Nearly Zero Water Buildings

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Abstract. In the use phase, buildings are high resource consumers, especially energy, water and even nutrients. The relationship between these resources is inseparable, and the nexus energy–water–food (or energy–water–nutrients) is currently recognized as the essential connection for the sustainable development of mankind. In the current scenario of climate change, "nearly zero energy" buildings begin to enter the reality of cities in many parts of the world, but "zero buildings" in general (and not just with regard to energy) should integrate and enhance constructive solutions in the future. Taking into account the water–energy nexus, reduction of water consumption in the building cycle is also reflected in significant energy efficiency, considering the reduction of energy needs to heat sanitary hot water and to pressurize water in buildings and also in public systems, in abstraction, pumping and treatment of water and wastewater. The design of "nearly zero water" buildings should be based on the 5R principle, which can be summarized as follows: Reduce consumption; Reduce losses and wastes; Reuse water; Recycle water; and Resort to alternative sources. This paper is a short review of techniques for increasing water efficiency in buildings, based on the principle of 5R, analyzing several solutions for "nearly zero water" buildings, with special focus on the use of efficient products, the harvesting of rainwater and the reuse of greywater. The first two technologies are already well technically dominated, while the reuse of greywater, although not a novelty, still lacks certain developments with a view to their generalization, especially with regard to health and quality control issues.

Keywords: Water efficiency · Buildings · Sustainability

1 Introduction

In the use phase, buildings are high resource consumers, especially energy, water and even nutrients. The relationship between these resources is inseparable, and the nexus energy–water–food (or energy–water–nutrients) is currently recognized as the essential connection for the sustainable development of mankind.

Water is crucial in the production of most forms of energy, and energy is needed for almost all uses of water [1]. Water and energy are also closely linked with food. In a world with a rising global population, agriculture accounts for 70% of global water

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withdrawal [2], while food production and the supply chain account for about 30% of total global energy consumption [3].

Taking into account the water–energy nexus, reduction of water consumption in the building cycle is also reflected in significant energy efficiency [4]. In addition to reducing the need of energy to heat sanitary hot water (SHW) and to pressurize water in buildings, there is also a reduction in energy consumption in the public systems, in abstraction, pumping and treatment of water and wastewater. Therefore, the nexus between water efficiency and energy efficiency should be one aspect that must be necessarily noted when considering the conception of "nearly zero energy" buildings [5, 6].

A study developed in a medium-sized city in Portugal (Aveiro) by ANQIP, a Portuguese association for quality and efficiency in building installations, found that energy savings due to the adoption of water-efficient products in buildings (classified in the category "A" of the ANQIP labeling scheme for water efficiency) can be very significant [7]. It should be noted that in Portugal, energy consumption for heating domestic hot water represents over 30% of the total housing energy consumption.

That study shows a reduction in emissions greater than 100 kg of CO_2 per capita per year, in relation to the present scenario, taking into account the heating of domestic hot water in buildings and energy consumption in public water and sewage networks [7, 8]. With regard to reductions in energy consumption in public systems resulting from reduced consumption in buildings, the same study also allowed to conclude that a discharge of a 6-liter flushing cistern implied an energy consumption close to 10 Wh, equivalent to a common 3 W LED lamp connected for 3 h.

In the current scenario of climate change, the "nearly zero energy" buildings begin to enter the reality of cities in many parts of the world, as a contribution to the mitigation of the phenomenon of climate change. However, "zero buildings" for all resources should integrate and enhance constructive solutions in the future, with a view to increasing environmental sustainability in urban areas, they should take into account the intrinsic relationship between water, energy and nutrients in urban environments, favoring an integrated approach.

The "zero building" concept is not, however, similar for all resources. In the case of energy, the concept of "nearly zero energy" buildings does not mean a circular use of the resource, but rather that the total amount of resource used by the building is approximately equal to the amount of renewable resource produced or available on the site.

In the case of water, part of the resource can be used in a circular way (water recycling), but renewable local sources alternative to the supply from the public network, such as rainwater, can also be considered [9–12]. In the case of "nearly zero nutrient" buildings, the resource shall be considered to be circular [13]. Nutrients such as phosphorus can be recovered from urine in the buildings and used as fertilizer in green roofs or urban agriculture [14–16].

In this paper, short review of techniques for increasing water efficiency in buildings is done, aiming to demonstrate the possibilities of developing "nearly zero buildings". Solutions such as the use of efficient products, he harvesting of rainwater and reuse of greywater are described and analyzed.

2 Method: The 5R Principle

The design of "nearly zero water" buildings should be based on the 5R principle of efficient use of water in buildings [17], which can be summarized as follows:

- Reduce consumption
- Reduce losses and wastes
- Reuse water
- Recycle water
- Resort to alternative sources

The first R—Reduce consumption—includes the adoption of efficient products and devices, without being prejudicial to other measures of an economic, fiscal or sociological nature. The second R—Reduce losses and wastes—may involve interventions such as monitoring losses in buildings (flushing cisterns, garden irrigation systems, etc.) or the installation of circulation and return circuits of sanitary hot water.

The third and fourth Rs—reuse and recycling of waste water—are important measures for the design of "nearly zero water" buildings, which are distinguished by the fact that reuse is a serial use and recycling is a re-introduction of water at the beginning of the circuit (after treatment). Reuse has undergone some development in recent years in relation to greywater, in particular the reuse of effluents from baths and washbasins for discharges in toilets and watering.

The last R—Resort to alternative sources—may involve rainwater harvesting or the use of salt water, for example. This concept of alternative sources refers to waters that do not come from the public distribution network and which, in some cases, can be directly used for purposes that do not require drinking water.

3 Discussion

3.1 Reduce Consumption

A number of studies, including some from the European Commission [18], show that the adoption of efficient water-using products (WuP) in buildings can reduce consumption by about 30% compared to the current scenario, a very important value with significant implications with regard to energy consumption, as mentioned above.

One of the measures that is considered fundamental for reducing consumption (1st R) is the water efficiency labeling of the WuP, which makes it possible to raise awareness and help consumers in choosing the most efficient products. With regard to energy efficiency, labeling of products and buildings is already a mandatory measure in many countries, a tendency that has not been verified in relation to water efficiency.

In the case of Europe, energy labeling has already been mandatory for a number of years, under the so-called Energy Directive, but there is still no compulsory labeling of water efficiency of products, although the southern Mediterranean countries suffer from increasing water scarcity as a result of climate change.

Interestingly, the Energy Directive provides for compulsory labeling of products using hot water (taps and showers), but only at the level of their energy efficiency, although the energy consumption in these products is also directly related to the consumption of water. In the absence of a mandatory European labeling scheme for WuP, voluntary labeling has been promoted in Europe in several countries or by sector associations most sensitive to this problem.

At present there are three voluntary water efficiency labels in Europe, namely the German WELL label, the European Water Label (EWL), supported by the European Industry for Taps and Valves (CEIR) and the Portuguese label of ANQIP (Fig. 1) [19]. As the European Commission has not implemented the energy label for taps and showers, two countries where energy issues are very relevant (Sweden and Switzerland) have in the meantime adopted voluntary energy labels for WuP.

Given the current situation, with a wide dispersion of labeling schemes, damaging information to consumers, ANQIP, EWL and the Swedish and Swiss labels decided to join together, creating a unique label for water and energy efficiency—the Unified Water Label (UWL) (Fig. 2)—which was recently officially presented. The launch and consolidation period of this initiative is scheduled for two years, and a specific platform based in Brussels for the management of this new unified label—the European Bathroom Forum (EBF)—is being set up.

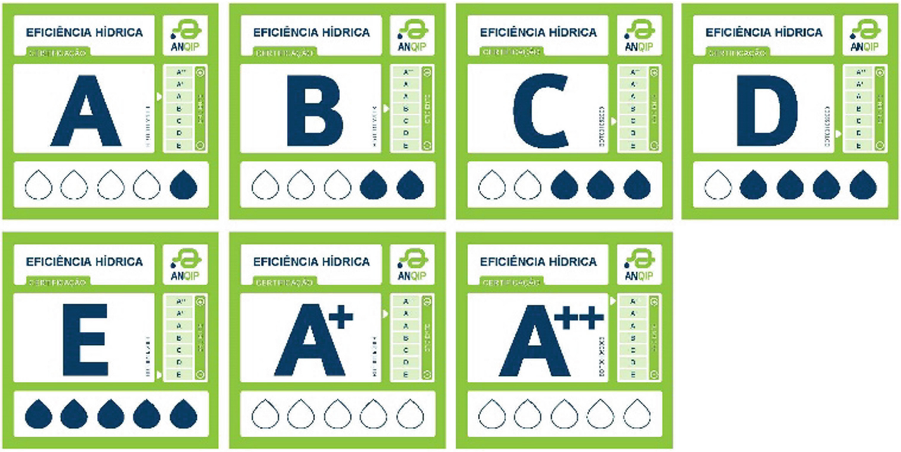

Fig. 1. Water efficiency labels for products (ANQIP) [19]

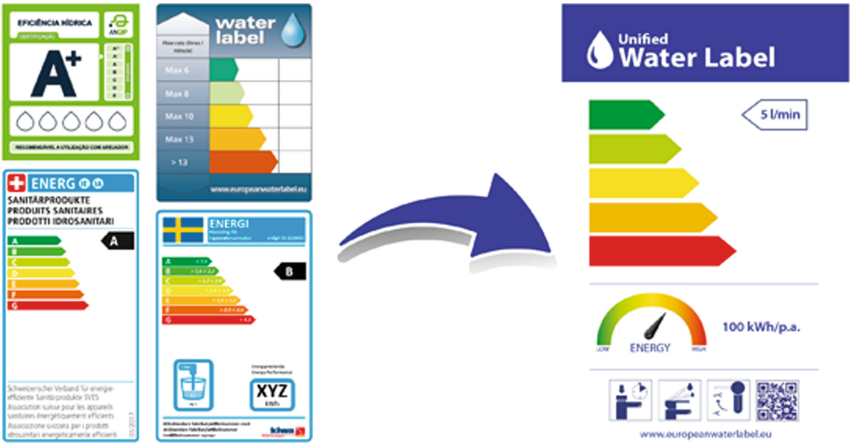

Fig. 2. New European Unified Water Label (EBF) [20]

The European Commission has supported this process, admitting the possibility of establishing a voluntary agreement with EBF, dispensing with its energy label for taps and showers. One of the conditions for the acceptance of the new unified label by the European Commission is that it reaches 80% of the market.

At the moment, the label provides information about volume or flow rates for 13 different categories of WuP and covers 34 countries across Europe, with over 12,500 products and 148 brands already using the Unified Water Label. At the European level and beyond, this label will help consumers to understand how much water they use within the building environment and will be an essential contribution to the design of "nearly zero water" buildings.

3.2 Reduce Losses and Wastes

In the use of water, the concept of waste is different from loss. The concept of loss can be easily understood based on terms used in economics, where losses are defined as goods or resources consumed but not incorporated in the final product. Thus, the deficiencies of a certain system that lead to a physical/real loss of water, forcing a consumption of the resource superior to that necessary for the "production" are integrated in the definition of the losses.

In buildings, losses are common, for example in flushing cisterns and watering systems. However, not being an inherent problem in the design of the building, but rather repairable faults, they are not relevant in the design of "nearly zero water" buildings, as opposed to wastes of water.

The concept of waste essentially corresponds to an unnecessary consumption of the resource (in excess) in the "production" process, for example, negligent use of water or poor general functioning of water systems. To put it another way, waste of water is essentially a set of actions and processes through which one spends without profit or simply misuses water.

The amount of water consumed in a building can then be described by the following expression:

$$\text{Consumption} = \text{Use} + \text{Losses} + \text{Wastes}.$$

The concept of use corresponds to the amount of water required to perform a certain activity. Eventually, it may be feasible to obtain the same "end product" (cleaning a toilet bowl by discharge of a flushing cistern, for example) using less water. In this case, we talk about water efficiency by reduction of consumption (the 1st R).

In buildings, the most common waste of water results from the lack of circuits of circulation and return of sanitary hot water, causing high waiting times of hot water. Therefore, the circulation and return of sanitary hot water (SHW), or equivalent solutions, have been increasingly considered in regulations in many countries. In Europe, the installation of SHW return circuits is mandatory in many construction regulations when the distance between the WuP and the equipment of production or accumulation of SHW is relevant (10 or 15 m, depending on the country).

The water savings resulting from the installation of return circuits of SHW can be significant. Taking into account, for example, a shower with a flow rate of 20 L/min and a distance of 20 m between the hot water accumulator and the shower, leading to a waiting time of approximately 40 s, the savings will be of approximately 13.5 L, equivalent to three discharges of a flushing cistern with average volume of 4.5 L.

With regard to the energy balance when return circuits of SHW are installed, the balance can be positive or negative, depending on the characteristics of the solution adopted for the return, the consumption diagram in the building, etc. In fact, if it is evident that there is an increase in energy consumption when return pumps are installed, there is also an energy saving, corresponding to the energy absorbed in the water saved.

3.3 Reuse and Recycle Water

In fact, all the water we use is recycled by nature. But total water recycling at the level of buildings, considered as closed systems, is not yet a technology considered of interest, given its costs and the alternatives generally available, although there are already partial solutions, with water recovery for non-potable purposes. The exception is, of course, space missions…

Israel and Singapore already have high levels of water recycling at the level of urban systems, although the applications for reclaimed water are essentially agriculture and industry, respectively. However, the Singapore National Water Agency states that reclaimed water is already within the requirements of the WHO (World Health Organization) and the US-EPA (United States Environmental Protection Agency) for drinking water [21].

Recycling is the only measure that, in itself, would theoretically allow zero water buildings. In practice, however, a recycling of 100% of the water consumed is never feasible, since there is consumption for food, watering, evaporation, etc., which do not allow to recover all the water consumed in the building. Even at the International Space

Station (ISS), the percentage of recycling ranges from 85% to 93%, according to data from NASA and the Canadian Space Agency [22, 23].

On the other hand, the reuse in buildings of water without fecal contamination, from discharges of bathtubs, showers, washbasins and, in certain situations, washing machines and kitchens, which are generically designated as greywater, begins to emerge. In general, the water from showers, baths and washbasins, called “light greywater”, is not very polluted. Water from washing machines usually has a higher pollutant level, and water from the kitchen (sink and dishwasher) has an even greater pollutant level (dark greywater) [24].

The substances present in greywater usually result from personal hygiene products, detergents, hair, skin, particles of dandruff and possibly dirt from clothing, and are easily biodegradable. Due to this biodegradability, the later use of greywater cannot be too delayed as decomposition processes involving sulphates and unpleasant odors can be unleashed.

Chemical characteristics of greywater may also vary depending on the quality of the tap water or treatments carried out in the building network (for example, a higher concentration of nitrates in the overall network or the addition of polyphosphates in the building installation to prevent the corrosion of pipes). Relatively high concentrations of phosphates may result also from dishwashing detergents.

In terms of microbiological contamination, a large number of studies performed in recent years on bath, shower and washbasin waters have shown much lower levels of total and fecal coliforms (*E. coli*) in comparison with total domestic wastewater. It is worth noting that in the effluent from washing machines, the concentrations of bacteria depend on the washing temperature.

In terms of present knowledge, it is considered that greywater can be used in flushing toilets, washing clothes and watering gardens, after an appropriate treatment in the case of systems with a long retention time. In systems with direct reuse or short retention time, with a single user or users of the same family, it is accepted that treatments can be simplified or even avoided, provided that suitable maintenance routines exist.

In a building, the total amount of greywater produced can vary considerably depending on the sanitary habits and living standards of families. In the absence of specific studies, it is estimated that greywater production accounts for about 70% of consumption, 40% of which is light greywater and 30% is dark greywater [25].

For a capitation of 100 L/(inhab. and day), the production of light greywater will therefore correspond to about 40 L/(inhab. and day). This production is sufficient for flushing toilets, which corresponds to a value between 25% and 35% of consumption, and can also be used for washes. At the limit, it is assumed that use and greywater can reduce the consumption from the public network in a value close to 50%.

In collective-use buildings with multiple users, where greywater collection is centralized and retention times can be significant (student residences, for example), it is necessary to treat greywater, including a disinfection, before their subsequent use. Equipment for this purpose is available on the market, but in most countries there are no specific health control schemes for these types of installations (mandatory certification schemes or regulation), which is the current major weakness of this measure.

Small compact installations are also available in the catalogs of various manufacturers of sanitary ware, combining washbasin with toilet. The storage period of the greywater is short, considering in such cases that a complex treatment is unnecessary, bearing in mind that they are intended only for one user or persons of the same family.

Between the large centralized systems, requiring extensive treatment of effluents, and the monobloc systems, with high aesthetic commitments in the bathrooms, it is possible to develop other solutions for single-family dwellings. A number of proposals have been developed recently in this area, either in new construction or in the context of refurbishment of housing [26].

The reuse of greywater can be an essential component of "nearly zero water" buildings. As previously mentioned, this reuse can lead to a reduction in the consumption of the public network between 25% and 50%, depending on the solutions adopted. As regards the water–energy nexus, it can be said that compact installations without treatment reflect energy savings, since the reduction of water consumption from the public network also corresponds to a lower energy consumption in the urban water cycle.

With regard to installations with a long retention time, with a "conventional" treatment for this type of effluent, the energy consumed in the treatment makes the system "energy neutral", i.e. the energy expended in the treatment of greywater, about 1.8 kWh/m^3, is equivalent to the energy saved in the urban water cycle.

However, since the greywater temperature of the showers, for example, is generally higher than 30 °C, the use of this thermal energy for preheating hot water allows savings of around 3 kWh/m^3, making these facilities advantageous not only from the point of view of water efficiency but also in relation to energy efficiency.

The separate recovery of urine, which may be important in the design of "nearly zero nutrient" buildings, is not, however, significant in "nearly zero water" buildings since it accounts for only about 1% of the total volume of effluents.

3.4 Resort to Alternative Sources

Alternative local sources may include, for example, wells, desalinated water or rainwater. For some uses, these local waters can be used directly, without any treatment, as is the case of Hong Kong, where salt water is used in discharges in toilet bowls.

Desalination can be an interesting solution in places with high freshwater shortage and located near salt water bodies. However, it is not yet a generalizable solution in all cases, even on the seafront, as there are some known drawbacks, such as the environmental impact of brines returned to the sea and high energy consumption [27].

As regards brines, they have a high concentration of salt and a higher density (and possibly even higher temperature, in particular in thermal processes), which entails environmental hazards at the point of discharge. In relation to energy consumption, values above 3 kWh/m^3 are usually indicated for the best available reverse osmosis technologies, values still high when compared to usual energy consumptions in conventional systems (in the aforementioned study carried out for the city of Aveiro, Portugal, total energy consumption in the water supply network was 0.838 kWh/m^3).

Rainwater harvesting in buildings is a technology that responds not only to concerns about reducing freshwater consumption from traditional sources but also to other situations that climate change makes more intense and frequent, for example, exceptional precipitation events. In the latter case, rainwater harvesting systems in buildings contribute to a damping of the flood peak, thus reducing floods in urban areas.

Due to its many advantages, rainwater harvesting systems have seen a great increase in many countries and are even mandatory in some cities, for some urban areas or certain buildings (S. Paulo, for example).

In buildings, rainwater can be used for a number of non-potable purposes such as flushing, washing machines, watering, floor washing, etc. In general, they are competing uses with the reuse of greywater but with less sanitary risk and less demand of treatment. It should be noted that these two water efficiency measures can be used cumulatively.

It is understood that rainwater can supply close to 30% to 80% of the consumption in buildings, without any complex treatment (in addition to a simple filtration and a natural decantation in the tank). However, there are already on the market individual equipment for the purification of these waters (to the level of drinking water). Thus, a total supply of the building with rainwater is feasible at present, completely replacing the supply of the public network, provided that local precipitation is sufficient. Water treatment equipment for rainwater can also be used for water from other low-polluted sources.

A constructive solution that will probably become generalized in the future in urban environments, for its many advantages, is the green roof. Although they affect the collected volumes, these coverages are compatible with rainwater harvesting, and there are several studies in this area [28, 29].

As rainwater harvesting systems also reduce drinking water consumption in houses, they additionally entail reductions in water and energy consumptions in public networks. Although rainwater harvesting systems demand a pressurization system in the building, the corresponding energy consumption is equal to or less than those that occur when the supply comes from the public network.

4 Conclusions

The technologies currently available make “nearly zero water” buildings possible, although, from an economic point of view, their viability is still reduced in most situations. In any case, the application of various measures of water efficiency in buildings, in accordance with the 5R principle, allows to reduce significantly the consumption of freshwater from the traditional origins and thus contribute to the preservation of this resource, which is becoming scarce in many areas of the planet.

The application of efficient water-using products, for example, can reduce significantly the consumption in buildings, with a potential of the 30% reduction indicated as reference in face current devices in the market. Rainwater harvesting is also a viable measure in many situations, which can reduce the consumption of drinking water in buildings between 30% and 80%, as well as other advantages that it presents in the urban environment as a measure of adaptation to climate change.

However, urban water efficiency measures that use non-potable water, such as rainwater or greywater, are recent trends that have not been accompanied in general by the implementation of adequate sanitary control systems. This is the main current weakness of these solutions, which must be overcome through appropriate regulation or mandatory certification schemes.

Most of the stated measures of water efficiency can contribute not only to the design of "nearly zero water" buildings but also to the reduction of energy consumption, favoring the realization of "nearly zero energy" buildings. The possibility of "nearly zero nutrient" buildings, with recovery of urine or specifically of phosphorus, is also linked with the water–nutrient nexus in the building and in its surroundings.

The possibility of buildings "nearly zero", insofar as they can be independent of public infrastructures, can create new challenges in territorial planning. In fact, considering additionally the social networks, the e-learning and the working-at-home, they may contribute to reverse the current trend of urban concentration, reducing their environmental impacts.

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