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ORIGINAL ARTICLE

Assessment of water consumptions in small mediterranean islands' primary schools by means of a long-term online monitoring

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Abstract A key challenge of our society is improving schools through the sustainable use of resources especially in countries at risk of desertification. The estimation of water consumption is the starting point for the correct dimensioning of water recovery systems. To date, unlike the energy sector, there is a lack of scientific information regarding water consumption in school buildings. Available data refer roughly to indirect estimates by means of utility bills and therefore no information on the role of water leakage in the internal network of the school is provided. In this context, the aim of the work was to define and implement an on-line monitoring system for the assessment of water consumptions in a small Mediterranean island primary school to achieve the following subgoals: (1) definition of water consumption profile considering teaching activities and secretarial work; (2) direct assessment of water consumptions and leakages and, (3) quantification of the behaviour parameters. The installed monitoring system consisted of 33 water metres (3.24 persons per water metre) equipped with sensors set on 1-L impulse signal and connected to a data logging system. Results showed consumptions in the range 13.6–14.2 L/student/day and leakage equal to 54.8 % of the total water consumptions. Considering the behavioural parameters, the consumptions related to toilet flushing, personal, and building cleaning were, respectively, 54, 43 and 3 % of the total water ones. Finally, the obtained results could be used for dimensioning the most suitable water recovery strategies at school level such as grey water or rainwater recovery systems.

Keywords Online monitoring system · Primary school · Sustainable use of resources · User behaviour · Water consumption · Water leakage

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Introduction

The majority of the Mediterranean islands encounter water scarcity challenges due to their small catchment areas as well as the impacts of emerging climate vulnerability and change. Malta and Cyprus have been acknowledged as the water poorest countries in Europe (European Commission 2008, 2012), while a large number of Italian and Greek islands depend on desalination and even on water transfers by tankers (Viola et al. 2014).

Often, water supply companies and Authorities undertake activities to promote efficient use of water. Considering the civil building sector, conservation measures (or water saving measures) generally encourage residents to instal and use high efficiency plumbing fixtures and educate them about water saving habits. Furthermore, interventions aimed at the reuse of water (rainwater and grey water) are strongly recommended and incentivized (Wung et al. 2006). In this regard, the knowledge of water consumptions (per family or per person) is a key issue, useful to planners to build the water reuse systems.

To date, detailed information at the scale of individual building or residential buildings are available. While, at scale of public non-residential buildings (i.e., schools) data 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 (Almeida et al. 2014; Farina et al. 2011, 2013).

Current literature shows that water consumptions in primary school are generated by the combination of the following factors: (1) behaviours of the staff and student; (2) which and how the didactic activity develops; (3) the services and utilities present in the school (refectory, gardens, swimming pool, etc.) and, finally; (4) the level of the hydraulic infrastructures both in terms of water saving and presence of harvesting and reuse schemes (Almeida et al. 2014; Cheng and Hong 2004; Farina et al. 2011, 2013). In addition, water consumptions were estimated indirectly using input data listed in bills.

Consequently, taking into account the activities that take place in a primary school, an accurate assessment of water consumptions has never been carried out. To the best of our knowledge, no information on the role of water leakage is provided.

In this context, we think that 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 school buildings.

Thus, the aim of this work was to define and implement an on-line monitoring system for the assessment of water consumptions in a small Mediterranean island primary school. More specifically, the sub-goals are:

- The definition of the profile of water consumptions during the year considering the teaching activities and secretarial work;
- The “direct” estimation of water consumptions and, consequently, leakages;
- The determination of the behaviour parameters useful for sizing the most suitable water management strategies (i.e., rainwater system, grey water one, etc.).

To the best of our knowledge, the estimation of consumptions by means of data directly acquired considering a long period (1 year) as well as the possibility to link this estimation to the activities that take place in the school is the main elements of novelty. In fact, to date, consumption data are acquired solely through water bills and as such does not take into account the water leakage contribution. To achieve these goals, the case study of a primary school located in a small Italian Mediterranean island was addressed, as herein described.

Materials and methods

Background information

The school under study is located in the Favignana island (coordinate 37°55′34″N, 12°19′16″E), in the Egadi’s archipelago (Sicily, Southern Italy), as shown in Fig. 1. The school, built in the years 70–80, 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 (See Fig. 1b–d). 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 visible in Fig. 1c.

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 about 80 %. Students are provided with separate bathrooms while teachers and auxiliary personnel have sheared bathrooms. All the bathrooms are equipped with toilet (WC) provided with single push both for faeces and urine flushing (the volume discharged is 7 L at time) and sinks provided with faucet with maximum flow rate of 12 L/min. The teaching activity is developed in five morning hours, 5 days a week. Gym activities are comprised into the 5 h in the morning and no shower for students is provided. Internal building rooms sweep is operated once a week whilst bathrooms are cleaned every day. In the school a refectory is not present and during the monitoring period no irrigation of the green area was operated.

Online monitoring system

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 irrigation) located upon the terrace and completely intercepted. This characteristic made possible to easily instal all the water metres necessary to monitor the consumptions of flush water (this subdivided into staff, female, and male students) as well as water for personal cleaning, building sweep and for garden irrigation. All the metres were equipped with sensors set on one litre impulse signal and connected to a data logging system. The data were acquired for 1 year starting from February 2014 (Month 1) to January 2015 (Month 12), evaluating fluctuation between every month. Overall, 33 water metres were installed with a proportion of 3.24 person per water metre. In this regard, Fig. 2 shows the hydraulic scheme as well as the electric one.

Instead, Fig. 3 highlights a typical screen output (at the ENEA research centre in Bologna, Northern Italy) related to a counter installed.

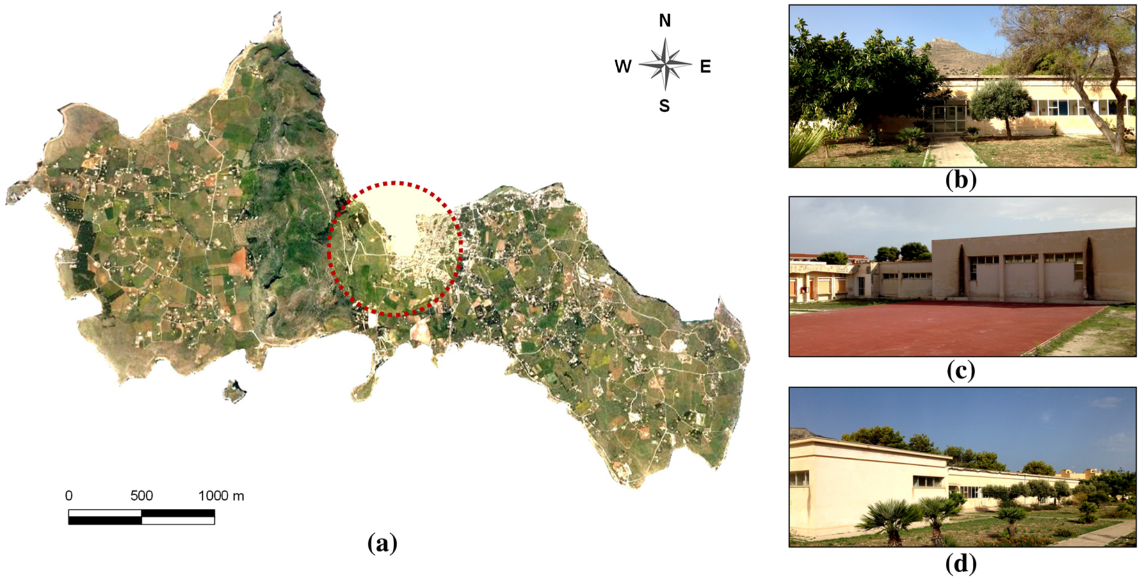

Fig. 1 The school under study in the Favignana island (Sicily Region, Southern Italy)

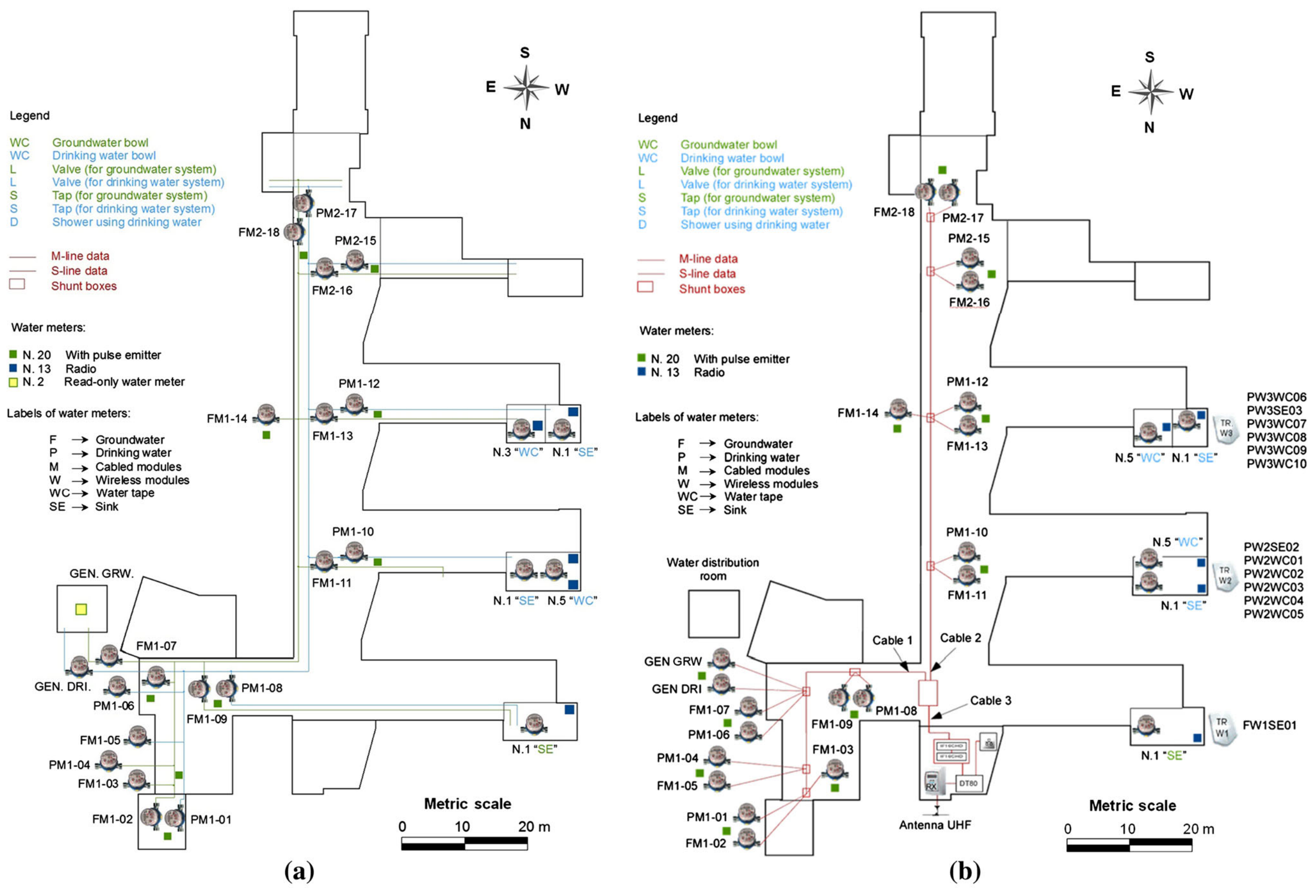

Fig. 2 The adopted online monitoring system: **a** hydraulic and **b** electric scheme

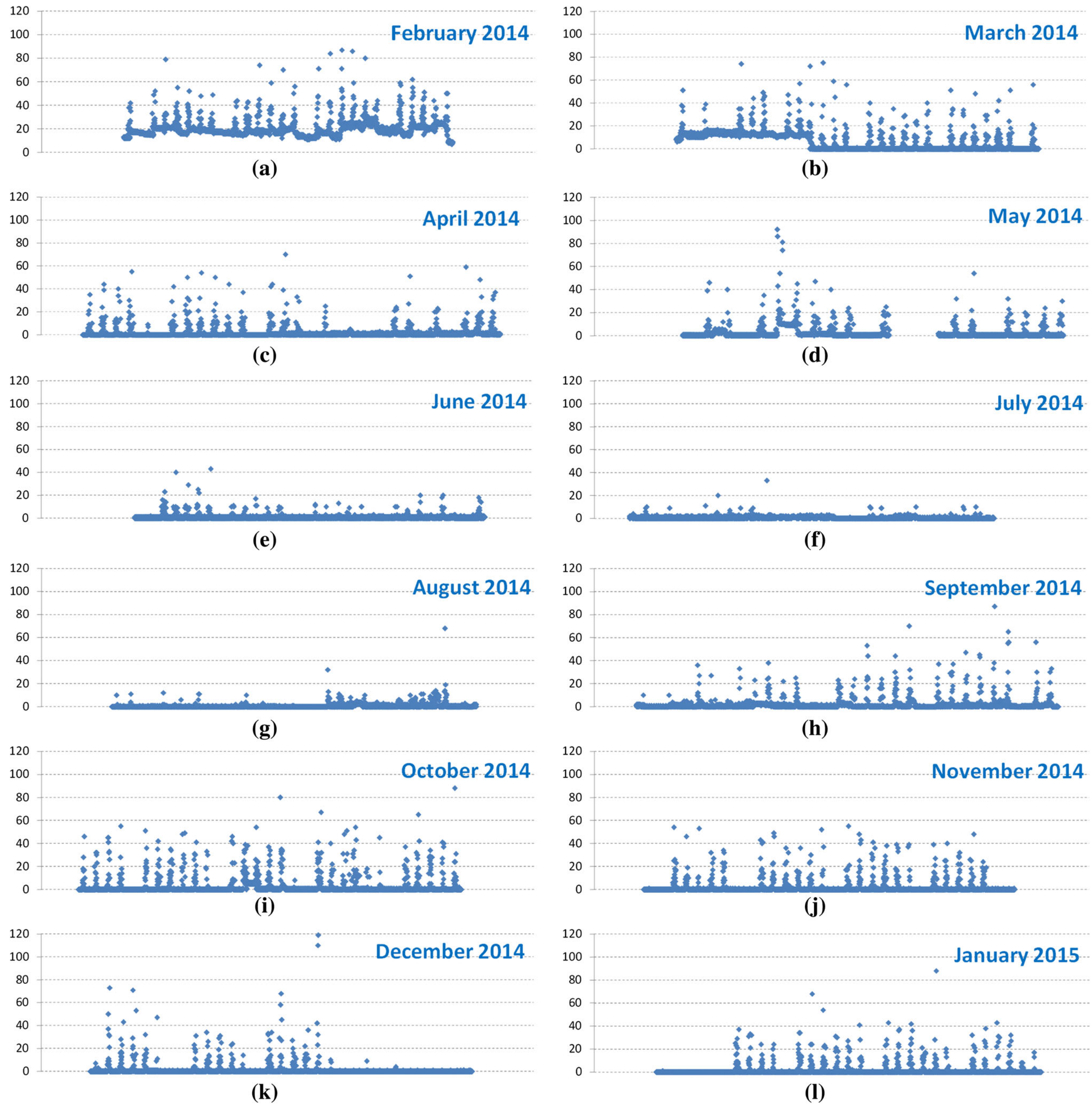

Fig. 3 Typical output related to the PM1-10 m of the on-line monitoring system installed at the Favignana primary school. From **a** February 2014 (*Mouth* 1) to (l) January 2015 (*Mouth* 12). On the *Y*-axis, water consumption is given in litres

Experimentation framework

To highlight how the knowledge of water consumption by the school staff and students is important, our experimentation has included the following main phases in accordance with Sauer and Rüttinger (2007) and Zhou et al. (2014):

- Consumption measurement and real-time communication;
- Consumption measurement without communication.

Still, due to poor condition of the school, some corrective measures were performed before starting the measurement of consumption. As described in the "Results and discussion", these measures have included the replacement of all damaged devices such as trays for toilet or taps for sinks. Furthermore, to quantify the rate of water leakage, the ratio between the monthly water leakage (WL) and the monthly total water consumption (TWC) was defined and computed.

Results and discussion

Water consumptions

Figure 4 shows the main results of the monitoring. In particular, with reference to a monthly basis, water consumption for toilet flushing (Fig. 4a, b), personal cleaning (Fig. 4c, d) and total (Fig. 4e, f), are reported. Figure 4e shows how total water consumptions related to the first month of measurement (February 2014) were widely larger than those of the remaining months, highlighting in this sense, the role of water leakages. In fact, having identified these losses by means of our monitoring system, appropriate corrective measures have been undertaken. Overall, a reduction of total water consumption and leakage was observed as visible from Fig. 4.

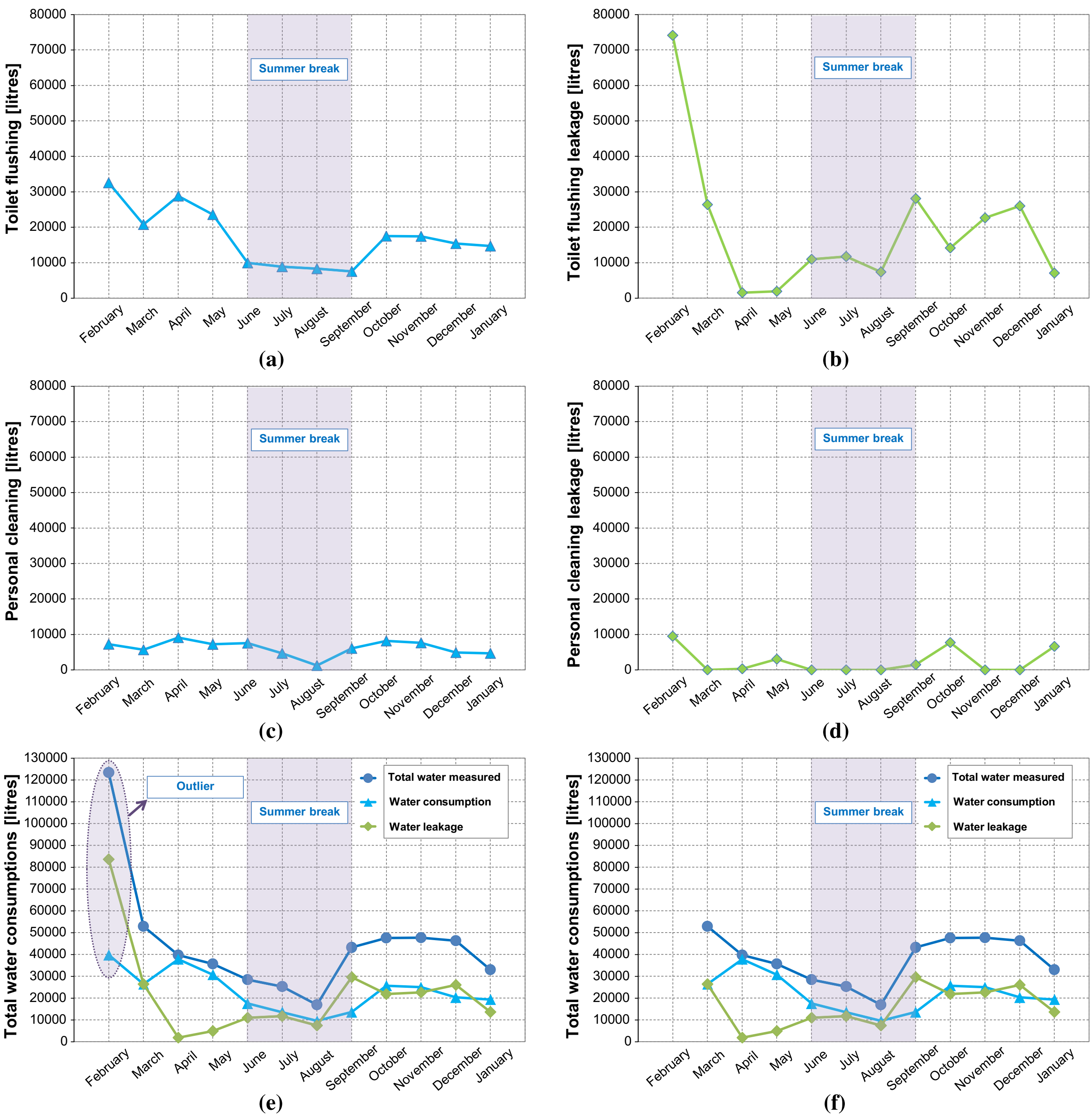

Fig. 4 On-line monitoring system water consumptions considering the Favignana primary school case study: **a** toilet flushing without water leakage and **b** including water leakage; **c** personal cleaning consumptions without water leakage and **d** including water leakage; **e** total water consumptions during the experimentation; **f** total water consumptions during the experimentation without the outlier

The profile of water consumption shows a trend roughly constant with an inflexion corresponding to summer break months (see Fig. 4f). Furthermore, the profile of Fig. 4f does not take into account the month of February (Fig. 4e) that we considered as outlier.

The above findings show how it was possible to rebuild the profile of water consumption due exclusively to educational and staff activities overcoming, in this sense, the limitation highlighted in Almeida et al. (2014). Thus, the adoption of water bill-based data did not allow a reliable reconstruction of water consumption profile.

With reference to the aspect of water consumption estimation, Fig. 5a and b show, respectively, consumptions per student and per occupant, having considered all the months of experimentation.

Referring to students (see Fig. 5a, c), the median of water consumptions "purified" by losses (see mark C) was as follows: 7.9 and 7.2 L/day/student considering all the experimentation data and all data with the exception of the outlier, respectively. Furthermore, differently from Almeida et al. (2014) and Farina et al. (2011), the interquartile range was very small highlighting how 50 % of the observations were concentrated around the medians. Also referring to students (see Fig. 5a, c), the median of water consumptions "inclusive" of losses (see mark D) was as follows: 14.2 and 13.6 L/day/student considering all the experimentation data and all data with the exception of the outlier, respectively. Compared with the previous case, it was observed how the interquartile range was roughly constant while the upper whisker is varied.

Generally, considering only the schools with educational activities, our findings were lower compared to those reported in the recent literature (Almeida et al. 2014; Farina et al. 2011).

Furthermore, the trend was roughly the same considering an analysis per occupant (see Fig. 5b, d). As above reported show how the adoption of our monitoring system allow for reliable water consumption estimation. In

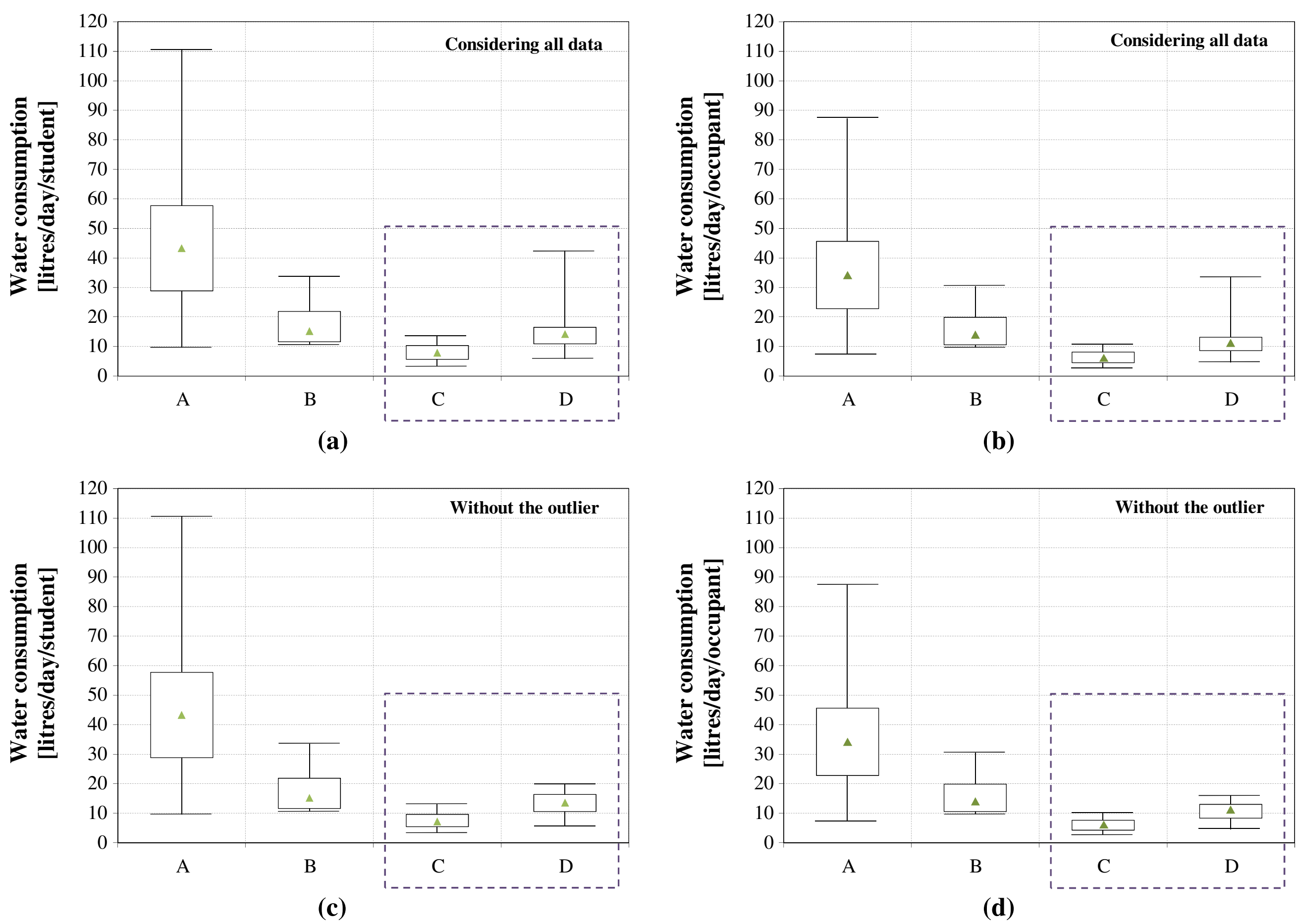

Fig. 5 Comparison of the obtained results with those of other studies: **a** values per student and **b** per occupant considering all data acquired during the experimentation; **c** values per student and **d** per occupant considering data without February 2014 (the outlier). In the figures: *A* Almeida et al. (2014), *B* Farina et al. (2011), *C* our work without water leakage, *D* our work including water leakage

addition, our results were lower if compared with those obtained from the analysis of water bills (Almeida et al. 2014; Farina et al. 2011).

Water leakage contribution

The adoption of data coming from water bills does not allow a reliable reconstruction of water consumption profile. Consequently, water leakages occurring in the internal network of the school can not be quantified. Thus, it is necessary to adopt a monitoring system as that put in place in our investigation.

Figure 6 shows the weight of water leakages in the internal network of the school. In particular, considering a monthly basis, the rate of water leakages on the total consumption of water has been expressed by means of the WL/TWC index defined in the "Experimentation framework".

The observation of Fig. 6a has allowed the identification of four main phases in line with the assumptions of our experimentation (see "Experimentation framework"). The first phase, indicated with "identification phase", refers to the identification of initial water leakage (the current scenario of the school). The WL/TWC index corresponding to

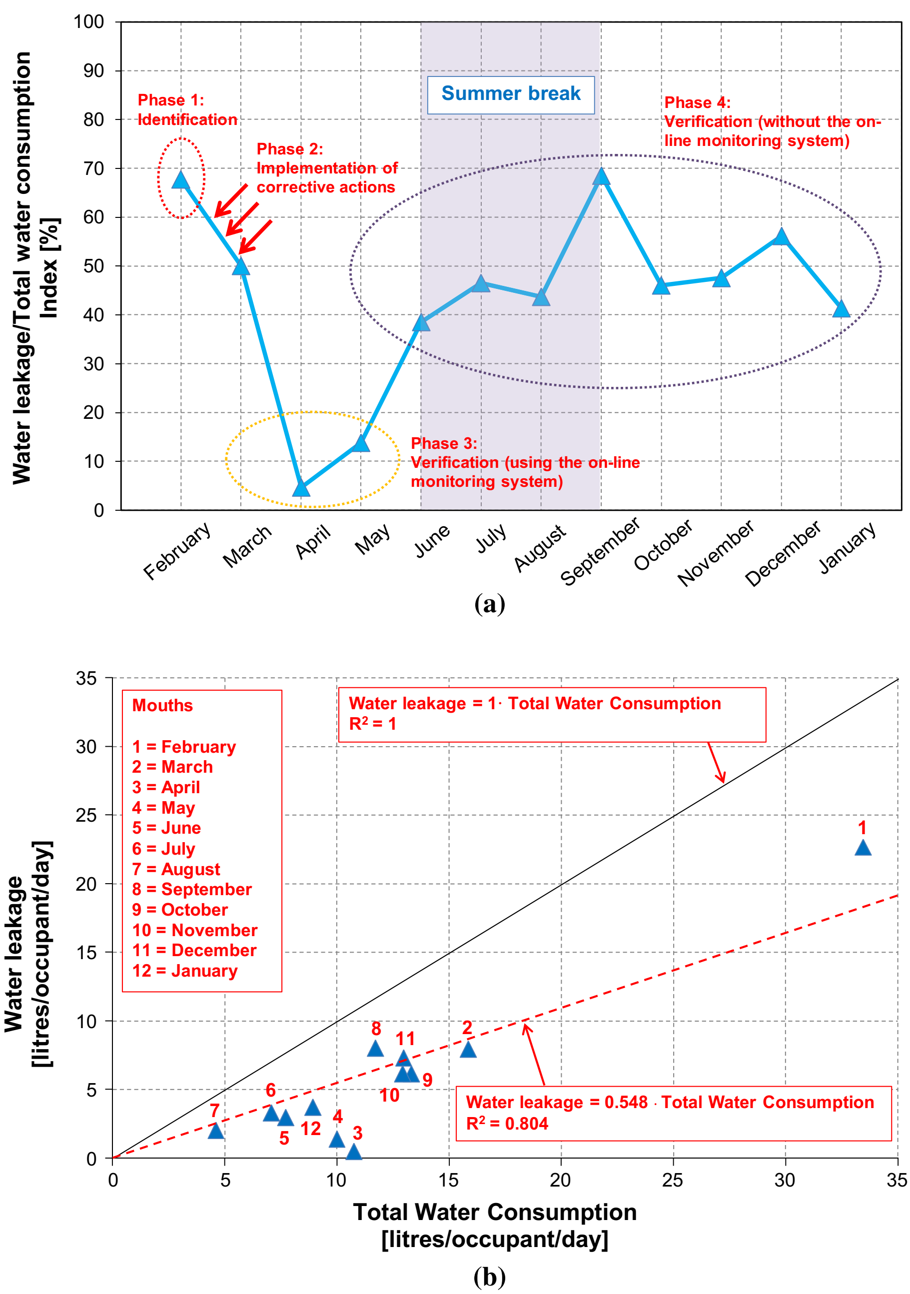

Fig. 6 Contribution of water leakage: **a** water leakage/total water consumption index (WL/TWC) during the experimentation; **b** correlation between water leakage and the total water consumption

the first month of measurement, equals to about 67 %, was higher than in the other months.

The second phase, indicated with "correction actions phase", provides for the implementation of specific corrective measures. Interventions on damaged toilets (the online monitoring system allowed to determine which toilet was damaged) were carried out in March, after the first measurement. It is noted that the WL/TWC index was reduced from 67 % in February to 50 % in March.

The third phase, indicated as "outputs communication phase", was focused on water consumption communication to the school staff and students. In fact, monitor consumption by knowing values is the principle to which we have been inspired. Still, this principle is in line with advances in recent years in the field of home automation (Sauer and Rüttinger 2007; Zhou et al. 2014).

In this sense, Fig. 6a shows how the WL/TWC index corresponding to April and May was significantly lower than other months with values of 6 and 14 %, respectively.

The fourth phase, referred as "no outputs communication", was focused on water consumption monitoring without communication of data to the school staff and students. This phase involved the remaining mouths of the experimentation as shown in Fig. 6a. The objective of this phase was to highlight the contribution of water leakage in a situation where the staff (and above all the students) do not know the instantaneous measurement of consumption (and as such water leakage). In addition, this scenario is the most common one in a school. Figure 6a shows how the WL/TWC index tends to rise with the exception of the month of September. Roughly, the average value was equal to about 50 %. The above findings show that the instant knowledge of measures generates a sort of "preventive action" reducing consumption and simultaneously water leakages (Sauer and Rüttinger 2007). Finally, Fig. 6b shows the relationship between water leakages and the total water consumption during our experimentation. Broadly, water leakage was approximately 54.8 % of the total water consumption.

User behaviour

Water in the school was used as shown in Fig. 7. Toilet flushing, even if it is the primary entry, was quite similar to the amount of water used for personal cleaning. Instead, building cleaning was responsible only for the 3 % of the total water consumption.

With reference to toilet flushing consumptions, Fig. 7b shows the following percentages: 24 % of consumptions were related to male students, 41 % to female ones and 35 % to staff. Moreover, Table 1 shows the behaviour parameters elaborated by means of our monitoring system.

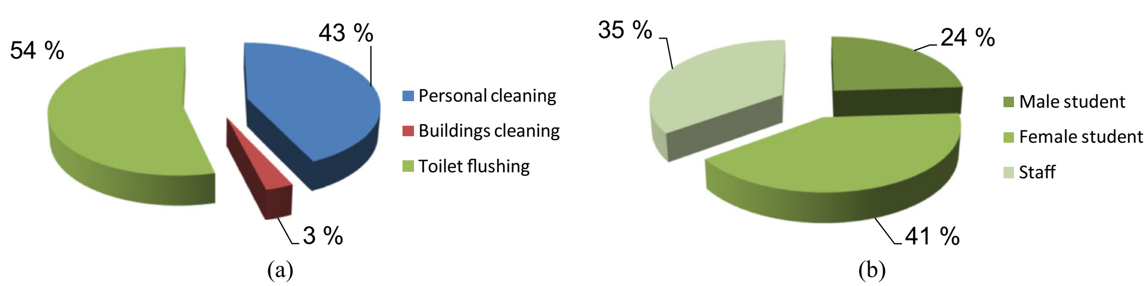

Fig. 7 Water utilisation in the school: **a** types of use; **b** types of occupant considering only toilet flushing

Table 1 Behavioural parameters

Type of person	Type of water	Behavioural parameters	
		Frequency (time/day/person)	Demand (L/day/person)
Male student	Flush water	0.94	6.59
Female student		1.43	9.99
Staff		2.63	18.38
Average value		1.48	10.36
Average value	Cleaning water	4.19	8.38
Average value	Building sweeping	–	0.02[a]

[a] Value in L/day/m^2

Toilet usage data highlight how the staff, due to a longer presence at school, had a higher frequency respect to students (see Table 1).

Female and male students have shown a quite different behaviour so that, despite they were present with similar number, the female were responsible for almost double of the consumption (see Table 1). Even though the Italian socio-economic context is different, our results confirm the existing proportions among male and female students as reported in Cheng and Hong (2004) with reference to the Taiwan situation.

A further considerable result is the comparable quantity of water used for both cleaning and flushing purposes equal to 8.38 and 10.36 (L/day/person), respectively. The water consumption for the internal building rooms sweep appears very low. This result was due to a very high building surface in relation to the number of occupants (23 m^2/occupant). In fact, some rooms are neither used nor have a very low frequency use so that the sweep was reduced.

Conclusions

The online monitoring system allowed evaluating water consumption due to educational and staffing activities of a small Mediterranean island primary school. The monitoring involved the installation of 33 water metres, annual-basis experimentation with the possibility to communicate the instantaneous values of consumption to the school staff.

Following, the mains results have been identified:

- Water consumptions were in the range 7.2–7 L/student/day and 13.6–14.2 L/student/day in the case of network without water leakage and network with water leakage (the most common situation), respectively;
- Water leakage was 54.8 % of the total water consumption. Values of 10 % were obtained in cases where consumption has been communicated instantaneously to the school staff highlighting the importance to know consumption in real time;
- Considering the behavioural parameters, water consumption related to toilet flushing, personal cleaning and building cleaning were 54, 43 and 3 % of the total water consumption, respectively. Considering only toilet flushing, frequencies (in terms of time/day/person) were 0.94, 1.43 and 2.63 for male student, female student and staff, respectively. On average, the corresponding water demand was 10.36 L/day/occupant considering both students and staff. Instead, cleaning water demand was 8.38 L/day/occupant comparable to this way, to the toilet flushing water and, finally;
- Obtained data could be used to implement at school level water recovery strategies such as grey water or rainwater recovery systems.

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Compliance with ethical standards

Conflict of interest There are no conflicts of interest.

References

Almeida RMSF, Ramos NMM, Simões ML, de Freitas VP (2014) Energy and water consumption variability in school buildings: review and application of clustering techniques. J Perform Constr Facil. doi:10.1061/(ASCE)CF.1943-5509.0000663

Cheng CL, Hong YT (2004) Evaluating water utilization in primary schools. Build Environ 39(7):837–845. doi:10.1016/j.buildenv.2004.01.006

European Commission (2008) Mediterranean Water Scarcity and Drought Report. Technical report on water scarcity and drought management in the Mediterranean and the water framework directive. Produced by the: Mediterranean Water Scarcity and Drought Working Group (MED WS&D WG). http://ec.europa.eu/environment/water/quantity/eu_action.htm#2008_report. Accessed 13 Mar 2016

European Commission, DG Environment (2012) Water Performance of buildings, Final Report. http://ec.europa.eu/environment/water/quantity/pdf/BIO_WaterPerformanceBuildings.pdf. Accessed 13 Mar 2016

Farina M, Maglionico M, Pollastri M, Stojkov I (2011) Water consumption in public schools. Procedia Eng 21:929–938. doi:10.1016/j.proeng.2011.11.2096

Farina M, Maglionico M, Pollastri M, Stojkov I (2013) Water consumption in public schools for the city of Bologna, Italy. Wa Sci Technol 13(2):257–264. doi:10.2166/ws.2013.013

Sauer J, Rüttinger B (2007) Automation and decision support in interactive consumer products. Ergonomics 50(6):902–919. doi:10.1080/00140130701254266

Viola F, Sapiano M, Schembri M, Brincat C, Lopez A, Toscano A, Diamadopoulos E, Charalambous B, Molle B, Zoumadakis M, Torrens Armengol A, Gallinas Vich M, Noto MR (2014) The state of water resources in major Mediterranean islands. Water Resour 41(6):639–648. doi:10.1134/S0097807814060207

Wung T-C, Lin S-H, Huang S-M (2006) Rainwater reuse supply and demand response in urban elementary school of different districts in Taipei. Resour Conserv Recycl 46:149–167. doi:10.1016/j.resconrec.2005.06.009

Zhou S, Wu Z, Li J, Zhang X-P (2014) Real-time energy control approach for smart home energy management system. Electr Power Compon Syst 42(3–4):315–326. doi:10.1080/15325008.2013.862322