Towards a behaviour model for the evaluation and optimization of water consumptions in primary schools

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Introduction

Water conservation has become global issue and its importance to society in recent years has grown more and more. This challenge has to be played not only in the industrial sector but also in civil buildings. In fact, the public water supply represents 21% of the total water use in Europe. Furthermore, buildings account for the major use of potable water which, once used, has to be treated due to its high level of pollution (European Commission, 2012).

Actually, data related to water consumption of public non-residential buildings (i.e., schools) are inadequate and generally outdate. An example is represented by primary schools where the few available data of water consumptions are also characterised by great discrepancies (Farina *et al.*, 2013). In addition, these data refer to countries different from European ones as reported in Cheng and Hong (2004). The consumptions of water in a school are generated by the combination of a huge set of factors: (i) behaviours of the staff and student; (ii) which and how the didactic activity develops; (iii) the services and utilities present in the school (presence of refectory, gardens, swimming pool, etc.) and, finally; (iv) the level of the hydraulic infrastructures both in terms of water saving and presence of harvesting and reuse schemes.

A factor affecting the overall consumptions that is difficult to be defined is the behaviour of the persons present in the building. Cheng and Hong (2004) have tried to overcome this difficulty defining an evaluation model that hypothesizes frequency in the use of WC, frequency and time of flush from taps for body cleaning, specific consumption of water for sweep, garden watering etc. This model, although has shown good results, cannot be directly applied to Italian schools and have to be tuned to our different didactic modality and culture. A more clear and detailed knowledge of the amount and type of water consumption in primary schools is fundamental to give right data useful to implement water saving strategies for both renovation and construction of new schools buildings.

In this context, the aim of this work is to define and to implement a complete monitoring plan for the evaluation of water consumptions in a primary school. Consequently, the definition of a mean behaviour model for students and personnel is carried out and is used as benchmark to define the potential benefit from hypothetic water saving strategies.

Materials and methods

The school and the monitoring system

The school under study is located in Favignana Island (Coordinate 37°55′34″ N 12°19′16″ E) in the Egadi's archipelago (Sicily, Southern Italy) as shown in Figure 1.1.
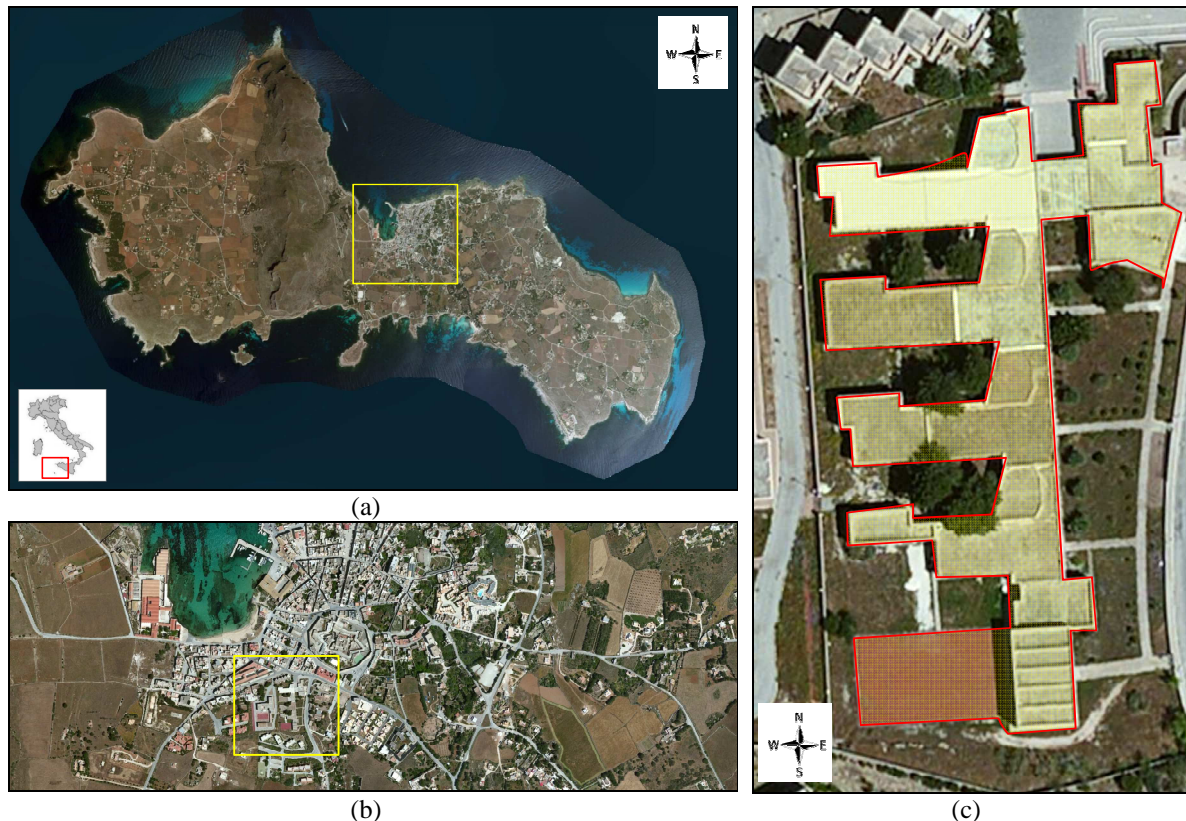
Figure 1.1 The primary school under study: (a) Favignana island in the Egadi's archipelago (Southern Italy); (b) the most popular area of the island (so called "Capoluogo"); (c) plant of the school.

The school is a one floor building roofed with a terrace surrounded with green area cultivated with typical bushes of the zone and some big pine trees. It has an internal surface of 2500 m^2 and is equipped with a gym furnished with external playground covering an area of 790 m^2.

In the school there are 40 male students, 46 female students, 16 teachers and 5 auxiliary personnel units so that the rate student/occupant is 80%. Students are provided with separate bathrooms while teachers and auxiliary personnel have sheared bathrooms. All the bathrooms are equipped with wc provided with single push both for feces and urine flushing (the volume discharged is 7 litres at time) and sinks provided with faucet with maximum flow rate of 12 L/min.

The teaching activity is delivered in five morning hours, five days a week. Gym activities are comprised into the five hours in the morning. Internal building rooms sweep is operated once a week whilst bathrooms are cleaned every day. In the school is not present a refectory and during the monitoring period no irrigation of the green area was operated due to the lack of personnel.

The school was chosen due to its particular water network distribution system. It is constituted by a dual line for both tap water and well water (this one used for flush water, sweep and garden watering) located upon the terrace and completely intercepted.

This characteristic made possible to easily install all the water meters necessary to monitor the consumptions of flush water (this subdivided into staff and female and male students) as well as water for personal cleaning, building sweep and water for garden watering. All the meters were equipped with sensors set on one litre impulse signal and connected to a data logging system. The data were acquired for one year in order to evaluate fluctuation between every month.

Figure 1.2 shows the hydraulic scheme as well as the water meters installed.
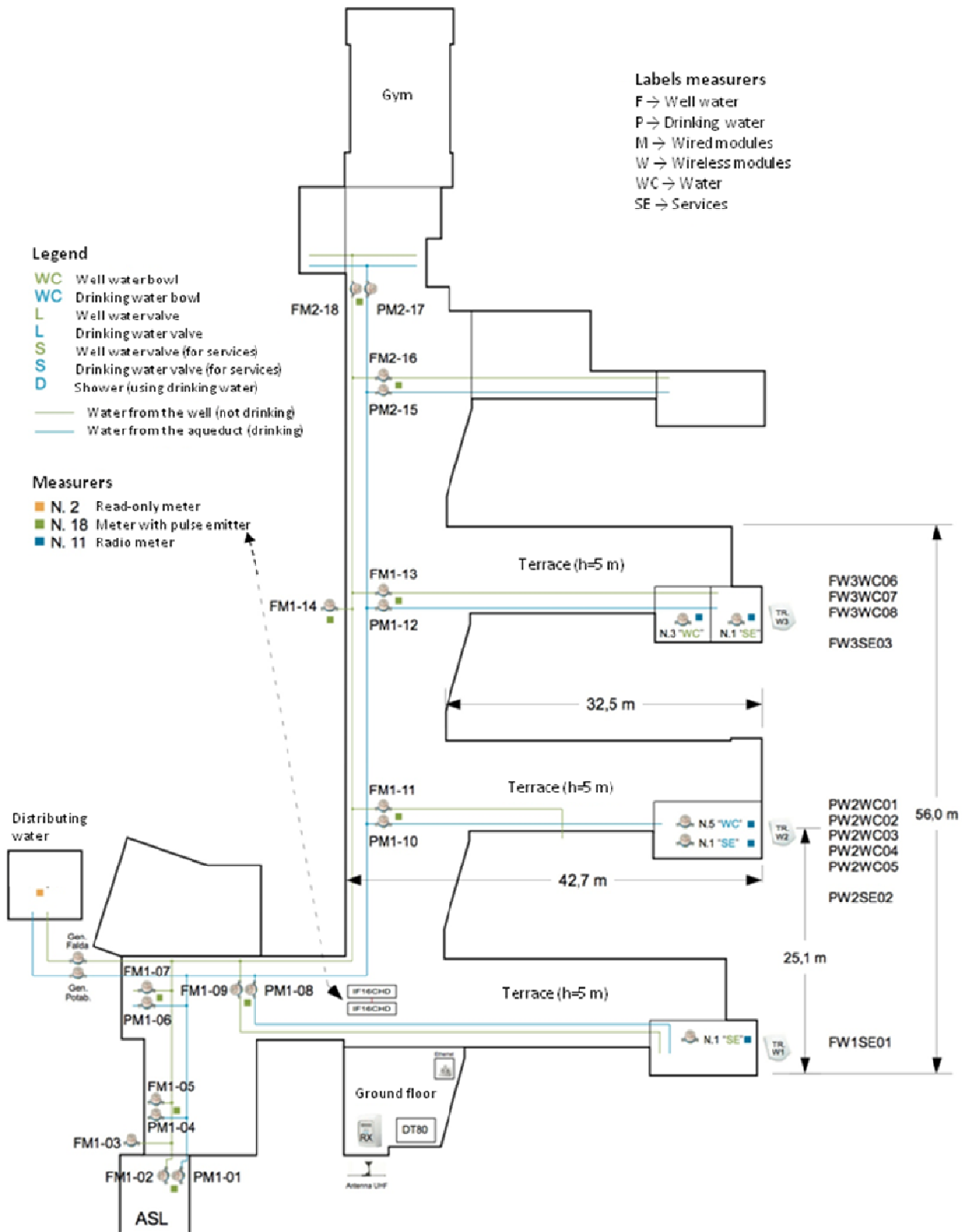
Figure 1.2 Hydraulic scheme of the school under study

Framework of the proposed methodology

In this section, the framework of our methodology is described. In particular, it is possible to distinguish two main steps: (i) the determination of the behaviour model; (ii) definition and assessment of the potentially suitable water saving strategies.

With reference to the first step, the determination of the different daily flushing frequency was obtained directly by dividing the total amount of water used for that purpose for the flushing volume discharged per time (in this case this volume is equal to 7 litres). The monitoring system, due to the presence of traditional full flush toilets, does not allow distinguishing the different use of the toilet for both urine and faeces.

According to the model proposed by Cheng and Hong (2004), the following frequencies were used in order to further distinguish the frequencies of daily flushing respect to urinal and faeces: 2.8 and 0.5 time/day for flushing of urinal and faeces respectively in case of both male and female student and 4 and 0.2 time/day for flushing of urinal and faeces in case of staff.

The frequency of the cleaning water usage was calculated by dividing the quantity of water used for the mean water volume used for that purpose, this last hypothesized at 2 litres per time by supposing a mean usage of 10 seconds with tap fully open (12 L/s).

With reference to the second step, the behaviour parameters were used as base for the analysis of different strategies for water saving. Six different approaches based on different type and combination of technologies involving rising level of modification into the existing infrastructure were analysed. (See Table 1.1).

The performance of the hydraulic devices adopted for the calculations were chosen according to the standards given by the EU for awarding the EU Ecolabel to flushing toilet and urinal equipment (European Commission, 2012).

In particular for toilet equipment a volume of 6 and 3 litres/time were adopted for full flush and half flush respectively while 1 litres/time was adopted for flushing urinal equipment. For the taps with aerator a flow rate of 6 litres/min was adopted in case where the maximum performance was required.

The concept adopted in strategies based on grey water recycle and the rain water harvesting is the re use of the water for toilet flushing.

Table 1.1 Performances of hydraulic devices adopted for the different strategies: dual flushing toilet (DF), tap aerator (TA), urinal (UR), grey water recycle (GW) and rain water harvesting (RW)

Parameter	Unit	Hydraulic device[a]						
		A	B	C	D	E	F	G
Feces flush	L/time	7	6	6	6	6	6	6
Urine flush	L/time	7	3	3	3	3	3	3
Urine flush with urinals	L/time	-	-	-	1	-	1	1
Tap max flow rate	L/min	12	12	6	6	8	7	6

[a]: A = actual configuration; B = dual flushing toilet (DF); C = DF + tap aerator (TA); D = DF + TA + urinal (UR); E = DF + TA + grey water recycle (GW); F = DF + TA + UR + GW; G = DF + TA + rainwater harvesting (RW).

Results and discussion

The first phase of data acquisition, thanks to high sensitivity of the meters adopted, allowed the detection of some leakage from WC. These were able to generate more than 80% of total school consumption.

The capability to detect and discriminate leakages from real consumptions has been fundamental for a correct definition of the behaviour model as it is not easily possible to validate and to correct results with the comparison of other similar schools.

Once this trouble was solved the monitoring allowed acquiring all the provided data. The trend of water demand for both potable and not potable water is stable during the months in which the lessons are present. During the summer months all the activities are stopped so that also the water demand drops to zero.

The results regarding the mean water demand in the school obtained in this study are the following: 19.35 Litre/day$_l$/persons, 24.08 Litre/day$_l$/student, 11.13 Litre/day$_{365}$/persons and 13.85 Litre/day$_{365}$/student, where the first two data refer to mean consumptions effectively observed during lesson days whilst the second two indicate the mean consumptions on yearly base.

This data are lower but comparable with the average water consumption reported in the work of Farina *et. al.* (2013). In this work 16.4 Litre/day$_{365}$/occupant and 18.0 Litre/day$_{365}$/student are reported as total mean consumption for elementary schools in Bologna Municipality.

The lower consumption in this case studied can be due to the total absence of extra activities like laundries and kitchens and due to the suspended irrigation of the green areas. The water in the school is used as shown in Figure 1.3. The toilet flushing, even if is the primary entry, is quite similar to the amount of water used for personal cleaning while the buildings cleaning is responsible only for the 3% of the total consumption.

Further results from the monitoring system are reported in Table 1.2 which reports the behaviour parameters obtained.
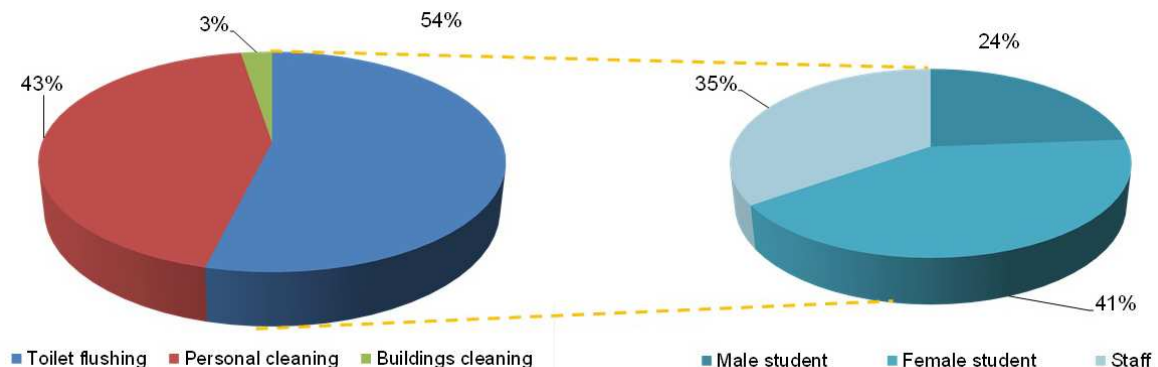

Figure 1.3 Water utilisation in the school

Table 1.2 Water demand and behaviour model as daily frequency utilization

Type of person	Type of water	Behavioural parameters		
		Frequency [time/day$_l$/person]	Demand [litre/day$_l$/person]	Distribution [%]
Male student	Flush water	0.94	6.59	24%
Female student		1.43	9.99	41%
Staff		2.63	18.38	35%
Average value		1.48	**10.36**	-
Average value	Cleaning water	4.19	**8.38**	-
	Building sweeping	-	0.02[a]	-

[a]: value in litre/day$_l$/m^2

WC usage data shows how the staff, due to a longer presence at school, has a higher frequency respect to the students. Female and male student have shown a quite different behaviour so that, despite they are present with similar number, the female are responsible for almost double of the consumption (see Figure 1.3 and Table 1.2).

One further considerable result is the comparable quantity of water used for both cleaning and flushing purposes equal to 8.38 and 10.36 (litre/day$_l$/person) respectively. This suggests good opportunity for the implementation of gray water reuse schemes.

The water consumption for the internal building rooms sweep appears very low. This result is connected to a very high surface of the building relate to the number of occupant, (equal to 23 m^2/occupant), in fact some rooms are not used or have a very low frequency use so that also their sweep is reduced.

The behaviour parameters obtained have been used to evaluate potential water saving strategies. The simple reduction of the maximum faucet flow rate (through the insertion of aerator device) in combination with the installation of dual flushing toilet can generate 50% water saving while, on the contrary, the addition of urinals generates only 3% more savings.

This result derives from the high quantity of water used for toilet flushing in the school and suggest how simple adjustment of the hydraulic device performance (Strategy C: TA + DF) could generate a big water save.
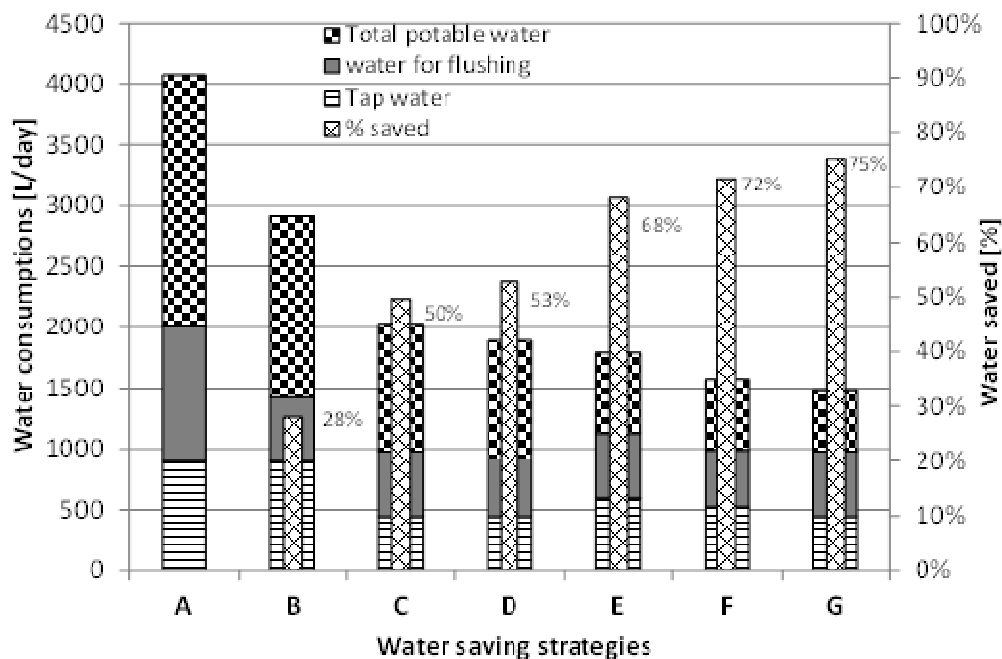

Figure 1.4 Water consumptions improvement for different strategies (A = actual configuration; B = dual flushing toilet (DF); C = DF + tap aerator (TA); D = DF + TA + urinal (UR); E = DF + TA + grey water recycle (GW); F = DF + TA + UR + GW; G = DF + TA + rainwater harvesting (RW)).

The introduction of grey water reuse could be a viable solution in terms of quantity of water saved but some aspects have to be considered.

In this case, in fact, maximum taps performance improvement can lead to have not enough water to recycle for flushing so that with strategies based on DF+TA+GW (Strategy E) or DF+TA+UR+GW (Strategy F) the tap aerators have to be chosen in order to match the flushing water quantity with the grey water produced (in this case a maximum

flow rate of 8 and 7 L/min have to be set for DF+TA+GW (Strategy E) and DF+TA+UR+GW (Strategy F) respectively, see Table 1.1).

Moreover, the grey water treatment could not be implemented as centralised system but as individual one into each bathroom due to the layout of the school. The maximum water saving can be obtained with rain water harvesting combined with the improvement of the hydraulic device performance (Strategy G: DF+TA+RW). This strategy lead to 75% water saving.

The implementation of this strategy needs to be carefully evaluated because of the great number of variables to be evaluated such:

- Effective type and time distribution of the consumptions;
- Characteristics of the building (e.g. ratio between catchment surfaces and amount of consumptions, layout of the school);
- Climate of the area, type and availability of land for the installation of the technological devices.

Conclusion

The monitoring system allowed quantifying how much water and how the water is consumed into an elementary school during a year. The school, in this case study, have shown a level of consumption comparable with other schools in Italy.

Following, the mains results are identified:

- A behaviour model for students and staff has been propose;
- The behaviour model can be used as tool for the identification of good strategies for saving water. In this case study a great benefit could derive from easy modification of the infrastructural level of hydraulic devices i.e. installation of dual flushing toilet and introduction of tap aerator;
- The implementation of strategies for water saving like grey water or rainwater harvesting in elementary schools can lead to very high level of water saved but their implementation must be carefully evaluated on a case-by-case;
- Finally, the behaviour model could be further validated with data of water consumptions from other schools and used as tool to verify the success of awareness campaigns among the students.

Acknowledgments

Nomenclature

DF	Dual flushing toilet
GW	Grey water recycle
Litre/day$_{365}$/person	Litre per person per days of the year
Litre/day$_{365}$/student	Litre per student per days of the year
Litre/dayl/person	Litre per person per days of lessons
Litre/dayl/student	Litre per student per days of lessons
RW	Rain water harvesting
TA	Tap aerator
UR	Urinal

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