Water Hub @ NEST: A Living Lab to Test Innovative Wastewater Treatment Solutions

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Abstract
The NEST building (nest.empa.ch) accelerates the process of innovation in the building sector. The modular building provides the experimental space and a living lab for applied research on materials, energy, and water. NEST consists of a central “backbone” and three open platforms, where individual research and innovation modules can be installed based on the “plug-and-play” principle. Waste streams from the sanitation infrastructure are separated at the source, i.e. urine, greywater and brownwater are piped separately to the basement, where novel resource-oriented sanitation technologies will be evaluated at the building scale in the so-called Water Hub (www.eawag.ch/waterhub). NEST thus allows showcasing the implementation of source separation technologies in a building. This paper describes the overall philosophy and technologies implemented in the NEST building. Furthermore, the potential for new research projects will be emphasised, extending an invitation to researchers and practitioners around the globe to participate in NEST.

Keywords
NEST, Source Separation, Nutrient Recovery, Resources-Oriented, Decentralised Systems

SOURCE SEPARATION TO ACCESS RESOURCES

Conventional sewer systems blend diverse types of wastewaters. With the complex mixture generated, it is difficult to efficiently recycle valuable substances and water for further use. In order to orient sanitation towards resource recovery, separation of waste streams at the source (source separation) has been suggested and thoroughly studied at various scales (Larsen et al., 2013). In terms of nutrients, urine contains the majority of nutrients (e.g. 90% nitrogen, 60% phosphorus), but contributes less than 1% of volume of total domestic wastewater (Larsen & Gujer, 1996). Therefore, if urine and faeces are separated at the source, recovering nutrients becomes more effective. Furthermore, humans excrete the main part of pharmaceutical residues and metabolites via urine (Lienert et al., 2007). With separate urine treatment, the targeted substances can be eliminated, before urine reaches a sensitive environment in water bodies.

The NEST building (nest.empa.ch) was created to take a short-cut from research to application. Therefore, the building features modular units, where new technologies can directly be tested in a real-life setting. The units host office and living space for researchers of the Swiss Federal Institutes of Materials Science and Technology (Empa) and of Eawag – the Swiss Federal Institute of Aquatic Science and Technology. NEST interlinks autonomous and intelligent systems at the building level. It provides the ideal experimental space combining material, energy, and water research and brings together researchers, engineers, and practitioners. For a rapid testing and implementation of new technologies, NEST closely collaborates with industrial partners. Thereby, practice-relevant research questions can be directly addressed and the knowledge transfer from research to application is encouraged.

RESOURCE-ORIENTED BUILDING

NEST embraces the concept of source separation. The so-called Backbone provides the structural framework to accommodate up to twenty exchangeable living and working units.

Pipe Network. The pipe network in the Backbone intercepts the wastewater streams from each modular unit via five different pipes: urine, more concentrated greywater (from kitchens), less concentrated greywater (from bathrooms), brownwater (containing faeces and flush water), and mixed wastewater (Figure 1). All pipes lead to the Water Hub – the experimental facility located in the basement (www.eawag.ch/waterhub). NEST thus acts as a living lab to test innovative wastewater treatment solutions.

Figure 1. Five different pipes convey the various wastewater types to the Water Hub: light and heavy greywater, urine, brownwater, and mixed wastewater. Not on the picture: rainwater pipe.

Urine-Diverting Toilets. As a centrepiece of source-separation, eight novel urine-diverting flush toilets separate urine from brownwater in the building's backbone (Figure 2). The toilets contain a sensor, which is able to distinguish flush water and urine. Depending on what liquid enters the toilet bowl, the sensor triggers a valve to open or close, hence to drain urine to the urine pipe or flush water, along with faeces to the brownwater pipe. The toilets have been developed by Duravit and the first set of prototypes is tested in NEST.

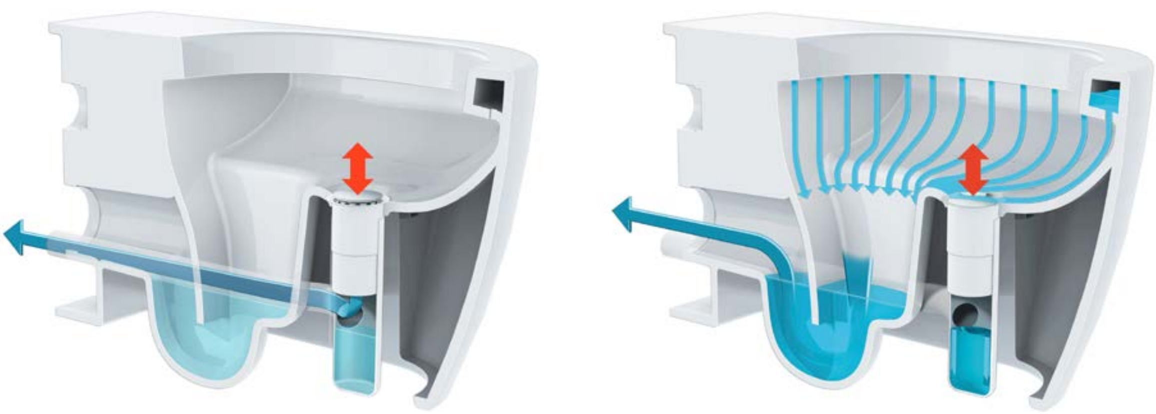

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Figure 2. New electronically controlled urine-diverting flush toilet: A sensor detects the presence of urine and opens the corresponding pipe (left) or closes the urine pipe to flush the faeces (right).

Greywater Sources and Users. Two different types of greywater will be collected. More concentrated heavy greywater from the kitchens and less concentrated light greywater from the bathroom sinks and showers. The building is constructed to allow for the distribution of treated rainwater or greywater back to the units. Greywater reuse for toilet flushing can be considered state of the art. Further application of treated greywater for the washing machine or for showering requires more advanced treatment and at this point is not an established technology. In the current phase of NEST, the focus is on research, development, and testing of a range of technologies. Currently the treated greywater is not being reused within the building – this is the goal for a future phase of NEST.

NOVEL TREATMENT OF THE DIFFERENT WASTESTREAMS

Starting in the fall of 2016 NEST will be hosting residents and employees and receiving visitors, who all contribute wastewater to the Water Hub. Currently, three different treatment systems operate in the NEST basement:

Urine

Nutrients are extracted from urine using the VUNA process (Etter et al., 2015): In a first step, the urine is stabilised by nitrification in a moving-bed biofilm reactor (Figure 3). In this process, the ammonium contained in urine is partially converted into nitrate. Secondly, the stabilised urine is distilled to obtain a concentrated nutrient solution (to be used as a fertiliser) and distilled water. The process has previously been tested and has proven its functionality. The fertiliser performed well in greenhouse trials on ryegrass in comparison with synthetic nitrogen and phosphorus fertilisers (Bonvin et al., 2015). The Swiss Federal Office of Agriculture issued a temporary fertiliser license for the fertiliser to be used on flowers, lawns, and ornamental plants. The temporary license will be extended to an unlimited license in 2018 under the condition that sufficient proof is delivered that all pharmaceutical residues be eliminated or degraded to negligible concentrations. Therefore, NEST is currently testing efficient pharmaceutical removal using granular activated carbon (GAC) columns to adsorb pharmaceutical residues, and to ultimately supply an uncompromised fertiliser product.

Figure 3. The VUNA moving-bed biofilm reactor stabilises the urine, before it is concentrated in an industrial distiller to produce a liquid fertiliser. A similar reactor is installed in the Water Hub.

In NEST, further treatment steps are tested to enhance process stability and quality of the final product. Research at Eawag has shown that intermediate nitrite accumulation is critical for the nitrification process' stability (Fumasoli et al., 2016). An additional biological pre-treatment and electro-chemical post-treatment step are currently studied to maximise process stability. In order to maximise the overall process stability, and to automate fertiliser production in future buildings with urine diversion, several existing computer models on process kinetics (Fumasoli et al., 2015), bio-chemical and chemical reactions (Udert & Wächter, 2012), and process control parameters (Mašić et al., 2015) are currently integrated into a single model. With the new global model comprising various processes and unit operations, the process will be tuned to efficiently deliver a sustainable and safe fertiliser as end-product.

Greywater

Greywater treatment will use a sequence of unit processes. Greywater will first be treated using a biologically activated membrane bioreactor (BAMBi) (Kuenzle et al., 2015) followed by a biologically activated carbon filter and then electrolysis. The first objective for this treatment approach is to provide water that is of a higher quality compared to conventional greywater treatment systems (membrane bioreactor followed by chlorination) (Luthy et al., 2016). Current practice for greywater treatment produces water suitable for toilet flushing but often is not hygienically safe for other household applications (Oesterholt et al., 2007). In the BAMBi process, a biofilm develops on the ultrafiltration membrane leading to improved permeate water quality (Chomiak et al., 2015). Biologically activated carbon filtration combines physical sorption processes with biological degradation for further removal of slowly biodegradable organic carbon. Electrolysis further oxidizes organic pollutants and colourants and disinfects the water. The second objective is to develop a treatment system that is simpler to operate and requires less energy compared to conventional systems based on membrane bioreactors. Tolerating biofilm formation on the membrane in the BAMBi process means that no energy is needed for high shear by coarse bubble aeration or cross flow. In addition, process complexity is significantly reduced as no chemical cleaning or backwashing is required. This treatment approach has initially been developed and long-term tested for water reuse of wash water in the Blue Diversion toilet – a urine diverting dry toilet with internal recycling of wash water (Larsen et al., 2015). The processes were further developed for a self-sufficient living unit (SELF, www.empa.ch/web/self). In the NEST building the focus will be on understanding the interactions between treatment processes, produced water quality, and deterioration of water quality in the downstream distribution network.

Brownwater

In order to safely recover energy or nutrients from brownwater, or faecal sludge, dewatering has been identified as a critical process to be optimised (Gold et al. 2016). Although dewatering of sludge from municipal wastewater treatment has been extensively researched, faecal sludge collected from on-site sanitation sources has been shown to exhibit much different dewatering behaviour (Spellman et al. 1997, Cofie et al. 2006). The mechanisms influencing faecal sludge dewatering are not yet fully understood. At NEST Water Hub, collected brownwater will be fundamentally characterized and dewatered using various techniques. Results will provide a better understanding of suitable dewatering technologies for decentralized waste streams, which will assist the optimisation of suitable technologies for faecal sludge treatment and resource recovery at a global scale.

SYSTEM INTEGRATION

With source separation, different types of waste streams can be created: every household device can give rise to one or more separate waste streams (e.g. urine and brown water from the toilet). These waste streams can either be treated separately or mixed in different ways: shower water, for instance, can be treated directly in a recycling shower or together with other household streams. In principle, n streams can be combined in 2^n-1 ways, but clearly there are combinations that are more obvious than others. Not only are there many possible combinations of input waste streams, treatment also generates a number of different output streams, primarily water, energy, nutrients, and sludge in different qualities. In order to optimise on-site treatment, structured generation of good combinations of waste streams (e.g. by using a strategy generation table, Lienert et al., 2015) as well as a comprehensive modelling approach is required, taking into account the competition and synergies of the different treatment technologies. For instance, a recycling shower may compete with a treatment process for combined light greywater to generate irrigation or flush water, whereas a sludge-producing greywater process may profit from the availability of blackwater treatment in the same setting. Ideally, the modelling approach should generate input to different decision support tools like Life Cycle Assessment (LCA) and Multi Criteria Decision Analysis (MCDA).

CONCLUSIONS & OUTLOOK

The NEST Water Hub has been developed as a comprehensive case study for the implementation of source separation water technologies in a building. Already during the planning and construction phase, it has produced valuable results on the feasibility and compatibility of resource-oriented sanitation technologies with the building industry. Beyond the technologies, the case study also incorporates the collaboration across sectors, from academia, across industry, to public authorities and utilities. With the opening of NEST in June 2016, the planned testing of innovative resource-oriented wastewater technologies commenced. As NEST will remain an uncompleted, i.e. constantly evolving structure, it will keep providing the space to implement and test new technologies in a real-life setting over the years. Thus, with this article we extend the invitation to researchers and practitioners across the globe to collaborate with NEST. For more information, visit www.eawag.ch/waterhub.

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