* heating faecal matter from UDDTs in a black drum in Chile (photo: A. Foote, 2010).

Solarisation under plastic sheets[25] may be an option in hot climates. Solarisation is a simple method widely used in agriculture to control diseases, nematodes and weeds in sludge (Elmore et al., 1997). The plastic sheets allow the sun's radiation to be trapped, causing high temperatures in the soil's upper layers. The faecal matter needs to be wet in order to conduct the heat. Hence it is not a method for drying. However, this method has not yet been documented for post-treatment of faeces, and therefore is not recommended until more conclusive data becomes available.

In ***heat treatment*** the faecal matter is heated up by means of electrical power, microwaves or other heat sources to high temperatures that will achieve quick sanitisation. Such a system is currently being tested for pit latrine sludge in South Africa, called LaDePa (Harrison and Wilson, 2012).

7.5.3 Application guidelines in agriculture

As mentioned before, the use of faeces from UDDTs as a source of organic matter and nutrients for crop production involves some health risks. Therefore, additional safety barriers should be applied according to the multi-barrier approach such as crop restriction, withholding time and hand washing with soap to minimise possible routes of disease transmission (see Section 7.2). The most important rules for the safe application of treated faeces are described below:

- Treated faeces should be worked into the soil rather than distributed on the surface. Ideally, treated faeces will be buried under at least eight centimetres of soil (Schönning and Stenström, 2004).
- Treated faecal matter should not be applied to fields where it may be re-exposed through tillage or soil erosion.
- Application of treated faeces is safest when applied to fruit trees, rather than vegetables or root crops. Crops that are processed further, such as coffee or cotton, are also low-risk crop options.

Faeces are valued in agriculture for their high content of organic matter which acts as a soil conditioner. The organic matter increases the soil's water holding and ion-buffering capacity, serves as food for sub-surface microorganisms and improves soil texture (WHO, 2006). Moreover, faeces contain considerable amounts of the nutrients nitrogen, potassium and phosphorus, as well as other micronutrients. These nutrients are slowly released as the faeces are degraded in the soil by microbial activity. If ash has been used as cover material in the UDDT, it may also provide an additional source of potassium.

If non-biodegradable materials, such as sanitary pads, have been discarded in the faeces vaults, the treated vault contents need to be sieved or screened prior to agricultural reuse.

7.6 Disposal of urine by infiltration

The infiltration of urine into the soil can be a viable option to dispose of urine in instances in which the risks of groundwater pollution are negligible or groundwater is not used as a source of drinking water. On-site infiltration is the simplest method of urine management, as it does not require storage, treatment or transportation of urine.

On the other hand, disposal of urine can be regarded as wasteful of valuable resources contained in urine such as phosphorus, nitrogen, potassium, sulphur and micronutrients that can stimulate plant growth. However, there are valid reasons why urine might not be used as fertiliser, including land limitations, distances to agricultural areas and social or cultural reasons. This is for example the case in peri-urban and rural areas of eThekwini Municipality, South Africa, where urine from 75,000 UDDTs is being disposed of via infiltration since 2003 (Roma et al., 2011).

Infiltration can also be done in a productive and environmentally safe manner. Urine can be infiltrated close to fruit trees, bushes or other plants that can make use of the nutrients contained in urine, and thus reduce the risk of contaminating groundwater with nitrate and other pollutants like pharmaceutical residues.

7.6.1 Soak pits and infiltration trenches

Urine can be disposed of via on-site infiltration in a soak pit or subsurface infiltration trench.

[24] http://www.susana.org/images/documents/07-cap-dev/b-conferences/12-FSM2/a4.4-fsm2-woods-sanivation-georgia-usa.pdf
[25] http://www.infonet-biovision.org/default/ct/238/recipesForOrganicPesticides

A *soak pit* – also called a soak away or leach pit – can be covered or uncovered, and either empty or backfilled with coarse material. Depths can range from about 1.5-4 m, depending on the anticipated volume of urine and the hydraulic conductivity of the soil. The pit may be lined with a porous wall to provide structural support. Technical details for construction can be found in Tilley et al. (2008).

Figure 43. Left: Construction of a subsurface infiltration trench with gravel for greywater and urine at a school in Peru (photo: H. Hoffmann, 2009). Right: Urine is infiltrated next to an *Arborloo* in Zimbabwe (photo: P. Morgan, 2007).

A concrete ring beam with a lid should be placed at the top of the soak pit to raise it slightly aboveground level and thus clearly demarcate its location. Foreign materials often fall into or are placed in uncovered pits, increasing the likelihood of clogging. Therefore a cover is of advantage.

Alternatively, an *infiltration* trench offers another infiltration option. Such a trench is composed of an approximately 5 cm diameter punched pipe, or diffuser, that is attached at the discharge point of the urine drainage system. The diffuser is placed in an approximately 0.5-1 m deep gravel lined trench (see Figure 43) and the urine is discharged into the subsurface over the length of the diffuser. Vegetation can be planted alongside the trench to make use of the urine nutrients.

Under certain circumstances urine may be drawn back towards the surface by evaporation and capillarity, leading to salinity issues but also increasing the likelihood that the nutrients in urine will be taken up by plants which may be planted next to the infiltration trench. The fate of the infiltrated urine depends on the quantity, infiltration basin size, as well as soil and climatic conditions.

Urine can infiltrate deep into the soil, potentially reaching groundwater resources. Therefore it is important to conduct an assessment of groundwater pollution (see following Section) prior to the implementation of urine infiltration in order to prevent unexpected environmental pollution.

7.6.2 Assessment of groundwater pollution

As with pit latrines, infiltration of urine from UDDTs may cause elevated nitrate (NO_3) concentrations in groundwater. The risk of disease transmission from urine into groundwater is rather negligible, unless there is significant cross-contamination with faecal material.

Therefore, the decision to opt for infiltration of urine must be based on the identification of current and medium-term drinking water resources. If local groundwater is the sole source of drinking water, a thorough risk assessment must be conducted to assess the potential impacts on the aquifer due to urine infiltration. Such an assessment must take into account the groundwater level, soil conditions and evapotranspiration potential of vegetation above.

Groundwater with elevated nitrate concentrations which is drunk by infants has been linked to the disease *methaemoglobinaemia*, or 'Blue Baby Syndrome'[26]. Widespread nitrate contamination of groundwater resources and its effect on public health has been well documented in several countries, for example in Romania.[27] Nitrate concentrations of less than 25-50 mg per litre are generally considered acceptable drinking water standards in Europe (Foppen et al., 2011).

A recent study from South Africa on the migration of contaminant plumes from low-flush toilets with leach pits suggests that concentrations of bacteria, nitrates and phosphorus decrease very rapidly with distance from the infiltration basin (Still and Louton, 2012).

In the event that a detailed risk assessment is not feasible, the general guidelines for the placement of pit latrines may be applied to soak pits. In this case, the bottom of the soak pit should be located a minimum of 1.5 m above the maximum groundwater level and at least 30 horizontal metres from the nearest groundwater well (Tilley et al., 2008). In areas with a high risk of groundwater contamination (highly conductive soils, high water table, heavy precipitation) and where groundwater is the sole source of water, soak pits should not be used. In such scenarios, reuse of urine in gardening and agriculture should be promoted instead.

7.7 Off-site transportation of urine

Vehicular transport of urine may be necessary when on-site disposal or reuse is not possible and the location for agricultural use, storage treatment or disposal is far from the UDDTs. Urine may be transported in plastic vessels, barrels or 'big packs' (1 m^3 plastic cubes) loaded on trucks or donkey drawn carts (see Figure 44).

Very large volumes of urine may even make the use of vacuum trucks necessary. Transportation systems have been successfully implemented at a pilot scale in Burkina Faso (Fall and Coulibaly, 2011) and Bolivia (Suntura et al., 2012). Transportation costs for urine may be prohibitive because of the much larger quantities compared to faeces, unless they can be recovered through the agricultural reuse of urine (see Section 9.2).

[26] http://www.wisegeek.com/what-is-blue-baby-syndrome.htm#did-you-know
[27] http://www.wecf.eu/english/publications/2006/sustain_all.php

Figure 44. Left: Urine transportation by tricycle in India (photo: S. Navrekar, 2010). Right: Donkey cart used for urine transport in Burkina Faso (photo: A. Kameni, 2010).

7.8 Use of urine in agriculture

7.8.1 Recommended hygienic quality for safe reuse of treated urine

If faecal cross-contamination is not significant, health risks associated with the reuse of urine are low as the urine from a healthy person is sterile (see Section 5.2). In general, the WHO guidelines described in Section 7.5.1 for faeces are also applicable for urine. It is also recommended that the multi-barrier approach is employed when handling urine to reduce the possibility of disease transmission (see Section 7.2).

7.8.2 Faecal cross-contamination of urine

When urine is separately collected using a UD toilet interface, some faecal matter may accidentally fall into the urine diversion section resulting in the cross-contamination of urine. Cross-contaminated urine contains faecal pathogens, presenting a risk of disease transmission during handling, application and harvest. Therefore, appropriate treatment measures – especially storage – and a multi-barrier approach must be implemented to reduce health risks.

The risk of faecal cross-contamination of urine is higher for *large-scale systems,* for example if urine is collected from public and institutional environments with a high fluctuation of users, many of which are not accustomed to UDDT use. The risk of faecal cross-contamination is considerably lower in household systems with experienced users or if urine is collected in urinals.

7.8.3 Treatment of urine by storage

Storage of urine in closed containers is a viable and practical treatment option for the purpose of preparing urine for use as fertiliser. See information on container and tank in Section 5.5.1.

The factors determining the survival of pathogens in urine are storage time, temperature, pH and ammonia concentration. Temperatures exceeding 20°C, pH greater than 9, high ammonia concentrations and prolonged storage times have been shown to decrease pathogen levels significantly. Ammonia concentrations and pH can be negatively influenced (reduced) by dilution of urine with water (Niwagaba, 2009).

The decomposition of urea in urine into ammonia and hydrocarbonate leads to an increase in ammonia concentration and an increase of pH value to above 9. Both processes are effective in killing of pathogens, and are more efficient in warm temperatures and with low dilution of the urine.

Recommended storage durations are dependent on ambient temperatures and on whether the urine was collected in households or large-scale systems and, whether the urine will be used to fertilise crops that are eaten by the household members or sold commercially (Richert et al., 2010). The following storage recommendations can be applied in most situations (Richert et al., 2010):

- Household systems or urinals require only *one to two weeks of storage* when the family is using urine in a local garden and the produce is consumed entirely by the household members (see Section 7.1).
- For large-scale systems and situations in which food was fertilised with urine and is consumed by others: If the urine is used on food or fodder crops that are cooked before consumption, it requires a urine storage time of *at least one month of storage*. For crops that are eaten raw, a storage time of at least *six months* is recommended.
- Fresh, unstored urine should *never be used as fertiliser in areas where typhoid and paratyphoid* cases are suspected.

7.8.4 Application guidelines

There is extensive documentation on how to use urine as a fertiliser in a wide range of contexts gathered over the last decades.[28] For this reason, only some key points regarding urine application are presented here.

- Urine is a well-balanced fertiliser containing nitrogen, phosphorus, potassium, sulphur and various micronutrients that can create crop yields consistent with those expected from synthetic fertilisers.
- The urine collected from one person over the course of one year is sufficient to fertilise 300-400 m² of crops[29] to a level of approximately 50-100 kg N/ha.
- Urine can be applied to the *soil* pure or diluted with water.
- Both pure and diluted urine should be applied to the soil around the plant, rather than directly onto the plant, to avoid 'burning' of plant leaves and reduce risk of disease transmission. Subsequent irrigation with pure

[28] See, for example, Gensch et al. (2011b) from the Philippines; Richert et al. (2010); Morgan (2004) from Zimbabwe; and Ecosan Club (2010a) from East Africa. Information gathered from rural Niger is available in French and English: www.susana.org/library?search=Aguie.

[29] 1 acre = 4,046 m², 1 hectare (ha) = 10,000 m²

- water and manual covering with soil are advisable. Most commonly, an approximately five centimetre deep depression is formed above the root mass, filled with urine and covered with soil.
- Urine should not be applied in the last month prior to harvest in order to decrease the likelihood of disease transmission.
- Fertiliser nutrients are typically most effective immediately before sowing and during the plants' vegetative growth period.
- Fertilisation of fruit and timber trees is the safest way of reuse of urine as potential transmission of pathogens is minimal.

If urine is mixed with anal cleansing water or greywater, it is getting contaminated and may be rendered unsafe for application as fertiliser. However, *subsurface irrigation* can provide a safe application technique and may be especially advantageous in arid regions. *Drip irrigation* systems have been adapted for using a mix of urine with shower water (Clouet, 2010). Drip systems distribute water directly to plants through a length of perforated hose that is placed at ground level adjacent to crop rows. Urine precipitation may clog the small holes though. Due to lack of data, this application method cannot be recommended.

8 Operation and maintenance

8.1 Overview

As with any toilet, the full benefits of UDDTs can only be realised when they are used, operated and maintained properly. However, operation and maintenance (O&M) activities are often inadequate due to a lack of 'maintenance culture', insufficient sense of ownership, poor training and minimal funding. Successful models of O&M systems for UDDTs are described in Ecosan Club (2010b) and Müllegger et al. (2012).

UDDT operation is relatively simple, with certain rules and routines that must be regularly followed. If the toilet is operated properly, the need for intensive maintenance is very infrequent. Adherence to a regular O&M programme will keep the toilet clean, free of odour and flies, and urine pipes free of blockages. All basic O&M tasks can be performed by the user, including the emptying of vaults and maintenance. However, most UDDTs installed in schools, institutional settings and urban areas will benefit from the use of service providers to conduct O&M activities (see Section 8.5).

Experience has shown that in the case of shared communal toilets, each toilet cubicle should be allocated to specific families, so that they feel responsible for cleaning it and for instructing guests on its proper use. It is very important to clarify the O&M processes during the planning stages, and to clearly allocate responsibilities and incentives to certain caretakers or providers before the toilet becomes operational.

8.2 Using the toilet

The user needs to be made fully aware of the toilet's usage procedures, and must be able to differentiate between the urine diversion and faeces section of the user interface.

One of the UDDT users or the caretaker should be responsible for refilling the container with cover material. In the event that adequate cover material is unavailable, consult Table 5 in the trouble shooting section of this document.

Faeces fall straight down the drop-hole without touching or soiling the walls. However, when ash is used as cover material, it can easily soil the pan or pedestal. Moreover, instances of diarrhoea, drunkenness, use by unaccompanied children, and acts of mischief may require cleaning. A rag, sponge or toilet paper should be available for the user or caretaker to quickly clean up. A small spray bottle filled with water or with a water-vinegar solution may be beneficial to help wipe clean the urine pan during menstruation.

Figure 45. Left: A student demonstrates how to spread sawdust over the faeces in Tajikistan; Right: Use of covering material in Bulgaria (photos: WECF, 2009 and 2007).

Prior to anal cleansing with water, the user of a squatting pan should always cover the faeces drop-hole and shift his or her position over the anal washing basin (see Section 3.3.3 and 3.4.3).

The installation of illustrated posters inside the toilet cubicle helps to encourage correct toilet use (see Section 11.2.5 and Figure 47). A training on both day-to-day toilet use and basic trouble shooting measures should be mandatory for users, owners and caretakers of all new UDDT installations.

8.3 Routine operation

8.3.1 Daily and regular tasks

Proper operation of UDDTs requires the following tasks to be performed daily or when necessary:

- Provision of cover material;

- Provision of water or toilet paper for anal cleansing;
- Provision of water and soap for hand washing;
- Sweeping the toilet cubicle and cleaning with a mop or rag;
- Cleaning of the urine diversion seats or squatting pan with a damp cloth or water-vinegar solution;
- Emptying the waste bin;
- Checking the volume of faeces in the dehydration vaults and levelling the pile when necessary (this is important because the faeces tend to form a mound under the drop hole; the levelling is best done by using a stick or long-handled shovel either via the drop hole or via the vault door if the pile is not so high already that it would spill out when the vault door is opened); and
- Checking the level of urine in the collection vessel and emptying when necessary.

8.3.2 Cleaning urine piping system

In the event that the urine piping system becomes obstructed, simple tools such as mechanical pipe cleaning snakes or bottle cleaners can be used. Access points should be installed at each bend to allow for the insertion of cleaning tools. Periodic rinsing of the urine discharge piping with warm water and caustic soda can be an effective measure to prevent the build-up of urine stone deposits (see also Table 5).

Figure 46. Cleaning and maintenance tools for a UD toilet (photo: E. Peterson, 2006).

8.3.3 Switching dehydration vaults

When the active vault becomes full, the faeces drop-hole of the user interface should be covered (if two user interfaces are installed) and the vault should be allowed to rest. The lid should be fixed tightly so that it is not mistakenly removed. The lid prevents the addition of fresh faeces to the contents of the resting vault.

If only one user interface is used, it needs to be moved above the second vault and the opening in the toilet slab above the first vault should be covered (see poster in Figure 47 and Figure 52 on the right). When realigning the UD interface over the second vault, the urine funnel must be perfectly aligned over the fixed discharge pipe to avoid urine spillage into the faeces vault.

8.3.4 Emptying dehydration vaults

When the inactive dehydration vault has rested for at least six months (after last use) it should be emptied by using the vault access doors at the rear of the toilet. The dry faeces can be removed using long-handled shovels. They are then placed in a wheelbarrow or other means of transport, and taken to the designated disposal, reuse or post-treatment site (see Figure 37).

Health risks during emptying are generally high, especially for service providers who are more frequently exposed. In order to minimise health risks the multi-barrier approach should be followed (see Section 7.2). Accordingly it is critical that during emptying and transport of dried faeces the involved persons (users or service providers) make use of personal protective equipment such as boots, gloves, face masks and clothing that provides full body coverage. After handling of dried faeces, hands should be washed with soap and the equipment should also be cleaned. Care should be taken to ensure that the area surrounding the vaults is not contaminated through spillage.

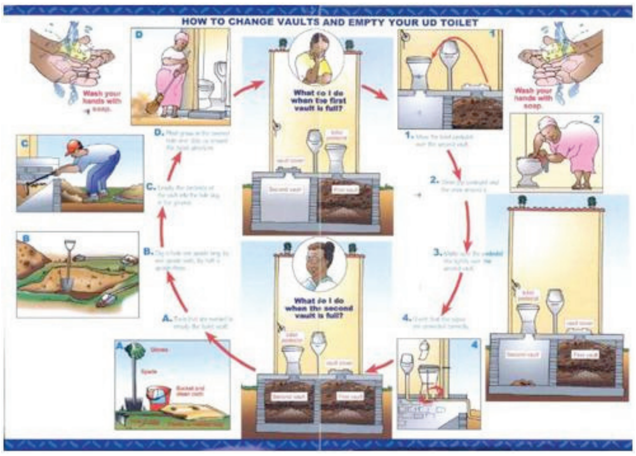

Figure 47. Instructional poster depicting how to switch between vaults and empty dehydrating vaults from eThekwini Municipality, South Africa (source: Roma et al., 2011).

Ideally, households should have the option paying a commercial service provider to empty the vaults, as is usually possible for emptying septic tanks and pit latrines. Such service providers will most likely offer their services once there is a sufficient demand for faecal matter management in a given area.

For example, several affordable service providers have been established in Kampala, Uganda. UDDT owners who prefer not to empty the vaults themselves can contract the private providers.[30] Successful vault emptying services have also been implemented in Ouagadougou, Burkina Faso (see Figure 48 and Section 9.2), eThekwini, South Africa and in El Alto, Bolivia. Descriptions of available services and tariffs for each of these examples can be found in Fall and Coulibaly (2011), Roma et al. (2011) and Suntura et al. (2012), respectively.

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[30] Information obtained from Dr. C. Niwagaba, Makerere University, Uganda

Figure 48. Left: Emptying the inactive vault of a UDDT after a six-month storage period in Ouagadougou in Burkina Faso. Right: Emptying the urine containers in Ouagadougou (photos: S. Tapsoba, 2009).

8.3.5 Switching interchangeable containers

Once a faeces container becomes full it must be switched with an empty container. The full container can be pushed into a corner of the vault for temporary storage, or immediately removed from the vault. The container should be covered with a lid during removal and transport to prevent spilling of faecal material into the environment. Containers should be superficially cleaned after emptying. The use of disposable or biodegradable bags or newspaper inside of the container may reduce the required cleaning.

Exchanging containers is a relatively frequent process, occurring on average between once per week and once every three months. The fresh faeces on top of the pile should be well covered with dry cover material, making the container removal inoffensive. When done properly, no direct contact with the faecal matter is taking place.

8.3.6 Emptying urine containers and tanks

When urine is collected in containers or tanks, the user, caretaker or service provider must replace or empty the containers before they overflow. Installing a security overflow pipe on bigger storage tanks into a soak pit can mitigate the effects of accidental overflows (see Section 5.5.1).

8.4 Routine maintenance

Maintaining any type of sanitation system requires careful planning and may demand additional financial expenditures in the event of hardware failure or to pay service providers. UDDTs may require the following maintenance routines:

- *Removing obstructions from the urine piping*, such as ash, faeces, dirt or precipitates that may accumulate over the period of the toilet's use;
- *Keeping the vault doors intact* in order to protect the vault contents from rainwater and animals. This may include replacing door locks and hinges, and resealing the door panels;
- *Maintaining the ventilation pipes* and their rain covers;
- Regular *inspection of the urine infiltration system* for pooling and other indicators of clogging; and
- *Minor repairs* related to wear and tear**.**

8.5 Service providers for O&M

In urban contexts and institutional settings, service providers should be engaged to deal with collection, transport and disposal or treatment of excreta in a manner that is not hazardous to human health or detrimental to the environment.

Faeces management may be complicated in urban areas. Most urban dwellers prefer not to interact with faeces at all, especially where shared toilets are used. Furthermore, the limited land space for disposal may make it impossible for users to deal with their own excreta within their plot. While urban UDDT owners are usually willing to pay for such services, capable service providers are often not available or affordable. Also it can be difficult to make such a service commercially viable if the number and density of UDDTs is not high enough in a given area. Accordingly, when implementing UDDTs in urban areas, an affordable and reliable sanitation services provider must be established.

It is essential to provide a financially feasible service provision to guarantee long-term performance (Section 9.2). Prohibitive service fees and weak environmental enforcement are likely to increase the risk of users or service providers practicing clandestine dumping of untreated excreta. Such behaviour has serious implications for public health. Encouraging affordable service provision for comprehensive collection, transport and disposal or reuse services may be the most practical way of discouraging this practice. Ensuring affordability may, in many cases, be dependent on subsidies of services.

Additionally, it must be enforced that service providers use disposal methods that are in compliance with environmental laws or other accepted standards. In areas with no reliable service providers, it may be safer to begin with building UDDTs with dehydration vaults that can be converted to containerised collection systems later when service provision becomes viable.

8.6 Common problems and trouble shooting

The use and maintenance of UDDTs is not always intuitive or immediately apparent to users who are accustomed to 'drop-and-forget' or 'flush-and-forget' systems. Consequently, toilet owners, users and service providers should be trained in UDDT specific O&M procedures and protocols during the planning and implementation phases of the sanitation system. Furthermore, a clear chain of responsibility for the maintenance and trouble-shooting procedures should be established.

UDDTs are often abandoned because of common, easy to solve problems. The following section describes the most commonly encountered operational problems with UDDTs, and describes possible solutions for each (Table 5). It is recommendable to develop short trouble shooting manuals for users, as problems should be attended to immediately.

Table 5. Trouble shooting for UDDTs including problems observed (symptoms), possible causes and how to rectify them.

1. Urine has accumulated in the UD (urine diversion) section of the user interface

Possible causes

Foreign objects, such as ash, toilet paper or faeces, have been deposited in the UD section of the user interface and become lodged in the urine drainage funnel or discharge piping. The formation of urine precipitates or various construction problems, like small pipe diameter, insufficient slope and poor material selection, may also be the cause.

What to do?

- ✓ Unblock the urine pipe. This is usually easily done with a rod, wire, mechanical snake or similar tool.
- ✓ If the pipe has clogged due to urine precipitates and slime, scrub with a bottle cleaning brush. If persistent, pour hot water with caustic soda into the piping to remove precipitates that stuck to the pipe walls. Half a litre of solution should be poured through each urinal and UD pan, and flushed with warm water.
- ✓ Make sure the piping is at least five centimetres in diameter and installed with a minimum slope of 5%.
- ✓ Make sure there are no sharp bends (kinking) in hoses. If bends are present, the hosing should be replaced with rigid pipes.
- ✓ Mount instructional posters in the toilet cubicle and offer continued training to toilet users.
- ✓ Provide special seats for children in the case of sitting toilets and insist that mothers or other responsible persons accompany small children in the toilet.

2. Foul odours are emitted from the faeces vault

Possible causes

The contents of the faeces vault have most likely become too wet. The most common cause is user error, resulting from male users urinating into the faeces vault, anal wash water entering the vault, carelessness while cleaning the toilet cubicle, showering or washing hygiene articles, insufficient application of cover material, or too many users. Construction errors, such as leaking urine pipes, holes in the toilet floor and material fatigue should also be investigated.

What to do?

- ✓ Add more cover material and make sure all the faeces are covered. To ensure the proper volume of dry material is applied following defecation, a plastic bottle can be cut to the recommended size and kept with the bucket of cover material.
- ✓ Check the plumbing system and seal all points of water or urine leakage.
- ✓ Make sure the urine piping is properly aligned with the urine drainage funnel and has not been damaged when the user interface was switched from one vault to the other.
- ✓ Make sure cover material is dry and absorbent. If a consistent supply of one type of cover material cannot be secured, explore alternative cover material options. It is also possible to mix available materials, such as rice husks, sawdust, wood ash or dry soil in order to provide a sufficient quantity of cover materials.
- ✓ Make sure the roof overhang extends beyond the vault doors, shielding the vault from rainfall.
- ✓ Make sure the pedestal or squatting pan is tightly fixed to the slab. Fill any void space with an appropriate sealant.
- ✓ Make sure the vault doors are intact and prevent the infiltration of rain or floodwater. Certain causes of leakage through the doors, such as termite damage, may necessitate rebuilding with more resilient materials.
- ✓ Check if liquid has collected on the vault floor. This may occur if the floor slopes away rather than *towards* the vault door, thus causing liquids to accumulate. Redo floor with corrected slope.
- ✓ Reduce the incidence of accidental misuse by installing men's urinals. This is especially important in schools and public toilets, where also women's urinals can be a possibility.
- ✓ Check the ventilation system to ensure that it is allowing for sufficient air circulation. This can be tested by holding a lit cigarette in the faeces vault and tracking the smoke.
- ✓ Count all the persons who make regular use of the toilet. If the toilet is being used by more people than it was designed for, more toilets should be built or dehydration vaults should be retrofitted with a containerised collection system.
- ✓ Check if the toilet is located in a low lying area which is flooded after heavy rains. If so, the toilet will likely need to be relocated.
- ✓ If the toilet is periodically overused, during a community meeting or family gathering for example, the faeces may be immediately removed and treated elsewhere. This can eliminate any odours and allow for normal toilet operation to resume quickly.

3. Foul odours are emitted from the urine drainage or collection system

Possible causes

Urine has become stagnant. This may result from leakages that cause urine pooling on surfaces, accumulation of urine in the piping system or from a waterlogged or clogged soak pit.

What to do?

- ✓ Inspect the plumbing system and seal all points of leakage. Leaks are most likely to occur at bends or couplings.

- ✓ Ensure that all urine and anal wash water pipes have adequate slope.
- ✓ Check if the soak pit is clogged. If yes, dig a new soak pit and backfill with coarse material.
- ✓ Check the pipes for blockages and, if necessary, unblock.
- ✓ Make sure the toilet floor and pedestal or squatting pan is always clean.
- ✓ Check if supplementary odour control measures (see Section 3.8.3) are properly functioning.

In case of urine storage:

- ✓ Make sure that the end of the urine outlet pipe is submerged into the urine of the container with approximately five centimetres above the bottom of the collection container. This will create a liquid seal and prevent back flow of odours into the toilet cubicle.
- ✓ Check the urine containers or tanks to identify possible overflow (see Section 5.5.1). When possible, use translucent containers in order to easily see the level of urine.
- ✓ Install an overflow pipe on the urine container if appropriate in order to avoid accidental overflow and thus pooling of urine (see Section 5.5.1).
- ✓ Check if the chamber of the urine container or tank is well ventilated.

4. The vault is infested with flies, insects or rodents

Possible causes

Faecal matter is wet or cover material has been insufficiently applied. It is also likely to occur if one or more users are suffering from diarrhoea, or if there has been a spike in the number of untrained users, for example during a social gathering or meeting. Consult also Point 2 in this table.

What to do?

- ✓ Make sure that all possible users have been trained in basic UDDT operation.
- ✓ Ensure that a sufficient amount of dry cover material has been provided and is consistently applied.
- ✓ Check if an insect screen on the vent pipe has been installed or is intact. If necessary installed it or replace it.
- ✓ In the case of persistent fly and insect infestation, the system may be switched to a containerised faeces collection system to allow for the immediate removal of faeces upon the first indication of infestation.

5. There are fresh faeces in the inactive vault (relevant only for double dehydration vaults)

Possible causes

Users or caretaker have removed the lid and defecated in the resting/inactive vault. This can interrupt the cycle of vault alternation and lead to both vaults being filled with untreated faeces.

What to do?

- ✓ Make sure the drop-hole cover on the inactive vault is tightly fixed and clearly demarcated to prevent accidental misuse.
- ✓ Conduct training activities to ensure that all users are familiar with the UDDTs operation procedures.
- ✓ Ensure that there is no reason why emptying of full vaults might be delayed beyond the required resting period.
- ✓ Ensure affordable service provision for collection, transport and disposal or reuse of faecal matter.

9 Costs of UDDTs

9.1 Capital costs

By comparing the overall costs of UDDTs to conventional toilets, decision-makers can make an informed choice regarding their possible sanitation solutions. In particular, the common perception that UDDTs are too expensive (compared to pit latrines) needs to be challenged. A wide range of available designs and construction materials can provide solutions for virtually any budget. Furthermore, UDDTs are so far usually built or manufactured in small quantities, providing little or no economies of scale. UDDT installation costs are likely to come down as consumer demand and competition increase.

The comparative cost overview provided in Figure 49 indicates that worldwide installation costs of UDDTs with double dehydration vaults can range *from approx. 100 EUR to 600 EUR*, depending on material choice and local prices, labour costs, and the desired level of 'beauty and comfort'. It should be noted that most of the projects included in Figure 49 were primarily pilot projects, built 'elegantly' for promotional purposes.

A worldwide list of suppliers and prices for prefabricated UD squatting pans, pedestals and waterless urinals is maintained by GIZ[31]. Some ceramic UD squatting pans are manufactured in India in large-scale production and are available for less than 10 EUR.

The implementation of designs with low-cost, locally available materials may be the best way of ensuring UDDT affordability for low-income groups (see Section 9.3). However, for the poorest segments of the population, even a toilet costing only 50 EUR is often not affordable. In such

[31] http://www.susana.org/library?search=appendix+urine

instances, other strategies, such as subsidisation of toilet construction, should be considered.

Additionally, the integration of UDDTs into existing homes can be an effective means of reducing installation costs, as the material requirements of the super-structure are minimised.

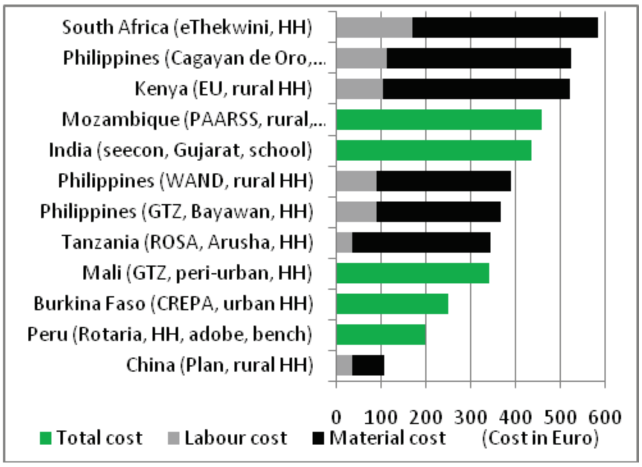

Figure 49. Comparitive costs of UDDTs with double dehydration vaults from various projects (source: adapted from Rieck et al., 2011). HH stands for household.

9.2 Operation and maintenance costs

Typical O&M items for UDDTs are described in Table 6. The actual cost of each item is dependent on local availability and, consequently, widely variable; therefore, no costs are displayed in the table.

Toilet owners themselves can perform all necessary O&M activities (see Section 8). This scenario is most practical in rural and peri-urban settings, where sufficient space for disposal and reuse of excreta is available. Middle and high-income households as well as urban households in general may wish to contract service providers to perform O&M activities that they find unpleasant.

Only a few examples of functioning UDDT service provision schemes are known:

- *Burkina Faso*: In an existing sanitation service provision scheme in Ouagadougou, the costs for collection and handling amounted to approximately 2 EUR for a six-person household per month (Fall and Coulibaly, 2011). Stored urine and dried faeces from over 900 households were collected by an association, and transported by donkey cart to one of four eco-stations for storage and treatment. Treated fertiliser was sold to local vegetable farmers. Costs were recovered through fixed monthly fees paid by the toilet owners and through the sale of the fertiliser. However, users showed a reluctance to cover the service fees, creating serious problems with regard to financial sustainability.

- *Peru*: A theoretical study conducted by Platzer et al. (2008) calculated the operation and maintenance costs for flushing systems and 'dry sanitation', including costs of transport and treatment of dried faeces and stored urine. The approximate service cost for a small city in Peru was calculated to be 2 EUR per four-person household per month. Potential income from the sale of excreta as fertiliser, or from fruits and vegetables grown with the excreta fertiliser, was not included.

  Uganda: A feasibility study conducted by Schröder (2011) calculated the costs of transport and treatment for separated excreta for a slum in Kampala. It was determined that the market value of the urine fertiliser and faecal soil conditioner alone would not cover the entire cost of service provision, unless a minimum of 400,000 users and very large local fertiliser consumers, like flower farmers, could be serviced. The transport distance between the UDDT users and fertiliser consumers had a major influence on operational costs.

Table 6. Required items for operation and maintenance of a household UDDT.

Required O&M item	Frequency of use	Comments
Water for anal cleansing and toilet cleaning	Daily	Typically a few litres per day
Cleaning materials and labour	Daily to weekly	Usually done by households
Dry cover materials	Daily	Widely available for free
Toilet paper and soap	Daily	Varies
Emptying and transport of urine (if applicable)	Daily to weekly	Performed by household or service provider (see Section 8.5)
Emptying and transport of faeces (if applicable)	Weekly to 3 months* 6-12 months**	
Post-treatment of urine and faeces (if applicable)	according to emptying cycles	
Off-site disposal of urine and faeces (if applicable)	according to emptying cycles	Performed by service provider
Clearing of urine pipe blockages	Infrequent	Usually done by households
Repair or replacement of system components	Months to years	Varies

* for UDDTs with single vaults
** for UDDTs with double dehydration vaults

The biggest cost determinants for the O&M of sanitation systems in urban situations are transport and treatment or disposal costs. Transport distances should be kept as short as possible to reduce costs. The relatively small volumes of faeces generated, as compared to urine, usually means that faeces transport is easier to make financially viable than transportation of urine. The possible sale of excreta-based fertiliser might also offset service costs but the demand for such products is difficult to estimate. Such a business concept is currently being implemented for example by the company *Sanergy* in Kenya (see Section 10.1).

In general, feasible financing options for service provision schemes must be developed if a project is to become financially sustainable. Financing options can be developed in accordance with the ‘3Ts’ in which initial investment and life-cycle costs are covered by *tariffs* (tariffs and other user charges), *taxes* (tax-based subsidies) and/or *transfers* (external transfers such as official development assistance grants). [32],

9.3 Low-cost UDDTs

UDDTs can become more affordable with creative designs, the contribution of the owner’s labour and the use of locally available building materials. Examples from Ecuador (Canaday, 2011) and the Philippines (Sayre and Sayre, 2011) showcase how ‘minimalist’ UDDTs, especially with single vaults can be built for less than 50 EUR. Single-vault systems with interchangeable containers usually require lower upfront installation costs, but require more frequent emptying than double vault UDDTs.

UDDTs with double dehydration vaults can have installation costs of less than 100 EUR if they use low-cost designs and materials. For example, the double vault ‘Easy Shower’ latrine developed by IDE in Cambodia makes use of cheap building materials and cost-efficient pre-fabricated components to bring installation costs below that of standard pour-flush and pit latrines[33]. UDDTs built with adobe bricks in Peru have provided another low-cost design option (see Figure 50 and Figure 14). The adobe bricks are made by mixing sand, clay, water and fibrous or organic material and can be produced virtually free of cost. Installation expenses of these toilets are then only limited to piping, urine diversion inserts, roofing, doors and labour.

Figure 50. Left: Low-cost model of a UDDT with single vault system in the Philippines (photo: R. Gensch, 2009); Right: Low-cost UDDT built with adobe bricks in Peru (photo: H. Hoffmann, 2009).

Alternative user interface designs have also been effective in bringing down construction costs. Plastic funnels can for example be used as an effective urine diversion mechanism in squatting pans or urinals (see Figure 51). Such materials with smooth, non-porous plastic surfaces are also a less likely source of odours than moulded concrete basins. Other solutions use simple concrete moulds (see Figure 12) or wood painted with ceramic glaze[34].

Figure 51. UDDT interface made from pipe and moulded urine section by WECF (photo: S. Deegener, 2010). A waterless urinal from the ROSA project in Arba Minch, Ethopia (photo: R. Ingle, 2009).

There is inevitably a trade-off between price and luxury. Expensive items like concrete, ceramic tiles and paint normally create an appealing and durable toilet that can hardly be achieved with low-cost UDDT solutions. Nonetheless, the latter can allow even the poorest members of society to implement a safe sanitation system with good performance. Construction materials and decorations can be incrementally upgraded as funds become available, allowing households the option of striking a balance between luxury and cost.

9.4 Economic benefits

The life-span of a UDDT is expected, under normal circumstances, to be at least 15 years. This depends on the quality of materials and craftsmanship, as well as the regular maintenance of the system. In comparison, unlined pit latrines have typically shorter life spans, especially in institutional settings, as they are often abandoned when full because they are prone to collapsing when emptied.

UDDTs also have lower emptying and disposal costs than pit or septic tank systems. Dry faeces from UDDTs can easily be shovelled, eliminating the need for pumps or difficult manual labour for removing wet faecal sludge. Therefore, long-term operational costs are lower for UDDTs than for pit latrines, and much lower than for any water-based toilet system.

UDDTs may also prove to be a ‘productive asset’ for households that reuse treated excreta in agriculture. The use of excreta based fertilisers may result in lower synthetic fertiliser expenses, and allow households to become more self-sufficient with regard to food production.

[32] http://www.oecd.org/env/42350563.pdf

[33] http://blog.ideorg.org/category/water-and-sanitation/ and construction guideline with detailed costs in Section 11.2.4. See also www.susana.org/library?search=GRET.

[34] http://www.facebook.com/photo.php?fbid=10150155073513640&set=o.319887603833&type=1&theater

The value of urine produced by one person is estimated to be in the range of *4 to 7 EUR* annually, as calculated by chemical fertiliser equivalence (Richert et al., 2010). Similar studies conducted in Burkina Faso and Philippines found that the predicted market value of both urine and faeces was approximately 6.2 EUR/person/year and 4.6 EUR/person/year, respectively (Gensch et al., 2011a). For more information on the possible economic benefits of fertiliser production from UDDTs, see Schuen et al. (2009).

The value of excreta-derived phosphorus fertiliser is expected to rise as the cost of mined phosphate rock increases (UNEP, 2011). The production of synthetic nitrogen fertilisers is an energy intensive process, and it is anticipated that the market value of excreta-based nitrogen fertilisers will rise with rising energy prices. The current trends indicate that the economic benefits of excreta recycling will increase and UDDTs will be seen as an increasingly viable means of fertiliser production.

10 Project examples for different settings

Additional information on the projects discussed below can be found in the SuSanA case studies[35] and the online photo database[36].

10.1 Outdoor installations

Outhouse or outdoor UDDTs are by far the most common form of UDDT installation worldwide. Outdoor installations have the advantage of good passive ventilation, but compromise the convenience and security of the users. Four project examples are briefly described below.

A large programme in the peri-urban and rural areas of the eThekwini Municipality in Durban, **South Africa** has resulted in the installation of more than 75,000 household UDDTs since 2003 (Roma et al., 2011).

Figure 52. Left: Exterior view of a double vault UDDT in a peri-urban area of the eThekwini Municipality, South Africa (photo: eThekwini Water & Sanitation Unit, 2005). Right: Interior view of a similar toilet in eThekwini Municipality (photo: E. v. Münch, 2005).

Toilet users made no financial contributions to the UDDT's installation, but bear sole responsibility for vault emptying and other operation and maintenance tasks. The programme currently has no focus on excreta reuse. Urine is infiltrated into a soak pit adjacent to the unit and dry faeces are buried on-site or transported by a service provider for off-site disposal. A mobile plastic pedestal supplied by the company *Envirosan* is used for the active vault and a plate is provided to cover the inactive vault (see Figure 52).

Household and school UDDTs were installed in rural areas of **Kenya** as part of the *Ecosan Promotion Project*, jointly implemented by the EU, Swedish International Development Cooperation Agency (Sida) and GTZ. The project was intended to benefit users involved in subsistence agriculture and placed a strong emphasis on excreta reuse (Rieck, 2010; Kraft and Rieck, 2011). The programme was developed as a pilot project, and utilised rather 'luxurious' toilet designs (see Figure 24, Figure 56). The toilets were built with 20% user financing and the remainder was covered through project funding.

The NGO *Sanergy*[37] has also implemented a UDDT enterprise called 'Fresh Life' in slum areas of **Nairobi, Kenya**. The project has installed single vault UDDTs with underground vaults and urine collection vessels that are exchanged daily (see Figure 53 and Figure 38).

Figure 53. Left: 'Fresh Life' toilet, a UDDT with single vault for public use, with the franchise operator in a slum area of Nairobia, Kenya. Right: The interior of a 'Fresh Life' toilet with a removeable plastic slab with urine-diverting squatting pan (lifted up in the photo) and interchangeable containers for faeces and urine (photos: D. Mbalo, 2012).

The toilets are integrated into an innovative, four-part business model involving: (1) building a network of low-cost public toilets; (2) franchising the public toilets to local entrepreneurs; (3) collecting the excreta; and (4) transforming the excreta via composting into fertiliser that can be sold. .

A project with about 900 UDDTs in peri-urban areas of El Alto, **Bolivia** was developed by the NGO Fundación Sumaj Huasi (La Paz) and fully funded by the Swedish Development Cooperation, Sida (Suntura et al., 2012). The bathroom buildings are located close to the houses, and access to the UDDT is through steps within the building,

[35] http://www.susana.org/case-studies
[36] http://www.flickr.com/photos/gtzecosan/collections/

[37] http://saner.gy/

supported with internal walls facilitating the use for people with mobility limitations. Showers are incorporated. The technology applied is a UDDT outhouse toilet with single vaults and interchangeable containers, treatment of grey water at the household level, and collective management of the urine and faeces (see **Figure 54** and also drawing in **Figure 35**).

Figure 54. Top: A bathroom building with shower, urinal and a UDDT with single vault in El Alto, Bolivia (photo: S. Frenzel, 2012 and source: Suntura et al., 2012). Bottom: Interior of the toilet with UD pedestal (left), urinal and shower in the foreground and two access steps leading to toilet in the background (photos:K. Andersson, 2011).

10.2 Indoor or attached installations

There are many documented examples of UDDTs installed inside of private homes and public buildings. These range from sophisticated pre-fabricated models produced by Separett (see Figure 55), to multi-story designs installed in the Gebers housing project[38] in Stockholm, Sweden, to simple bench, pedestal and squatting pan toilets. Two examples are briefly described below.

A project in **Peru** with involvement of the company *Rotaria del Peru* and GIZ formed a public-private-partnership (PPP) to construct UDDTs in households and schools at a pilot scale. The UDDTs were mostly built in the bench design with either double dehydration or single vaults, and were installed either inside of the home, attached to an exterior wall or outside (see Figure 55, right). Users bore sole responsibility for purchasing toilet hardware, with only software such as labour and training provided by the PPP. The UDDT design and various project pictures can be found in the construction manual provided in Section 11.2.4.

The NGO WECF has piloted UDDTs in rural households and schools throughout **Central and Eastern Europe** and the **Caucasus and Central Asia**. Project sites were often selected based on elevated nitrate concentrations in groundwater caused by pollution from livestock and pit latrines. Users have generally appreciated the higher degree of comfort provided by the indoor UDDTs compared to outdoor pit latrines, especially in the cold winter months. Many innovative indoor UDDT designs were implemented in these cold climates (see Figure 34), as well as some attached to buildings (Stintzing et al., 2007). Toilet owners contributed between 25-100% of construction costs (Wendland et al., 2011a).

Figure 55. Left: Indoor urine diversion dry toilet with single vault and electrical ventilation manufactured by *Separett* (photo: E. v. Münch, 2008). Right: A single vault UDDT with wooden bench and interior vault door built by *Rotaria del Peru* in Lima, Peru (photo: H. Hoffmann, 2010).

10.3 Installations in schools

UDDTs can work well in school settings if O&M routines are strictly followed and if there is a strong sense of ownership. This requires regular training of new students, teachers and staff and the presence of service providers or a caretaker to maintain the system. It is important to prevent misuse and ensure quick action when misuse does occur. Training programmes could be incorporated into regular school activities. A cleaning schedule and clear delegation of responsibility is critical, and should involve the support staff, school clubs and external service providers whenever possible. Motivated leadership within the school is often the key to the sustainability of the system (Pynnönen et al. 2012).

We recommend constructing UDDTs with double dehydration vaults in schools in order to minimise health risks during handling, and to reduce the work load to school staff. We strongly advise against the arrangement that students are managing the human excreta themselves.

We further recommend that the faeces produced in school UDDTs are buried or otherwise disposed of, rather than

[38] Project description from 2005: http://www.susana.org/lang-en/library?view=ccbktypeitem&type=2&id=1216

reused. The high number of users in schools will increase the likelihood of disease transmission during handling or reuse, and may result in substantially more work than unpaid school groups may be willing to undertake. For the same reason, subsurface infiltration may be the most practical means of managing urine (see Section 7.6.1). The possible impact of urine infiltration on groundwater quality should be evaluated on a case-by-case basis in order to protect drinking water resources.

With regard to emptying the dehydration vaults, regular maintenance and technical trouble shooting, schools often depend on external assistance from NGOs, donors or service providers. However, for long-term financial sustainability, the school staff should be trained to do regular maintenance. If the use of external service providers is preferred, viable financing arrangements must be implemented using school budgets or external contributions. Private service providers will usually require training and O&M manuals on the unique characteristics of servicing UDDTs.

Maintenance is typically being neglected for all types of sanitation installations in schools and institutional settings, which accounts for the high rates of misuse and malfunction of such toilets in general. UDDTs do require more attention than pit latrines, but this is usually warranted by the cleaner and odour-free toilet experience, as well as lower environmental pollution.

Figure 56. Top left: UDDTs in a school in Ukraine are attached to the school building, so that students can enter the restrooms from indoors (photo: WECF, 2006). Top right: A school near Machakos, Kenya with UDDT and attached boys urinal (photo: EPP, 2009). Bottom left: Girls urinals with UDDTs in Valalore secondary school in India. Bottom right: Detail of a squatting pan with anal washing section in a Sri Ramalingar secondary school in India (photos: NGO Wherever the Need, 2011).

The following design recommendations apply in particular to UDDTs for schools. These guidelines should be considered as supplementary to those outlined in Section 4.6 and Section 5.3.

- Toilet seats and pans should be built with sturdy and easily cleaned materials and firmly attached or mounted.
- The number of toilets built must accommodate the anticipated number of students at the school in order to ensure correct user frequency and storage time in the vaults (Kraft et al., 2011 and Adams et al., 2009).
- Installation of waterless urinals for both boys and girls is recommended, as pupils are more likely to urinate than defecate while at school. The availability of urinals will also reduce the likelihood of urine entering the faeces vault.

Differences in day and boarding schools should be considered when designing school UDDTs. In day schools, the amount of faeces is often surprisingly small, as students prefer to defecate in the early morning or in the evening at home.

Instructional posters should be hung inside the toilets, and O&M manuals must be available to school administrators and school health and environmental clubs. All other design recommendations for conventional toilets in schools also apply to the implementation of UUDTs, including gender separated facilities, screens or privacy walls in front of toilet, menstrual hygiene management facilities, barrier-free access for pupils and staff with disabilities, hand washing stations and generally a ‘child-friendly’ set-up.

More information on school sanitation can be found in Abraham et al. (2011), Deegener et al. (2009) and on the *WASH in schools*[39] website.

Examples for UDDTs in schools can be found in the same projects in Peru, Kenya and Eastern Europe as mentioned in the two previous sections. Other examples of school UDDTs are available in several SuSanA case studies.[40]

10.4 Accessibility for people with disabilities

The most significant challenge for users with disabilities is the presence of stairs, which are commonly built to reach the toilet cubicle above the dehydration vaults of UDDTs. Some alternative designs such as the bench design can eliminate the need for stairs (see Section 6.3). One or two steps might still be required to reach a comfortable sitting height. These stairs can be bridged by ramps and equipped with handrails to provide easier access. Construction costs for accessible toilets are only marginally higher than standard UDDT designs when accessibility design elements are planned from the start.

With regard to accessibility, indoor UDDTs are the most appropriate sanitation option for people with disabilities, as they can provide very short and convenient access routes. This is especially important in areas where the terrain is difficult and unpaved. In comparison, pit latrines are usually

[39] http://www.washinschools.info/ and http://www.washinschoolsmapping.com
[40] http://www.susana.org/lang-en/case-studies?search=schools+UDDT

located far away from houses or classrooms due to their odour, tendency to attract flies and need to infiltrate liquids.

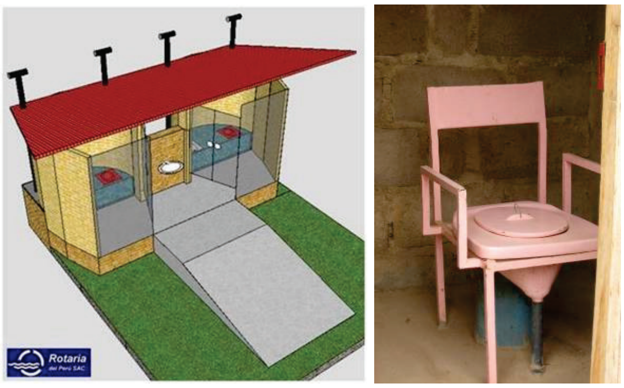

Figure 57. Left: Sketch of two bench UDDTs with a ramp for a public toilet in Peru, which could easily be modified with handrails and handlebars to increase accessibility for people with disabilities (source: *Rotaria del Peru SAC*, 2010). Right: A metal chair is used to hold a UD insert for use by elderly people in Burkina Faso (photo: M. Fogde, 2010).

The toilet cubicle may need to be enlarged to accommodate wheelchair and crutch users. The standard considerations and design recommendations for inclusive sanitation facilities with regard to hardware and software should be followed (von Münch and Düring, 2011).

10.5 Mobile UDDTs

Mobile toilets are often required in very densely settled areas or where land tenure is insecure. They may be a suitable solution in informal settlements, for large events or disaster-relief situations.

Figure 58. Left: A light-weight single vault UDDT designed for high density informal settlements in Bangladesh (photo: M. Mijthab, 2011). [41] Right: A mobile toilet from India[42] in a spot previously used by women for open defecation (photo: Wherever the Need, 2009).

Mobile toilets can be manually lifted or are installed on trailers and wheeled by hand, bicycle, draft animals or other mechanical arrangement.

Mobile UDDTs are most commonly designed as single vault units, as it is quite impractical for a mobile unit to store faeces for the six-month period prescribed for double dehydration vault system. An interesting prototype was for example developed and tested in Bangladesh (Mijthab, 2011).

10.6 Public toilets

UDDTs are, in principle, also applicable in public settings. Single vault systems are recommended for public toilets since the high frequency of users will generate large quantities of excreta rather quickly. A service provider, possibly the toilet operator, must be engaged to collect and exchange the excreta containers and guarantee for proper disposal or treatment.

Public toilets work best when an operator is on-site fulltime to instruct users, clean toilets and quickly react in cases of misuse. It must be the aim of the operator to keep the dehydration vaults as dry as possible, thus rendering the toilet odourless and attractive for costumers. Maintaining a comfortable and attractive facility will likely increase the toilet's profitability.

Examples of public UDDTs are rare or not well documented. *The Austrian Red Cross* has constructed public UDDTs in local markets in Mozambique (see Figure 59, left) and the Rwandan Ministry of Infrastructure has installed public UDDTs with full-time operators along highways and at public institutions, but experiences have not yet been published (see Figure 59, right). The Indian NGO *Scope* has also constructed several public UDDTs.

Figure 59. Left: A public toilet with integrated showers built by *the Austrian Red Cross* at a market place in Mozambique (photo: M. Fogde, 2006). Right: Rear view of underground single vaults of public toilet at UTC roundabout in Kigali, Rwanda (photo: L. Dagerskog, 2011).

A pilot installation for a public UDDT system in a shipping container was set up in 2011 in Cape Town, South Africa with funding from the Netherlands. It consists of a 20 feet shipping container equipped with 13 urine diversion dry toilets and 13 urinals. The content in the faeces chamber is

[41] http://mosan-bangladesh.tumblr.com/
[42] Mobile Unit (Cuddalore) http://www.wherevertheneed.org.uk/projects/indian-projects/mobile-unit-cuddalore/

transported to a second chamber using a mechanical mixing device that is installed along the full length of the tank. [43]

10.7 Flood plains and 'floating villages'

Areas with recurrent flood events require specific structural engineering to keep the vaults dry and the toilet structure stable. A standard UDDT with access stairs can stay dry up to a flood level of about 10 to 20 cm. Additional safety measures against flooding can be generated by raising the level of access vault doors above the ground as seen in Figure 60. The dehydration vaults must then be built with a very high standard of water tightness. An example for this are the UDDTs which were built by *Terre des Hommes* in Bangladesh after a cyclone (Delepière, 2011).

Figure 60. Left: A UDDT with vault doors elevated above the flood line (photo: A. Delepière, 2009). Right: Detail of raised access vault doors that prevent water entry into the dehydration vaults (photo: M. Alam, 2011).

In some flood prone areas, houses or huts may be built on pillars or stilts. UDDTs can be built in a similar fashion or even integrated into the housing structures. Single vault designs with interchangeable containers have been employed in such situations, for example in the Philippines (see Figure 61). The choice of appropriate materials ranges from wooden or bamboo poles to stone and cast concrete.

Figure 61. A hanging single vault urine-diverting dry toilet at a shore line area in the Philippines[44] (photos: R. Gensch, 2010).

[43] A case study on MOBISAN http://www.susana.org/images/documents/07-cap-dev/b-conferences/12-FSM2/b4.5-fsm2-muanda-cape-peninsula-university-south-africa.pdf

[44] Low-cost sustainable sanitation solutions http://www.susana.org/lang-en/library?view=ccbktypeitem&type=2&id=964

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11.2 Further resources about UDDTs

11.2.1 Case studies

- Case studies for UDDTs are available here (select UDDTs from the menu on the right hand side): http://susana.org/case-studies

11.2.2 Photos and videos

- All pictures of this publication: http://www.flickr.com/photos/gtzecosan/sets/72157628912448797/
- Additional photos of UDDTs: http://www.flickr.com/photos/gtzecosan/collections/72157626092760863/
- More photos of UDDTs are available in the country collections here: http://www.flickr.com/photos/gtzecosan/collections/
- Videos on UDDTs: http://susana.org/lang-en/videos-and-photos/resource-material-video and http://www.youtube.com/user/susanavideos

11.2.3 Hygiene and sanitation software

- Hygiene and Sanitation Software. An overview of approaches by WSSCC (2010) http://www.wsscc.org/node/745

User training UDDTs:

- eThekwini water and sanitation programme facilitator training manual, Durban, South Africa http://www.susana.org/lang-en/library?view=ccbktypeitem&type=2&id=1181

11.2.4 Construction manuals and guidelines

- Low-cost sustainable sanitation solutions for Mindanao and the Philippines, by Gensch et al. (2010), http://www.susana.org/lang-en/library?view=ccbktypeitem&type=2&id=964
- Design manuals for bench UDDTs by the company Rotaria del Peru SAC, www.susana.org/library?search=Rotaria
- Toilets that make compost, by Peter Morgan (2007), http://www.susana.org/lang-en/library?view=ccbktypeitem&type=2&id=195
- Urine diversion toilets - principles, operation and construction by Deegener et al. (2006), http://www.susana.org/lang-en/library?view=ccbktypeitem&type=2&id=770

- Safe and profitable toilets - Urine diverting toilets - A solution for health and wealth by WECF (2008), http://wecf.eu/download/2008/2008_10_ecosan_guide_engl.pdf
- UDDT – construction manual (with anal cleansing) by Panse et al. (2009), http://susana.org/lang-en/library?view=ccbktypeitem&type=2&id=384
- Easy shower latrine - technical handbook by IDE and GRET including costs: http://www.susana.org/lang-en/library?view=ccbktypeitem&type=2&id=1409
- Construction of ecological sanitation latrine – Technical handbook by WaterAid (2011), Nepal. http://www.wateraid.org/documents/plugin_documents/technical_handbook__construction_of_ecological_sanitation_latrine__5_september_2011.pdf
- More manuals on construction are available here: http://www.susana.org/lang-en/library?search=UDDT+manual

11.2.5 Drawings, BoQs and instruction posters

- Technical drawings of UDDTs (some with BoQs, which stands for bills of quantities): http://susana.org/lang-en/library/rm-technical-drawings?vbls=7&vbl_7=28&vbl_0=0
- Drawings and BoQs are included in various case studies http://www.susana.org/lang-en/case-studies?search=UDDT
- Posters explaining the use of UDDTs: http://susana.org/lang-en/library/rm-posters

11.2.6 Suppliers and costs

- Worldwide list of suppliers for waterless urinals, urine diversion squatting pans and seats: http://www.susana.org/library?search=appendix+urine

11.2.7 Hand washing units

- WSP database on hand washing: http://www2.wsp.org/scalinguphandwashing/enablingtechnologies/index.cfm?Page=Browse
- Publications on hand washing in SuSanA library: www.susana.org/library?search=handwashing
- Photos of hand washing facilities on flickr: http://www.flickr.com/photos/gtzecosan/sets/72157625967026368/
- Group hand washing facilities (NGO fit for School in the Philippines) http://www.fitforschool.ph/resources/info-materials.html

    

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