Grey Water Phytodepuration Systems Integrated in Flat Green Roofs

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Abstract

The research about new grey water reuse systems can not only help to reduce the volume of drinkable water applied in domestic uses, besides allows to diminish the urban wastewater volume to be treated.

Because of that, the proposal aims the adjustment of green roof surfaces to new uses, in relation with grey water phytodepuration systems. The main problems of traditional reed bed systems are their large dimensions, their high weight and the roots growth in the substrate subsurface.

The developed system optimizes the traditional treatments with the design of industrialized channels, improving the contact between bacteria-roots and water. This optimization allows to reduce the treatment surface needed.

The analysis of the most suitable species and their roots length, facilitates to diminish the channels depth; and for this reason the system is much lighter than the traditional ones. Moreover, the use of floating systems, reduce the common roots problems and diminish the maintenance requirements.

Also, grey water phytodepuration systems integrated in flat green roofs, contribute not only to develop the hygrothermal benefits of green roofs, but allow to incorporate low energy water treatment systems in buildings, and to reuse it by flushing toilets and irrigation, with drinkable water saving of more than 40%.

Keywords: water management benefits, biodiversity benefits, phytodepuration, green roof

Background

Industrial Context

The research has been developed in the frame of the subproject 10-Optimization Systems for Efficient Behaviour in Housing, belonging to the Strategic and Singular Project INVISO (Industrialization of Sustainable Housing).

The research, developed since 2007, has four main phases with the aim of designing industrialized prototypes associated with water saving systems.

These phases are:

1. Cataloguing phase. There have been analysed and classified 166 strategies that nowadays are used in sustainable water management area. They have been organized in the next 7 categories: Rainwater, water consumption reduction, irrigation, grey water, waste water and water quality.

2. Selection phase. Each strategy has been detailed described through analytical and graphical parameters, in order to define their level of Sustainability, Innovation and Functionality. As result of the strategies comparison, grey water treatments have been determined as the ones with greater development potential in industrialized housing field. Their application supposes important drinkable water saving, good possibilities of spatial innovation and relative easy application in housing.

3. Development of a phytodepuration system for grey water reuse. Although these systems are normally used in communities with large free country extensions; the development of the proposed strategy tries to adapt traditional systems into industrialized modular products, which can be applied in urban building roofs or gardens.

4. Prototype construction and monitoring. This phase is being developed during 2010.

Particularly, the traditional phytodepuration systems have been accurately studied, in order to define their main disadvantages and their improvement possibilities. The reed bed treatment systems (RBTS) were first investigated by Seidel and Kickuth, in the 1960s in Germany.

They are based in the removal of water pollutants, when contaminated water is passed through large areas of beds of reeds, planted in soil or gravel. The principles behind the process are in relation with the rhizomes growth. Roots grow vertically and horizontally, providing oxygen to large populations of common aerobic bacteria, which breakdown water organic components. Because of that, the industrialized reed bed system tries to take advance of this process, by reducing the area requirements and optimizing water and roots bacteria contact.

Problem

According to the National Statistics Institute (INE 2005), Spain has an average domestic water consumption of 167 litres per person per day. Wash-basins and showers represent the highest values of 60 litres per person per day; while each inhabitant spends diary 45 litres by flushing the toilet. It implies that practically both uses require the same volume of potable water; and both together suppose the diary unload of 105 litres per person to the public pipeline net. Because of that, it is important to reconsider new ways of water reuse, especially in countries with low rainfall levels, like Spain.

Some authors define grey water as wastewater without any input from toilets, which so generally includes sources from showers, basins, washing-machines, dishwashers and kitchen sinks. Meanwhile, other authors define grey water as the low polluted waste water from bath uses and washers.

If Kitchen sink load is being included as grey water, Biological Oxygen Demand (BOD) and Phosphorus levels increase at similar as WC load levels. Because of that, the proposed system will consider only grey water as the product of showers, baths, bidets and washbasins.

Main problem of grey water is his highly variable organic concentration and the high Chemical Oxygen Demand (COD) and BOD levels, on the contrary it has low suspended solids turbidity ratio and low concentration of coliforms. These characteristics suggest the use of advanced biological processes, which combine bioreactor with efficient solid separation process, as the most suitable technology for grey water recycling.

	Water consumption (l/person day) (INE 2005)	Water consumption (l/person day) (ECODES)
Shower/bath bidet and washbasin	60	46
Toilet	45	16
Washing machine	33	18
Cooking and drinking	19	13
Cleaning	10	7
Total water consumption	93	64

Table 1. Average water consumption values in Spain.

Learning Objectives:

- Industrialized phytodepuration systems in flat green roofs.
- Flat roofs situation in Spain.
- Grey water management in urban areas, by using phytodepuration systems in flat green roofs.
- Benefits of the system integration in flat green roofs.

Approach

Industrialized Phytodepuration System

The industrialized phytodepuration system aims to purify the grey water, in order to the reuse in irrigation and flushing toilets. In this way, it is possible to diminish the potable water consumption and the volume of water that daily overloads the urban wastewater treatment plants.

Because of that, a centralized system has been proposed and the following process has been studied: The grey water from each apartment is conducted by an independent pipeline, separating the water produced in the showers, washbasins and bidets. This water is pre-filtered by a centralized unit, in order to remove suspended solids; and then is storage in a preliminary cistern. Daily, the water is pumped to a main centralized tank, and from there is pumped again to the phytodepuration industrialized tanks, where the macrophytes are floating. The tanks are organized on the flat roof, optimizing the use of this building area.

The design of modular tanks, allows a lot of distribution combinations; at the same way it makes possible to build a circuit, where the water flows. The optimization of the tank dimensions and the circuit design, contributes to increase the contact between rhyzosphere and grey water. The aerobic bacteria, which are responsible of the purifying, are developed on the roots, so the increase of the water-root contact allows to improve the efficiency of the system.

The necessary period to purify the water is a week. After this period, the cleaned water is circulated to the storage cistern, waiting to be reused.

Analysis

Spanish Urban Context

The population distribution of the Spanish cities differs markedly from the most of the Occidental European countries; mainly from these like United Kingdom or Central Europe, where has been developed great amount of reed bed systems. The population density in Spain is 91.4 inhabitants per km^2; while other countries, with similar dimensions, reach the 250 inhabitants per km^2 (Germany) or the 243 inhabitants per km^2 (United Kingdom).

Unlike these European Countries, the population in Spain is focused in medium and large cities, distributed on seaside and valley metropolitan areas that are densely populated. Also, there are some interior metropolitan areas, like Madrid, Zaragoza, Córdoba or Valladolid. This territorial organization, concentrates the 45% of the population in only 7 provinces.

The Metropolitan Area of Madrid

The Metropolitan Area of Madrid is the third larger in the European Union, after London and Paris. It had an important development from the sixties, which allowed the growth of the peripheral cities with a high and medium density planning. This urban model promoted the construction of high multi-storey housing buildings without public green spaces.

Respect to the urban water management, many centralized wastewater treatment stations were built in outer parts of the city. But nowadays, the continuously growth has contributed to their incorporation of the urban space and to the installations overload.

Because of that, there are two main actions that can be adopted. First of all, the grey and black water separation, and then the rethinking of new grey water treatments focused on the districts, taking advantage of the large surface of flat roofs existent in these cities.

Case Study

The city of Alcalá de Henares, is situated in the Metropolitan Area of Madrid and it is a good example of the urban growth developed in the sixties and seventies. It has been selected a high density area of this city, in order to study the benefits of the industrialized phytodepuration system associated to the large flat roof surface existing.

The studied area was built in the seventies, and it is formed by two blocks and a central volume with a tertiary use, and is bounded by the Complutense Avenue with the Ribera, Murillo, Caballería Española, Juan de Arellano and Manuel Azaña streets.

The dwelling building has seven storeys plus a commercial level, and a installations and storage basement. The dwellings have a medium built surface of 100-130 m^2, organized in for bedrooms and two bathrooms. Because of that, it has been calculated a medium of 3 equivalent inhabitants per dwelling.

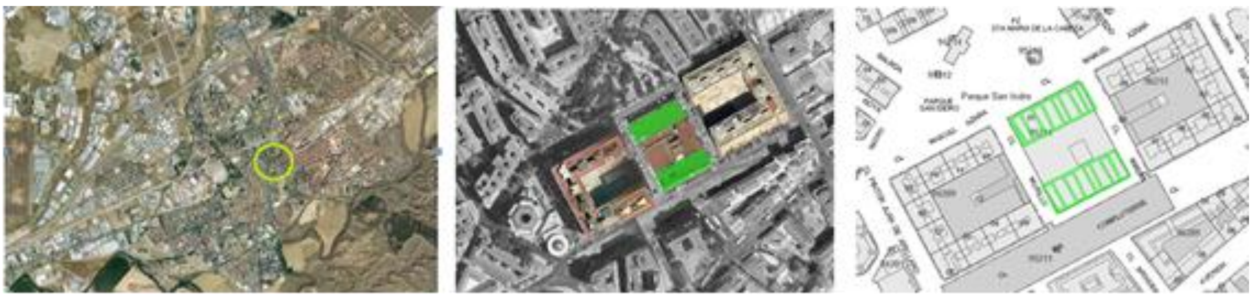

Figure 1. Alcalá de Henares aerial view and studied area

The whole block, is formed by 10 portals, and 28 dwellings per portal, that makes a total of 280 dwellings per block; and 1,680 equivalent inhabitants in the whole area.

The tertiary block is used as commercial centre, and has a main floor and another used as parking. This building has a large flat roof of 4.690 m^2, mainly free and without any use.

block A		block B		Comercial Building	
Roof surface (m2)	4,300	Roof surface (m2)	4,400	Roof surface (m2)	4.690
Block surface (m2)	7,100	Block surface (m2)	6,900		
Block density (inhabitant/km2)	118,310	Block density (inhabitant/km2)	121,739		
Total					
block surface (m2)	13,390	Total surface, included roads (m2)	20,900	Density, included roads (hab/km2)	80.383

Table 2. Average water consumption values in Spain.

Strategy

It has been considered the opportunity of reusing the large roof surface of the central building. This proposal, will take advantage not only from the lack of direct contact between inhabitants and grey water, but also it can configure a new urban landscape to the surrounded dwellings.

Also, the bathroom distribution of this building typology helps to reduce the length of the greywater pipeline; due to the two bathrooms of each dwelling share a same technical wall.

The grey water from each portal is collected by an individual pipeline and circulated to a primary deposit. Every 24 hours, the grey water is pumped from there to the centralized storage cistern; and from there to the flat roof, where the phytodepuration tanks are. The water should be kept there at least 7 days. Then, the purified water is storage again in another centralized cistern, waiting to be reused in flushing toilets or irrigation the rest of the roof and the nearly green public space.

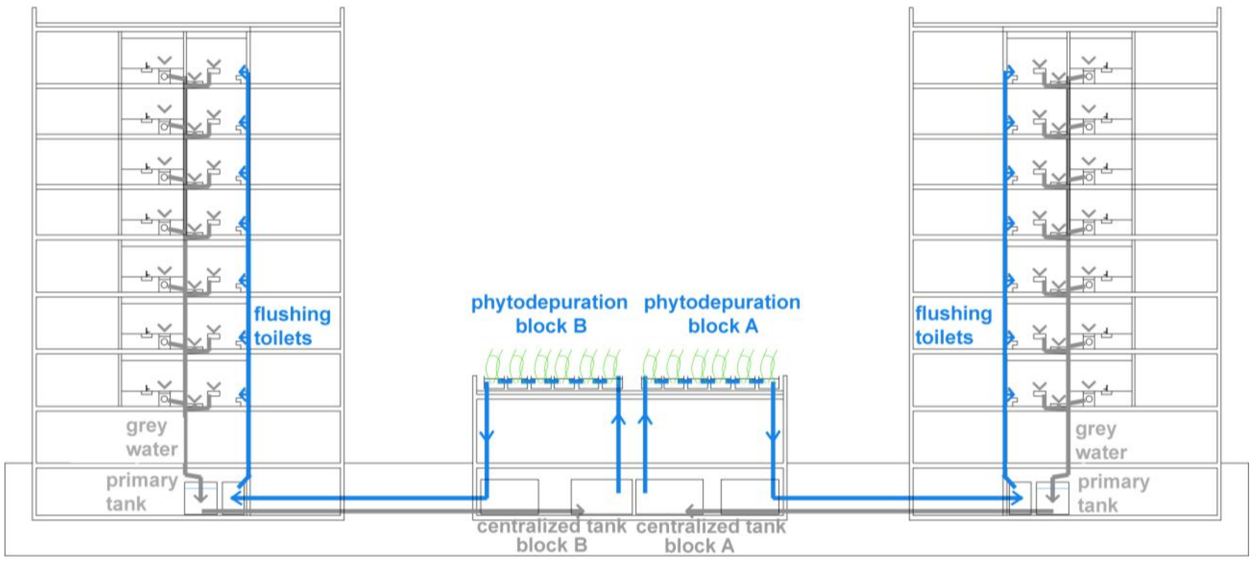

Figure 2. Organizing principle

Components

Dual Plumbing

The installation of the dual plumbing is necessary to collect the grey water and separate it from the black water from toilets and kitchen sinks. The grouping of bathrooms in the existing dwellings diminishes the necessity of large pipelines construction, minimizing the economic and environmental costs of the project.

Then, grey water is conduced to a pre-filtration system, where solid particles are taken out. Pre-cleaned water is later stored in a preliminary tank, where should not be more than 24 hours, in order to avoid bacteria development. Each staircase has a preliminary cistern, from where water is then pumped to the centralized deposits, one per block. These centralized deposits are placed in the basement of the central commercial building.

The daily pumped water for the whole complex is 1.680 litres; due to the daily consumption of 93 litres per person. Because of that it is necessary the use of coordinated primary deposits, in order to diminish the volume of the centralized tank.

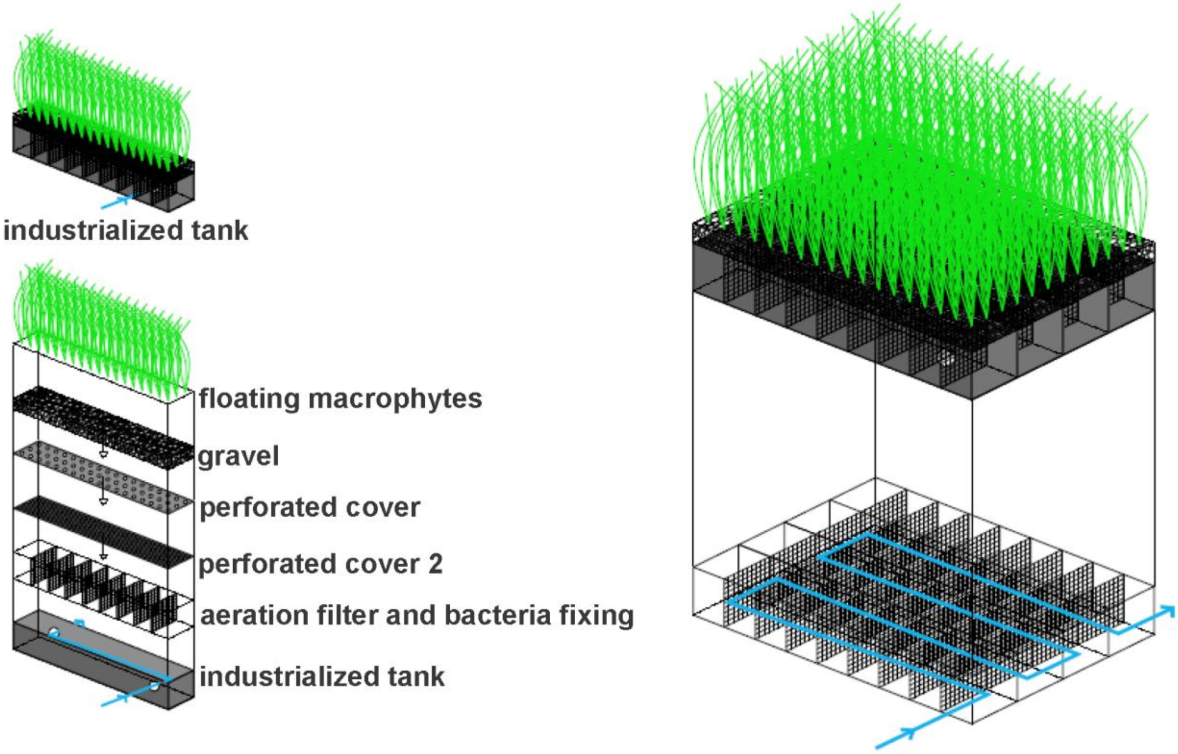

Figure 3. Components of the industrialized phytodepuration system

Phytodepuration area

The main innovation has being developed in relation with the phytodepuration area. As traditional wetlands are so bit that is not possible to define the tour wastewater does, the strategy proposes to reduce drastically the required water treatment surface. Because of that, the industrialized tanks have been designed, controlling the water circulations.

Subsurface reed beds have normally a 4.00 m width, and are normally disposed linearly. However, the developed strategy will reduce the width to 1.50 m, in order to increase contact between roots, bacteria and water, optimizing the system and reducing the space needed. Also, the tanks length is 10 m, in order to facilitate the portability and transport of the system.

In order to diminish the roots growth in the connection pipelines between industrialized tanks, tree different areas have been design in each tank. The central area is the largest and is where the macrophytes float; while the end sides are free of roots, in order to facilitate the water circulation. Also, a platform over the tank has been projected, providing to the system an air chamber which will avoid disgusting smell. A layer of gravel is disposed over this platform, in order to protect the water from exterior pollution components, sheets or insects.

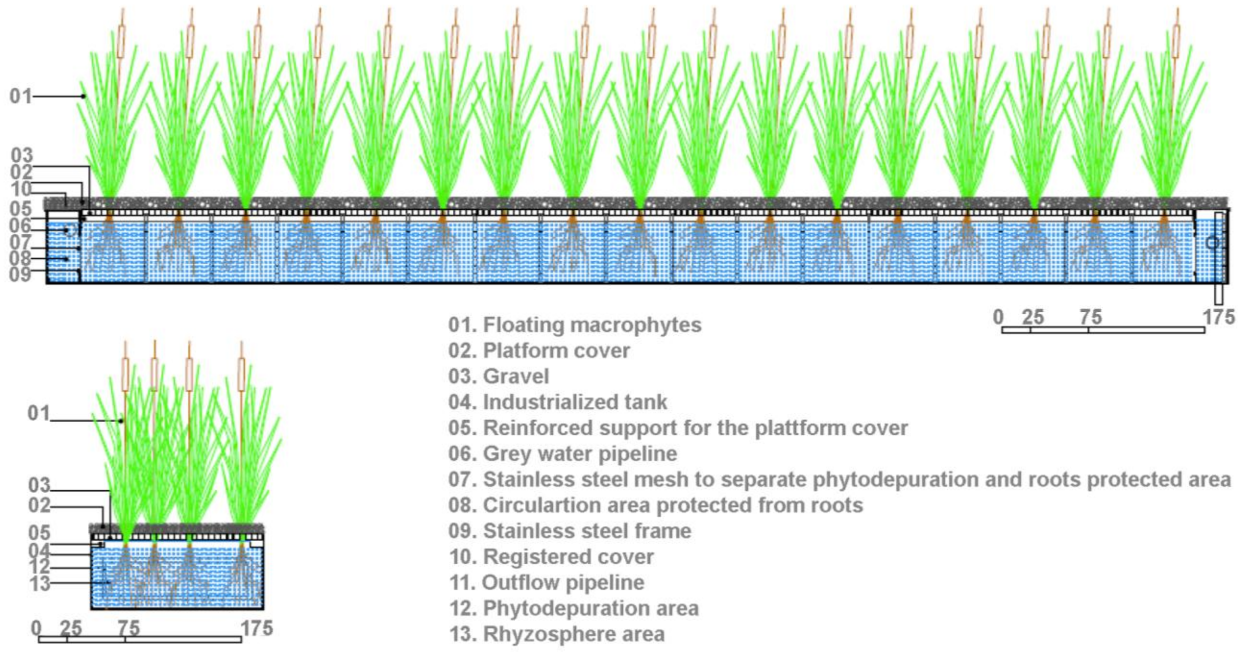

Figure 4. Detail of the industrialized phytodepuration tanks.

Macrophytes in flotation

Macrophytes in flotation filters (FMF) have been firstly developed by the Grupo de Agroenergética of the Universidad Politécnica de Madrid, leaded by the Proffesor J. Fernández. The technical consist in combining the benefits of emergent and floating plants. Emergent plants, like Praghmites or Typhas, have an important rhyzosphere volume. When they have sufficient growth, they are adapted to the aquatic medium by the used of buoys. As the rhizosphere volume is greater, more aerobic bacteria rise, and the system efficiency increases. Roots are floating and there is avoid the traditional substrate problem.

The other important innovation consists in the incorporation of the transitivity platform over the tank. This platform contributes to the macrophytes support, avoiding the necessity of buoys. It is supported by two lateral tank reinforcements and transversal polypropylene cells transversally disposed. These cells contribute to the oxygenation of the water which passes through them.

Storage system

The storage system has been organized in two centralized deposits where the clean water is circulated, and from where is again pumped to the storage tank of each staircase. This cleaned water can be reused in flushing toilets, in irrigating green public spaces or in street flushing.

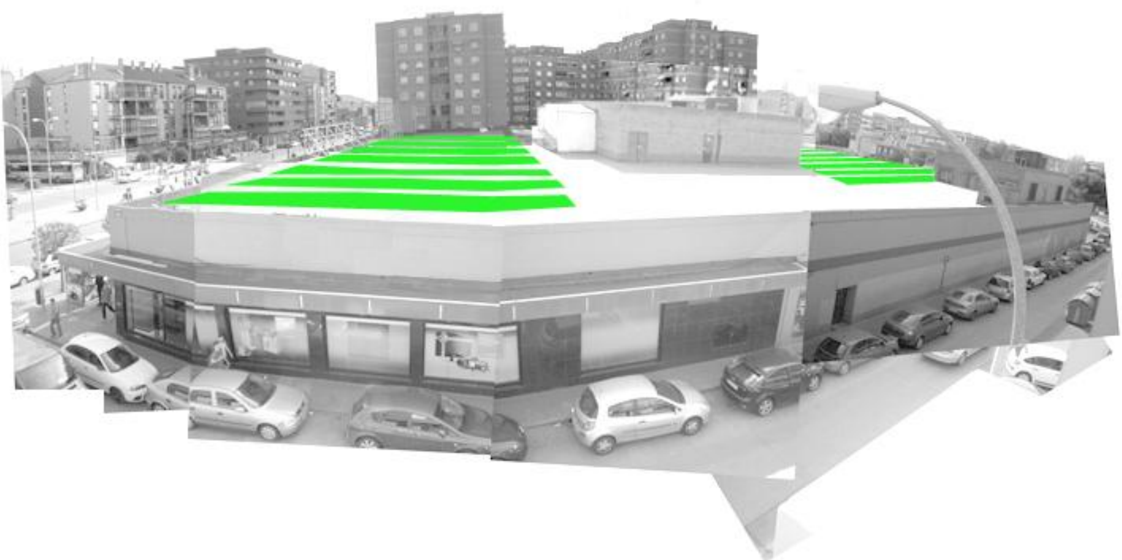

Figure 5. Proposal

Results and Business Impacts

Key Findings

It has been studied many different situations, in order to quantify the impact of the use of phytodepuration systems in flat green roofs. The parameters of study depend on the source of the grey water and the combination with other complementary actions associated to the water consumption reduction.

WATER FROM SHOWERS, WASHBASIN AND BIDET		
hypothesis A_ only phytodepuration		
percentages of daily water reuse		
total equivalent inhabitants	1.680	
grey water produced (l/inhab.eq)	60	
total litres	100.800	
total cleaned water	70.560	100,00%
wc flushing (l/inhab.eq)	45	
total litres	75.600	107,14%
need extra water (litres)	-5.040	-6,67%
hypothesis B_ included change of low consumption toilets		
percentages of daily water reuse		
total equivalent inhabitants	1.680	
grey water produced (l/inhab.eq)	60	
total litres	100.800	
total cleaned water	70.560	100,00%
wc flushing (l/inhab.eq)	16	
total litres	26.880	38,10%
irrigation reuse	43.680	61,90%
hypothesis C_ global strategies of water reduction consumption		
percentages of daily water reuse		
total equivalent inhabitants	1.680	
grey water produced (l/inhab.eq)	46	
total litres	77.280	
total cleaned water	54.096	100,00%
wc flushing (l/inhab.eq)	16	
total litres	26.880	49,69%
irrigation reuse	27.216	50,31%

Table 3. Water from showers, washbasin and bidet

WATER FROM SHOWERS, WASHBASINS AND WASHMACHINE		
hypothesis A_ only phytodepuration		
percentages of daily water reuse		
total equivalent inhabitants	1.680	
grey water produced (l/inhab.eq)	93	
total litros	156.240	
total cleaned water	109.368	
wc flushing (l/inhab.eq)	45	
total litres	75.600	100,00%
extra water produced (litres)	33.768	44,67%
hypothesis B_ included change of low consumption toilets		
percentages of daily water reuse		
total equivalent inhabitants	1.680	
grey water produced (l/inhab.eq)	93	
total litres	156.240	
total cleaned water	109.368	100,00%
wc flushing (l/inhab.eq)	16	
total litres	26.880	24,58%
irrigation reuse	82.488	75,42%
hypothesis C_ global strategies of water reduction consumption		
percentages of daily water reuse		
total equivalent inhabitants	1.680	
grey water produced (l/inhab.eq)	64	
total litres	107.520	
total cleaned water	75.264	100,00%
wc flushing (l/inhab.eq)	16	
total litres	26.880	35,71%
irrigation reuse	48.384	64,29%

Table 4. Water from showers, washbasin and washmachine

Business Impacts

This industrialized and modular system can be used not only in roofs, but also in gardens or other parks. Due to its dimensions optimization, the economic and environmental costs associated to the use of materials are considerably diminished. Also, the industrialization provides important benefits in relation with construction and deconstruction periods. Respect to the economic costs, it has been estimated that a system in a single house with 5 equivalent inhabitants is around 1.200 euros/inhabitant, including installations and construction. But also, the use in a centralized district context diminishes the price per inhabitant, around a 40% less.

The phytodepuration system in roof will be built and monitored in a single house for 5 inhabitants in the city of Tembleque, Toledo (Spain).

Conclusions

After the analysis of each studied hypothesis, there can be concluded the following estimations:

WATER FROM SHOWERS AND WASHBASINS

Hypothesis A_ Only the phytodepuration system

_the grey water produced is not enough to reuse the 100% in flushing toilets

_the system is saving 25% respect to the actual water consumption

Hypothesis B_Use of the phytodepuration system with the replace of existing toilets for others of low consume

_the strategy is saving 34% respect to the actual water consumption

_the combined strategy is saving 27% respect to replace only the toilets, without phytodepuration system.

Hypothesis C_Use of the phytodepuration system, including global water reduction consumption strategies

_the strategy is saving 45% respecto to the actual water consumption

_the combined strategy is saving 32% respect to apply only global water reduction consumption strategies

WATER FROM SHOWERS, WASHBASINS AND WASHMACHINE

Hypothesis A_ Only the phytodepuration system

_ the strategy is saving 39% respect to the actual water consumption

Hypothesis B_Use of the phytodepuration system with the replace of existing toilets for others of low consume

_the strategy is saving 43% respect to the actual water consumption

_the combined strategy is saving 48% respect to replace only the toilets, without phytodepuration system.

Hypothesis C_Use of the phytodepuration system, including global water reduction consumption strategies

_the strategy is saving 59% respect to the actual water consumption

_the combined strategy is saving 67% respect to replace only the toilets, without phytodepuration system.

Also, the industrialized system provides an important surface reduction, compared with the traditional Macrophytes in flotation filters. Due to the optimization of channels dimensions, the required surface is diminished in four and a half times less.

Macrophytes in flotation filters (FMF)	
total equivalent inhabitants	1.680
m2/equivalent inhabitant[1]	5
total surface need	8.400 m2

[1]J. Fernández, Filtros de macrofitas en flotación. Ed. Ayuntamiento de Murcia, 2005.

Grey water circulation optimized		
Total volume to depure	156,2	m3
Industrialized tanks high	0,5	m
total daily surface need	312,5	m2/día
Evaporation losses	30	%
Phytodepuration period	7	día
total surface need	1.531,2	m2
total surface, included, transitivity areas	1.840	m2

Table 5. Difference between traditional phytodepuration systems and the proposed system

The conversion of traditional flat roofs into grey water phytodepuration systems, supposes important benefits associated to the urban water management. This system allows the reduction of potable water consumption, in uses that does not require it; meanwhile it diminishes the volume circulated to urban wastewater treatment stations, in more than 50%.

Key Lessons Learned:

- It is necessary to rethink the traditional use of grey water systems.
- The large flat roof surfaces existing in Spain, supposes an important opportunity to design new green phytodepuration systems, which optimizes urban space.
- The industrialized phytodepuration system allows the reduction of potable water consume in more than a 50%, in comparison with the current systems.

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