URINE DIVERSION

STRATEGY

Urine contains most nutrients and pharmaceuticals excreted, though accounts for less than 1% of the mixed wastewater flow. Diverting urine from other wastewater streams sent to sewer reduces nutrient and micropollutant loads to centralized treatment plants extending their operating capacity and increasing their treatment performance. Recovering nutrients from urine to produce fertilizer can help close nitrogen, phosphorus and other nutrient cycles, and reduce reliance on synthetic fertilizers in agriculture. Urine diversion via urine-diverting flush toilets or dry toilets also enables the separate collection and treatment of blackwater via flush toilets or feces via dry toilets. Urine diverting dry toilets, as well as waterless urinals are water efficient fixtures that reduce water use.

INPUT STREAMS

- Urine
- Yellow water

TARGET OUTPUTS

- Liquid fertilizer
- Solid fertilizer

TOILETS

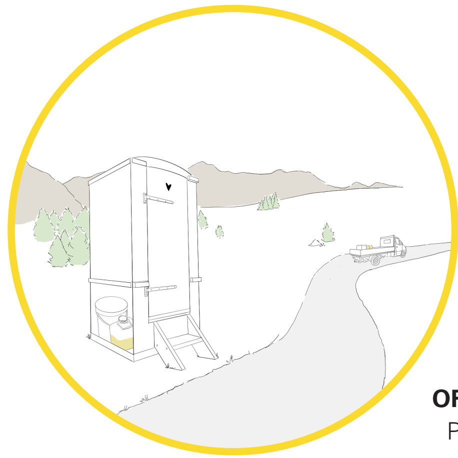
Commercially available urine-diverting toilets, separate urine from feces and most flush water while waterless urinals and urine-diverting dry toilets allow for the undiluted collection of urine. Portable fixtures (e.g., funnel attachment on a jerrycan) are a low-cost urine collection option.

PIPING | TRANSPORT

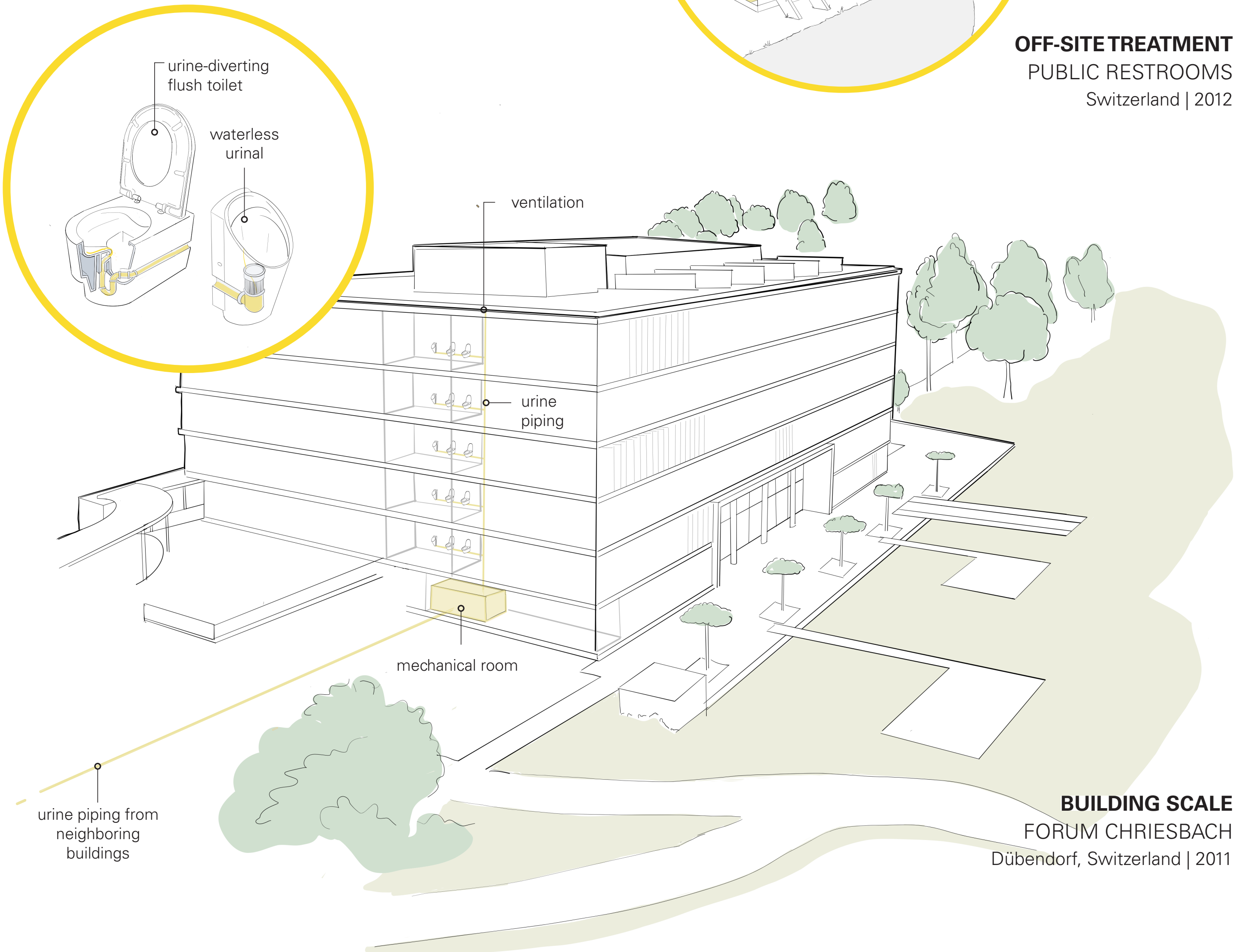
At building and neighborhood scales, designated urine piping leads urine to a storage tank for collection. Pipes and pumps can lead the urine further through on-site urine treatment, if available. Alternatively, urine can be transported in containers to a centralized treatment point (e.g., by truck). Adequate access points for collection should be considered.

TREATMENT

Treatment of the urine can take place on site or off site. On-site treatment usually takes place close to the urine collection tanks in a mechanical room in the basement. Off-site treatment can require the pumping of urine from smaller containers to larger tanks. Urine treatment integrated into the toilet/bathroom is also possible.



OFF-SITE TREATMENT
PUBLIC RESTROOMS
Switzerland | 2012



BUILDING SCALE
FORUM CHRIESBACH
Dübendorf, Switzerland | 2011

TO CONSIDER

COLLECTED STREAM

Approximately 0.5 m³ of urine can be collected per person per year. A urine stream collected with flushwater has a significantly larger volume. Spontaneous mineral precipitation in toilets and pipes can lead to deposit build-up and clogging. Flushing with rainwater reduces mineral precipitation compared to flushing with (calcium- and magnesium-rich) tapwater.

SPACE & PLACEMENT

Unless urine collection occurs at bathroom scale, or in portable fixtures (e.g., jerry cans), urine diversion requires designated piping. Space requirements for a mechanical room for storage and treatment depend on the volume of the collected urine and the treatment process of choice. A mechanical room is often placed in the basement.

RESOURCE INTENSITY

There are initial material, planning and installation costs for toilets, pipes, storage and treatment, which vary with the configuration and technology selected. To prevent deposit build-up and clogging of pipes, regular cleaning and maintenance is needed. In the case of urine collection in containers, transport of urine to a treatment hub should be considered. Some treatment processes (e.g., struvite precipitation) require additional chemical dosing.

NEW BUILD VS. RETROFIT

The installation of urine-diversion toilets and designated urine piping is easiest in new build planning and construction where designated piping can be incorporated into the building skeleton. However, urine diversion is possible when retrofitting buildings. The planning process is critical for a coordinated and well-executed implementation.

HYBRID VS. DECENTRALIZED

Urine diversion can be implemented in a hybrid scenario, where other streams are sent to the centralized sewer, or as part of a decentralized solution, in combination with treatment of fecal and greywater streams.

USER EXPERIENCE

Urine-diverting toilets typically require all users to sit while urinating for optimal collection and separation, though urinals are also an option. Awareness among users about appropriate cleaning products is critical for biological treatment processes and fertilizer end use of recovered products.

TREATMENT OPTIONS

Urine treatment aims to degrade organic substances (to prevent malodor and unwanted biological processes), minimize volatilization of ammonia (causing nitrogen losses, air pollution, and bad smell), remove or kill pathogens and micropollutants, and concentrate or extract nutrients. Different treatments yield urine-based fertilizers with different physico-chemical characteristics (e.g., solid/liquid; basic/acidic) and composition, suitable for different agricultural uses (e.g., hydroponics, soil injection, fertigation, broadcasting).

TREATMENT OF THE URINE STREAM

Treatment of the full urine stream yields multinutrient fertilizers. Concentration is not strictly necessary, but reduces the need for storage space and facilitates transport and fertilizer application.

NUTRIENT EXTRACTION

Processes for the targeted extraction of phosphorus and/or nitrogen from urine yield single-nutrient fertilizers which can be used directly or in fertilizer manufacturing.

SAFE END USE

PATHOGENS & PHARMACEUTICALS

Pathogens in urine mainly come from fecal cross-contamination during excretion, while pharmaceuticals, and their metabolites, come from consumed, and subsequently excreted, medication. Treatment of urine inactivates pathogens and removes pharmaceutical compounds to varying degrees depending on the treatment technology applied. It is recommended to follow safety measures during fertilizer application (lag time between last application and harvest and soil application or injection as opposed to foliar application) to further reduce risks arising from the presence of pathogens in urine based fertilizers.

Risks arising from pharmaceuticals include plant take-up of these substances, or dissipation into the environment. Targeted micropollutant removal steps, like the activated carbon filtration, ensure high removal.

PROCESS OBJECTIVES | TECHNOLOGY | PRODUCT(S)

Hygienization involves the reduction of pathogens, via ammonia sanitization or heat. Micropollutant removal is achieved to varying degrees by filtration and sorption.

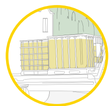
Stabilization processes (e.g., biological treatment or acid/base addition) limit nitrogen losses during treatment and other steps of the value chain (e.g., field application).

Processes of distillation and evaporation separate out water to concentrate target nutrients and reduce volume.

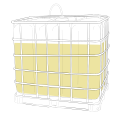
VOLUME REDUCTION | STABILIZATION | HYGIENIZATION

The extraction of one or more nutrients via chemical and physical mechanisms. Additives are often required (e.g., magnesium for precipitation).

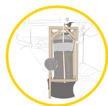
NUTRIENT EXTRACTION



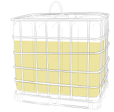
T1 URINE STORAGE | PASTEURIZATION



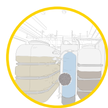
STORED URINE



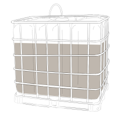
T2 NITRIFICATION ON BIOCHAR



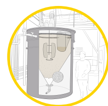
NITRIFIED URINE



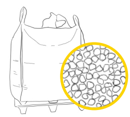
T3 NITRIFICATION - DISTILLATION



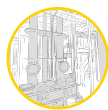
NITRIFIED-CONCENTRATED URINE



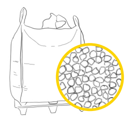
T4 STRUVITE PRECIPITATION



STRUVITE



T5 AMMONIA STRIPPING



AMMONIA SALTS

DRY SANITATION

STRATEGY

Dry sanitation refers to the collection of excreta or feces without flush water. The low-energy and low-tech requirements of dry systems make them suitable for rural, off-grid settings, and areas with water shortages. In multistory buildings, dry collection of excreta or feces is a challenge, yet has been successfully implemented in buildings of up to three stories with straight-drop pipes to the basement, and in larger housing complexes by means of collection of feces at the toilet level and transport to a treatment site. Aside from significant water savings compared to flush sanitation, dry sanitation facilitates the recovery of nutrients and organics and can be an attractive solution for communities in which inhabitants want to manage their own sanitary system off the grid. Dry sanitation is usually combined with urine diversion and often complemented with on-site greywater treatment.

INPUT STREAMS

- Feces
- Excreta

TARGET OUTPUTS

- Soil amendments

DRY TOILETS

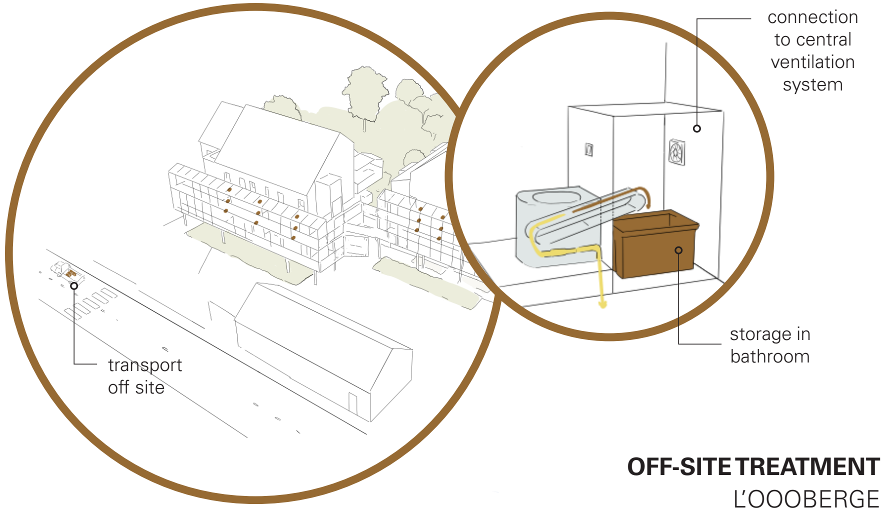
A wide variety of dry toilets are commercially available: from simple models with a "drop hole", to more sophisticated configurations with e.g., conveyor belts. Separation of urine can take place in the toilet itself (e.g., by a separate bowl on the front) or by gravity in the collection and treatment unit. The toilet should be designed to continuously draw air into the toilet bowl, preventing odors.

PIPING

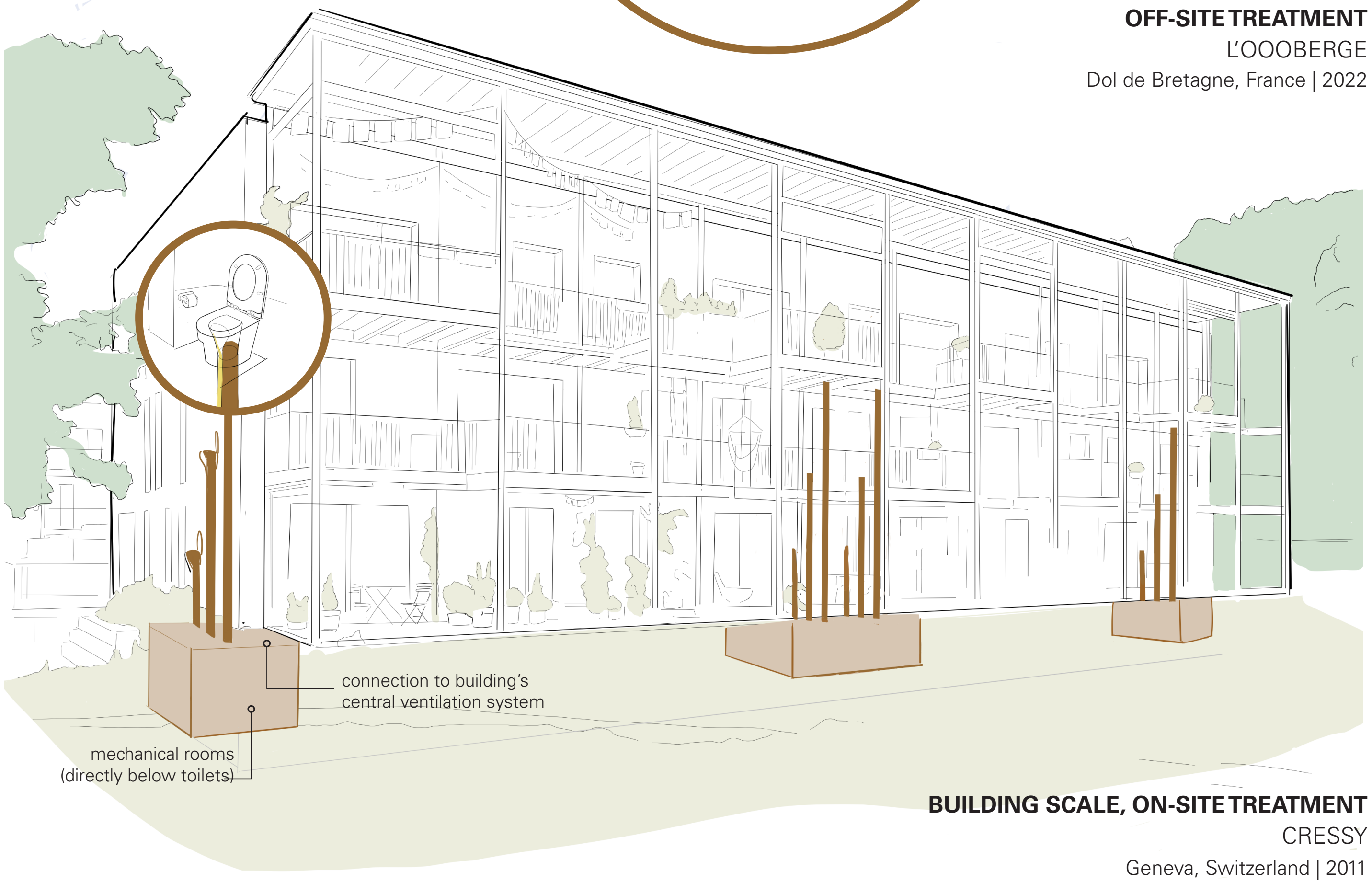
When not collected at the bathroom level (e.g., in containers), feces/excreta can be conveyed one to three stories down via large diameter, straight-drop pipes.

TRANSPORT | TREATMENT

Excreta or feces can be treated on site at building level or can be simply contained/stored on site (at bathroom or toilet level) before transport, often via truck, to an off-site treatment location.



OFF-SITE TREATMENT
L'OOOBERGE
Dol de Bretagne, France | 2022



BUILDING SCALE, ON-SITE TREATMENT
CRESSY
Geneva, Switzerland | 2011

TO CONSIDER

COLLECTED STREAM

Dry toilets collect excreta, or feces with separate collection of urine. When urine and feces are treated together, a bulking agent (e.g., sawdust) is usually added to the stream. Dry sanitation yields relatively small volumes (e.g., 0.15 m³ of fresh feces per person per year, plus toilet paper) with a high solids content of ~25% dry matter. The volume is reduced further during collection and treatment due to evaporation.

SPACE & PLACEMENT

Collection at bathroom level requires space in the bathroom for storage and adequate access for collection. In buildings, straight-drop pipes are needed with collection/mechanical rooms placed directly below the pipes. This poses a limitation on the amount of stories the building can have, and takes up a considerable amount of space in the building. Ventilation is key for dry sanitation: pipes, chambers and mechanical rooms can be connected to the building's central ventilation system.

RESOURCE INTENSITY

Dry sanitation systems are usually low-tech solutions, requiring little energy consumption, and little-to-no water demand. Passive or active ventilation is required. Maintenance of more sophisticated dry toilet models (e.g., conveyor belt dry toilet) should be carried out periodically.

NEW BUILD VS. RETROFIT

Given the architectural considerations imposed by dry sanitation (i.e., piping constraints, ventilation needs, collection space) implementation is easiest in new builds. Collection at toilet and bathroom scale is more accessible for retrofits.

HYBRID VS. DECENTRALIZED

Dry sanitation is usually implemented together with treatment of the remaining streams (i.e., urine and greywater) for holistic and off-grid solutions. Excreta or feces collected in containers (e.g., via dry porta pottys), are often transported to a semi-centralized treatment hub.

USER EXPERIENCE

When designed properly, odor nuisances from dry toilets can be less than for conventional flush toilets, with the added advantage that no aerosols are produced. Bathroom lighting can be adjusted to avoid lighting the inside of the toilet directly. Users may be required to add bulking materials (e.g., sawdust) after toilet use, and to adjust toilet cleaning practices.

TREATMENT OPTIONS

Treatment of feces or excreta is often includes a single treatment step to either stabilize the organic matter, via aerobic decomposition (i.e., composting) or via thermal decomposition (i.e., incineration or pyrolysis).

VALORIZATION OF ORGANICS & NUTRIENTS

Biological treatment, like composting, and thermal treatment, like pyrolysis, converts feces, or excreta, into soil amendments. These soil amendments contribute to long term fertilization, humus reproduction, carbon binding and carbon storage in the soil.

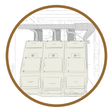
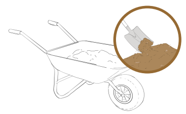
VALORIZATION OF NUTRIENTS

Incineration is a thermal treatment process that combusts organic matter and evaportates water, rendering an inorganic ash rich in nutrients, such as phosphorus and potassium.

SAFE END USE

PATHOGENS & PHARMACEUTICALS

Fecal streams contain human pathogens, posing significant health risks. The collection and handling of feces (e.g., transport for off-site treatment) is the primary disease transmission pathway, with guidelines in place to minimize these risks. Treatment, whether on site or off site, should ensure pathogen inactivation. Pharmaceuticals and other micropollutants will mostly remain in the compost, though health risks from their accumulation in plants using feces-based soil amendments are considered low. The environmental risks from pharmaceuticals or antibiotic resistance genes in soil remain unclear, though are likely lower than those from applying animal manure. Similarly, the risks of heavy metals and micropollutants in feces-based soil amendments are lower compared to sewage sludge because of the exclusion of industrial wastewater and stromwater from the fecal stream.

PROCESS OBJECTIVE		TECHNOLOGY	PRODUCT(S)
Aerobic biological treatment stabilizes the organic matter (and nitrogen), reduces the volume of the stream, and generates heat, which contributes to hygienization.	BIOLOGICAL TREATMENT	 T.21 ON-SITE COMPOSTING	 COMPOST
		 T.22 OFF-SITE COMPOSTING	 COMPOST

VACUUM SANITATION

eawag aquatic research

STRATEGY

Vacuum sanitation systems are based on suction for the removal of excreta with minimal water for flushing, which results in important water savings compared to flush sanitation systems. The concentration of the vacuum-collected blackwater facilitates the recovery of nutrients and valorization of organics from the stream. Compared to conventional gravity sewerage systems, vacuum sewers enable flexible piping installations regardless of topography. A growing number of neighborhoods combine vacuum sanitation with food waste management strategies for biogas production, and with water reuse and heat recovery from greywater for a holistic, off-grid solution. Implementing vacuum sanitation can help projects attain green building certificates.

INPUT STREAMS

- Vacuum-collected blackwater

TARGET OUTPUTS

- Biogas
- Soil amendments & fertilizers
- Treated water

TOILETS

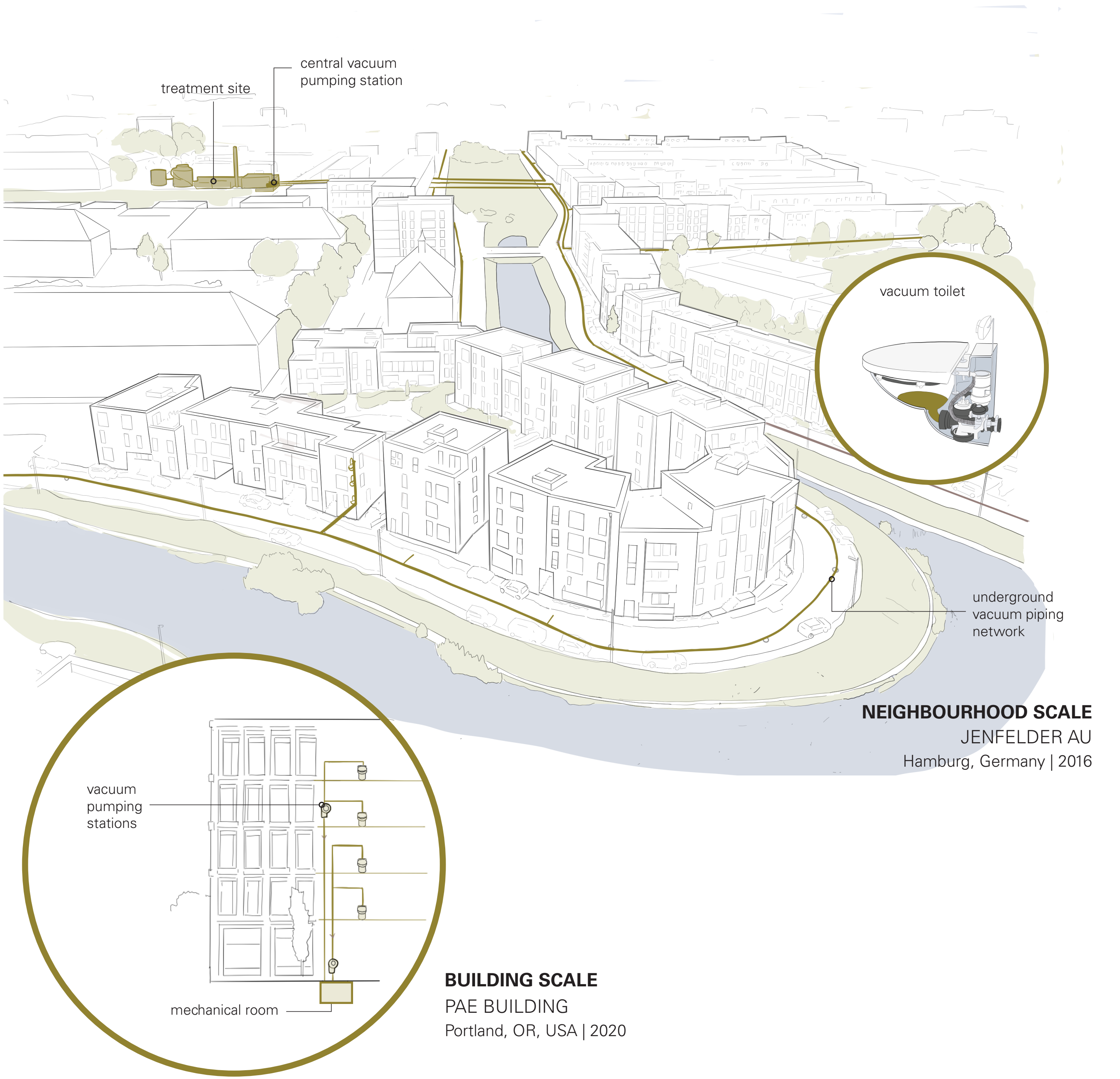
Commercially available vacuum toilets are similar in appearance and user experience to conventional flush toilets. When flushing, a small diameter opening at the base of the toilet bowl opens, and the vacuum in the pipes "sucks" out the excreta, toilet paper, and a small amount of water used to rinse the bowl.

PIPING

Vacuum systems require pumps that generate a vacuum, or negative pressure, in the vacuum piping system. Carefully planned vacuum piping systems can cover whole neighborhoods, with central underground pumping stations keeping the pipes under constant vacuum. At a building or household scale, vacuum pumps can be located close to the toilet or within the building and can operate on demand.

TREATMENT

Treatment and recovery sites can be integrated into a building structure or in a separate treatment location. Alternatively vacuum-collected blackwater can be sent to sewer for centralized treatment.



NEIGHBOURHOOD SCALE
JENFELDER AU
Hamburg, Germany | 2016

BUILDING SCALE
PAE BUILDING
Portland, OR, USA | 2020

TO CONSIDER

COLLECTED STREAM

The low water requirement of vacuum toilets (< 1 L, compared to 3-6L in conventional flush toilets) yields a concentrated blackwater from which organics and nutrients can be more effectively recovered. Solids in vacuum-collected blackwater are "macerated," due to shearing forces in the pipes.

SPACE & PLACEMENT

Vacuum pipes require a smaller pipe diameter than gravity systems, making them lighter and more compact. Independence from gravity offers additional layout flexibility (e.g., pipes can be installed vertically or laid in ceilings). Soundproofing measures should be considered during floorplan design and construction (guidelines exist), as well as the inclusion of inspection points.

RESOURCE INTENSITY

Vacuum sanitation requires more sophisticated technology and more regular maintenance than conventional toilets and gravity drainage. Spontaneous mineral precipitation in pipes can lead to deposit build-up and clogging which require preventative maintenance. Additionally, a constant, though small, energy source is needed to keep vacuum in the pipes. Contingency plans and careful design are thus necessary for power shortages and during maintenance.

NEW BUILD VS. RETROFIT

The installation of vacuum toilets and sewerage is easiest in new build planning and construction as it requires good coordination between all stakeholders. However, vacuum sanitation can also be retrofitted into buildings, which is facilitated by its high flexibility in piping layout.

HYBRID VS. DECENTRALIZED

Vacuum sanitation is implemented in combination with greywater reuse for a holistic, off the grid, solution. When reducing water demand is the primary driver, or in cases where the scale of recovery is not efficient, sending vacuum-collected blackwater to the sewer may be preferred.

USER EXPERIENCE

There is no significant change in user experience with respect to conventional flush toilets apart from a change in flush sound, which is slightly louder. However, vacuum toilet systems also provide certain advantages from the user perspective including lower risk of user exposure to pathogens (no aerosols are generated during flushing), better ventilation (a large volume of air is flushed with the vacuum), and lower water bills.

TREATMENT OPTIONS

Treatment trains for vacuum-collected blackwater typically consist of a biological treatment step for valorization of the organics (e.g., as biogas or compost) followed by nutrient extraction from the digestate or leachate, and sometimes water recovery.

VALORIZATION OF ORGANICS & NUTRIENTS

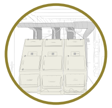
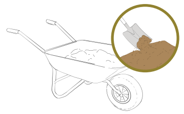
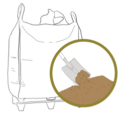
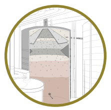
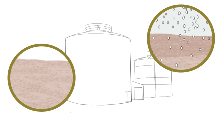
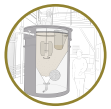
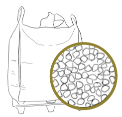
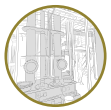
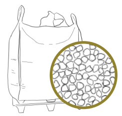
Biological anaerobic or aerobic treatment of vacuum-collected blackwater yields biogas and/or a soil amendment (e.g., compost, anaerobic sludge).

NUTRIENT EXTRACTION

Processes for the targeted extraction of phosphorus and/or nitrogen from digestate or leachate yield single-nutrient fertilizers (e.g., struvite, ammonia salts) which can be used directly or in fertilizer manufacturing.

WATER REUSE

Biological treatment, filtration and disinfection technologies can treat the remaining water stream, though the volume of the remaining effluent is usually small and thus, it often makes sense to treat it together with greywater (see ◖ for water reuse treatment options).

PROCESS OBJECTIVE		TECHNOLOGY	PRODUCT(S)
Anaerobic or aerobic biological treatment converts organics into biogas or compost. While vacuum-collected blackwater can be directly composted, more often composting (of the digestate) follows anaerobic digestion.	BIOLOGICAL TREATMENT	 T21 ON-SITE COMPOSTING	 COMPOST
		 T22 OFF-SITE COMPOSTING	 COMPOST
		 T23 ANAEROBIC DIGESTION	 SLUDGE, BIOGAS
The extraction of one or more nutrients via chemical and physical mechanisms. Additives are often required (e.g., magnesium for precipitation, sulfuric acid for stripping).	NUTRIENT EXTRACTION	 T4 STRUVITE PRECIPITATION	 STRUVITE
		 T5 AMMONIA STRIPPING	 AMMONIA SALTS

SAFE END USE

SAFE HANDLING OF BIOGAS

Biogas can be converted into heat via a burner or used in combined heat and power (CHP) systems for electricity and heat (often also used to heat the anaerobic reactor). Biogas is flammable and a greenhouse gas 28 times more potent than carbon dioxide (CO_2). Safety measures should be considered for storage and use, and to avoid release of biogas to the atmosphere.

PATHOGENS & PHARMACEUTICALS

Risks from pathogens in blackwater-derived soil amendments and fertilizers can be reduced through additional treatment (e.g., compost maturation, struvite drying) or application measures (e.g., lag time between last application and harvest). Micropollutant removal varies per treatment. Risks are likely lower compared to sewage sludge or animal manure application.

FLUSH SANITATION

eawag aquatic research

STRATEGY

Flush sanitation refers to the standard practice of using flush toilets to handle human excreta. A separately-piped flush stream is called blackwater, which contains urine, feces and flush water. When mixed and piped together with greywater it is referred to as mixed wastewater. Like water reuse from greywater, blackwater or mixed wastewater can also be treated for fit-for-purpose water reuse to save water. Recovery of nutrients and organics from these streams remains a challenge due to their strong dilution and the lack of simple and efficient solid-liquid separation technologies that enable recovery from the solid fraction. Flush sanitation can be combined with urine diversion, via urine diverting flush toilets, to enable nutrient recovery from urine. This strategy allows for resource recovery where a flush toilet already exists or is desired.

INPUT STREAMS

- Blackwater
- Mixed wastewater

TARGET OUTPUTS

- Treated water for non-potable water reuse (see)
- Soil amendments & fertilizers

FLUSH TOILETS

Flush toilets are the standard fixture in contexts with centralized, water-based sanitation, though they can also be installed in decentralized systems. Flush toilets often use 3 -13 L/flush depending on the toilet type. Variations include: dual flush, low flush, pour flush, and pressure flush. Commercially available urine diversion flush toilets further separate urine from the blackwater stream (see).

PIPING

Flush water can be piped separately (blackwater with or without urine diversion), which requires designated piping, or together with other streams (mixed wastewater). The latter requires only one pipe, as is conventionally installed for sewered systems.

MECHANICAL ROOM

Treatment of the collected stream(s) typically takes place in a mechanical room, integrated within a building, in underground tanks, or in a neighboring building for a semi-centralized treatment solution. Proper ventilation of mechanical rooms is crucial.

NEIGHBORHOOD SCALE
LA BISTOQUETTE
Geneva, Switzerland | 2025

BUILDING SCALE
ALPINE HUT
Rossinière, Switzerland | 2022

TO CONSIDER

COLLECTED STREAM

Flush water often contributes 20 - 40% of total domestic water use. Flush toilets mix urine and feces, and toilet paper, with large volumes of water resulting in a diluted stream. The flush stream can be collected separately, or together with greywater. The addition of greywater further dilutes the stream.

SPACE & PLACEMENT

No additional space is required for piping when flush water is mixed with other wastewaters; for blackwater collection designated piping is needed in parallel to greywater, and/or urine piping. Space requirements for a mechanical room for treatment depend on volumes collected and treatment technologies selected. While technologies can be quite compact (e.g., MBR), the series of technologies together do require space.

RESOURCE INTENSITY

Operational costs for treatment of streams containing flushwater are generally higher than for cleaner streams, such as greywater. When considering treatment options, the costs of advanced systems (e.g., membrane bioreactors) should be compared to real estate costs of space-intensive systems (e.g., nature-based solutions). Energy use varies by technology. Separate blackwater piping adds capital costs.

NEW BUILD VS. RETROFIT

Flush sanitation lends itself to building retrofits, where flush toilets are already installed in existing buildings, as well as to new build where flush toilets are preferred. Mixed wastewater requires single piping (e.g., existing piping). Blackwater, collection requires separate designated piping, next to other collected streams, and is therefore easiest in new build planning and construction.

HYBRID VS. DECENTRALIZED

Treatment of and recovery from collected blackwater or mixed wastewater can be implemented in hybrid or decentralized scenarios. Where a connection to the sewer is available, remaining streams or byproducts (e.g., from a liquid-solid separation step) can be discharged to sewer for a hybrid configuration.

USER EXPERIENCE

In many contexts, flush toilets are already installed, or are preferred. Implementing flush sanitation does not change the user experience at the user interface. Awareness among users about appropriate cleaning products is critical for biological treatment processes and fertilizer use of recovered products.

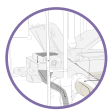
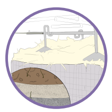
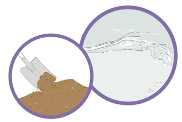
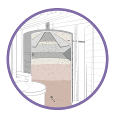
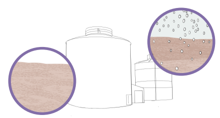
References and further information available at www.eawag.ch/en/wh/toolbox

TREATMENT OPTIONS

A typical treatment train for blackwater or mixed wastewater begins with a solid-liquid separation step, followed by technologies that valorize the organics and nutrients from the solids fraction or treat the liquid fraction for water reuse. In remote areas, where treatment is needed independent of the grid, infiltration or discharge are also possible solutions.

WATER REUSE	Treatment of the liquid fraction for fit-for-purpose reuse via biological treatment, filtration and disinfection technologies (see for water reuse treatment options).
WATER INFILTRATION & DISCHARGE	Treatment (e.g., septic tanks or aerobic treatment of mixed wastewater, or after a solid-liquid separation step) that produces an effluent that can be discharged to the environment or infiltrated on site.
VALORIZATION OF ORGANICS & NUTRIENTS	Biological anaerobic or aerobic treatment of the solid fraction after solid-liquid separation that yields a soil amendment (e.g., compost, anaerobic sludge) or biogas.

BELOW: Treatment options for valorization of nutrients and organics from the solids fraction. For water reuse treatment options see .

PROCESS OBJECTIVE		TECHNOLOGY	PRODUCT(S)
Solid-liquid separation removes grit, debris, and grease, and/or separates suspended solids (toilet paper, feces) from the liquid fraction.	S-L SEPARATION	 T.42 SETTLING TANKS | SCREENS	 LIQUID FRACTION
	S-L SEPARATION / BIOLOGICAL TREATMENT	 T.43 VERMIFILTERS	 COMPOST, LIQUID FRACTION
Anaerobic or aerobic biological processes, driven by microorganisms, convert organics into biogas or compost. Limited pathogen and micropollutant removal is achieved.	BIOLOGICAL TREATMENT	 T.22 OFF-SITE COMPOSTING	 COMPOST
	BIOLOGICAL TREATMENT	 T.23 ANAEROBIC DIGESTION	 SLUDGE, BIOGAS

SAFE REUSE

SAFE WATER REUSE

See for details on pathogen removal and inactivation, preventing microbial regrowth, and dealing with micropollutants for safe water reuse.

PATHOGENS & PHARMACEUTICALS

Pathogen risks in fecal-derived soil amendments can be reduced by combining treatment steps (e.g., compost maturation following vermifiltration or digestion) or by application measures (e.g., lag time between last application and harvest). Pharmaceutical and micropollutant removal varies per treatment. Their environmental risks in soil remain unclear, though are likely lower than those from applying animal manure or municipal sewage sludge (which also includes industrial wastewater and stromwater).

WATER REUSE

STRATEGY

Collecting and treating greywater or mixed wastewater for reuse in irrigation, non-potable building uses, or even potable reuse, results in significant drinking water savings. Reuse can also alleviate pressure on existing sewage infrastructures by reducing the volume of wastewater produced. Implementing water reuse can contribute credits, via water savings and supporting blue-green infrastructure, to attain green building certificates. For holistic water management solutions, water reuse is best integrated with water efficient fixtures, rainwater harvesting, and heat recovery. Cities like Melbourne, San Francisco, and Barcelona are pioneering legislative frameworks enabling widespread on-site water reuse at different scales.

INPUT STREAMS

- Greywater
- Mixed wastewater

TARGET OUTPUTS

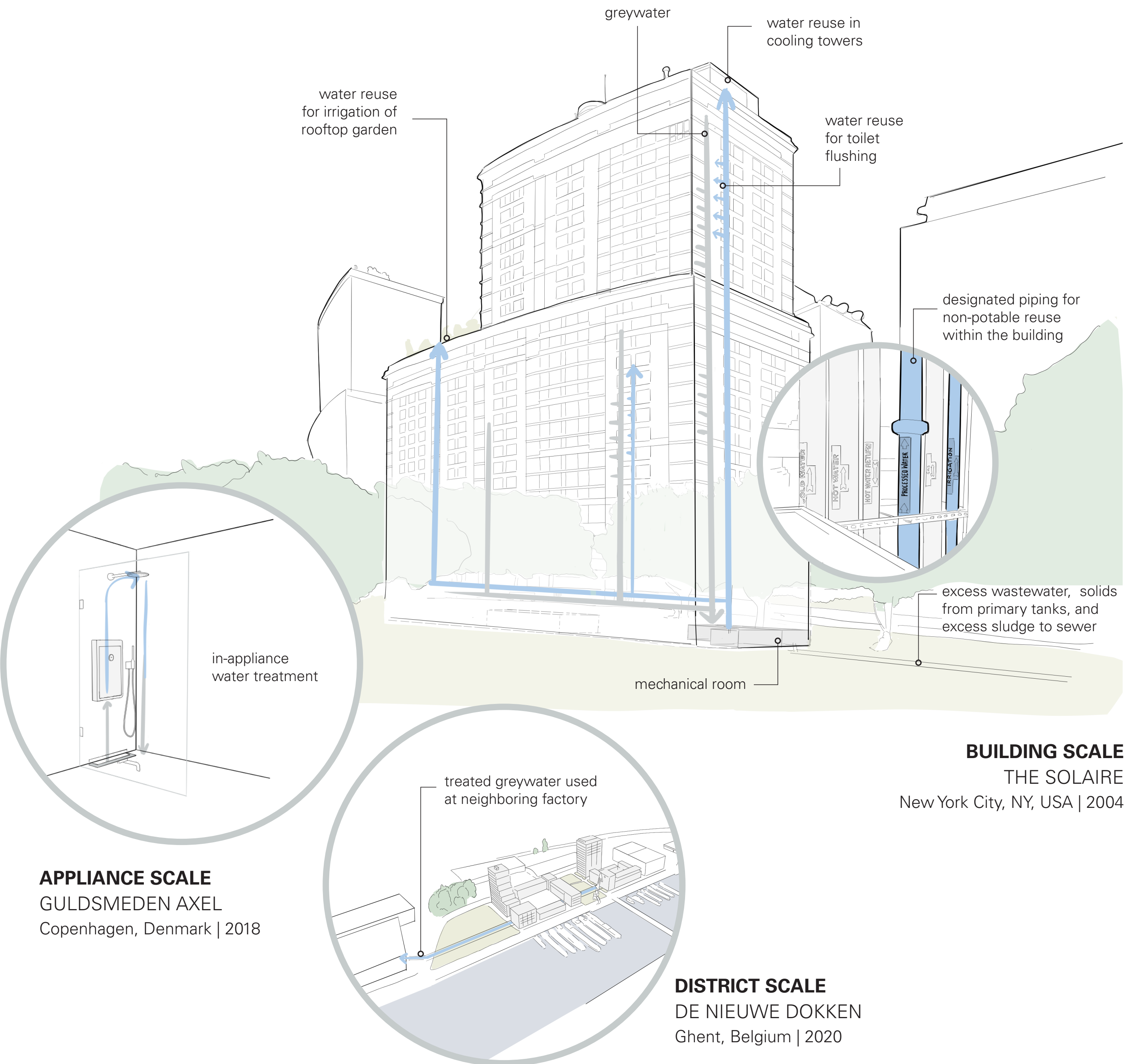
- Treated water for non-potable reuse (toilet flushing, irrigation, infiltration, laundry)
- Treated water for potable reuse

PIPING

Building scale water reuse must consider needs for additional piping for collecting greywater (if implemented) and/or for distributing treated water to the point of use. For non-potable, in-building reuse, adequate measures should be taken to prevent cross connections and backflow between treated water pipes and drinking water pipes and to minimize microbial regrowth in storage tanks and pipes.

TREATMENT

Mechanical rooms for water treatment and recovery are typically placed in the basement for building scale reuse or at a neighboring treatment facility in larger district-scale projects. Some treatment technologies can be placed outdoors, either underground or integrated in the (urban) landscape (e.g., constructed wetlands).



BUILDING SCALE
THE SOLAIRE
New York City, NY, USA | 2004

APPLIANCE SCALE
GULDSMEDEN AXEL
Copenhagen, Denmark | 2018

DISTRICT SCALE
DE NIEUWE DOKKEN
Ghent, Belgium | 2020

TO CONSIDER

COLLECTED STREAM

Both greywater or mixed wastewater can be reused. Greywater collection requires designated piping, though keeps the greywater from mixing with streams containing urine and feces, often requiring less intensive treatment than for mixed wastewater. Treating greywater yields smaller volumes than mixed wastewater, especially in non-residential buildings.

SPACE & PLACEMENT

The space required for treatment varies greatly depending on the technologies selected: higher tech solutions (e.g membrane bioreactors) can be very compact, while lower tech or nature-based solutions (e.g., constructed wetlands) require more space. Collection and storage tanks also require space.

RESOURCE INTENSITY

Operational costs for mixed wastewater treatment are generally higher than for greywater treatment. Separate greywater piping adds capital costs. When considering treatment options, the costs of advanced systems (e.g., membrane bioreactors) should be compared to real estate costs of space-intensive systems (e.g., constructed wetlands). Energy use varies by technology.

NEW BUILD VS. RETROFIT

Reusing treated mixed wastewater is easier to integrate into existing buildings, where greywater separation is not implemented. It is easier to plan for and implement separate greywater collection in new construction, although retrofitting existing buildings is possible.

HYBRID VS. DECENTRALIZED

If connected to the sewer, excess wastewater, solids from separation, or excess sludge can be discharged, ideally during low-flow periods to reduce strain on sewer and treatment infrastructure. A connection to the drinking water network provides backup if treated water volumes are insufficient.

USER EXPERIENCE

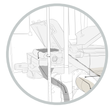
Nature-based treatment technologies may bring added value to the user by improving biodiversity, air quality, and aesthetics. For all water reuse scenarios, willingness of users to use lower than drinking water quality for applications where high quality is not necessary is important.

TREATMENT OPTIONS

A typical water reuse treatment train combines technologies from four process groups. Treatment trains do not need to include technologies from all process groups and can include more than one technology from the same process group.

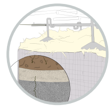
S-L SEPARATION

Solid-liquid separation removes grit, debris, and grease, and/or separates suspended solids (from toilet paper, feces) from the liquid fraction.



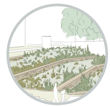
T42 SETTLING TANKS | SCREENS

BIOLOGICAL TREATMENT

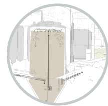


T43 VERMIFILTERS

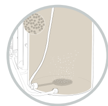
Biological processes, driven by microorganisms, remove organic compounds and can be designed to remove nitrogen as well as phosphorus. Limited pathogen and micropollutant removal is achieved.



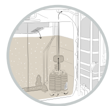
T44 CONSTRUCTED WETLANDS



T45 TRICKLING FILTERS



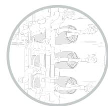
T46 AERATED BIOREACTORS



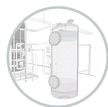
T47 MEMBRANE BIOREACTORS

FILTRATION

Filtration is the removal of particles and colloids using membranes or granular media. Pathogen and micropollutant removal is achieved to varying degrees.



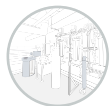
T48 MEMBRANE FILTERS



T49 GRANULAR MEDIA FILTERS

DISINFECT. & ADV. OX.

Disinfection is the inactivation or removal of pathogens to ensure microbial safety for reuse. Advanced oxidation processes also provide targeted removal of micropollutants.



T50 UV & CHLORINE DISINFECTION

T51 OZONATION & ADVANCED OXIDATION

SAFE REUSE

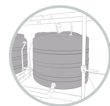
PATHOGEN REMOVAL & INACTIVATION

Enteric viruses, protozoa, and bacteria pose health risks, and their removal or inactivation, measured by log reduction, is essential for safe reuse. The required treatment level depends on 1) the source water (e.g., mixed wastewater will require higher log reductions than greywater), 2) the reuse application (e.g., irrigation has lower pathogen risk than indoor use), and 3) acceptable risk or regulatory standards. Water reuse treatment trains should be designed using a multi-barrier approach, which includes redundancies against pathogenic risks.

PREVENTING MICROBIAL REGROWTH

Trace levels of biodegradable organic matter and nutrients can cause microbial regrowth in storage tanks and pipes, affecting water color, odor, and system maintenance. Growth of opportunistic pathogenic microorganisms, like *Legionella pneumophila* or *Legionella spp.*, is a major concern for water reuse.

To minimize microbial regrowth, measures include: 1) filtration to remove organics and nutrients, 2) disinfection (e.g., with residual disinfection) 3) reducing treated water temperature, and 4) regular cleaning of tanks and pipes.



T41 WATER TANKS | CISTERNS

DEALING WITH MICROPOLLUTANTS

Treated water may contain organic micropollutants from cleaning products, pesticides, pharmaceuticals, and personal care products. While exposure is low for most non-potable uses, it poses a concern for potable and agricultural applications, as well as irrigation or infiltration where water enters the environment without further treatment.

Micropollutant removal depends on the sequence of technologies in the treatment train. Targeted removal (e.g., with activated carbon or advanced oxidation) can achieve desired removal for specific pollutants.

WATER-EFFICIENT FIXTURES

STRATEGY

Water-efficient fixtures are products designed to reduce overall water consumption in buildings without compromising performance. These fixtures replace typical fittings and appliances with, for example, low-flow shower heads and faucets, low-flush, dual-flush or waterless urinals and toilets, and/or water-efficient household appliances. Implementing water-efficient fixtures often does not require large infrastructural changes, yet reduces water consumption by 20-60%, depending on the type and usage. Water savings also reduce energy demand for hot water and contributes credits to attain green building certificates. Together with rainwater harvesting and water reuse, water-efficient fixtures can contibute to an overall water saving and reuse strategy.

INPUT STREAMS

- Drinking water
- Treated water

SHOWERS & FAUCETS

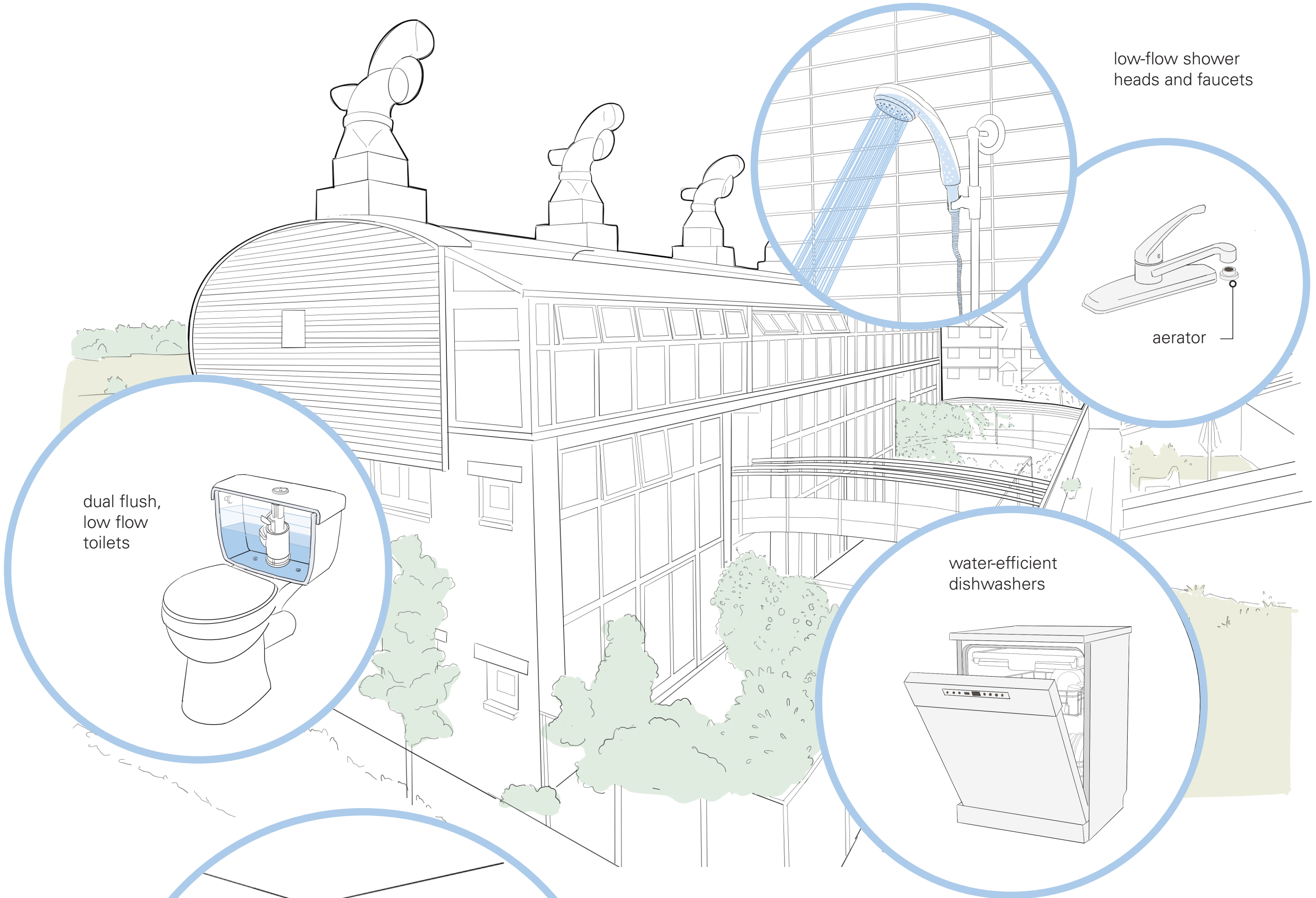
Watersaving flow restrictors (e.g., aerators) in shower and faucet fittings can be installed to reduce water consumption at the tap. Some bathtubs are sculpted to lower the volume of water they can hold. Showers that recirculate water, via in-appliance treatment also reduce water use.

APPLIANCES

Water efficient washing machines and dishwashers are examples of appliances that reduce water use. For washing machines, front-loaders generally save more water in comparison to top-loaders.

TOILETS

Flush toilets use large quantities of water per flush (~9 liters). Dual flush toilets allow users to control the amount of water per flush. Waterless urinals, vacuum toilets and dry toilets significantly reduce overall water use. However, their implementation may require additional planning of and infrastructure for the collected streams if they are not sent to sewer. See



APPLIANCE SCALE
BedZED
London, United Kingdom | 2000

APPLIANCE SCALE
GULDSMEDEN AXEL
Copenhagen, Denmark | 2018

TO CONSIDER

COLLECTED STREAM

Water-efficient fittings and fixtures use the same source water as regular ones. Faucet and shower aerators mix small air bubbles into the water to maintain water pressure, while using less water. Reduced water consumption reduces the volume of greywater or mixed wastewater produced, which can impact other water reuse strategies.

SPACE & PLACEMENT

Water-efficient fixtures can replace or be attached to conventional ones, occupying the same amount of space. Usually they are compatible with existing hardware.

RESOURCE INTENSITY

Installing water-efficient faucets and shower heads is often cheap and simple. Dishwashers and washing machines account for higher initial costs, although through the long-term water (and often energy) savings, water-efficient appliances can be a better investment over time. Upfront costs for water-saving toilets are often also higher than conventional ones. Installing dry/vacuum toilets may require a larger infrastructural change.

NEW BUILD VS. RETROFIT

Most fixtures are easily placed in both existing and new build infrastructure. Replacing toilets in existing buildings can require some additional construction, especially for the installation of vacuum and dry sanitation.

HYBRID VS. DECENTRALIZED

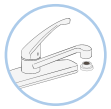
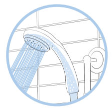
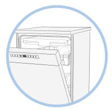
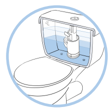
Water saving typically makes sense in all contexts, particularly water-scarce areas.

USER EXPERIENCE

Most water-efficient fittings and fixtures do not compromise their performance or the user experience. Dry toilets are the only fixture that may require a few behavioral changes (e.g., users may be required to add bulking materials, like saw dust after toilet use, and to adjust toilet cleaning practices).

FIXTURE OPTIONS

There are several types of water-efficient fixtures designed to reduce water consumption without compromising performance and user experience. Common fixtures, together with their water use, are listed below.

		FIXTURE	WATER USE
FAUCETS		REGULAR FAUCETS	10 - 15 L/min
		LOW-FLOW FAUCETS	5 - 8 L/min
SHOWERS		REGULAR SHOWERS HEADS	12 - 20 L/min
		LOW-FLOW SHOWER HEADS	6 - 9 L/min
		RECIRCULATING SHOWER	60 - 90% reduction
APPLIANCES		REGULAR DISHWASHERS	~20 L/load
		WATER EFFICIENT DISHWASHERS	9 - 12 L/load
		REGULAR WASHING MACHINES	~150 L/load
		WATER-EFFICIENT WASHING MACHINES	50 - 80 L/load
TOILETS		FLUSH TOILET	6 - 13 L/flush
		LOW-FLUSH TOILET	4 - 6 L/flush
		DUAL-FLUSH TOILET	3 - 6 L/flush
		VACUUM TOILET	<1 L/flush
		WATERLESS/LOW-FLUSH URINAL	0 - 1 L/flush
		DRY TOILET	0 L

USE

WATER & ENERGY SAVINGS

Water-efficient fixtures reduce overall water consumption, conserving valuable resources, especially in drought-prone areas. These fixtures often also reduce energy consumption by reducing the amount of hot water used; less water means less energy required to heat it up.

Water and energy reductions can lead to savings in utility bills over time. Calculated savings vary depending on 1) type and number of fixtures installed, 2) household size, 3) water usage, and 4) local water and energy rates.

RAINWATER HARVESTING

STRATEGY

Rainwater harvesting is the collection of rainwater from rooftops, balconies and/or other (above grade) surfaces during rainfall events. Collection is dependent on precipitation intensity, and by means of storage, collected rainwater can be used at a later point in time. Using rainwater for non-potable, even potable uses, results in drinking water savings. In off-grid locations, rainwater can be an important primary water source. Rainwater harvesting can be key to supporting urban blue-green infrastructure and is often included in sustainable building certification criteria. Rainwater harvesting can be part of a larger water saving and reuse strategy in combination with water efficient fixtures, and the reuse of greywater or mixed wastewater.

INPUT STREAMS

- Rainwater (from roofs, balconies)
- Rainwater from green roofs
- Stormwater (from lawns, pavement, roadways, etc.)

TARGET OUTPUTS

- Treated water for non-potable reuse (toilet flushing, irrigation, infiltration, laundry)
- Treated water for potable reuse

COLLECTION & STORAGE

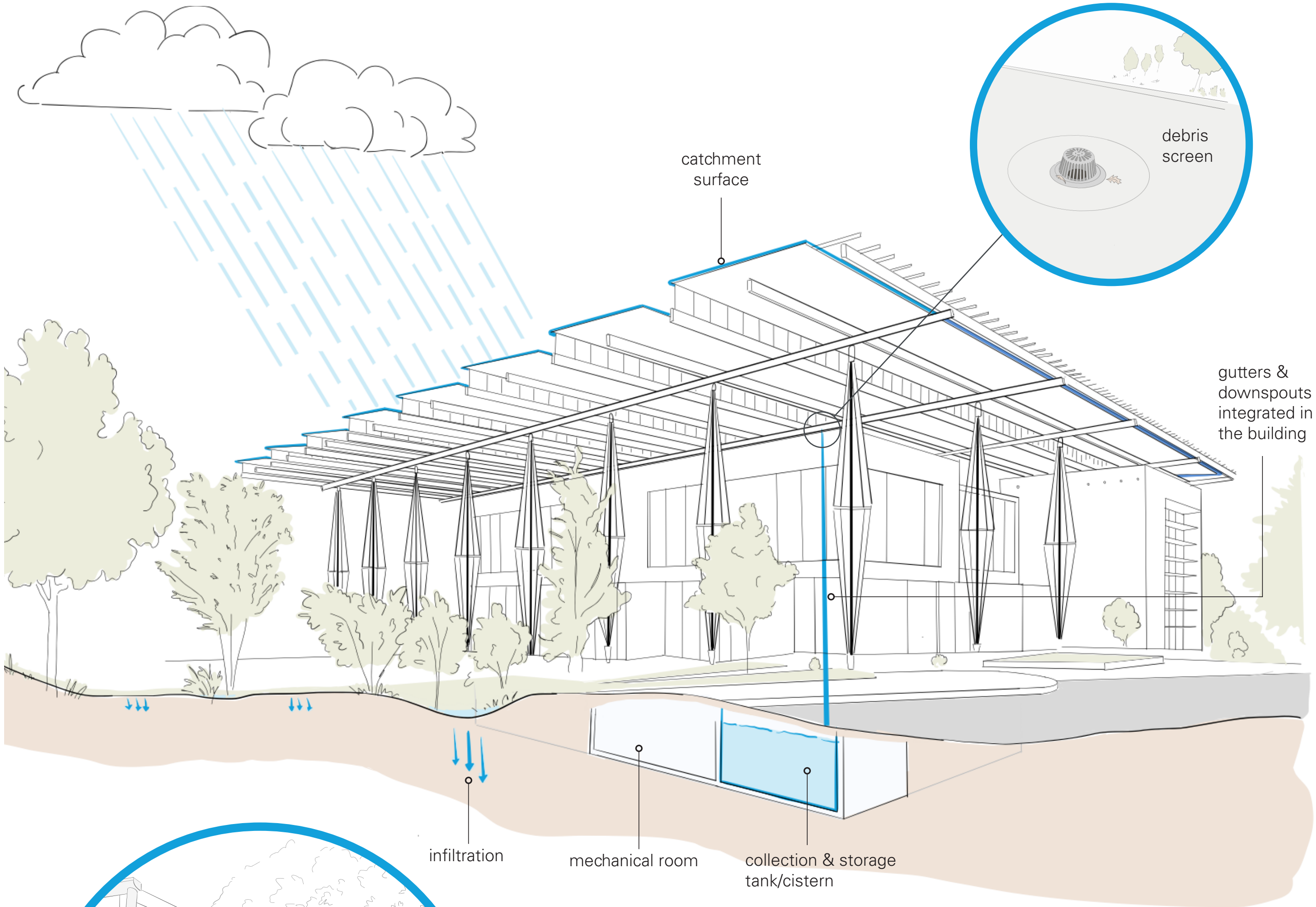
Gutters and downspouts direct rainwater from catchment surfaces to storage tanks or ponds. Ponds additionally support local biodiversity and cooling. Pre-storage measures include debris screens, filters, and first-flush diversion. Storage helps bridge the gap between wet and dry weather, and between collection, treatment, and reuse.

TREATMENT

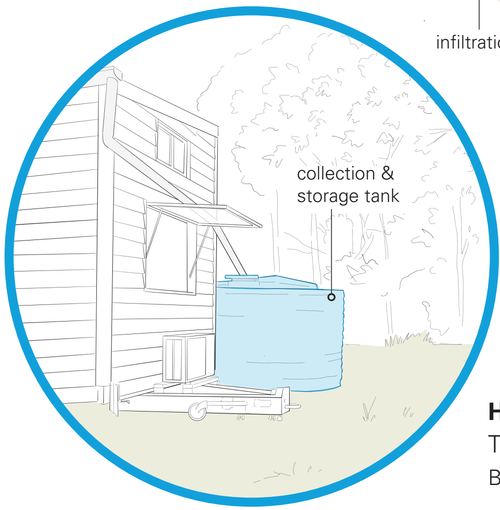
Rainwater can be directly reused for non-potable purposes like toilet flushing and irrigation, though treatment expands safe reuse, especially indoors. Treatment is typically done in a basement for building-scale projects or at a decentralized facility for neighborhood or district-scale systems.

PIPING & REUSE

A separate piping network distributes treated rainwater to reuse applications. For in-building non-potable reuse, precautions must prevent cross-connections and backflow between treated and drinking water pipes, and minimize microbial regrowth in tanks and pipes.



BUILDING SCALE
KENDEDA BUILDING
Atlanta, GA, USA | 2017



HOUSEHOLD SCALE
TINY HOUSE
Bryon Shire, Australia | 2019

TO CONSIDER

COLLECTED STREAM

Rainwater is a relatively clean stream, though its quality can be reduced by deposition and leaching of metals, nutrients and microbial pathogens from dust, debris, animal droppings and from collection surfaces themselves. The quantity of rainwater available for collection depends of local precipitation, and catchment surface area. Rainwater can also be collected (and treated) together with other water sources (see).

SPACE & PLACEMENT

Catchment surface area is an important determining factor in rainwater harvesting potential. Space requirement is most demanding for the storage tank(s), which can be located aboveground (e.g., rain barrels) or belowground (e.g., cisterns). Tank volume depends on rainwater supply and reuse demand balances. Water mass balance models and control units can help users monitor rainwater storage levels, automatically discharging water from the tank before a next rainfall event.

RESOURCE INTENSITY

Most buildings already account for initial material and installation costs for gutters and pipes. Above ground rain barrels are a cheaper add-on than underground storage tanks. Regular, though low, maintenance is required to clean filters. Energy is required to pump rainwater to place of reuse, when gravity-driven distribution is not feasible.

NEW BUILD VS. RETROFIT

Catchment surface materials need to be appropriate to prevent leaching of pollutants into the water (e.g., copper) in both existing and new build construction. Indoor reuse of rainwater requires an additional piping network, which lends itself better to new build construction.

HYBRID VS. DECENTRALIZED

In off-grid, decentralized settings, rainwater can be an important water source. In urban and suburban contexts, harvested rainwater can be used in parallel to other water sources (e.g., drinking water from distribution network), and the harvesting system can benefit from a sewer connection (e.g. to receive first-flush diversion water).

USER EXPERIENCE

Rainwater is generally accepted as a non-potable water source, and often also as a potable water source after sufficient treatment.

TREATMENT OPTIONS

Rainwater can be directly reused or treated for non-potable, and even potable, reuse. Treatment typically includes filtration and/or disinfection processes. Treatment of stormwater may require additional steps for pollutant removal (see Water Reuse).

DIRECT REUSE

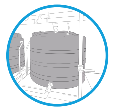
Rainwater reuse without treatment is common at the household level, typically for garden irrigation, cleaning, and toilet flushing. The water may have a yellow tint due to tannin staining from organic material like leaves, seeds, and pollen.

TREATMENT BEFORE REUSE

Treatment technologies for rainwater reuse target the removal of heavy metal, nutrient and microbial pollutants. Treatment trains are typically more complex for high-quality reuse and less complex for non-potable applications.

STORAGE

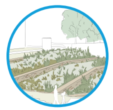
Storage tanks and cisterns store water before treatment and/or reuse.



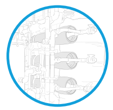
T.41 WATER TANKS & CISTERNS

FILTRATION

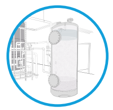
Filtration is the removal of particles and colloids, as well as microbial and chemical contaminants, using membranes or granular media. Biological degradation also occurs where microorganisms in a biofilm are present.



T.44 CONSTRUCTED WETLANDS



T.48 MEMBRANE FILTERS



T.49 GRANULAR MEDIA FILTERS

DISINFECT. & ADV. OX.

Disinfection is the inactivation or removal of pathogens to ensure microbial safety for reuse. Advanced oxidation processes also provide targeted removal of micropollutants.

T.50 UV & CHLORINE DISINFECTION

T.51 OZONATION & ADVANCED OXIDATION

SAFE REUSE

POLLUTANTS

The removal of pollutants, originating from dust and debris, or from collection surfaces themselves, depends on treatment steps and sequence. User exposure to these pollutants is considered small for most non-potable applications but is a concern for potable applications. A treatment step for targeted micropollutant removal (e.g., activated carbon or advanced oxidation) can be included.

Stormwater, collected from roads and terraces, typically contains more pollutants (e.g., organic and chemical pollutants and heavy metals) than rooftop-collected rainwater. Treatment may require additional steps for pollutant removal (see Water Reuse).

SAFE STORAGE

Trace levels of pathogens (e.g., from animal feces), organic matter and nutrients can lead to microbial regrowth in storage tanks and pipes. Growth of opportunistic pathogenic microorganisms, like *Legionella pneumophila* or *Legionella spp.*, is a major concern for human health. Additionally, for potable reuse, tank liners and coatings need to be food grade.

Measures for safe storage include: 1) removing organics and nutrients from water before storage, 2) ensuring tanks are opaque to prevent algal growth, 3) including a disinfection step (e.g., with residual disinfection) 5) regular cleaning of tanks and pipes.

BLUE-GREEN INFRASTRUCTURE

Rainwater harvesting, treatment, and reuse can be combined with blue-green infrastructure (BGI) to support local biodiversity, increase urban cooling, irrigate green areas and add aesthetic value. Examples of synergies between rainwater harvesting and BGI include: collection via green roofs, treatment with constructed wetlands, water storage in open retention ponds, and irrigation of public areas.

HEAT RECOVERY

eawag aquatic research

STRATEGY

Residual heat in greywater or mixed wastewater, from showers, laundry and dishwashers, can be passively recovered via heat exchangers to heat a building's hot water supply. Heat can also be actively recovered via heat pumps and added to a building or district's heat network. The recovery of this residual heat can reduce the energy demand of a building or district by roughly 30%. Heat recovery can be implemented in single- and multi-family homes and residential buildings, as well as in non-residential buildings with high hot water consumption (e.g., sports complexes, commercial washing facilities, hotels). Heat recovery can be coupled to on-site water reuse. The resulting lowered water temperature also helps reduce microbial regrowth in storage tanks.

INPUT STREAMS	TARGET OUTPUTS
Greywater	Recovered heat
Mixed wastewater	

IN-APPLIANCE RECOVERY

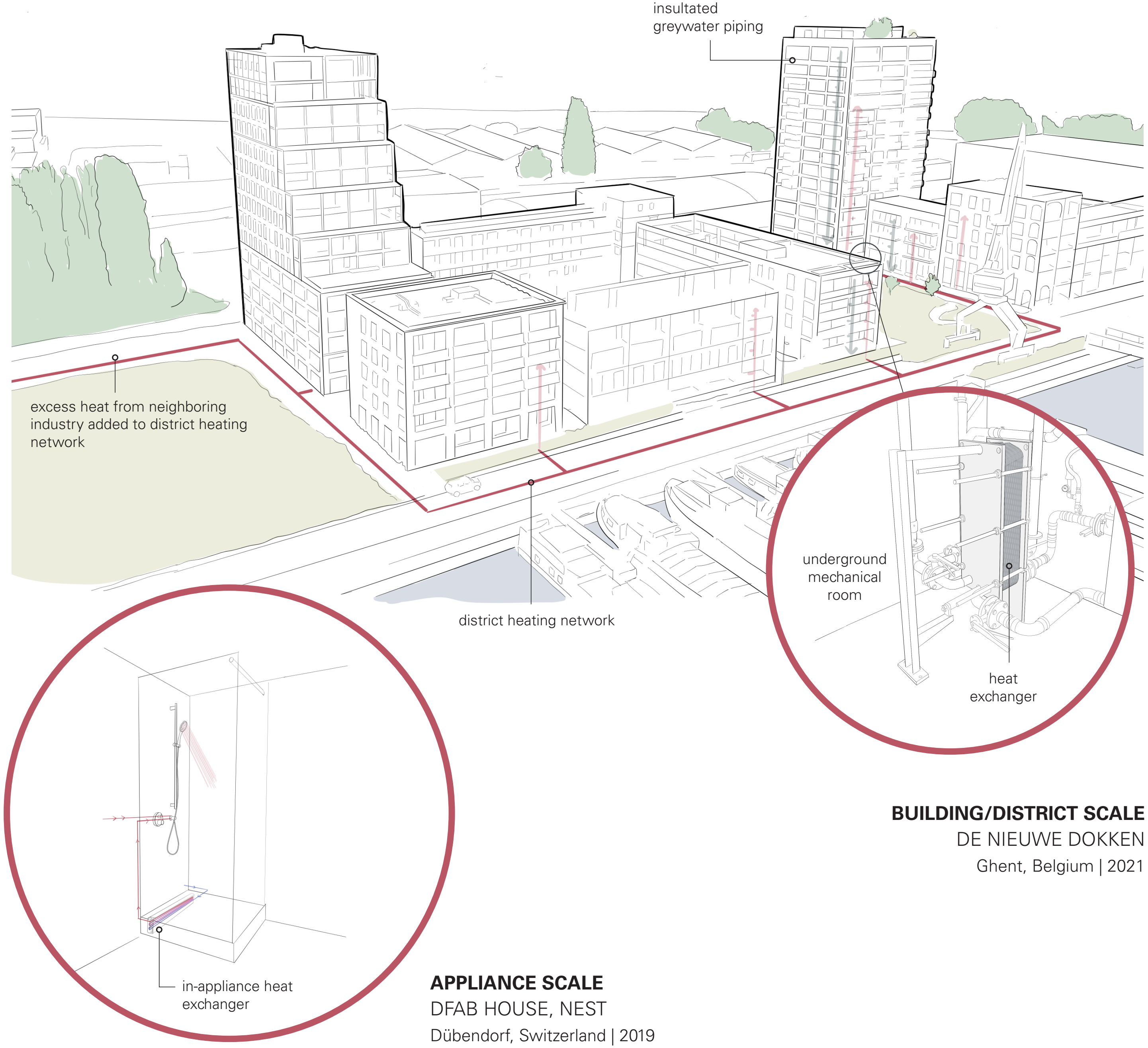
Heat exchangers implemented in or close to a shower, recover heat from the draining greywater to pre-heat the incoming water (by ~15 °C) before the mixing valve. Recirculating showers, that reuse shower water after in-appliance treatment, directly recirculate heat.

INSULATION

Greywater or mixed wastewater piping should ideally be insulated to avoid heat dissipation before reaching the heat exchanger or heat pump. Thermal storage tanks, also known as hot water storage tanks or buffer tanks, are commonly used to store heat between intermittent heat recovery and use. Storage tanks should also be insulated.

MECHANICAL ROOM

Heat exchangers or pumps, as well as storage/buffer tanks, are typically placed in a mechanical room, for example, in a basement. The closer the heat exchanger or pump is to the source, the lower the dissipation of heat during conveyance and the higher the heat recovery potential. Ventilation of the mechanical room is important to allow excess heat to dissipate and prevent overheating of the heat exchangers and pumps, and for humidity control.



BUILDING/DISTRICT SCALE
DE NIEUWE DOKKEN
Ghent, Belgium | 2021

APPLIANCE SCALE
DFAB HOUSE, NEST
Dübendorf, Switzerland | 2019

TO CONSIDER

COLLECTED STREAM

Most of the heat is present in streams including greywater from showers, washing machines, and dishwashers. Heat recovery is therefore implemented from greywater (if separated) or mixed wastewater. Greywater (temp. range: 25 - 38 °C) contains more thermal energy than mixed wastwater (15 - 30 °C). It is important to consider that recovering heat can impact further performance of treatment and recovery technologies.

SPACE & PLACEMENT

Unless appliance scale recovery is implemented, a mechanical room is used to house the heat exchangers and/or pumps, as well as heat storage/buffer tanks. Heat exchangers are often designed for modularity; depending on the volume of the collected stream and heat demand, the setup can expand. The insulation of pipes requires a bit more space between/behind walls. If integration in district heating network is desired, proximity to the network is essential.

RESOURCE INTENSITY

The initial investment for a heat exchanger or pump can be significant, although the long-term energy savings often justify the expenditure. Heat pumps are often most financially suitable at larger scales with high wastewater volumes. Heat recovery requires little additional resources, and minimal operation and maintenance.

NEW BUILD VS. RETROFIT

Heat recovery is suitable for both new constructions and retrofitted buildings. In existing buildings, implementing heat exchangers or pumps may require modifications to plumbing. New build contexts lend themselves for integration of onsite heat recovery into a networking heating distribution model.

HYBRID VS. DECENTRALIZED

Heat can be recovered at a centralized location, for example in conventional sewers and wastewater treatment plants. However, recovery close to the source reduces heat losses (i.e., dissipation) and increases recovery potential. Heat recovery can be part of a larger water saving strategy, however it can also be implemented for wastewater streams sent to sewer.

USER EXPERIENCE

Properly designed and maintained systems operate quietly and without odor, ensuring a positive user experiene. Lower heating bills are often a welcome result of heat recovery.

RECOVERY OPTIONS

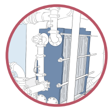
Heat recovery passively transfers (via a heat exchanger) or actively transfers (via a heat pump) residual heat, which would otherwise be lost, to either preheat or heat a cold water stream. Heat recovery reduces the energy required for heating the stream.

RECOVERY VIA HEAT EXCHANGERS

In a heat exchanger, the greywater or mixed wastewater passively transfers its thermal energy via conduction through metal plates or coils to a separate secondary stream, often colder water. This preheated water is then directed to the building's heating system or storage tank.

RECOVERY VIA HEAT PUMPS

A water-source heat pump can elevate the temperature of the cold water stream (also after heat recovery via heat exchanger) by actively extracting heat from the greywater or mixed wastewater stream via a vapor compression cycle that moves heat from one place to another.



T.61 HEAT EXCHANGERS & HEAT PUMPS

REUSE

STORAGE TO BUFFER SUPPLY & DEMAND

Heat in greywater and wastewater streams varies in depending on user behavior - of showers, dishwashers and washing machines. Not only does the volume and temperature of the flow vary, but the thermal energy in the flow is intermittent. Storing recovered heat is crucial to bridge supply (of recovered heat) and demand (for hot water or heating). Storing heat effectively ensures that it can be used when needed, such as during periods of low wastewater flow or high demand for hot water.

REUSE IN HEATING NETWORK

At scales beyond in-appliance recovery, the heat transferred to the secondary stream, can be used and distributed on site, for space heating or hot water, or into a larger heating network, via another heat exchanger. The heat can then be distributed to other users.

ENERGY SAVINGS

Energy reductions can lead to savings in utility bills over time and pay off initial investments. Calculated savings vary depending on 1) heat recovery efficiency and capacity of the heat exchanger and/or pump installed, 2) household size, 3) hot water usage, and 4) local energy rates.