Water self-sufficiency with separate treatment of household rainwater and greywater

Joaquim Lloveras, Elisa García, Anna García, María Planas, Ariadna Rodríguez

Dpt. of Engineering Projects, Eng. School of Barcelona, Tech. University of Catalonia (UPC)
+34 934016642. E-mail: j.lloveras@upc.edu

ABSTRACT
This paper is based on an academic work conducted by a group of students of the Engineering Project course within the Chemical Engineering Degree at the Engineering School of Barcelona. The objective of the exercise was to design a rainwater harvesting and greywater recycling system for a detached house and calculate the number of people that could be self-sufficient. Local rainfall, roof area for collecting rainwater and daily water consumption per inhabitant were considered. The effective amount of rainwater and purified greywater was also obtained.
In this design, the rainwater is filtered, stored and preserved in a tank, and disinfected with UV light. A small quantity can be made drinkable. The greywater is filtered, treated in a biological reactor, flocculated, sedimented and finally disinfected with UV light.

Keywords: Rainwater, greywater, depuration, drinkable, self-sufficiency

1. Introduction

All water molecules on the earth must have been boosted by the Sun in the water cycle several times. Water is essential for life. Moreover, it is a great solvent. This means that water molecules accept a large number of substances. The resulting solutions have numerous properties, but the natural cycle of water returns pure water in the form of rain.

Water in developed countries follows a special cycle. Water collection, treatment and distribution activities are commonly centralized in huge installations; for example, water is stored in dams, transported to treatment plants where it is physically and chemically treated, and distributed to consumers by a network of pipes. Once it has been used, water becomes wastewater. Then, it is channelled to large treatment plants and finally returned to rivers or the sea. Apart from requiring constant maintenance, this process has high energy consumption and a strong environmental impact. Furthermore, it leads to some dependence on the system. This system is mainly of an open cycle.

Household water is used for drinking, cleaning and sanitary purposes. Although household water consumption represents only about 8% of the global water use [1], this figure can be further reduced.
One of the pillars of civilization is life in the cities. The sanitary solution that made it possible is the household water supply. A network of sewer pipes carries the wastewater from homes to a treatment plant. Several products are dissolved in the wastewater, like soap, shampoo, detergents, etc. This combination is known as greywater. On the other hand, wastewater containing faecal matter and urine is called blackwater.
Apart from its solvent properties, water can drag several problematic particles out of the house. For example, human urine is about 95% water, and has only 13.8 g/L of urea and other problematic substances [2]. This means that, for a normal urination of one third of a litre, only 4.6 g is waste to be eliminated, for which an efficient toilet uses 3 litres of clean water. Perhaps in the future new solutions will emerge to the problem of removing human urine and faecal matter from houses by safe systems with very low or no water consumption which will ideally return these residues to the natural cycle.
Other examples could be found in houses, which show that a great quantity of water is generally needed compared to the effective quantity of contaminant substances to be removed.
One possible solution could involve the mimicking of the natural water cycle by the new recycling water technology. To this end, alternatives could be found for the currently centralized system, e.g. small-scale systems that provide economical and environmentally-friendly treatment and distribution of reusable

water. A paradigmatic example is the International Space Station (ISS) [3], where used water is recycled in perfect sanitary conditions over and over again for new uses in the spacecraft. The water system is a small-scale closed cycle, very different from the current open cycle in most households.

Current wastewater technology allows partial regeneration at a reasonable cost and with equipment of small size for household use. With this in mind, a group of students [4] chose a household greywater recycling and rainwater harvesting system as a work topic. The objective was to approach the use a semi-closed water recycling system and rainwater, which results less water consumption and calculate the number of household members who could be self-sufficient.
This paper presents a decentralized water system with separate rainwater and greywater treatment for a detached house. The design project was conducted by a group of students of an Engineering Project course [5] within the Chemical Engineering degree [6] of the Technical University of Catalonia (UPC).

2. Case study

In order to make the necessary calculations, some data about the selected house were collected. The house is located in central Catalonia in an area with L = 690 l/m^2 rainfall per year [7] and has a 150 m^2 roof provided with a rainwater collection system.

The efficient daily water consumption per person in a house with 4 inhabitants was considered to be C= 99 l/person/day, distributed according to figure 1.

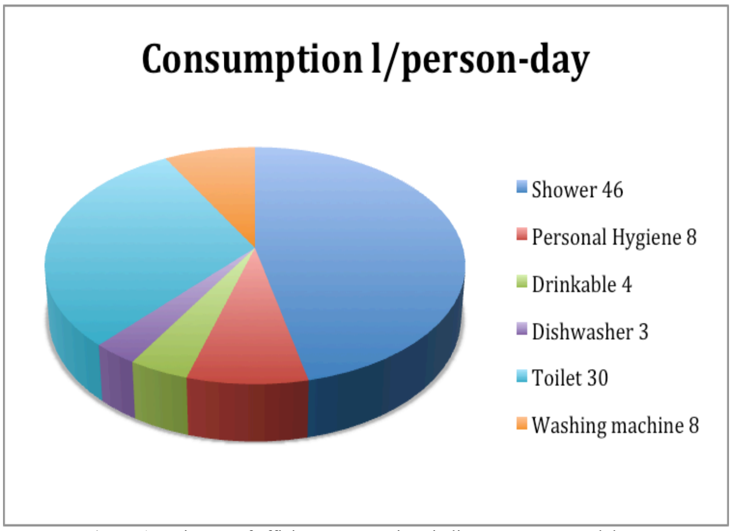

Figure 1. Estimates of efficient consumptions in litres per person and day

As can be seen, the greywater, i.e. wastewater from the laundry, bathroom (excluding toilet waste) and dishwater, accounts for 69 l whereas the blackwater, i.e. wastewater from the toilet, represents 30 l. The latter is disposed of through a sewer system and requires a more complicated treatment process. With these data, the aim was to work out how many household members could be self-sufficient in water, that is, did not need water from the main supply network [8].

2.1 General approach of the project

The total amount of rainfall collected is 690 l/m^2 year x 150 m^2 = 103500 l/year (average = 284 l/day). But is considered a factor for effective use of rainwater fp1 = 0.85, i.e. an approximate volume of 240 litres per day is available.

Greywater production is Gr= 62 l/person/day. If a factor of fp2 = 0.9 is estimated for losses in the recycling process, an approximate volume of 56 l/person and day is available for reuse. This means that the difference between individual consumption, C=99 l, and reusable greywater, C-Gr·fp2= 43 l/person/day, is the final consumption of water.

The total amount of available rainwater is 240 litres per day, which must be balanced with the final consumption of N persons, i.e. 43 l/person/day. Therefore, the system here described is theoretically self-sufficient for N= 5.6 persons (5 – 6 persons).

The total water consumption for five members is 99 x 5= 495 l/day, resulting in 62 x 5= 310 l/day of total greywater, that is, 280 l/day of effective recycled greywater.
In this case, the water requirements (495 l/day) are lower than the possibilities of the system, i.e. 280 l/day of recycled greywater plus 240 l/day of rainwater = 520 l/day. That is, the system can save 520 – 495 = 25 l/day in the form of rainwater or greywater. Alternatively, this excess of water can be stored in a tank for other purposes.

2.2 The installation

The classical type of household water system installation is an open cycle with a two-pipe system: one for incoming water and one for outgoing wastewater. However, the new water recycling techniques for a semi-closed water system like the one here described require several pipes, tanks, filters, pumps, etc. Figure 2 shows a schematic view of the system installation in the selected house including consuming points, rainwater pipes, drinkable water pipes, greywater pipes, purified greywater pipes, tanks, purification system, etc.
The quality of rainwater is usually high. Actually, only some quantity that drags dirt from collection surfaces must be discarded; the rest only requires some filtration and UV light for cleaning and storage purposes. This water is appropriate for showers, the washing machine, or toilet flushing, but with the right treatment it can be made into drinking water.

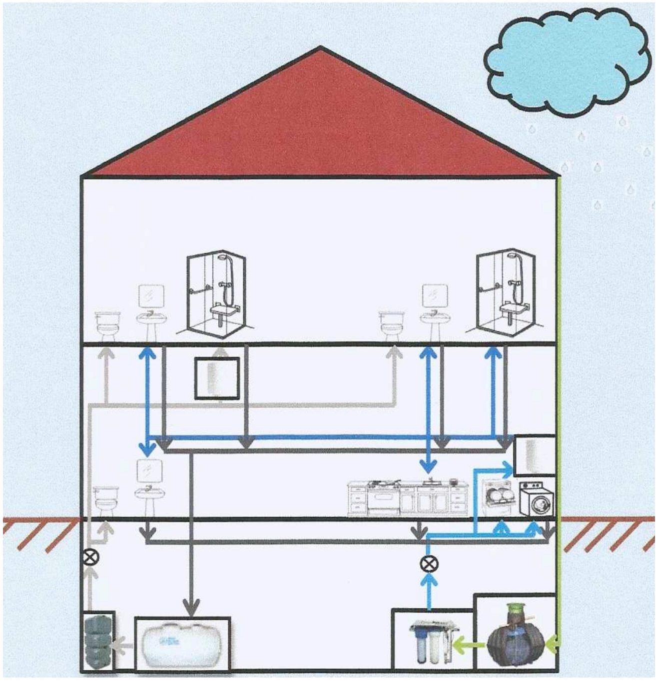

Figure 2. Rainwater and greywater system

The process of recycling greywater is divided into several different stages according to use. The first stage involves low purification of water for reuse in toilets. In the second stage, the degree of purification is increased for use in showers or for the washing machine. Finally, complete purification of water for drinking, cooking and dishwashing uses is also possible but this practice is not currently allowed. In the presented design, greywater is purified by a biological reactor system, flocculated and sedimented, and finally UV sanitised.

The system needs a properly-sized tank for rainwater storage because of the irregular rainfall in the Mediterranean area. Namely, there are two periods of intense precipitation, i.e. September-October and April-May [9] whereas rainfall decreases significantly the rest of the year. In the study case here presented, a tank with a capacity of 9600 l is necessary to ensure constant rainwater supply.

For the project work, several patents were consulted: Spanish: ES 1050181 U / ES 1060169 U / ES 1063 09 U, ES 1069262 U [10]. International: FR2976819 A1 / WO2011151168 A1 / FR2976936 A1 / EP 2014837 A2 / EP 2223898 A1 / US 0199220 A1 / WO 056935 A1 / US 0200484 A1 / GB 2449534 A / US 6905607 B2 [11].

Several national and international guidelines on water qualities were also applied. Also, commercial catalogues were used for designing the parts of the system.

3. Discussion and Conclusions

The average annual rainfall in Catalonia ranges between 350-400 and 1200 l/m^2 [7]. In the above case, this would imply water self-sufficiency for 3 to 12 people, respectively.

The decentralization of small-scale water collection and processing could be more sustainable than the current large-scale production paradigm because rainwater and recycled water are used in the same place, eliminating the need for transport, except for sewer water. The system is comprised by hydraulic circuits for rainwater, filtered rainwater, hot filtered rainwater for showers, drinkable water, greywater, treated greywater and sewer water. An extra advantage is that there is flexibility to use rainwater or recycled greywater according to use.

In order to increase savings, the inhabitants must be aware of their water consumption, use water wisely and invest in efficient appliances. The system, however, consumes energy, requires maintenance by end users and takes up space. Moreover, for optimal operation, the system parameters need adjustment according to incoming rain and consumption figures.

The availability of rainwater is logically of the utmost importance. Thus, periods of drought can be particularly negative. In order to solve this problem, this decentralized system could rely on neighbouring support micro-networks or small-shared rainwater tanks. Alternatively, water could be purchased when necessary.

The project work was completed with the calculation of costs. It is true that a long payback period was estimated. However, semi closing the cycle of household water is a step forward towards closing the technological and biological cycle [12], which would contribute to global sustainability.

4. References

[1] Water resources http://en.wikipedia.org/wiki/Water_resources (Accessed 01/14/2014).
[2] Urine composition http://en.wikipedia.org/wiki/Urine (Accessed 01/14/2014).
[3] International Space Station (ISS) http://en.wikipedia.org/wiki/International_Space_Station (Accessed 05/16/2014).
[4] G2: Elisa García Blanch, Anna García Gispert, María Planas Gisbert, Ariadna Rodríguez Farré (2013). "Estalvi d'aigua mitjançant tractament d'aigües pluvials i grises" (Water saving by rainwater and greywater treatment). Final project of Engineering Project course. 2nd semester of 2012-13. Degree in Chemical Engineering. Eng. School of Barcelona (ETSEIB). Technical University of Catalonia (UPC).
[5] Engineering Project course: http://guiadocent.etseib.upc.edu/guiadocent/fitxes/EQ/ESP/25763_ESP.html (Accessed 05/10/2014).
[6] Chemical Engineering degree. http://www.etseib.upc.edu/en/course-online-catalogue > First and Second Level > Degree in Chemical Engineering. (Accessed 05/10/2014).
[7] Clima de Catalunya, http://es.wikipedia.org/wiki/Clima_de_Cataluña http://ca.wikipedia.org/wiki/Clima_de_Catalunya (Accessed 01/13/2014).
[8] Lloveras, J. (2008), "Consideracions sobre l'enginyeria per a l'estalvi d'aigua al sector domèstic a Catalunya" (Engineering considerations for saving water in the domestic sector in Catalonia). *Programa III Congrés d'Enginyeria i Cultura Catalana.* Tecnologia Territori i Societat. Associació Enginyeria i Cultura Catalana. Palma de Mallorca, (Illes Balears), 4, 5 i 6 de desembre de 2008. Resum Ponència DV3.17, p. 61.
[9] Average rainfall in Barcelona http://www.fabra.cat/meteo/dades/dades.html (Accessed 01/13/2014).
[10] Oficina Española de Patentes y Marcas, http://www.oepm.es/es/index.html (Accessed 05/16/2014).
[11] European Patent Office. Espacenet. http://www.epo.org/searching/free/espacenet.html (Accessed 05/16/2014).
[12] McDonouugh, Braungart, M. (2002). Cradle to Cradle: Remaking the Way We Make Things. Ed. North Point Press (Farrar, Strauss), p. 193.