Evaluation of water saving by the use of rain water for toilet flushing

Analyse de l'économie d'eau générée par l'utilisation d'eau de pluie pour les chasses d'eau

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RÉSUMÉ

Cette communication présente et explique les premiers résultats d'une recherche sur l'estimation des économies d'eau réalisables par la récupération des eaux de pluie de toitures et leur utilisation à des fins sanitaires (WC). L'estimation des économies d'eau a été réalisée par simulation de bilans hydriques quotidiens sur une période annuelle, semestrielle (hiver et été) et mensuelle (Juillet) en utilisant les données de précipitations d'une station pluviométrique de la Sicile. Les résultats, présentés avec des graphiques adimensionnels, permettent d'estimer les économies d'eau réalisables en fonction de la superficie de couverture des bâtiments, de la demande hydrique quotidienne pour les chasses de toilettes et du volume du réservoir de stockage. Les résultats montrent la possibilité de parvenir à des économies d'eau appréciables même avec des réservoirs de dimensions modestes.

MOTS CLÉS

Economie d'eau, eau de pluie, chasses d'eau

ABSTRACT

In this paper the first results of an investigation on the evaluation of the potential water saving which can be obtained by using rain waters from roofs for the purpose of toilet flushing in domestic bathrooms, are presented. The evaluation of benefits in terms of water saving was carried out by performing water balance simulations at a daily scale for every year, separately for the winter and summer semesters, and for the month of July. For the application of water balances, the data of a Sicilian rain gauge station were used. Results are presented by means of dimensionless graphs and allow to evaluate the obtainable water saving according to the roof area, the toilet flushing daily water demand and the storage tank volume. Results show the potential for significant water saving values also in the case of tanks characterised by a limited size.

KEYWORDS

Water saving, rain water, toilet flushing

1 INTRODUCTION

In the last decades water saving practices in households have awakened increasing attention due to growing water demands in urban areas. Essentially, these practices have concerned with the adoption of basic devices to reduce the consumption of water in houses (i.e dual flush toilet systems, aerator devices to reduce tap flow, etc.) and with the set up of educational programmes aiming at diffusing water sustainability concepts within the population. Especially in areas affected by limited availability of water resources, in addition to previous practices, the choice to recur to rain waters for their specific use within houses can be considered. It is widely recognised that waters with less valuable quality characteristics, such as rain and grey waters, should be taken into account for civil uses except for drinking and sanitary purposes (Vickers, 2001; USEPA, 2004).

Accordingly, several schemes and systems for the domestic recycle of rain and grey water have been proposed by many researchers (Aylward et al., 2006; Ghisi et al., 2007; Rahman et al., 2007). However, very often, these systems have not found large diffusion, due to the high costs of construction and to the complex installation. In fact, the major part of these systems is based on the combined use of rain waters (usually from roofs) and grey waters coming from various sources in the house (i.e. washbasins, showers, sinks, etc.) for multi-purpose use (toilet flushing, washing machines, garden irrigation, etc.); then the operation of these systems requires to arrange specific separate piping networks in the house and high-capacity tanks for storing grey and rain waters with the evident drawbacks due to the high water detention times (Eriksson, 2002).

Results from different investigations concerning the analysis of water uses in urban households for water saving objectives (Butler et al., 1995; Mukhopadhyay et al., 2001; Lazarova et al., 2003) have shown that a significant part (close to 30%) of water in houses is actually used for toilet flushing. This value shows low variability in the examined literature suggesting potentially high water saving benefits deriving from the adoption of reuse systems which would address collected waters specifically to toilet flushing use in domestic bathrooms.

In this connection, simple "one source – one use" reuse schemes have been recently proposed in literature (Donati, 1995), focussing on grey water coming from just one source in the house and their prompt use for the flush of toilets. Experimental results and elaborations (Campisano et al., 2008) have shown that these systems can provide high water savings by adopting relatively small storage tanks, with the additional advantage of more easy and cheap installation and of improved system operation and maintenance.

Following previous considerations, also collected rain waters from house roofs could be primarily addressed to the flush of toilets (Glist, 2005; Jones and Hunt, 2008; Jones et al., 2009). Also in this case, in fact, only basic water treatment (i.e. filtration and chlorination) should be accomplished, being rain water quality typically compatible for this specific use. In addition, storage tanks with limited size would be required, being the daily water demand for toilet flushing operation relatively constant during the year. On the opposite, other uses characterised by highly variable water demand during the year (such as for private garden irrigation), would need to store high water volumes to use during dry periods.

According to the previous framework, a specific research programme aimed at investigating the potential water saving that can be obtained by using rain waters collected from the building roof for the flush of domestic toilets, has been recently setup at the University of Catania. In this paper the methodology and first results of the investigation are presented. In particular, the methodology, based on the use of daily rain data and on the development of long term water balance simulations, is here tested on the data recorded at one Sicilian rain gauge station. Results of water balance simulations referred to the entire year were compared with those concerning summer (april-september) and winter (october-march) semesters, and with those of July, typically the most dry month in south Italy.

2 METHODOLOGY

The adopted hydraulic scheme is based on the collection of rain waters coming from the building roof and to their storage within a rain water tank; stored rain water is then immediately conveyed to the toilet, as the toilet cistern has been emptied. According to this scheme, rain water is firstly used for flushing operations, with the recourse to potable water (from the aqueduct) just in the case that the rain water tank results empty. Rain water from the roof resulting in excess (with respect to the

maximum tank capacity) could be discharged as overflows to the sewer system. Adequate chlorination in the tank is to be considered in order to avoid problems of water quality decay, especially due to organics and particles (Winward et al., 2008).

The evaluation of the potential water saving deriving by the adoption of such a scheme was carried out by means of long term water balance simulations at daily time-scale which seemed to be the most appropriate for the examined investigation. In fact, longer time scale intervals (weekly or monthly) can provide only too rough indications on the obtainable water saving, while shorter time intervals (typically hourly) would require to treat a too large amount of rain data (often difficult to find) and to know also specific information concerning the use of toilets in houses (i.e. hourly distribution of toilet flushing operation during the day). In addition, the hourly time scale seems to be to short when compared with precipitation dry weather periods (weeks or more).

Daily water balances were conducted by referring to the following variables:

V_R (m^3) = volume of rain waters from the roofs,

V_{ST} (m^3) = volume of the storage tank,

D (m^3) = toilet flushing water demand,

V_O (m^3) = water volume discharged as overflow from the storage tank,

V_A (m^3) = water volume supplied by the aqueduct in case of tank empty.

In particular, potential water saving W_S and overflow discharges O_D from the tank were evaluated respectively as (in percent):

$$W_S = \left(1 - \frac{\sum V_A}{\sum D}\right) \cdot 100 \tag{1}$$

$$O_D = \frac{\sum V_O}{\sum V_R} \cdot 100 \tag{2}$$

being sums extended to the considered time length of the water balance simulation.

According to equations 1 and 2, water saving W_S assumes value 0% when only aqueduct water is used for toilet flushing ($V_A = D$) and assumes value 100% when only stored rain water is used for the same purpose ($V_A = 0$). Instead, overflow discharges O_D from the tank are evaluated as percentage of the entire rain water volume collected during the considered period.

Furthermore, to generalise the results of water balance simulations, the dimensionless variable:

$$v = \frac{V_{ST}}{D} \tag{3}$$

representing a measure of the available stored rain water volume with respect to the toilet daily water demand for flushing operations, and the parameter:

$$d = 1000 \cdot \frac{D}{A_{eff}} \quad (mm) \tag{4}$$

representing the toilet daily water demand for unit effective roof area A_{eff} (m^2), were considered.

Results of water balance simulations were statistically elaborated by a frequency analysis. In particular, obtained values of W_S and O_D were manipulated in order to determine values of water saving and overflow discharge characterised by prefixed levels of exceedance frequency.

3   THE CASE STUDY

3.1   Used data

The comprehensive plan of the research provides to evaluate potential water saving deriving by the use of roof rain waters for the domestic toilet flushing, by applying the presented methodology to the data recorded at several rain gauge stations in Italy, characterised by different climates. In this paper, first results of the application of the methodology are presented with reference to the data recorded at the rain station of Bronte (Sicily). Main characteristics of the rain station are summarised in Table 1. The table reports also the value of the average yearly rain height for the considered period of observations (47 years) which could be considered as representative of the average rain height over the entire Sicily island. In addition, distribution of precipitation during the year, is reported in Table 2 in terms of average monthly rain heights. The Table provides average heights of 413.3 mm and of 181.9 mm for the winter and summer semesters respectively.

Rain station	Type of device	Elevation (m a.s.l.)	Year of starting observations	Number of years	Yearly average rain height (mm)
Bronte	Rain gauge	780	1951	47	595.2

Table 1. Main characteristics of the considered rain gauge station.

G	F	M	A	M	J	J	A	S	O	N	D
84.3	55.5	53.3	43.1	29.9	16.9	12.1	34.7	45.2	73.3	65.0	81.9

Table 2. Average monthly rain heights (mm) at the gauge station.

Daily water balance simulations were carried out for each year of the series, for the winter and summer semesters separately, and finally also for the month of July. In particular, values of V_{ST}, D and A_{eff} within the usual ranges of practical applications were chosen for the simulations; correspondingly values of v e d in the respective ranges 0-10 and 0.5 mm-10 mm were considered.

In order to characterise the obtained results, exceedance frequency values equal to 25%, 50% and 75% were fixed for both W_S and for O_D. Moreover, taking into account that high values of water saving and low values of overflow discharge should be pursued, the two additional frequencies of 90% and of 10% were considered significant for W_S and for O_D respectively.

3.2   Results and discussion

Results of simulations are presented by means of specific dimensionless graphs which allow to evaluate, in correspondence of prefixed exceedance frequencies, water savings W_S and overflow discharges O_D as function of v and d. In particular, in the graphs of Figures 1 and 2, values of W_S and O_D (referred to the entire year) which can be exceeded for defined levels of frequency, are separately reported for 6 different values of the parameter d.

Curves plotted in the 6 graphs of Figure 1 show, as expected, that values of W_S increase as v increases (i.e. as storage tank volume V_{ST} increases and as daily water demand D decreases). Instead, curve derivatives tend to decrease, showing reduced marginal water savings as v increases.

The figure shows also that the values of water saving tend to decrease as d increases (i.e. as the daily water demand D for toilet flushing increases and as the effective area A_{eff} of the roof decreases). For instance, when increasing the value of d from d = 0.5 mm to d =10.0 mm, values of W_S decrease from about 58% to about 16% for 50% of the years in correspondence of v = 5 (tank volume set equal to 5 times the toilet daily water demand).

Finally, the graphs of the figure show that the curves tends to flatten as d increases, pointing out no advantage of adopting high-storage tanks in case of reduced roof areas and of high water demands for toilet flushing.
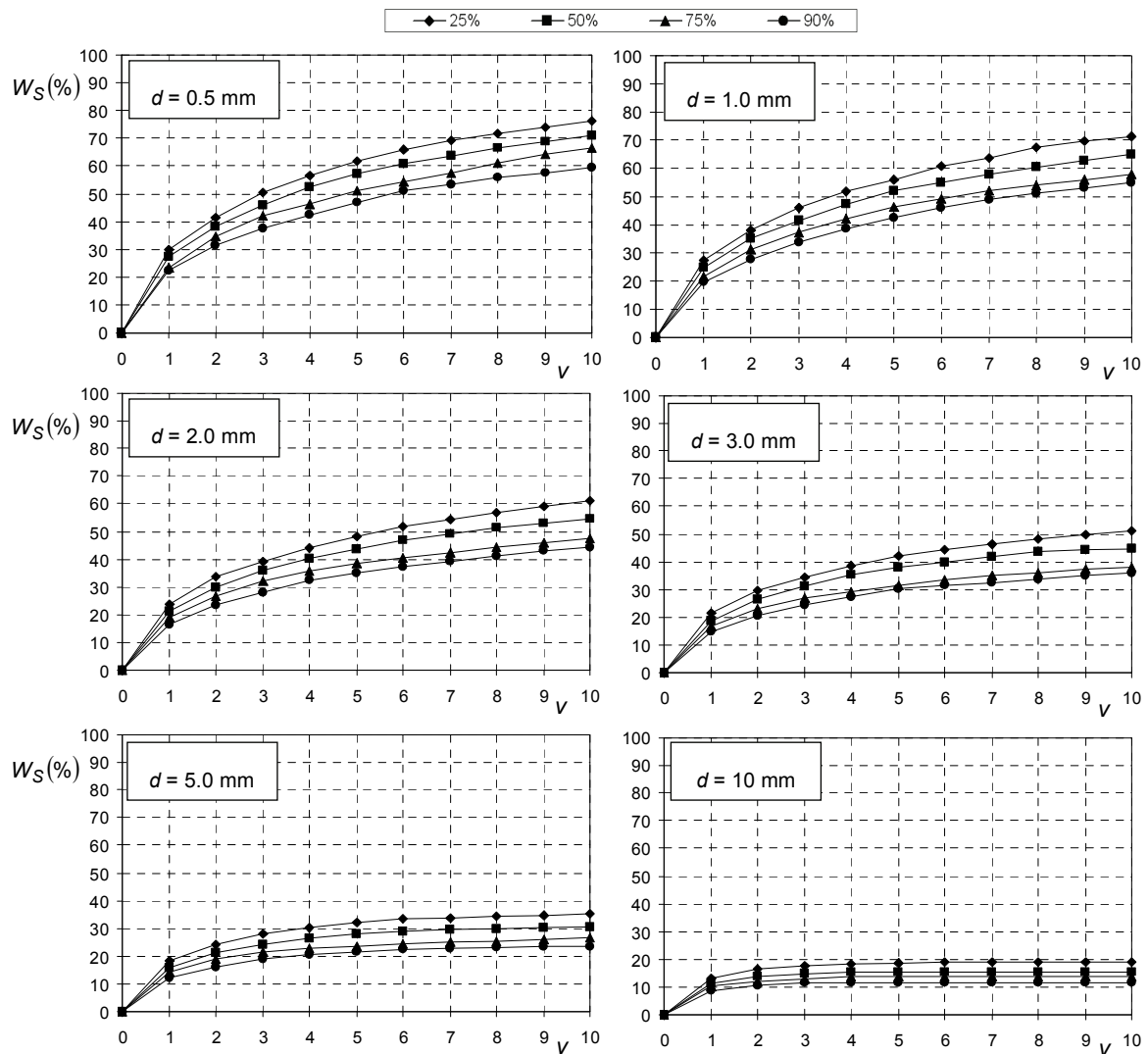
Figure 1. Water saving values as function of v and d obtained by water balances extended to the year.

Similar considerations can be carried out for curves reported in graphs of Figure 2. These graphs show decreasing values of O_D with increasing curve flattening as v increases. The figure shows also that overflow discharge values tend to reduce as d increases, with possible zero values (for $d > 5.0$ mm) for the large size tanks. As an example, values of O_D decrease from about 82% to 0% for 50% of the years in correspondence of a value v equal to 5 when increasing d from 0.5 mm to 10.0 mm.

The comparison between results obtained from water balance simulations extended to the entire year and to shorter time periods is shown (as an example and for the case d =1 mm), in the graphs of Figure 3. In particular, in these graphs, the values of W_S obtained from water balances relative to the entire year, to winter and summer semesters and to the month of July are reported, respectively.

The figure points out the significantly reduced water saving in summer semester with respect to winter semester. However, notwithstanding the long dry summer period which characterises the examined rain data series (and more in general the Sicilian rain series), the results show appreciable water saving potential also in the summer period.

Lowest values of water saving are obtained with reference to the month of July. For this case increased distance among the plotted curves can also be observed, due to the higher variability of observed rains during this month.
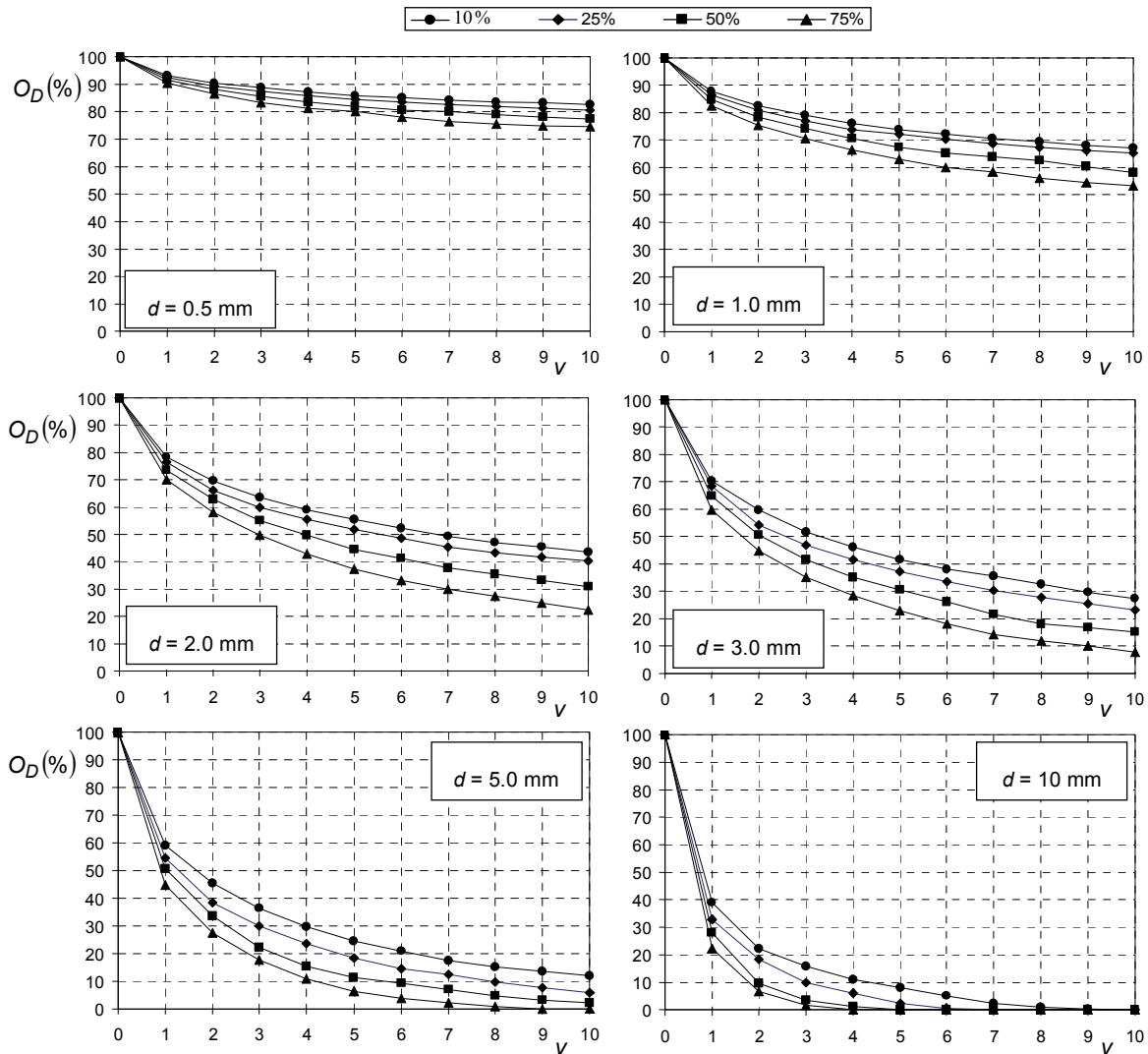
Figure 2. Overflow discharges as function of v and d obtained by water balances extended to the year.

Globally, an overview of obtained simulation results for different values of *d* have shown that, with a tank characterised by *v* = 5, water saving values in the range 22% - 72% for the winter semester and in the range 9% - 40% for the summer semester, can be achieved in at least 50% of the years. Minor values in the range 1% - 16% can be obtained for the month of July.

3.3   Example of application

A house with 4 people and roof effective area A_{eff} = 112 m^2 is considered as an example. Considering 8 daily (per capita) toilet flushes (7 litres per each one), a toilet daily water demand *D* equal to 0.224 m^3 corresponding to the value *d* = 2.0 mm is obtained. If a storage tank for rain water with volume V_{ST} equal to 0.5 m^3 is considered, a value *v* of about 2.2 is derived. From the graphs of Figure 1 a potential water saving at least of about 24% in 90% of the years is obtained for the considered case. Assuming a tank with V_{ST} = 1.0 m^3, would increase potential water saving to about 34%. Then, for the two cases, about a quarter or a third of the water needed for toilet flushing could be recycled by collected rain waters. For the examined situations, significantly high values of the overflow discharge would be obtained. In fact, from the graph of Figure 2, one would derive overflow discharges higher than about 67% and 58% in 10% of the years for the two considered storage tanks, respectively.
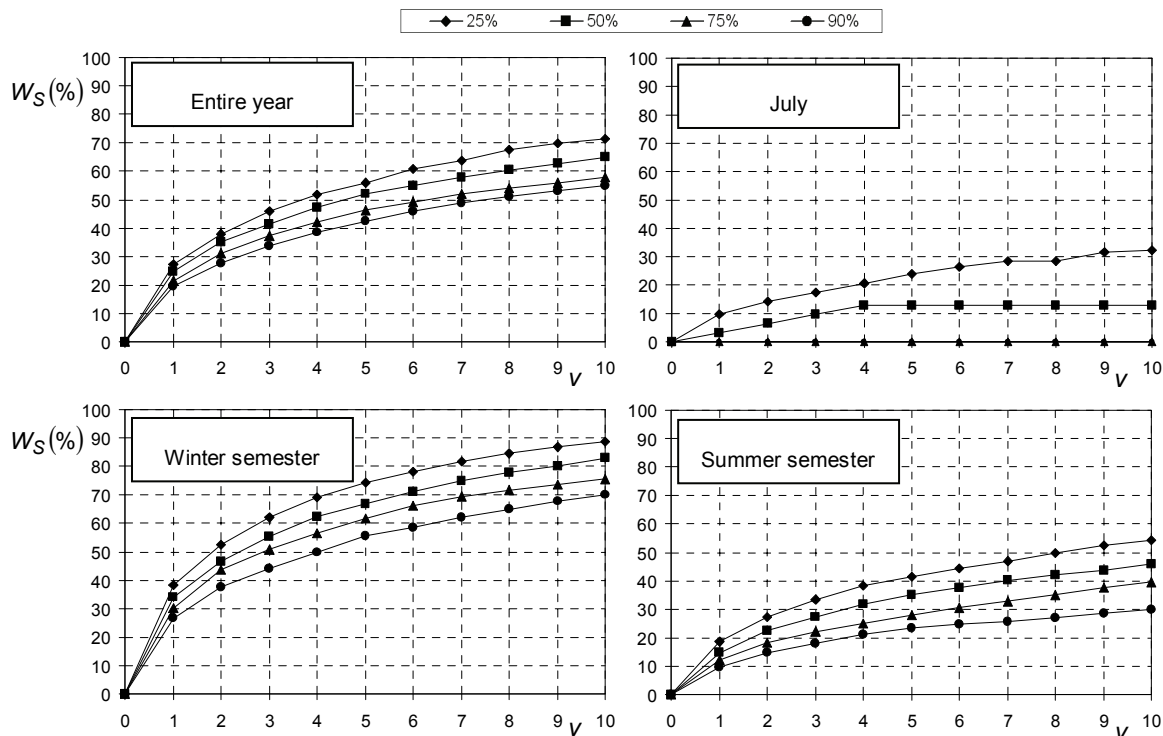
Figure 3. Water saving values as function of v obtained by water balance simulations extended to different time periods (d =1.0 mm)

4   CONCLUSIONS

In this paper the first results of an investigation on the evaluation of the potential water saving which can be obtained by using rain waters for toilet flushing in domestic bathrooms, is presented. The hydraulic scheme is based on the collection of rain waters from the building roof, on their accumulation within a storage tank and on their immediate conveying toward the toilet, as the toilet cistern has been emptied.

The evaluation of benefits in terms of water saving was carried out by performing water balance simulations at daily scale for every year, separately for the winter and summer semesters, and finally for the month of July. For the application of water balances, the data of the rain gauge station of Bronte (Sicily) were used.

The results of simulations are presented by means of dimensionless graphs which allow to evaluate water savings and overflow discharges from the storage tank in correspondence of prefixed exceedance frequency values. In particular, concerning water saving, graphs show that, in the major part of conditions, high values of water saving can be obtained with tanks characterised by volumes in the range 3-10 times the toilet daily water demand.

The comparison between the results concerning winter and summer semesters points out that, notwithstanding the long dry periods characterising the chosen rain series, significant water saving values are also potentially obtainable in summer semesters.

Concerning the economic feasibility of such a scheme of rain water use, specific local conditions (local costs of harvesting, water availability, population habits, financial incentives, etc.) should be taken into account for the evaluation of the correct size of the tank, considering also environmental and social benefits due to the saving of high-quality water.

The comprehensive plan of the research provides to derive more general indications on the potential water saving deriving by the use of rain waters in domestic toilets. For this purpose, for the next research step, the methodology will be applied to the data recorded at other rain gauge stations in Italy, characterised by different climate.

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