Net Zero Water Building

Obradović, Dino; Šperac, Marija

EJSDR
European Journal of Sustainable Development Research
e-ISSN : 2458-8091

Net Zero Water Building

Dino Obradović[1]*, Marija Šperac[1]
[1]*Josip Juraj Strossmayer University of Osijek, Faculty of Civil Engineering and Architecture*
Osijek, 31000 Osijek, Croatia.
**Corresponding Author email: dobradovic@gfos.hr*

Abstract

Water is essential for human life, health and overall well-being, i.e. to reduce poverty and hunger. As day after day the earth's population and the need for water are increasing, whereas the amount of water is decreasing, it is becoming increasingly difficult to satisfy people's water needs. Due to the trend of urban population concentration, it can be said without exaggeration that the functioning of cities will also depend on the quantity and quality of management and distribution of water resources within cities. Drinking water from public water supply system is used in households to cover all types of daily water needs. In order to preserve water as much as possible, in terms of its quality and quantity available for human consumption, an integrated approach to water management is needed. Integral water management is essentially water production and consumption management. Zero-use water building is a building that collects rainwater and recycles its wastewater for reuse, eliminating the need for water supply from public water supply and connection to the sewer network. Appropriately collected and stored rainwater can be used multiple times in dwellings, gardens, yards, parks, for washing public areas, etc. The benefits of rainwater use are ecological and financial. A zero-water building is technologically feasible for existing buildings, but costs are quite high, and various other constraints also arise. This approach is most suitable for new buildings, where space for containers, additional pipelines and filtering systems can be set from the beginning. Zero-water buildings aim to reduce total water consumption, maximise the use of alternative water sources and minimise wastewater discharges from buildings. The paper will present the general concept of zero-water buildings and highlight the importance of water conservation.

Key words

Net zero water building, Sustainability, Water, Water consumption

1. INTRODUCTION

Water is considered one of the basic components of life, and the entire history of mankind and civilization is largely related to it. Water is not only included in the composition of human organism and food, but it is also used to produce food and energy, as well as in industry as a raw material or auxiliary material. Due to its importance for the mankind, supply of water to settlements and the population is nowadays considered to be one of the primary branches of water management. Due to the tendencies of people to concentrate their settlements and themselves as consumers around water, and given the available water resources on Earth, the issue of water supply will become even stricter in the future. The rule of water supply, that every drop of water on the catchment is kept for as long as possible for its wider use, is becoming more and more present in our practice [1]. Only 1% of the total water resources on Earth is drinking water, and as much as a third of water consumed in households goes to flush the toilet that is mixed with faeces to form a substance (mixture) called wastewater [2], [3].

Wastewater is known to be composed of 99.9% water and 0.1% pollution. The primary purpose of wastewater treatment is to prevent infectious diseases and to protect from contamination of groundwater and surface water [4]. The biggest challenge for wastewater treatment is the mixture of human wastewater and factory chemicals with large amounts of water. In combined sewer systems, valuable drinking water is reduced to a carrier of waste substances [5], [6]. One adult is thought to produce about 500 litres of urine [5]–[8] and about 50 kg of faeces [5], [7], [8] over a period of one year. Faeces and urine are resources, not waste, and drainage systems bypass the natural flow of nutrients back into the soil and instead empty nutrients (chemical elements: phosphate, nitrogen, potassium, magnesium, etc.) into the water [6]. Looking at this process in which drinking water is used as means of transporting waste materials [9] from the household, it can be seen that there is a double cost (cost of water used and drainage/treatment of wastewater). This is a linear way of thinking [10]. In view of the above, it is important to preserve, manage and recycle water wherever possible.

A growing global population and economic shift towards more resource-intensive consumption patterns means global freshwater use - that is, freshwater withdrawals for agriculture, industry and municipal uses has increased nearly six-fold since 1900 [11]. This is shown in the Figure 1.

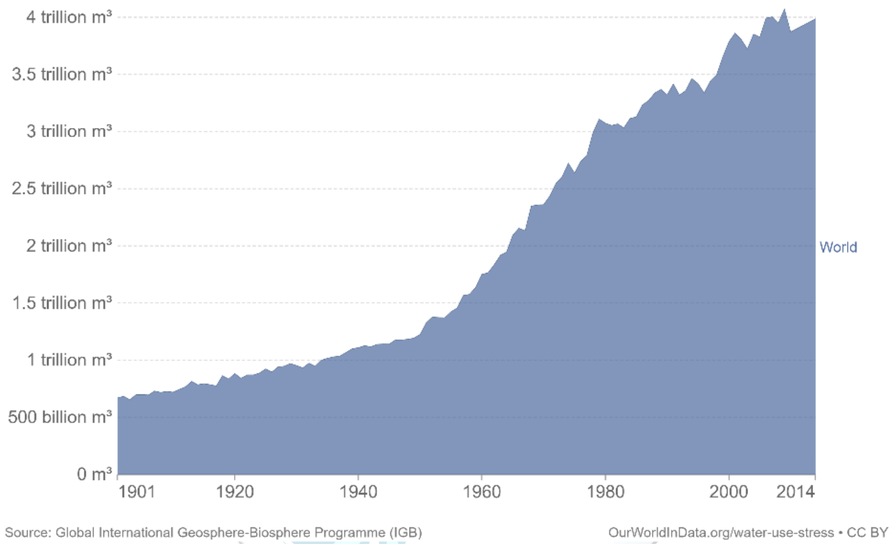

Figure 1. Global freshwater use for agriculture, industry and domestic uses since 1900, measured in cubic metres (m³) per year [11], [12]

People use water for different purposes. It is important to remember that water for different purposes does not have to be potable water. One person per day for survival (drink and food) needs 2.5 to 3 litres, basic hygiene needs 2 to 6 litres, and basic cooking needs 3 to 6 litres leading to a total of 7.5 to 15 litres per person per day for basic emergency needs [13], [14]. Non-drinking water can be replaced by rainwater. So on average, 45 litres of drinking water can be saved each day if replaced by rainwater. Rainwater can be collected on the roof and guided through filters into a container of appropriate size, placed in a suitable place and protected from direct sunlight in order not to start developing algae [15]. The average water consumption in the apartment for one person per day is shown in Table 1.

Table 1. Average daily needs for potable and non-potable water for one person (according to [15])

Potable water		**Non-potable water**	
Use	**Amount [l]**	**Use**	**Amount [l]**
Shower	35	Toilet flushing	18
Washing dishes	8	Clothes washer	18
Face washing	7	Cleaning	4
Drinking and cooking	3	Watering the garden	5
Total	53	Total	45

The use of water in the household is given in Table 2, and the average daily use of hot water in the household is given in Table 3.

Table 2. Indoor household use [16]

Fixture	**Use [%]**
Toilet	24
Faucet	20
Shower	20
Clothes washer	16
Leak	13
Bath	3
Other	3
Dishwasher	2

Table 3. Average daily hot water use per household [16]

Fixture	**Use [%]**
Shower	39.1
Faucet	33.8
Clothes washer	9.7
Bath	5.7
Dishwasher	4.8
Leak	4.6
Other	2.0
Toilet	0.0

2. LIVING BUILDING CHALLENGE

Water is an important economic resource and the basis for biodiversity, climate and ecosystem regulation. Protecting aquatic ecosystems from pollution and hydromorphological changes and sustainable use of water are essential to meet the needs of the current and future generations, as well as to maintain political stability at national and regional level. The overarching water policy aims to ensure that sufficient amount of quality water is available in the EU for human and environmental purposes by regulating the main pressures (agriculture, industry, municipal wastewater) and water use (bathing water, groundwater, drinking water) and integrated water management. The vast majority of European citizens have access to basic sanitation services and are connected at least to secondary wastewater treatment. In addition, European citizens have high quality drinking water. However, the pressure from urbanisation, diffuse pollution from agriculture, industry and climate change affect water quality and long-term water security. At a global level, the EU promotes water availability, sustainable water management and sanitation for all through the European consensus on development and EU neighbourhood and enlargement policies [17].

The Living Building Challenge - LBC is a certification program that defines the most advanced measure of sustainability - providing a framework for design, construction and the symbiotic relationship between people and all aspects of the built environment. It is one of most rigorous performance standards in the industry, as it requires net-zero energy, waste and water by every project. The LBC is comprised of seven performance areas (Figure 2), or “Petals” - Materials, Place, Water, Energy, Health, Equity and Beauty [18].

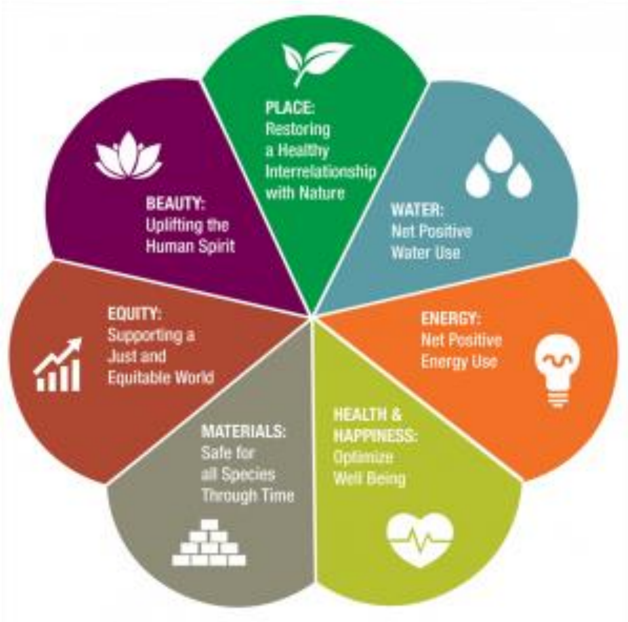

Figure 2. The Living Building Challenge Petals [19]

The petal Water requires net-zero water use which means all of the water used must come from the site. The intent of the petal is to consider water as a scarce resource and helps us think about questions of waste. 100% of water for drinking, cleaning and gardening is collected and treated on site. Rainwater captured on rooftops is purified using ultraviolet light. Low-flow fixtures and composting toilets minimize water demand and used water is treated in sub-surface wetlands. A monitoring system helps building occupants learn about and adjust consumption [19].

Living Building Challenge rewards facilities that achieve net zero water, where 100% of the facility's water use comes from collected sources or closed loop water systems. The impacts of water runoff on the eco system are being considered and whether they are adequately purified without the use of chemicals. Buildings that achieve sustainable water flow where 100% of rainwater and wastewater from the building is managed on site and integrated into a comprehensive system that meets project requirements are analysed as well. In many important facilities in the world, interesting architectural solutions incorporate elements of rainwater collection systems [20].

3. NET ZERO WATER BUILDING

An important water source for net zero water building is rainwater. A significant condition for adequate reduction of the flow of atmospheric waters is the use of water, either for internal purposes, which slows the flow rate, and the water is eventually returned to the catchment through wastewater, or for irrigation which maximizes local evapotranspiration. In suburban housing zones, acceptable reservoir volumes (ca. 2.5 m^3 per 100 m^2 of roof surface) for rainwater collection, which can later be used for a wide range of indoor and outdoor needs, can reduce the runoff of atmospheric waters to almost natural catchment conditions. In multi-dwelling areas with more population and higher potential water needs per unit roof area, the potential to reduce run-off is even greater [21].

An ideal net zero water building uses on-site alternative water sources to supply all of the building's water needs. All wastewater discharged from the building is treated on-site and returned to the original water source [22]. A net zero water building (Figure 3) is a building that collects rainwater and recycles its wastewater for reuse, eliminating the need for water supply from the public water supply and connection to the sewer network.

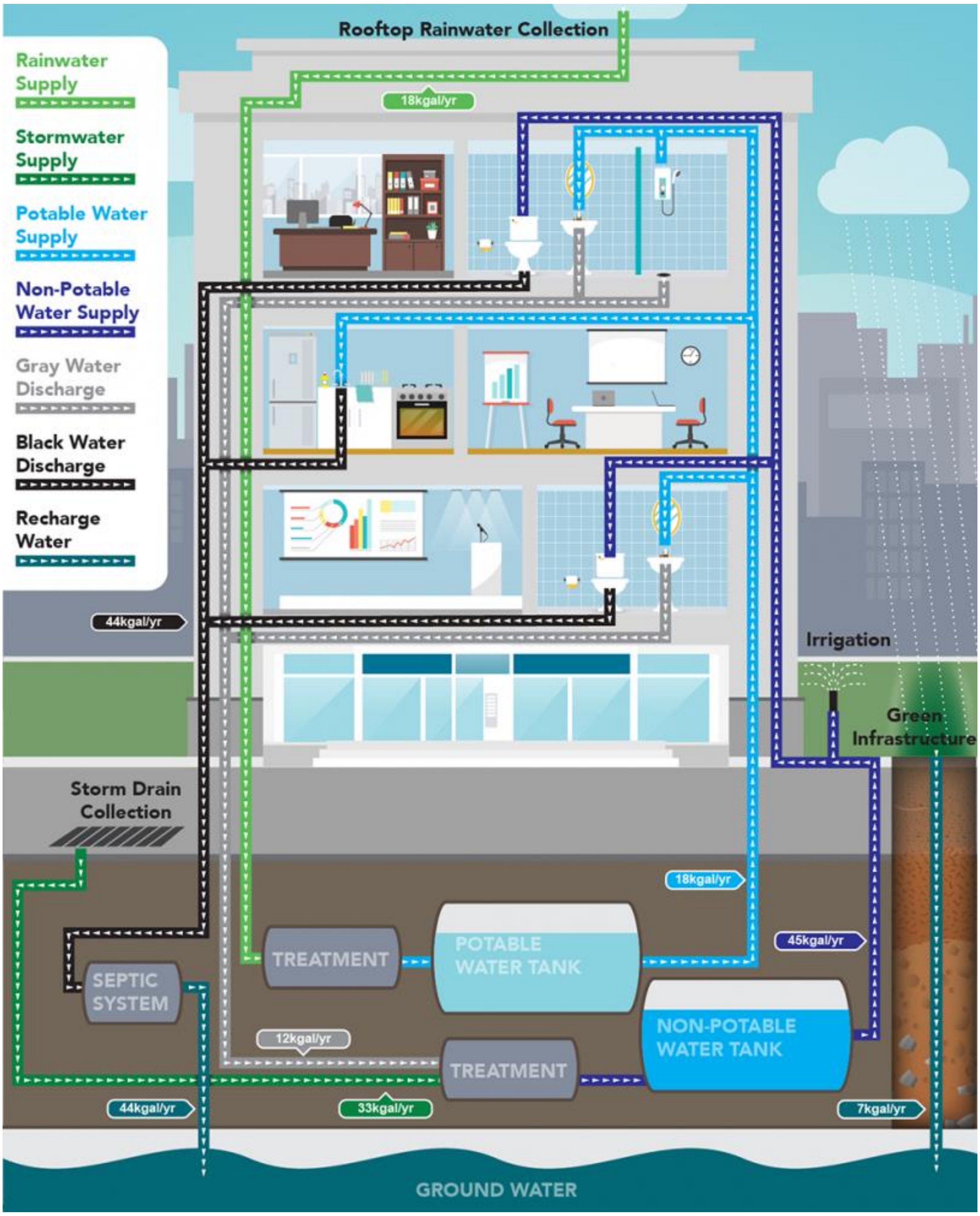

Figure 3. An ideal net zero water building [22]

Net zero water buildings includes the following key design elements:

- Reducing demand by employing innovative technologies that consume less water.
- Producing alternative water sources to offset purchased freshwater.
- Treating wastewater on-site and reuse or inject treated wastewater into the original water supply.
- Implementing green infrastructure by infiltrating stormwater to the original water supply [22].

The goal of net zero water is to preserve the quantity and quality of natural water resources with minimal deterioration, depletion, and rerouting by utilizing potential alternative water sources and water efficiency measures to minimize the use of supplied freshwater. This principle can be expanded to the campus level.

Back in the day, many of the oldest homes could have achieved the net-zero water designations that are cherished today. Rainwater was captured in cisterns, wells provided drinkable water and an outhouse served as a toilet [23].

When talking about net zero water building, it can be achieved gradually, i.e. not every building has to be net zero building, but it is necessary to try to reduce as much water consumption as possible. First, it is necessary to reduce the consumption of water by the householder. In houses, it is necessary to replace old equipment, toilets and appliances that use water, add new toilets that use one quarter of the water of the old ones, and faucets and showers that save water. Water and sewer installations should also be installed in the house to remove leaks, which can be the main source of water loss. All of the above can reduce water consumption by 60% [23].

The next step is to capture rainwater from the roof, just like people did long ago. The rainwater flows into storage tanks – after roof debris is diverted. To make it potable, the water is first filtered, then disinfected by exposure to ultraviolet light. It is ultimately directed to faucets and showerheads within the home [23]. The amount of rainwater that can be collected can be easily calculated. The surface of the roof (flat or pitched) should be calculated and then multiplied by the average annual rainfall. Losses must certainly be taken into account (due to evaporation, absorption, leakage, etc.), leading to a percentage of collected water of 70% to a maximum of 90%.

The most favourable are smooth surfaces, followed by clay covers or shale. Roofs with rough concrete tiles, bitumen cover and so-called green roofs (flat, grass-covered) are inappropriate. Dust and other impurities are preserved in these roofs. If the roof is covered by a metal cover, it must be calculated with a higher metal content in water, which is therefore less suitable for watering gardens [15].

An example of an underground rainwater storage tank is shown in Figure 4.

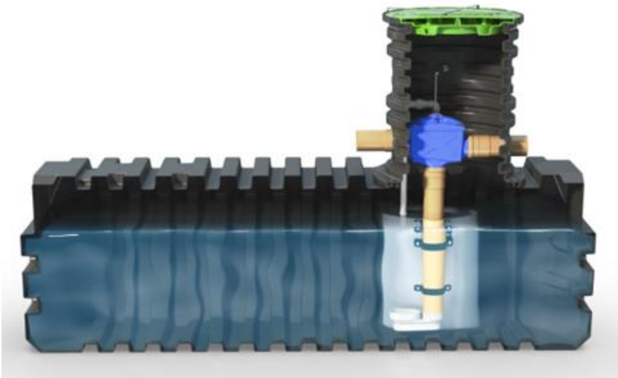

Figure 4. Rainwater harvesting storage tank [24]

Then came analyzing the potential for greywater recycled from sinks and showers to flush toilets. Researchers found that the shower and lavatory would produce slightly more water than the low-flush toilets would need. Extra greywater was dedicated to supplement the needs of the washing machines. One benefit of the greywater system is that potable water from the water company isn't used for toilets, where it isn't really needed. Toilets are the biggest users of water within the home [23].

It is likely that more net zero water homes will only appear in the coming years due to the emergence of a new rigorous certification program, the Living Building Challenge. Unlike green building programs that try to minimize the environmental impact of the house, the Living Building Challenge seeks to eliminate it completely. To earn a certificate, homes must be net-zero in their use of energy and water. Certification is tough because it requires a year's worth of real data, as opposed to a design computation [23].

Certain technologies that can be applied to net zero water building and technologies that can achieve advanced secondary treatment levels to support water reuse or release of less contaminated water back into the environment, taking into account the useful use and appropriate handling of nutrients, are also urine-diversion dehydration toilets - UDDT and urine-diversion flush toilets - UDFT.

Urine can be collected with urinals without water/dry toilets, and the resulting product is natural fertiliser. Faeces can be stabilized by anaerobic method, drying and composting (dry toilets), and biogas and fertilizer are produced as a product. Sanitary water can be purified in wetlands (marshes – artificial/natural), and the resulting water can be used for irrigation. Rainwater does not require any purification and can be directly infiltrated into the soil or collected in containers used for irrigation of agricultural areas [25].

The collection of urine and faeces and water saving can be done in several ways. One way is by using the urine-diverting flush toilet – UDFT (Figure 5). A urine-diverting dry toilet - UDDT is a toilet that operates without water and has a divider so that the user, with little effort, can divert the urine away from the faeces [26].

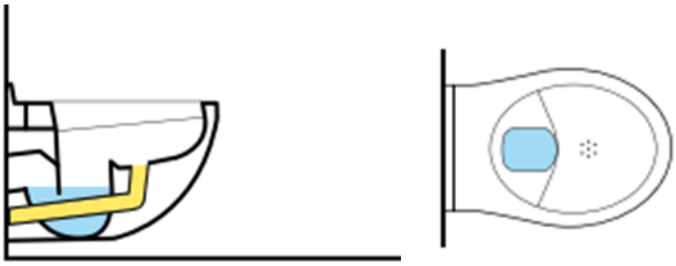

Figure 5. The urine-diverting flush toilet (UDFT) [26]

UDDT toilets are mostly used for family houses, schools (in underdeveloped countries), generally not widely used for multi-apartment buildings. The use of UDDT in multi-dwelling buildings is a major challenge. There are only a few examples of UDDT in multi-dwelling buildings in Germany and Mongolia. Faecal tanks are located in the basement and are dimensioned so that a family of five members can use one tank for about half a year. It is recommended to use ashes to cover the faeces. When the first container is filled, the second container shall be used so that the faeces can be sufficiently dried and ready for use [27]. Such toilets are harder to maintain and clean than ordinary toilets (with flushing). Faeces should be covered with sawdust, lime, dry soil, ash to reduce faecal moisture and increase PH due to pathogen extinction [5].

Composting toilets can be integrated into a building's net zero water strategies with opportunities for maximizing water conservation and reuse. Utilizing composting toilets can result in reduced systems needed for managing a building's remaining wastewater, including fewer pipes and smaller areas needed for on-site treatment [28].

In the case of waterless urinals, maintenance is simple. A urinal is used only for collecting urine. Urine is stored directly in containers and used later. Tanks can be underground or above ground, depending on the construction and location of the urinal in the building and the type of building. For water-based urinals, the water use per flush ranges from less than 2 l in current designs to almost 20 l of flushwater in outdated models [26].

For household urine, the recommended storage time is 1 to 6 months, depending on the storage temperature (below or above 20 °C). However, if urine is used for its own garden, this is not necessary. Storage time of 1 month is recommended for food and crops under cultivation (e.g. cooking). Six months of storage (if temperature > 20 °C) is required for commercial food production and when raw products are consumed. Urine from public places such as schools or restaurants takes 6 months to store. After this storage time, urine may be used to irrigate all crops (if temperature > 20 °C) [7].

Some of the advantages of the above mentioned technologies of separate collection of human urine and feces at the point of their production are: water savings, organic fertilizer production, energy savings since wastewater contains less nutrients and pathogens and less oxygen is needed during biological treatment, and since less water is in the system, less energy is required to pump water [5].

The lack of separation of urine and faecal matter and non-use of water when flushing toilets is the (non) willingness of people to change habits (people are considered not to be "civilized" if they do not have access to flushing toilets), additional maintenance is needed, the initial costs of such investments are higher, urine is less efficient fertilizer than synthetic fertilizers [5].

All of the above - the separation of types of wastewater and waste materials according to the place of their origin - is advocated by the material flow management method – MFM. The term material flow management covers a broad spectrum of methods and approaches in the literature. In general, material flow management refers to the analysis and specific optimization of material and energy flows that arise during manufacturing of products and provision of services. Material flow management can focus on very different levels of consideration [29]. The path of cross-company material flow management is also described as the product line or product lifecycle, from the input of raw materials, manufacturing, distribution and use consumption up to disposal [29], [30].

4. CONCLUSIONS

Water has always been of great importance and always will be. Preserving its quality and sufficient amount of water should be in our best interests. Climate change and the ever-accelerating urbanisation that causes increasing problems should be driver for a new way of thinking. Integral (sustainable) governance has increasingly been mentioned in all areas of work and life. It is evident that in recent times, much attention has been given to solving the problem of the drainage of atmospheric waters in developed countries, by applying an integral approach to precipitation water planning and management. This is an innovative approach that relies on the environmental principles of drainage planning and design according to the natural way of runoff.

The possibilities of using rainwater in buildings are high. Some of the ways or places where rainwater can be used are to flush toilets, wash clothes, irrigate gardens, etc. The most significant advantage of this approach is its positive influence on the characteristic biophysical features of the urban environment, where the negative effect of rainwater on the urban area is reduced. This approach has many advantages, but is still poorly applied. Changing the existing rainwater drainage systems is quite costly and complex, but nonetheless, the various possibilities and advantages of applying such an approach, its impact on improving the quality of living and housing, improving the protection of space as a whole, and ultimately mitigating the consequences of climate change, are becoming increasingly evident.

Less than 1% of the potable water on Earth is known to be used by humans, among other things (and in large part), to flush toilets. That water is called black water, and actually its only role is to be a transport agent for faeces and urine. Faeces and urine can be used as fertilizer. Of course, certain rules should be observed in such a use. Urine contains most of the nutrients of wastewater, and by volume it accounts for less than 1% of the total amount of wastewater. The separation of urine and faeces, without the use of drinking water as a transport agent, can be done by using water-free urinals, urine-diversion dehydration toilet - UDDT, urine-diversion flush toilet - UDFT where only faeces are rinsed with water and drained and urine is stored in a special tank, etc. A net zero water building (constructed or renovated) is designed to: minimize total water consumption, maximize alternative water sources, minimize wastewater discharge from the building and return water to the original water source. Net zero water creates a water-neutral building where the amount of alternative water used and water returned to the original water source is equal to the building's total water consumption.

The application, i.e. construction of net zero water building, finds many obstacles. Legal barriers - the complexity of managing the regulatory system around such systems at local, state and national level is the biggest obstacle for project teams seeking approval for net zero water projects. Currently, water is regulated in several jurisdictions and agencies. Financial barriers are then emerging as net zero water projects rely on local or distributed water supply and purification systems which are otherwise operated at municipal level by publicly owned utility companies. As such, the burden of costs for supply and processing systems - as well as their current operation, maintenance and replacement needs - is shifted from the utility company to the individual project. Cultural barriers and public perception of the safety of water reuse and on-site management of wastewater pose significant obstacles to net zero water projects. Such fears have roots in our historical management of water and waste and the resulting public health problems that have arisen. Today, education requires convincing the public of the safety of modern decentralised water systems and informing them of their environmental, social and economic benefits.

CONFLICT OF INTEREST STATEMENT

The authors declare that there is no conflict of interest.

REFERENCES

[1]. S. Milenković, *Vodovod i kanalizacija zgrada*, treće dopunjeno izdanje, AGM knjiga, Beograd, 2007.
[2]. M. Crnjak. (2007) Kompostni WC: Spasimo svijet prerađivanjem fekalija u hranu za biljke. [Online]. Available: https://www.poslovni.hr/lifestyle/kompostni-wc-spasimo-svijet-preraivanjem-fekalija-u-hranu-za-biljke-41620 (Accessed: 20.03.2023.)
[3]. B. Motik, *Tehnologije za održivi svijet*, Priručnik za održivo graditeljstvo i gospodarenje otpadnim vodama, EkoSense, Blatuša, 2009.
[4]. J. N. Počuča, *Ekohidrologija, Zagađenje i zaštita voda*, Građevinska knjiga, Beograd, 2008.
[5]. Đ. Mak, Održivo upravljanje otpadnim vodama: primjeri i rješenja iz prakse, 2012., [Online]. Available : http://www.obnovljivi.com/pdf/PDF_OBNOVLJIVI_COM/URH_T4_3.Dukan_Mak_Prezentacija_Vol_2.1.pdf (Accessed: 20.03.2023.)
[6]. L. Runko Luttenberger, "Prilog uspostavi decentraliziranih sustava otpadnih voda", *Pomorski zbornik*, vol. 40, no. 1, pp. 553-560, 2002.
[7]. S. Deegener and M. Samwel, *Suhi toaleti, Principi, upotreba i izgradnja*, Priručnik za dizajn, građenje, rad i održavanje, WECF- Women in Europe for a Common Future, 2015.
[8]. E. Roma, K. Philp, C. Buckley, S. Xulu and D. Scott, "User perceptions of urine diversion dehydration toilets: Experiences from a cross-sectional study in eThekwini Municipality", *Water SA*, vol. 39, no. 2, pp. 305-312, 2013., http://dx.doi.org/10.4314/wsa.v39i2.15

[9]. A. T. Larsen, I. Peters, A. Alder, R. Eggen, M. Maurer and J. Muncke, "Re-engineering the toilet for sustainable wastewater management", *Environmental Science & Technology*, vol. 39, no. 9, pp. 192-197, 2001.

[10]. F. Šrajer, A. Suić, H. Vidović, S. Kipson and H. Carić, *Mediteranska kamena kuća, korištenje u skladu s okolišom, energije, otpad, sanitarije*, Institut za turizam, Zagreb, 2006.

[11]. Our World In Data, Global freshwater use, [Online]. Available: https://ourworldindata.org/water-use-stress (Accessed: 31.03.2023.)

[12]. Global International Geosphere-Biosphere Programme (IGB), [Online]. Available: http://www.igbp.net/globalchange/greatacceleration.4.1b8ae20512db692f2a680001630.html (Accessed: 31.03.2023.)

[13]. World Health Organization, *WEDC: Technical notes on drinking water, sanitation and hygiene in emergencies*, July 2013.

[14]. Republika Hrvatska, Vijeće za vodne usluge, *Izvješće o radu vijeća za vodne usluge za 2017*., Zagreb, prosinac 2018.

[15]. T. Vrančić, "Građevni sustavi", *Građevinar,* vol. 61, no. 12, pp. 1207-1210, 2009.

[16]. Water Research Foundation: *Residantal End Uses of Water*, Version 2, executive report, 2016.

[17]. Europska komisija, *Dokument za razmatranje o održivoj Europi do 2030*., 2019.

[18]. T. Park. (2020) Understanding the Living Building Challenge and Its "Petals", [Online]. Available: https://www.hourigan.group/blog/understanding-living-building-challenge-petals/ (Accessed: 22.03.2023.)

[19]. Williams College. The Living Building Challenge (LBC), [Online]. Available: https://env-center.williams.edu/a-living-building/ (Accessed: 22.03.2023.)

[20]. D. Obradović, M. Šperac and Ž. Koški. "Upotreba kišnice u zgradama", *Hrvatska vodoprivreda*, vol. XXVII, no. 228, pp. 77-79, 2019.

[21]. D. B. Milićević, N. Lj. Anđelković and M. P. Mitić. "Nužnost integralnog pristupa planiranju i upravljanju atmosferskim vodama na primeru grada Pirota*", Tehnika - kvalitet ims, standardizacija i meteorologija*, vol. 15, no. 6, pp. 1065-1072, 2015.

[22]. Office of Energy Efficiency & Renewable Energy, Net Zero Water Building Strategies, [Online]. Available: https://www.energy.gov/eere/femp/scenario-1-ideal-net-zero-water-building (Accessed: 22.03.2023.)

[23]. House Plans, Zonda Media, Net-Zero Water Use Demonstration House, [Online]. Available: https://www.houseplans.com/blog/net-zero-water-use-demonstration-house (Accessed: 30.03.2023.)

[24]. Kingspan, Klargester AquaHarvest Domestic Rainwater Harvesting, Available: https://www.kingspan.com/gb/en/products/water-management/rainwater-harvesting/gamma-rainwater-harvesting-solution/ (Accessed: 30.03.2023.)

[25]. M. Šperac and D. Obradović. "Primjena metode "Material flow management" na upravljanje otpadnim vodama" Naučno-stručni simpozijum GEO-EXPO 2018 "Geotehnika, stijenska masa, rudarstvo, geo-okolinsko i građevinsko inženjerstvo", in *conference proceedings*, Tuzla: Društvo za geotehniku u Bosni i Hercegovini, 2018. pp. 109-116.

[26]. E. Tilley, L. Ulrich, C. Lüthi, P. Reymond and C. Zurbrügg. *Compendium of Sanitation Systems and Technologies*, 2nd revised edition, Swiss Federal Institute of Aquatic Science and Technology (Eawag), 2014., Dübendorf, Switzerland

[27]. F. Meinzinger, M. Oldenburg, A. A. Lisanework, K. Gutema, R. Otterpohl, P. Krusche and O. Jebens. Implementation of urine-diverting dry toilets in multi-storey apartment buildings in Ethiopia, 2009., [Online]. Available: http://www.susana.org/_resources/documents/default/2-1122-en-implementation-of-urine-diverting-dry-toilets-ethiopia-2009-2.pdf (Accessed: 30.03.2023.)

[28]. J. Sisolak and K. Spataro, *Toward Net Zero Water: Best Management Practices for Decentralized Sourcing and Treatment, Cascadia Green Building Council*, 2011.

[29]. B. Wagner and S. Enzler, (ed.). *Material Flow Management, Improving Cost Efficiency and Environmental Performance*, Physica-Verlag Heidelberg, 2006.

[30]. S. Zundel, D. Bunke, E. Schramm and M. Steinfeldt, *Stoffstrommanagement - Zwischenbilanz einer Diskussion*. Zeitschrift für Umweltpolitik und Umweltrecht. 1998. pp. 317-340.