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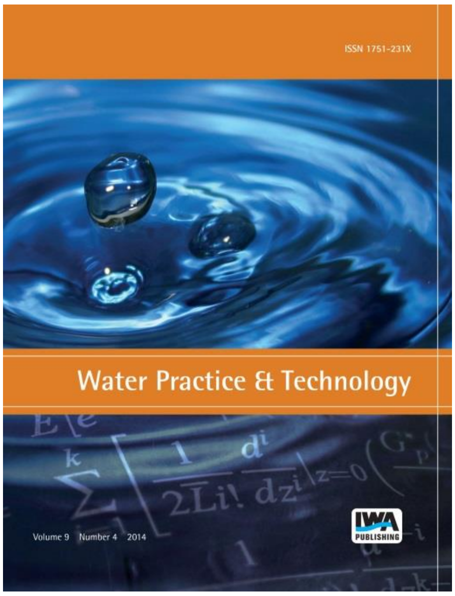

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Blue buildings: decentralized and integrated management of water from 'Source-To-Source, At Source'

S. Samuel[a,*], M. Lim[a], C. Hsien[a], A. Ho[a], U. Schraudolph[b] and S. White[c]

[a] ECOSOFTT Pte Ltd, Block 73, #03-10 Ayer Rajah Crescent Singapore 139952

[b] XENTIQ Pte Ltd, 35 Joo Koon Circle, Vicplas Building, 6th Floor, Singapore 629110

[c] Tsinghua University, 30 Shuangqing Rd, Haidian, Beijing, China

*Corresponding author. E-mail: stanley.samuel@ecosoftt.org

Abstract

The high upfront investments, inadequate funding, technical challenges and major gaps in implementing centralized water systems necessitate the exploration of more viable, environment friendly and economically sustainable options. At the same time, the increasing scarcity of water requires an 'end-to-end' or 'source-to-source' management approach.

This paper provides the framework for an alternative decentralized solution that can both complement the conventional centralized solution to water and wastewater management. It provides the vital building blocks for the development of SMART Cities by making homes, buildings and communities water sustainable through a new *Blue Building Standard* that uses economically and technically viable technologies. In such a framework, the end users become active partners and collaborators with service providers and utilities in the management of water from source to source, at source. Only with the development and adoption of new standards can decentralized solution realize its potential of becoming a mainstream solution in urban water management.

Key words: blue buildings, centralized, decentralized, environment, innovations, low cost, low energy, nutrient recovery, smart cities, urban water management, used water, water, wastewater, water smart

INTRODUCTION

In modern buildings such as schools, hotels, homes and commercial properties, non-potable water activities such as toilet flushing, cleaning, cooling towers and landscaping constitute a major percentage of total water consumption (PUB, Water Usage Breakdown for Typical Hotels 2014). These non-potable water applications frequently use potable-quality water from the municipal or clean ground water. The resulting wastewater is discharged into the sewer systems where they exist (PUB 2015). In 'off-grid' areas, they are mostly discharged into open areas untreated or semi-treated (Mallapur 2016). In both 'on-grid' and 'off-grid' areas, wastewater recycling or reuse rarely happens at source.

Such practices where high quality water is used for non-potable applications and wastewater is not recycled represent major wastages in water resources, energy, human effort and financial resources. This is especially significant in water-scarce developing countries where the growing demand for water and sewerage facilities outpaces the available financial resources and rate at which these facilities can be built (Ludwig Mohit & Gunaratnam 2003; Tecco 2008). With water coming under increasing stress, it is imperative for users to manage their water, waste and wastewater in an integrated way at source.

The decentralized solution has long been seen as a 'low end' or 'interim' solution for 'off-grid' communities long waiting for centralized solutions. (Massoud *et al.* 2009; Parkinson & Tayler 2003) However, the availability of economical, low maintenance and compact technologies have enabled decentralized solutions to become viable alternatives to complement or meet gaps in conventional centralized plants and networks. With decentralized solutions, it is now possible to reduce load on the water grid, plug gaps in water systems, enhance water security for users and conserve finite water resources.

METHODS

Blue Building Standard

The proposed *Blue Building Standard* provides a new paradigm through the decentralized and integrated management of water, wastewater and waste. It allows for homes, hotels, commercial buildings, schools and other facilities to: (a) reduce their water footprint and wastage by more than 50%; (b) recycle and reuse over 80% of the wastewater on site; and (c) discharge the balance 20% in an environmentally friendly way.

Figure 1 below illustrates the Blue Building Standard which is based on four overarching principals: (1) Water Source: Increase and diversify water sources, (2) Water Use: Integrate various water sources for different water use, (3) Water Recycling: Collect and recycle wastewater using appropriate technologies, and (4) Water Discharge: Safely discharge excess water for other community needs or into the environment.

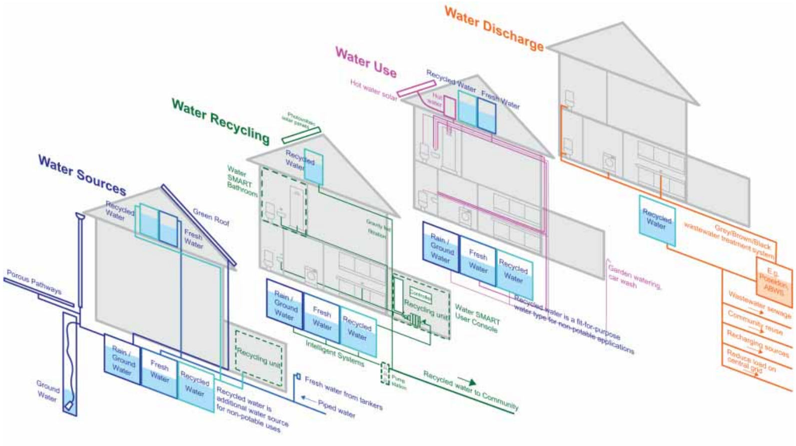

Figure 1 | Overview of the Blue Building Standard (A Single Home for Simplification).

1. Water Source: Increase and diversify water sources

The Blue Building integrates the management of multiple sources of water such as rainwater, groundwater, piped water, as well as recycled water from on-site water recycling and wastewater treatment systems. The diversification of water sources reduces users' reliance on a single source of water, reducing the risk of lack of water and making the compound more water secure.

2. Water Use: Integrate various water sources for different water use

The integration of various water sources enables users to use fit-for-purpose water, where water of different qualities can be used for specific activities. For example, recycled water can be used in non-potable applications like toilet flushing and landscaping. This reduces reliance on groundwater and prevents over-extraction of groundwater, or in the case of pipe water, reduces the intake of high quality piped water. This also shortens the urban and natural water cycle, where large amount of time and energy is used to treat wastewater to high quality.

3. Water Recycling: Collect and recycle wastewater using appropriate technologies

Wastewater collection, recycling, and reuse can be designed to suit a community's social, economic, cultural and environmental conditions. Depending on the water consumption and wastewater production patterns, wastewater can be separated at source (i.e. greywater and blackwater), and treated to varied levels for use in different activities. For example, secondary treated blackwater can be used for landscaping, while water reduced within the building needs to undergo an additional treatment step. The appropriate technology selected can be based on financial and space allowances. By recycling wastewater, every drop of water in the compound can be reuse multiple times.

4. Water Discharge: Safely discharge excess water for other community needs or into the environment

Users can choose to reuse the treated water within the compound for non-potable purposes like toilet flushing and landscaping, or discharge the treated water. Where there is excess water after reuse in non-potable applications or where recycled water reuse is not yet practiced, the water can be used to recharge groundwater or discharged safely into the environment. In addition, excess recycled water can supplement water needs in other parts of the community. For example, excess recycled water from a housing community can supplement non-potable water requirements for a nearby factory.

The decentralization aspect enables scalability and applicability of the Blue Building at various point-of-use levels, from single home to housing community, schools to commercial buildings. The implementation method is highly modular, enabling users to implement parts of the system depending on water needs and financial situation. For example, a campus can choose to implement rainwater harvesting to diversify it water source, and leave blackwater recycling for a future upgrading project when finances allow for it. Whether urban, rural or peri-urban settings, the Blue Buildings platform has proven to be a viable and economic model by the following:

- Embrace rainwater harvesting, a low cost source of water from the natural water cycle;
- Recover and reuse wastewater using low energy and high water recovery technologies;
- Reduce use of chemicals by using biological treatment processes;
- Add treated wastewater as a new and reliable source of water through decentralized treatment. This enables 'Point of Use Reuse';
- Take in all on-site wastewater sources including grey water and black water without dual plumbing to separate the wastewater types. This reduces the percentage of capital that property owners have to allocate upfront, and reduces implementation timelines;
- Better optimize water from different sources and use non-potable water for non-potable purposes;
- Deploy smart accessories to monitor and manage water usage that can be integrated with Building Management Systems;
- Engage users and sharing responsibilities in managing water from source to source, at source.

Technology selection

The Blue Building is not dependent on any single technology. Instead, it offers a platform where technology innovators can collaborate to create integrated solutions. Nevertheless, the treatment technologies to be deployed need to meet a set of criteria to maximize user benefits and environmental impact. Table 1 outlines the criteria for technology selection and the relevant benefits.

To date, we have tried and proven the following technologies that have met these criteria, with highly satisfactory results:

Table 1 | Technology selection criteria

Criteria	Benefits & Impact
1. Small footprint	• Minimize real estate cost. Blend into building environment
2. Low initial and infrastructure costs	• Minimize financing constraints
3. Low energy consumption and operating costs	• Lower cost of ownership
4. Recovery of over 80% of water	• Maximize reuse potential
5. Low use of chemicals through stable biological process	• Safer handling
6. No/Minimal sludge or nutrient recovery	• Eliminate challenges in handling toxic material
7. No odor	• Create pleasant environment
8. Reliable performance	• Create water security and peace of mind
9. Easy to operate	• Enable community and stakeholder engagement

- Aerobic Biofilter Without Sludge (ABWS - The Mizuchi): Low-cost wastewater solution for small communities based on the principles of bio-filtration and bio-remediation; (Soto & Toha 1998)
- Airlift Circulating Floating-Carrier Bed (ACFB - The Poseidon): Compact wastewater solution for individual homes, hotels, schools and commercial buildings based on principles of bacteria attached growth on floating carriers; (reference: Samuel *et al.* 2015)
- (AIRR/BRR – BioFiltration With Recirculating Reactors – The Terra): Low-cost wastewater solution, for individual homes and small communities by controlling biological/bacterial activities on the surface area of natural media in combination with high oxygenation. (Blood 2012)

The technologies selected are not static, but constantly evolving to incorporate viable and new technologies to meet changing user needs. As such, the Blue Building can be seen as an 'open-source' platform.

Advantages over current dominant solution

The *Blue Building* can operate without the existence of a centralized system with water grid, such as when the building is totally dependent on groundwater. Where a grid exists, significant reduction in load and improvement in efficiency can be achieved by managing water and reusing wastewater at source. It drastically reduces the wastages in the conventional centralized 'once through' system.

The Blue Building standard prevents commercial operators from having to use high-quality potable water for non-potable purposes which constitute the majority of their water consumption. As potable water has high embedded energy, financial and environmental costs, using potable water for non-potable purposes means that we are incurring significant embedded costs, even if these costs are not fully reflected in water tariffs. Using non-potable water instead of potable water for the majority of our non-potable water consumption can therefore reap significant savings in terms of these 'hidden' embedded costs.

Further, Blue Buildings at appropriate scales lessen the load on the sewer networks where they exist. They also form part of the solution to meet ever-increasing water demands in urban settings by generating an on-site source of non-potable water, thereby reducing a property's demand on piped freshwater. As a result, such an approach has the potential to be adopted on a massive level to bring reliable services to masses in water scarce countries, conserve water resources and maintain an ecological balance.

Case study: Xavier Institute of Development Action Studies

1. Site Profile

This educational institution is located in a region of City of Jabalpur without piped water and sewer coverage. It is a leading center of post-graduate education in the Central India region and Training Center for Water and Sanitation for Urban Local Bodies and Directorate of Urban Management. Approximately 500 students, staff, faculty and visitors use the facility on most days during the year.

2. Prior Water Situation

The only water source used to be ground water through bore wells on campus as it is not connected to any municipal water and wastewater network. The ground water table was depleting at a fast pace with new nearby developments all relying on same ground water supply. To cater to demand, it added 2 new bore wells to its existing one. All sewage generated was minimally treated using a septic tank. The septic tank had to be cleaned once every 3 months to maintain its basic wastewater treatment requirements. This caused contamination of groundwater, which threatened water sources further and contributed to pollution of nearby lakes, agricultural farms and the major Narmada River.

Key Issues:

- Depleting groundwater table
- Poor performing septic tank
- Minimally treated wastewater from the septic tank was discharged into a nearby drainfield
- Seepage of untreated wastewater into the ground caused groundwater contamination

3. Principles of Engagement

The management of Xavier Institute of Development Action Studies (XIDAS) set the goal for it to be water self-sufficient by managing their water and wastewater in a decentralized way, with all the recovered wastewater to be reused on campus. The surplus is to be used for ground water recharge and released into the nearby drainage system without causing contamination. Rainwater harvesting is to be implemented to augment supply further.

The aim is to create a green showcase site for students and visitors to learn how to better manage water and wastewater. In the process, students, faculty and staff are to be engaged so as to contribute to creating a model eco-friendly campus

4. Results

A combination of ABWS, AIRR and ACFB technologies was deployed for wastewater treatment. These technologies were selected based on the understanding of social, economical, and environmental conditions of the institute. The benefits of the technologies are:

- Blends into campus architecture
- Small footprint system
- Treated water is of high quality
- No odour
- Can be operated by an existing staff member, in this case, their gardener
- Minimal operation and maintenance requirement

- Treated water can be reused for gardening

Over 90% of the wastewater of approximately 60,000 liters is recovered each day. All these technologies do not generate significant sludge, odor, need low footprint, minimal maintenance and chemicals. The systems are simple to use and operated by the local gardeners, watchmen and service staff. The treated water quality of the ABWS and ACFB systems are shown in Table 2 and Table 3, respectively. Treated water quality is taken regularly to monitor the efficiency of the wastewater treatment systems. The treated water sample for the ABWS in Table 2 was taken 9 months after system installation while the treated water sample for the ACFB in Table 3 was taken 1 year after system installation. The treated water meets the Indian local standards for Class D which is minimally safe for discharge into the rivers (CPCB 2016). Figures 2, 3 and 4 are pictures of the project executed at XIDAS.

Table 2 | Treated water quality from ABWS at XIDAS

Water Quality Parameter	Value
pH	7.9
BOD (3 Days at 27 °C)	8 mg/L
COD	19 mg/L
TSS	12 mg/L
Fecal Coliforms	<2 CFU/100 mL
Ammonical Nitrogen	0.55 mg/L

Table 3 | Treated water quality from ACFB at XIDAS

Water Quality Parameter	Value
pH	7.2
BOD (3 Days at 27 °C)	4.4 mg/L
COD	24 mg/L
TSS	20 mg/L
Fecal Coliforms	<2 CFU/100 mL
Ammonical Nitrogen	0.2 mg/L

Figure 2 | ABWS System in XIDAS.

Figure 3 | ABWS Bioreactor in XIDAS.

Figure 4 | ACFB System in XIDAS Priest Quarters.

With the systems in place, the use of septic tank is eliminated. Treated water is reused within the compound for landscaping, reducing the intake of groundwater. The surplus water is used to recharge ground water. Nutrients recovered from sewage is transformed into fertilizer with a Carbon/Nitrogen ratio of about 20, ideal for organic agriculture. Using the *Blue Building Standard*, XIDAS became a 'Zero Discharge Campus' that no longer contribute towards the contamination and pollution of the nearby water bodies and groundwater sources.

DISCUSSION

Installing decentralized wastewater treatment system in areas that are not connected to a centralized sewer system helps to mitigate land and water pollution. In the case of XIDAS, septic tank effluent used to flow into a nearby drain field, polluting the land and groundwater. After installation of a decentralized wastewater treatment system, clean treated water no longer pollutes the land and groundwater. The land that was previously a drain field can gradually recover to become valuable land. The addition of the wastewater recovery system enables the facility to become more water secure, improving the property value.

Where treated wastewater is reused, the treated water quality need to be of a minimum level to ensure health and safety of users. (Crites & Tchobanoglous 1998) Technologies implemented must be stable and reliable to ensure that a minimum treated water quality can be consistently met. Treated water quality should be tested regularly to ensure treated water quality is within allowable limits. Despite regulations for discharge or reuse of treated wastewater, these regulations may not always be well enforced. As health risks due to use of poorly treated water must not be ignored, the onus of maintenance and ensuring that good quality treated water is used should lie on system users, owners, and operation and maintenance personnel. System maintenance should be done diligently to keep the system performing at high treatment efficiency. Simple maintenance can be done by users or *ad-hoc* maintenance personnel, whereas thorough maintenance is typically carried out by trained maintenance team. In the XIDAS wastewater treatment system, daily operations and *ad-hoc* maintenance are simple and can be done by the existing gardener. Maintenance of each system is done once in 3–6 months, during which the humus by-product from the ABWS is harvested and used to fertilize plants within the campus.

Depending on the scale and finances of the project, selected water quality sensors can be installed to provide real-time monitoring of selected treated water quality parameters at the facility. In monitoring of the wastewater recycling system, various decentralized plants can be installed with sensors and remote monitoring devices. These decentralized plants can be monitored for equipment failure or treated water quality at a centralized location, where skilled engineers are stationed. As more decentralized wastewater treatment and reuse systems are installed, more efficient methods of maintaining and monitoring the systems need to be developed and implemented in a cost-effective way.

With multiple sources of water, the integrated management of all water sources can be further developed to optimize water consumption at various points of a building or an estate. In developing smart management of water of a Blue Building, sensors can be installed at various points in the building and data capture and analyzed. With sensors and data analysis, smart management of the Blue Building could include spotting abnormal consumption, analyzing water quality, optimizing water usage from different sources and linking water usage with cooling tower performance and non-water factors. Such smart management system is current in development and will be especially relevant in water scarce urban areas.

CONCLUSION

Decentralized solutions and the integrated management of water and wastewater makes it feasible to manage water from ‘source to source’ in homes, buildings and communities in economically feasible, environmentally safe and scalable methods. The case of XIDAS proves that it is technical and economically viable.

To spur the mass adoption of decentralized solutions, the development of standards, deployment of appropriate technologies and engagement of users are critical. The *Blue Building Standard* represents a paradigm shifts from conventional thinking and water management approaches. It is a viable alternative to provide water access for the masses in urban areas and for managing the ecological balance.

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