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Article

Sustainable Urban (re-)Development with Building Integrated Energy, Water and Waste Systems

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Abstract: The construction and service of urban infrastructure systems and buildings involves immense resource consumption. Cities are responsible for the largest component of global energy, water, and food consumption as well as related sewage and organic waste production. Due to ongoing global urbanization, in which the largest sector of the global population lives in cities which are already built, global level strategies need to be developed that facilitate both the sustainable construction of new cities and the re-development of existing urban environments. A very promising approach in this regard is the decentralization and building integration of environmentally sound infrastructure systems for integrated resource management. This paper discusses such new and innovative building services engineering systems, which could contribute to increased energy efficiency, resource productivity, and urban resilience. Applied research and development projects in Germany, which are based on integrated system approaches for the integrated and environmentally sound management of energy, water and organic waste, are used as examples. The findings are especially promising and can be used to stimulate further research and development, including economical aspects which are crucial for sustainable urban (re-)development.

Keywords: sustainability; building integration; decentralized infrastructure; energy; water; organic waste; integrated resource management

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1. Introduction

Growing urbanization, increasing resource consumption, and limited resource availability mean that urban user behavior and infrastructure systems need to be transformed to become more efficient and for a more sustainable use and management of resources, particularly for the provision of primary services such as energy, water and food.

Our present civilization is to a large extent based on principles of centralization. The large technical effort for the construction, service, and maintenance of centralized infrastructure systems and the related processes involves high monetary and environmental costs endured by society. The dissipation caused by conventional centralized infrastructure systems is similar for energy, water supply and wastewater discharge. For example, almost 70% of the primary energy required for centralized electricity production in conventional power plants is lost. The building sector is responsible worldwide for more than 33% of the total resources and 40% of the total energy consumption [1]. The burning of fossil energy carriers contributes to most of the anthropogenic CO_2 emissions. The conventional global food production is responsible for most of the anthropogenic freshwater consumption, a large component of the global CO_2 emissions (from soil carbon losses and chemical fertilizer production) and energy consumption for farming, harvesting, storage, and transport of agricultural products.

Particularly relevant is the negative interrelationship between urban and rural areas. The decoupling of food and drinking water production and wastewater management results in the pollution of natural sources of livelihood and the elimination of resources. In contrast, sustainable infrastructure systems, based on the principles of circular flow economy, involve the efficient and local use and reuse of resources.

Many of the world's cities are expected to grow significantly during the following decades. While currently already more than 50% of the world's population lives in cities, it is expected that this percentage will grow to approximately 60%, with a yearly rate of 1.7% until 2030. Accordingly, the world faces a rural exodus and shrinking rural population as the urbanization rate exceeds the global population growth. In the framework of this urbanization process, 37 urban agglomerations are expected to become mega cities by 2025 [2].

Similar to rural area residents, many people dwelling in smaller cities will need to deal with the phenomenon of population shrinkage, particularly in countries with low birth and immigration rates, such as most European countries as well as Korea and Japan. Both of these situations put pressure on the operation and management of conventional centralized infrastructure systems for energy and water and organic waste management. The disadvantages of these systems include the lockup of capital for very long periods, limitations in provision and discharge such as the mixing of sewage streams with different noxious factors (being a barrier for appropriate treatment and reuse), the supply of drinking water only, and the in-adaptability to changing demographic structures and quantities, as well as high monetary costs. In contrast with such large-scale centralized infrastructures, the building integration of decentralized infrastructures for energy, water, and organic waste management has many advantages [3–6]. Furthermore, appropriate system approaches for supply, efficient use, treatment, recycling, and reuse facilitate the realization of so called zero-emission buildings.

However, the term "zero-emission" is generally associated with the reduction of specific emissions, particularly greenhouse gases such as CO_2 caused by the burning of fossil energy carriers for the generation and provision of thermal and electrical energy, such as by the use of renewable energy. For example, in 2009 in Milan, Italy, the Milano Scala, a self-declared zero-emission hotel, was established [7]. The concept includes the use of efficient electric devices for the provision of heating and cooling energy and the required electric energy originates from clean sources and therefore does not cause pollution at local and global levels. Additionally, water efficient technologies are applied. The building has achieved 2 of the 3 maximum available "tents", an award of the "ecoluxury" certification, which is provided by a collaboration of ecologically and socially responsible businesses in the luxury tourism sector [8]. Buildings aiming for zero-emission should not produce any harmful emissions but on the contrary, produce energy, water, and resources. Such an integrated approach was taken in the development for a youth center with seminar facilities and a restaurant in Berlin, Germany. The concept is based on the building integration of new and innovative technologies and systems, which have been proven in practice in different pilot projects. In the framework of this paper, the overall systems approach will be discussed, as well as the different sub-systems and technologies.

2. Objectives and Methodology

This article discusses the latest results from the authors' own investigation into the decentralized and building integrated management of energy, water, and organic waste in relation to the sustainable development of new and existing cities. The case studies presented act as examples of the applied research in integrated urban resource management in Germany, from the latest theories to selected detailed examples. This paper describes the most recent developments in decentralized technologies in, and system approaches towards, self-sufficient buildings with zero emissions. It aims to identify, examine, and demonstrate the effectiveness of decentralized systems approaches for energy, water, and organic waste management that face the latest challenges identified for the future design of urban infrastructures. Mainly based on the effective use, reuse, and production of energy, water, and organic waste as well as on the separation of sewage streams with different properties, the insights from case studies serve to prove the applicability of those approaches. Quantitative data on water and nutrient flows from specific case studies were collected, while qualitative analysis of approved resource management concepts was carried out based on recent research findings and the authors' own inquiries. Finally, the application of building integrated systems for the management of water, organic waste, and energy emerges as the appropriate procedure for the sustainable transition of conventional urban infrastructures for the management of these resources. The integrated concept for building integrated resource management in a youth center in Berlin, Germany was examined in terms of the applicability and a way forward for sustainable urban (re-)development.

The building integration of appropriate infrastructure systems for energy, water, and organic waste management can facilitate the realization of zero-emission buildings and can contribute to the sustainable development of new—or the redevelopment of existing—urban areas and cities. This approach has been successfully implemented in the concept of a new youth center (Figure 1) with accommodation and seminar facilities in Berlin, Germany (subsequently referred as "Berlin youth center"). The building owner is the registered "Ludwig-Wolker-Haus" association. The specific objectives of the project are:

- Reduction of the direct water footprint to the greatest possible degree through on-site Water Supply and Waste Water Management according to the principles of Integrated Water Resource Management. Minimization of fresh water demand by approximately 50% through the application of water efficient systems, the collection, processing and recycling of wastewater, rainwater harvesting and utilization for non-drinking purposes, and the augmentation of freshwater bodies.
- Operation of an organic waste free building through the collection of human urine and reuse as fertilizer, the collection of solids from black water and organic waste for fermentation and composting processing, and the subsequent local use of black fertile soil produced in horticulture and agriculture (for the production of food and renewable energy).
- Net zero energy consumption through minimization of the building's service energy demand, local production, and the efficient utilization, storage and export of surplus energy into external grids which also serve as energy providers in periods of need.
- No additional building and service costs in comparison with reference buildings through smart and integrated design and planning as well as savings in centralized infrastructure systems and conventional service costs.

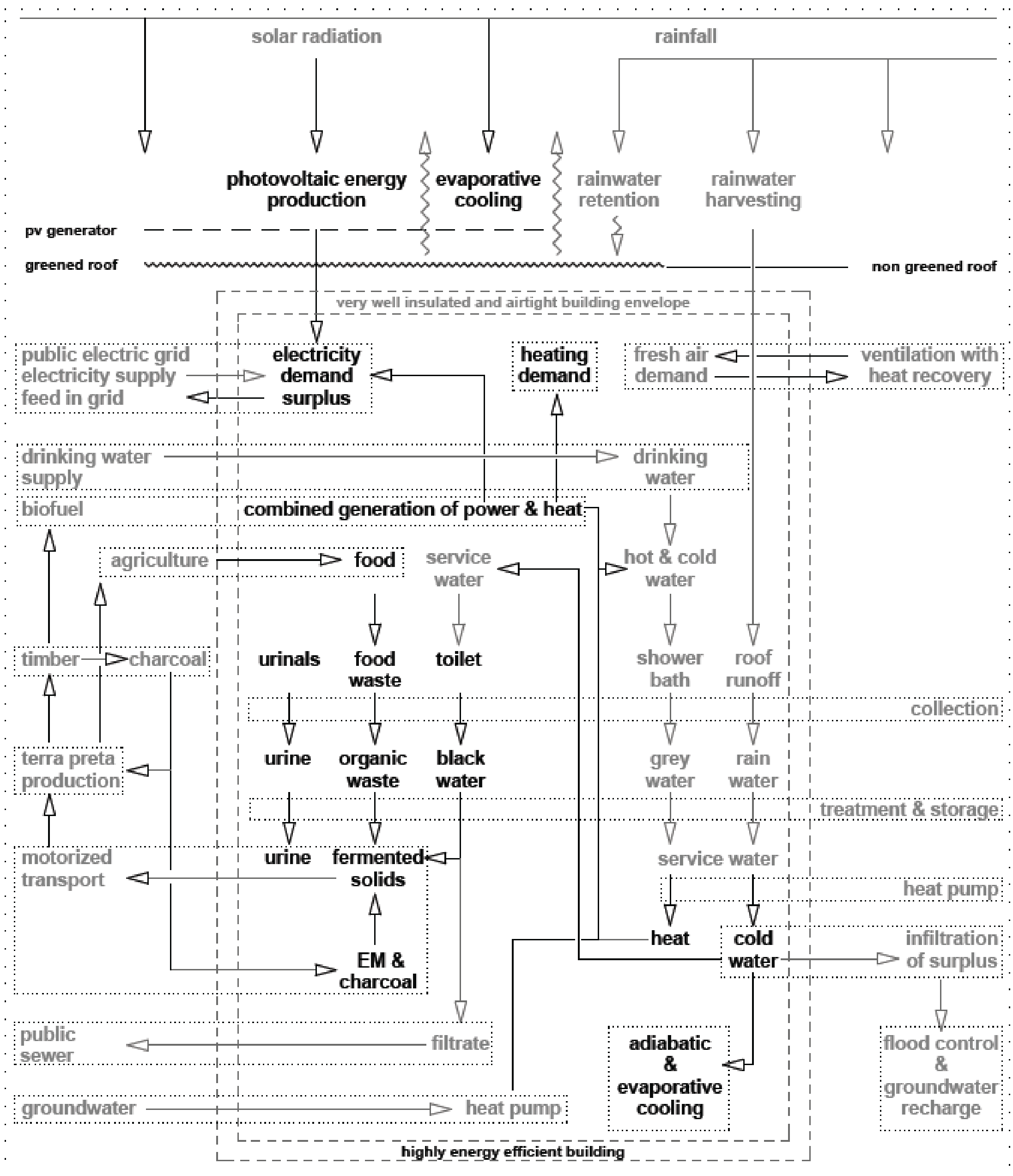
3. Results and Discussion

Integrated urban water resource management, including rainwater harvesting, the recycling of wastewater, as well as the recovery of nutrients and the processing of organic waste is essential for sustainable urban development and shows considerable potential for (urban) agriculture, but is as yet relatively underutilized. "Meanwhile, good agriculture and forestry practices can contribute to sound watershed management, safeguarding water catchment and reducing runoff and flooding in cities-ever more important as climate change increases the frequency of extreme weather events" [9].

3.1. Reduction of the Direct Water Footprint

Extensive quantities of water could be saved with technologies that allow for fresh water savings and water recycling. The first step for the reduction of water consumption is the installation of water saving toilets, showerheads, and taps, which for example allow a reduction of household freshwater consumption of approximately 30% without loss of comfort [4,5]. Such water saving measures are achievable without additional costs if they are installed in the framework of new installations in place of standard appliances. The Berlin youth center will be equipped with water saving taps (with flow rates of 3 liters per min), showerheads (with flow rates of less than 5 liters per min) and toilets (with flush volumes of 2 and 3.5 liters per flush). Additional savings will be achieved with the collection of rainwater and so-called "greywater" from showers and bathtubs and its decentralized recycling in the basement of the building. By means of water saving measures, the recycling of greywater and reuse in form of so-called service water for non-drinking purpose, the water consumption and related fees can be reduced by approximately 50% compared with standard water installations. Due to savings in drinking water fees (2,169 Euros per m^3 including VAT) and sewage fees (2,464 Euros per m^3 including VAT) which can be achieved in Berlin by reduced drinking water consumption [10], it is expected that the water system for the reduction of the direct water footprint in the Berlin youth center will be economically profitable. In comparison with the business as usual option, the operating savings of the described water system are expected to be sufficient to cover the service costs and initial capital costs.

Figure 1. Simplified diagram of the overall systems approach discussed in the framework of this paper. External and building integrated sub-systems and technologies for the sustainable management of energy, water and organic waste are briefly described by showing their relationship to each other as well as the connecting flows.



The service water will be used for toilet flush and irrigation of the green roof and garden. Surplus water will be infiltrated and recharge the groundwater. The advantage of the decentralized collection and processing of greywater and the direct reuse at the building level is the comparable small infrastructure, consisting of collection and supply pipes, which is required for its installation. Compared with the overall system costs and the achievable savings, the costs for such a system are comparatively low [4]. Furthermore, the system offers the potential for recycling of energy as will be further discussed subsequently.

By as early as 1996, Europe's first economically profitable large-scale greywater recycling facility was realized in a four star hotel in Offenbach/Main (Germany). The installation of the greywater recycling facility for 400 guests only occupies the equivalent space of two car-parking places in the underground parking lot of the hotel. The recycled water is used in the hotel for flushing the toilets and the surplus is used for irrigation. The payback period for the 72,000 Euros investment, operation, service and maintenance costs was only 6.5 years. Accordingly, the system has been economically profitable for more than 8 years. On average, 3,700 m^3 of drinking water could be saved per year, resulting in savings of 18,500 Euros in drinking water and sewage fees (which are in Offenbach approximately 5 Euros/m^3). The electric energy consumption of the greywater recycling facility including the distribution of service water is approx. 1.5 kWh. Over the past 15 years, since the installation of the described facility, the technology of greywater recycling facilities has been further developed, resulting in lower system costs and enhanced control and monitoring systems. The monitoring and control of contemporary facilities for water recycling can be executed by the company that also builds and installs the facility, therefore providing an overall integrated service [11].

In the case of the Berlin youth center, all greywater and rainwater will be managed on the property. It is expected that the investment service and maintenance costs for the decentralized rainwater management system will be covered by savings in drinking water and sewage fees, and the yearly fee of 1.897 Euros per m^2 property draining in the sewerage system of Berlin [10]. The small amount of sludge originating from the biological greywater treatment process will be collected and processed together with the separated solids from blackwater (sewage originating from toilets) processing and collected organic wastes.

3.2. Management of Organic Waste and Nutrients Using the Example of Case Studies

In the Berlin youth center, blackwater will be collected separately and filtrated in the basement of the building to recover the majority of the contained organic solids and nutrients. These substances can be used as resources for the production of fertile black soil to be reused in urban horticulture and agriculture. The remaining filtrate has a reduced pollution load and is easier to clean than untreated effluent from toilets. For example, in a public toilet facility in a central train station of the city of Hamburg (subsequently referred as "Hamburg toilet facility"), separated blackwater drainage, filtration, and a solid collection system have been successfully installed and operated since 2010. In the same facility, waterless urinals are also installed, facilitating the separate collection of undiluted urine for the purposes of both the reuse as liquid fertilizer and the reduction of the pollutant load of sewage streams. The experiences and findings from the separated urine and blackwater collection and treatment systems in the Hamburg toilet facility are also used for the planning and system optimization of the blackwater and organic waste processing system which will be installed in the Berlin youth center.

The separated solids (mainly feces and toilet paper) are transported automatically to a storage tank where they are mixed with a specific portion of vegetal charcoal powder (also known as "bio char") and liquid Effective Microorganisms (EM). The mixture of these ingredients causes a lactic acid fermentation process that has already started during the intermediate anaerobic storage in the container. No gas or malodor is emitted. Full containers are transported to a facility for the production of anthropogenic fertile black soil also known as "Terra Preta" (Portuguese: Black Soil). In 2011, parts of the collected and fermented solids were transported to the Botanical Gardens in Berlin (Germany) where they were used in the framework of the Terraboga research project [12] for the production of Terra Preta and its use in urban agriculture.

The Terraboga research project is built on the findings that the production of anthropogenic black soil (which has been originally produced by cultures in the Brazilian Amazon basin) is based on a lactic acid fermentation process which incorporates manure from humans and/or animals, organic material, as well as vegetable charcoal. The nutrients (mainly Nitrogen and Phosphorous) contained in the feces are bound to the charcoal particles and are locked until they are made available to the roots of plants by microorganisms. Therefore, Terra Preta facilitates the cultivation of plants in nutrient rich soil whereby the addition of artificial fertilizers is not required. Even though such soil is rich in nutrients, it could contribute to the purification of rainwater runoff, also in the case of heavy precipitation events. The good water storage facilities could help to cope with floods and periods of drought and could therefore be used for the adaptation to the effects of climate change. Furthermore, by utilizing vegetable charcoal in the soil, carbon can be stored (in contrast to soils which are used for conventional agriculture that release carbon to the atmosphere). Therefore, the application of Terra Preta could contribute to the mitigation of climate change [13].

In both cases of the Hamburg toilet facility and the Berlin youth center, the remaining filtrate from the blackwater separation process is discharged to the public sewer systems. While the filtrate should preferably also be treated on-site and be reused, due to the comparable small quantity, the related effort and mandatory requirement to connect the drainage systems to the public sewer system, it has been decided to discharge the filtered blackwater to the sewer system [14].

Depending on the amount of separated urine, it is estimated that more than 50% of the total Phosphorous and 10% of the total Nitrogen contained in the wastewater stream of the Berlin youth center can be collected and processed for reuse in fertile black soil. In the Berlin youth center, the filtered solids from blackwater will be collected in containers and pre-fermented with charcoal and EM together with the organic wastes from the restaurant. Effective recycling management and the link between organic waste and energy production is realized by applying Terra Preta for the cultivation of fast growing timber. This timber can be used for combined heat and power generation and the production of charcoal, which can then be reused in the previously described concept. It is planned to use Terra Preta for the enhancement of soils in urban horticulture not meant for human consumption (such as in parks and gardens), because there are concerns regarding the security of food grown with Terra Preta made from human feces. Terra Preta use for the cultivation of fast growing timber would facilitate the production of renewable energy carriers in the form of biomass.

To reduce the drinking water consumption and to facilitate the reuse of precious nutrients in human urine (yellow water), waterless urinals for the separate collection of urine will be installed in the men's toilets assigned to the restaurant and conference facilities. The undiluted urine will be collected by means of a separate drainage pipe system and stored intermediately in containers located in the basement of the hotel building. At specific intervals, the filled urine containers will be replaced by empty containers and transported to a central treatment facility for further processing and reuse as fertilizer or to produce nutrient enriched fertile black soil. Experiences with undiluted urine collection show that in drainage systems with open ventilation pipes, approximately 50% of the ammonia contained in urine evaporates and gets lost through the ventilation system [15]. The yellow water collection and storage system for the Berlin youth center will therefore be equipped with a newly developed and enhanced drainage and collection system which facilitates the reduction of ammonia evaporation losses.

The separated collection of urine offers considerable potential for pollution control, resource recovery, and the optimization of existing wastewater management systems because it contains up to 90% of the total Nitrogen and 50% of the Phosphorous as well as a large portion of the micro pollutants in domestic sewage. The separation of those nutrients enhances the efficiency of conventional sewage treatment processes and facilitates their reuse as fertilizer in agriculture [16]. The eco toxicological effect of human medicines in domestic wastewater (so called micro pollutants) could be reduced by 50% [17], and the part separation of urine could turn wastewater treatment plants from energy consumers to energy producers [18]. The experiences with building integrated urine separation systems show that waterless urinals work well, emit no malodor, and are convenient to use; however, functionality of the separation with so-called "separation" or "no-mix" toilets is still insufficient [19]. For an optimal operation, a close collaboration with the maintenance service provider proved to be a critical factor for optimal operation in the framework of a three-year operation and monitoring phase of no-mix toilets in the "Forum Chriesbach" in Switzerland [15]. Furthermore, the water consumption of available separation toilets (with 6 liters per flush) is similar to conventional water saving toilets. Therefore, in the investigated Hamburg toilet facility and the Berlin youth center rather than separation toilets, water saving toilets with maximum flush volumes of only 3.5 liters will be installed.

While the greywater recycling system in the Berlin youth center is expected to be economically profitable, because the operating savings will exceed the initial capital and service costs in less than 7 years, the separated collection and processing of or urine and blackwater with organic waste will produce additional service costs, because there is no market yet for products such as fertilizer and soil made from urine and blackwater. In comparison with the business-as-usual option, the operating savings of such a resource productive sanitation system are expected to be not sufficient to cover the service costs and initial capital costs. Therefore, this matter is being investigated in the framework of on-going research projects, such as for example in Terraboga, which examines how such productive sanitation systems can be integrated in suitable fee systems for circular flow economies. However, according to experiences in the Hamburg toilet facility and cost benefit calculations executed in the framework of the Terraboga project, the monetary savings in drinking water and sewage fees (compared with standard water and sanitary installations) can cover the additional construction costs of such decentralized collection and treatment systems.

3.3. Energy Efficiency and Productivity

The Berlin youth center is planned as "lowest-energy-building" with minimized energy demand for heating, cooling, and warm water production. The electricity demand for the operation of the building will be significantly reduced to limit the primary energy consumption for the operation of the hotel to 120 kW/m^2a. Low heating energy and Passive House concepts are transferable to commercial buildings and a primary energy consumption of less than 100 kWh/m^2a can be achieved without extra investment costs compared to conventional office buildings [20].

To realize a building with net zero energy consumption, the remaining primary energy demand must be produced on the building by means of renewable energy sources. The most common means for this purpose are building integrated photovoltaic generators as well as combined heat and power generators that use renewable fuels. By 2010, more than 300 building projects worldwide have been realized (mainly in Europe) which aimed to achieve a net-zero energy balance [21].

According to the European Energy in Buildings Performance Directive, by 2021 all new buildings in the EU must be built as nearly zero energy buildings with an energy demand of "zero" or "nearly zero" for heating, cooling, and hot water production; for public buildings, this must be achieved by 2019. The remaining energy demand must be produced to a very significant degree on the building or in the direct neighborhood by means of renewable energy sources. Also, in the framework of renovation of the existing building stock, important measures for enhancing the energy efficiency are required [22]. Accordingly, from 2020 all new building projects should be almost energy neutral and regarding the consumption of non-renewable energy resources already nearly zero-energy buildings.

The measures, which will be taken to achieve good energy efficiency, are a well-insulated building envelope, the reduction of thermal bridges, and the installation of a mechanical ventilation system with heat recovery. As these measures are quite common for energy efficient buildings, new and innovative measures for energy efficiency will also be applied that are based on the creation of synergies between the water and energy sectors.

For example, the previously described facility for the recycling of greywater will be used in the Berlin youth center for the recovery of heat. A pilot installation of the so-called "Pontos Heat Cycle" in student apartments still operates properly and has been monitored for a period of two years. The evaluation results indicate that monetary and energy savings are more profitable when greywater is combined with heat recovery. By using two heat exchangers, the cold freshwater is pre-heated by the comparable warm greywater. On a yearly average, approximately 20% less energy is required for hot water production compared with systems without heat recovery [23]. To enhance the energy efficiency of the heat recovery system, the greywater recycling facility for the Berlin youth center has a different system layout. The greywater will be collected and purified in a thermally insulated recycling facility. The resulting hot service water will be used as a heat source for a heat pump, which will facilitate a much higher heat recovery rate than the Pontos Heat Cycle. In comparison with a business-as-usual solution, the operating savings of such an integrated water recycling and heat recovery facility are expected to exceed the service cost and initial capital costs.

It is expected that the greatest portion of the hot water demand can be supplied by heat extraction from purified grey water. The cooled service water is stored in a thermally insulated tank that serves as a heat sink for the building's adiabatic cooling system. During the hot summer periods, when cooling may be required to provide comfortable indoor temperatures, the cold water can be used for the building component activation of floor slabs. Also, the use of purified grey water for irrigation and evaporation on the building's greened roof will contribute to cooling. Additional service water will be provided by means of rainwater harvesting from non-greened roof surfaces and utilization, collected from the non-greened roof surfaces. The evaporation cooling on the roof also creates synergies with photovoltaic energy production.

Photovoltaic generators will be installed on the flat roof of the building. Synergies between the photovoltaic energy production and the evaporative cooling with service water can be achieved on the greened roof areas. Due to the significant lower temperature of the intensively irrigated greened roof, the PV modules are expected to have a higher efficiency of 8–10% during hot summer days in comparison with modules, which are installed on conventional roofs (without evaporative cooling). Due to the comparable small roof surface area of the hotel, the PV modules can only contribute partly to the renewable production of the energy required for the building service. As the Berlin youth center is located in the city center and surrounded by relatively high buildings, the installation of Photovoltaic modules on the façades of the building was not regarded as productive.

Another renewable energy source that can be used is near-surface geothermal energy, which is extracted from the ground under the building. Since near-surface geothermal energy (up to a depth of 100 m) is actually stored solar energy, it is indeed renewable. Most of the hotel's remaining thermal and electrical energy demand during the winter will be covered by a biogas driven combined heat and power (CHP) generator. In the future the gas burner is planned to be replaced with a CHP that can burn solid biofuels such as fast grown timber originating from regional plantations and fertile black soil originating from the building's own organic wastes. A regional recycling economy could thus be realized. Technologies that facilitate the production of thermal and electric energy as well as vegetable charcoal at the same time, are not yet available but are in the focus of research projects executed by producers of CHP generators [24]. Such technology would indeed facilitate the creation of synergies between sustainable organic waste management, sanitation, food, and energy production, and would therefore prepare the ground for sustainable development.

4. Conclusions and Outlook

The application of building integrated sustainable infrastructure systems, which have been discussed in the framework of this paper can contribute significantly to both sustainable urban and rural development. According to the presented research findings, the direct water footprint of buildings can be reduced by 50% through water use efficiency and recycling measures. Furthermore, rainwater can be managed on building and property level by means of retention, harvesting, collection, utilization, evaporation and infiltration. The construction, service and maintenance of efficient water use, reuse and rainwater management systems can be realized with available technologies and, in the German cases, without additional costs compared with conventional water and sanitation systems, due to achievable monetary savings in drinking water-, sewage- and stormwater-fee. In comparison with a business as usual solution, the operating savings of such sustainable water management systems can cover the initial capital costs.

According to the experiences of the Hamburg toilet facility, the cost for the installation of decentralized urine collection and blackwater treatment systems can be covered in part by savings in drinkwater and sewage fee, which can be achieved by the installation of water saving toilets and waterless urinals. Regarding the cost and benefits for the operation, transport, and processing of human excreta together with organic waste for the production of Terra Preta, no evaluation of the economic data is yet available. However, it can be expected that the described system is not economically profitable in the current state, since the technology is still in development and there is no market yet for Terra Preta. In comparison with a business as usual solution, the operating savings of the described productive sanitation systems in the specific German cases could not cover the initial capital costs.

Nearly Zero Energy Buildings Energy can be realized by construction of energy efficient buildings and the renewable production of the remaining energy demand on building level, for example with solar thermal collectors and Photovoltaic (PV) generators. Worldwide a considerable amount of such buildings has been realized. It can be expected that zero energy buildings will be built with growing tendency and will become a common building type in many countries. In the EU regulation new buildings have to be built as nearly zero energy buildings by 2020 [22]. According to the Presidential Committee on Green Growth also in the Republic of Korea new buildings have to be build from 2025 as zero energy houses with an energy saving rate of 100% [25]. Declining costs for decentralized produced electricity with PV support the trend towards zero energy buildings. Countries with higher electricity consumer prices, such as Germany and Denmark reached already “socket parity” in 2012 while countries with lower electricity consumer prices are expected to reach socket parity in the coming years, e.g., France and Turkey in 2015 and the Republic of Korea in 2017. ‘Socket parity’ is defined in this case “as the point where a household can make 5% or more return on investment in a PV system just by using the energy generated to replace household energy consumption” [26]. Accordingly the decentralized production of electricity with Photovoltaic is in the German case economically profitable because the operating savings can cover and exceed the initial capital costs.

The transferability of the results presented in this paper, particularly regarding economical aspects and the decentralized management of rainwater are limited to environments, whose basic conditions are similar to the German case studies. The effort and the related costs for the decentralized management of rainwater can vary significantly depending on the local climate and soil properties. The balance of monetary costs and achievable savings for decentralized water and energy systems is for example heavily dependent on the specific fee levels and structures for the discharge of rainwater and domestic sewage, and the consumption of drinking water and energy.

High fee levels and specific fee structures encourage decentralized management of rainwater and sustainable water use. In Berlin for example 4.63 Euros/m^3 can be saved in sewage and drinking water fees per cubic meter drinking water [10]. In contrast, low fee levels inhibit efficient and sustainable water use. In the city of Seoul in the Republic of Korea the sum of the drinking water and sewage per m^3 ranges from 450 Won (approximately 0.31 Euros for public bath), over 480 Won (approx. 0.33 Euros for household) and 730 Won (approx. 0.50 Euros for business) and 970 Won (approx. 0.67 Euros for commercial) [27]. Accordingly, the achievable savings by efficient water use in Berlin are, depending on the building type, between 7 to 15 times higher than in Seoul. Therefore, the investment in sustainable water management is regarding economical aspects in Berlin more attractive than it is in Seoul. However, specific aspects of sustainable water management are stimulated in the Republic of

Korea by other means, such as legislations and tax reductions. According to the national water act, which is in effect since 2003, hotels, shopping malls and industries with specific water consumption have for example to install wastewater recycling facilities and reuse the water for non-drinking purpose such irrigation and toilet flush. The government subsidizes the investment costs through tax reductions [28].

Resource dependency, particularly regarding energy, food, and fresh water can be significantly reduced by an area wide application of building integrated sustainable infrastructure systems and the creation of synergies between different sectors, such as water, energy and organic waste. A circular flow economy could be introduced for growing and shrinking cities by decentralization, participation, and resource intelligence. This would result in lower construction, service, and maintenance costs and the protection of the environment and natural resources. Particularly, the large Korean and Asian market for the construction of new towns and cities that aim to be sustainable and "green," shows considerable potential for the application of such decentralized zero-emission concepts.

However, the worldwide development of integrated concepts for the green and sustainable (re-)development of rural and urban areas which are not based on conventional centralized infrastructure systems for energy and water supply, wastewater, organic waste management, and food production is still at its beginning stage. Therefore, further theoretical and applied research and development in the framework of pilot projects, and the dissemination of the results, is crucial to enhance public awareness, international and national recognition, and to introduce a paradigm shift in the design, construction, and operation of urban and rural infrastructure systems.

The first author of this paper is coordinating the research project ZEB-ISTIS Zero Emission Building-Integrating Sustainable Technologies and Infrastructure Systems supported by the KORANET Korean scientific cooperation network with the European Research Area, joint call on Green Technologies [29]. The aim of the project which will run until autumn 2014 is the further development and optimization of sustainable building integrated infrastructure systems, including the integration and creation of synergies between social, environmental and economical aspects. Furthermore, the project will contribute to the knowledge transfer between the partners form Korea and Europe (Germany, Switzerland, Turkey) and the dissemination of information for the adapted design, planning, operation and maintenance of Zero Emission Buildings.

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Conflict of Interest

The authors declare no conflict of interest.

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