Evaluation of water consumption in a university building

Avaliação do consumo de água em um edifício de um campus universitário

Evaluación del consumo de agua en un edificio de un campus universitario

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Abstract

The assessment of water consumption in buildings is important for planning actions to promote water conservation. This article presents the assessment of water consumption in a classroom building located on a university campus to identify the potential for reducing water consumption with the installation of dual-flush devices in toilets. Consumption measurements were conducted by installing consumption meters equipped with a data logger in the building plumbing system. Daily water consumption is shown, in addition to the number of uses on lavatory taps and toilets. The results show that the average reduction in daily water consumption in toilets was 24.63% in women's bathrooms and 31.56% in men's bathrooms. Considering the total water consumption in the building, the consumption reduction was 22.94%.

Key-Words: water consumption, toilets; lavatory taps, university campus.

Resumo

A avaliação do consumo de água em edificações é importante para o planejamento de ações com objetivo de promover o uso racional da água. Este artigo apresenta a avaliação do consumo de água em um edifício de salas de aula localizado em um campus universitário com o objetivo de identificar o potencial de redução do consumo de água após a substituição dos acabamentos das válvulas de descarga das bacias sanitárias por modelos com mecanismo de duplo acionamento. Foram realizadas medições de consumo nos equipamentos hidrossanitários da edificação por meio da instalação de medidores de consumo com registro de dados em data logger. O consumo diário de água é apresentado, além do número de acionamentos em torneiras de lavatório e em bacias sanitárias. Os resultados mostram que a redução média do consumo diário de água em bacias sanitárias foi de 24,63% nos banheiros femininos e de 31,56% nos banheiros masculinos. Considerando o consumo de água total no edifício, quando comparados os dados dos dois períodos de medições, a redução de consumo foi de 22,94%.

Palavras-Chave: *Consumo de água, bacia sanitária, torneira, universidade.*

Resumen

El análisis de consumo de agua en edificios es importante para crear acciones con el objetivo de hacer un uso racional de agua. En este artículo, se presenta un estudio del consumo de agua de un edificio situado en un campus universitario con el objetivo de identificar el potencial de reducción del consumo de agua con el uso de un mecanismo de doble accionamiento en sanitarios. Se realizaron mediciones en las instalaciones sanitarias de la construcción, registrando los datos con medidores en modo "data logger". El consumo de agua es mostrado, sumando la cantidad de usos del grifo y váter. Los resultados mostraron que se produjo una reducción del 24,63% en la media de los baños femeninos y una del 31,56% en los masculinos. Considerando el consumo total del edificio, comparado con los dos períodos de análisis el ahorro en el consumo fue de 22,94%.

Palabras clave: *Consumo de agua, váter, grifo, universidad.*

1. Introduction

Developing effective strategies, policies, and models for water conservation is essential for urban water resources management (MAKKI *et al.*, 2013). Water-saving strategies reduce water stress and contribute to reducing electricity consumption associated with water treatment and distribution systems and the collection and treatment of sewage (KUSKI *et al.*, 2020). In urban areas, water use efficiency in buildings is essential to achieve sustainability. Efficient water use in buildings of different typologies can significantly reduce urban water demand and promote long-term sustainability in cities (KONTOKOSTA e JAIN, 2015).

Fasola *et al.* (2011) emphasize the importance of water conservation actions in education institutions' buildings. Water conservation can contribute considerably to promoting sustainability on university campuses, generating financial and natural resource savings (MARINHO *et al.*, 2014). University campuses are generally large consumers of resources such as energy and water and can cause significant environmental impacts (ABDELALIM *et al.*, 2015). Yagoub *et al.* (2019) report initiatives universities can adopt to promote water conservation, such as educational campaigns aimed at students, professors, and staff, measuring consumption in real-time, and adopting water-saving equipment.

Evaluating measures to promote water conservation is essential and may impact technological innovation and behavioral issues (MARINHO *et al.*, 2014). In addition, obtaining information on building water consumption allows for planning actions for efficient water use (KUSKI *et al.*, 2020). Honorato and Campos (2019) also mention the importance of knowing users' habits in buildings and characterizing consumption profiles for designing building systems.

In this context, this article aims to determine the water consumption in a classroom building on a university campus and evaluate the potential for reducing water consumption after installing dual-flush devices in toilets. Water consumption in toilets is assessed in two distinct periods, with single-flush and dual-flush devices installed in toilets to verify the water-saving system's performance in women's and men's bathrooms.

2. Methods

In this study, the water consumption of a building on a university campus is evaluated by installing consumption meters with data logger registration. The meters were installed to determine the total daily water consumption of the building and the water consumption in each lavatory tap and toilet of the women's and men's bathrooms. The building has 18 classrooms and two men's and two women's bathrooms spread over two floors. Each men's bathroom has three lavatories equipped with mechanically-operated self-closing taps, four toilets, five urinals, and a drinking fountain. The women's bathrooms have four toilets, four lavatories equipped with mechanically-operated self-closing taps, a cleaning tap, and a drinking fountain. Due to the configuration of the existing cold water plumbing system, it was possible to install consumption meters with a data logger registration for each lavatory tap and toilets of the women's and men's bathrooms. Water consumption of the other plumbing equipment was measured by a consumption meter with a data logger registration exclusive for women's bathrooms and another exclusive for men's bathrooms. It is a building designed exclusively for classrooms, so all the plumbing equipment is in the bathrooms, where water consumption was measured. The occupancy of the building is variable during the days of the week, with a mean of 1,415 students per day, with classes in three shifts (morning, afternoon, and evening). Of the students who have classes in the building under analysis, 68.6% identify as male and 31.4% as female. Because it is a classroom building without

laboratories or administrative facilities, the population of students was considered for research purposes, considering the most representative variable of this typology of buildings (OLIVEIRA e GONÇALVES, 1999).

The flow rate of plumbing equipment installed in the bathrooms (except urinals and toilets) was initially determined by the gravimetric flow measurement method. The measurement was performed three times in each tap and drinking fountain. The flow rate adopted in the study was the arithmetic mean of these three values. The flow rates found for each plumbing equipment are described in Table 1. These measurements aimed to determine the types of meters to be installed according to the flow rate of each plumbing equipment. The flow rates mentioned in NBR 5626 (ABNT, 1998) were considered to determine the models of meters to be installed in the toilets and urinals, as it was not possible to perform the flow measurement.

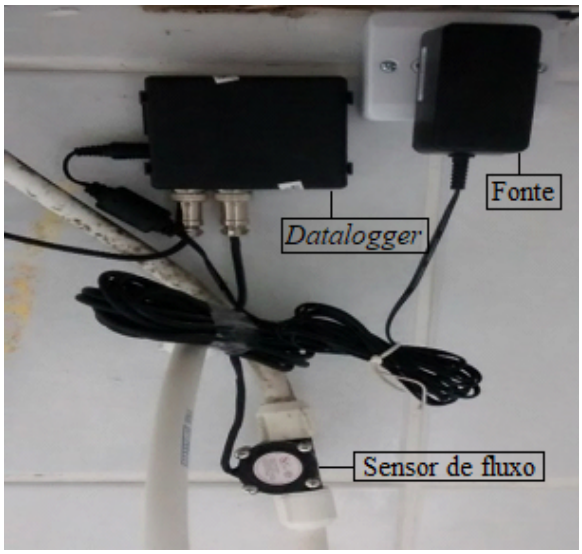
Table 1: Mean flow rates in the equipment installed in the building before placing water consumption meters with *data logger* registration and standard deviations (*s*).

Equipment	Mean flow rate (L/min)			
	Lower floor		Upper floor	
	Men's	Women's	Men's	Women's
Drinking fountain	1.480 (*s* =0.020)	0.298 (*s* =0.001)	0.716 (*s* =0.018)	0.504 (*s* =0.012)
Tap (cleaning)	*	3.636 (*s* =0.539)	*	4.992 (*s* =0.651)
Lavatory tap 1	3.699 (*s* =0.052)	7.526 (*s* =0.190)	6.619 (*s* =0.106)	3.362 (*s* =0.037)
Lavatory tap 2	3.632 (*s* =0.036)	9.457 (*s* =0.150)	2.725 (*s* =0.015)	2.738 (*s* =0.053)
Lavatory tap 3	9.794 (*s* =0.176)	7.497 (*s* =0.015)	9.500 (*s* =0.056)	7.744 (*s* =0.307)
Lavatory tap 4	**	8.811 (*s* =0.149)	**	2.816 (*s* =0.099)

Note:
* Men's bathrooms do not have a cleaning tap.
** Men's bathrooms have only three lavatory taps.

All the toilet valves installed in the building were from the same manufacturer. However, the other plumbing equipment installed in the building generally did not present uniformity regarding brands and models. Water consumption was measured in two periods: with single-flush (period 1) and dual-flush devices (period 2) in the toilets. The devices were adjusted and replaced by engineers provided by the manufacturer. Thus, the only change made during the period analyzed was the replacement of the toilet flush valve devices with dual-flush models. The initial stage of measurements occurred from March 27th, 2017, to March 7th, 2017, and the second stage began on August 8th, 2017, and ended on October 22nd, 2017. Weekend measurements were excluded; thus, period 1 presented 71 days and period 2, 54 days. Figure 1 shows the water consumption meter equipped with a data logger. The information obtained by the water consumption meters, saved on a memory card, consisted of the volume of water consumed in each activation, the date and time of the activation, and the duration of each event (activation). The bathroom was closed for a short time for the readings. The researchers read the memory cards on a laptop computer, and the card was returned to the equipment to perform new readings. Thus, it was possible to obtain the number of daily activations, the volume per activation, and the total volume consumed.

Figure 1: Water consumption meters installed on a tap



Water consumption was evaluated during the analysis periods by determining the total daily water consumption in the building by adding the consumption of the meters installed in the lavatory taps, toilets, and other plumbing equipment. The daily water consumption in the toilets and lavatory taps was also evaluated, considering the building's women's and men's bathrooms. The number of activations in the two periods was evaluated. This is important to determine whether users continued to use the system when dual-flush devices were installed or if a possible reduction in daily consumption would have been due to a reduction in the use of toilets. In addition, we also determined the consumption per activation in both analysis periods.

The Wilcoxon-Mann-Whitney test was applied to compare the differences between the consumption and number of activations in both periods. This test was applied because the data did not present normal distribution (WALPOLE *et al.*, 2009). Data normality was verified using the Shapiro-Wilk test. The statistical analysis was done using the R software (R CORE TEAM, 2022), adopting a 5% significance level.

3. Results and Discussion

3.1. Water consumption in toilets

A consumption meter with two sensors was installed in the pipeline responsible for supplying the toilets. One sensor was responsible for measuring the water consumption of the toilets for the two women's bathrooms and the other, for the toilets of the two men's bathrooms. Figure 2 shows the daily water consumption in the toilets of the women's bathrooms in the two analyzed periods (with single and dual-flush devices). Figure 3 shows the daily consumption of the men's toilets in the two measurement periods.

Table 2 presents the descriptive statistics for water consumption in the toilets of women's and men's bathrooms in the measurement periods. There was a decrease in water consumption in both women's (p-value < 0.001) and men's toilets (p-value < 0.001).

The mean reduction in daily water consumption was 24.63% in women's bathrooms and 31.56% in men's bathrooms. Although consumption decreased in the women's (p-value < 0.001) and men's toilets (p-value < 0.001) with dual-flush devices, the number of activations did not present significant changes, as shown in Figure 4.

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Figure 2: Daily water consumption in women's toilets, with mean values in red and blue for periods 1 and 2, respectively.

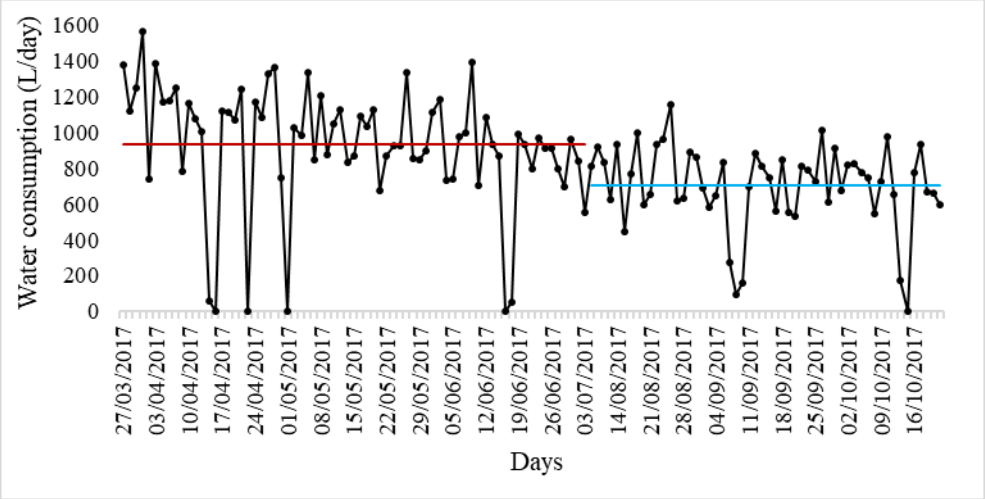


Figure 3: Daily consumption of men's toilets, with mean values in red and blue for periods 1 and 2, respectively.

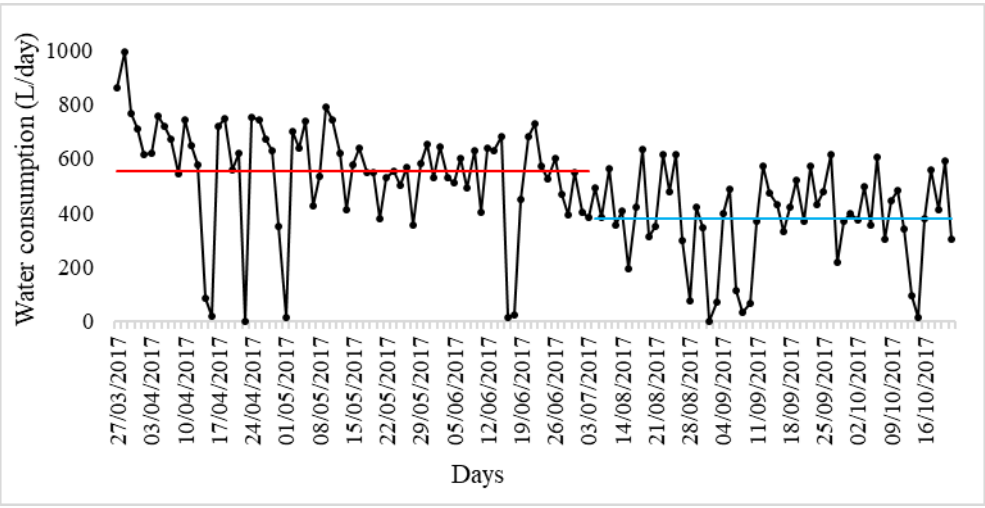
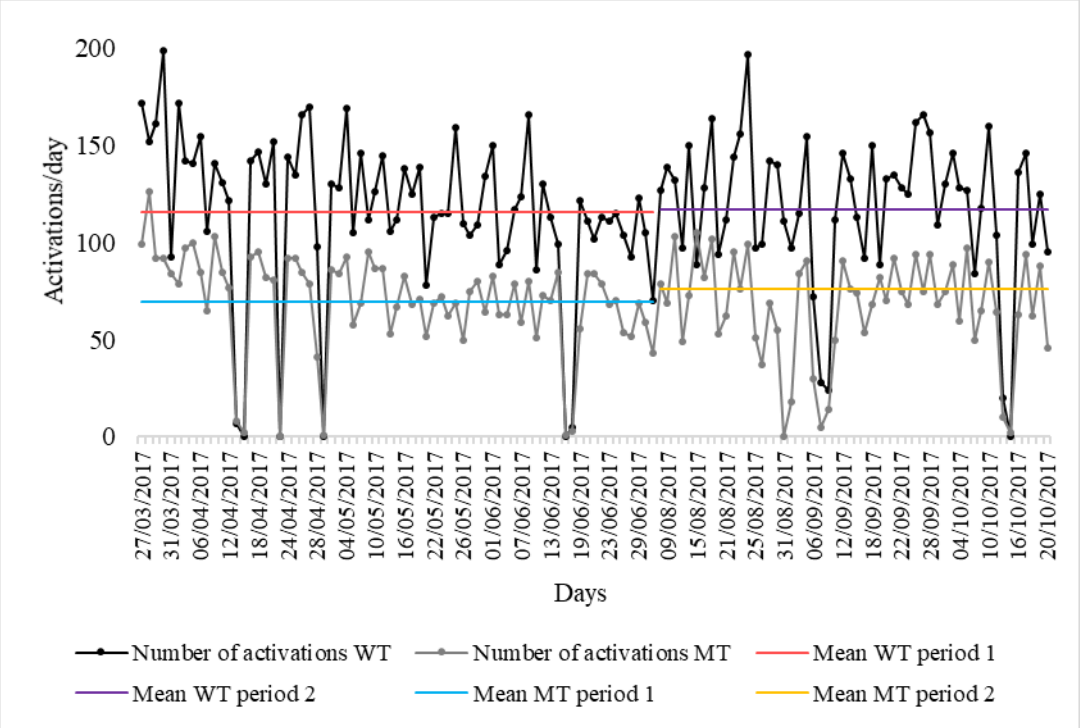


Table 2: Summary measurements for the water consumption (L/day) of the toilets of the women's and men's bathrooms in the two measurement periods

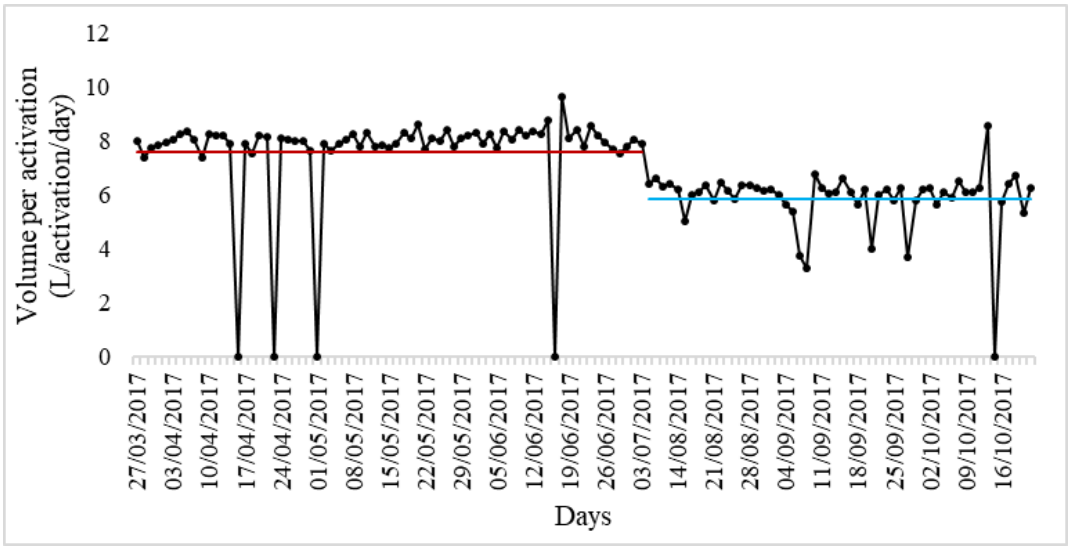
Period	Toilets	Median	Mean	*s*	Min	Max	p-value
1	Women's	979.20	931.99	344.57	0.00	1,561.00	< 0.001
2		735.00	702.46	233.20	0.00	1,155.00	
1	Men's	584.30	553.37	202.91	0.00	991.80	< 0.001
2		398.10	378.74	168.64	0.00	635.20	

Figure 4: Number of activations of the women's toilets (WT) and men's (MT) toilets and daily mean in analyzed periods



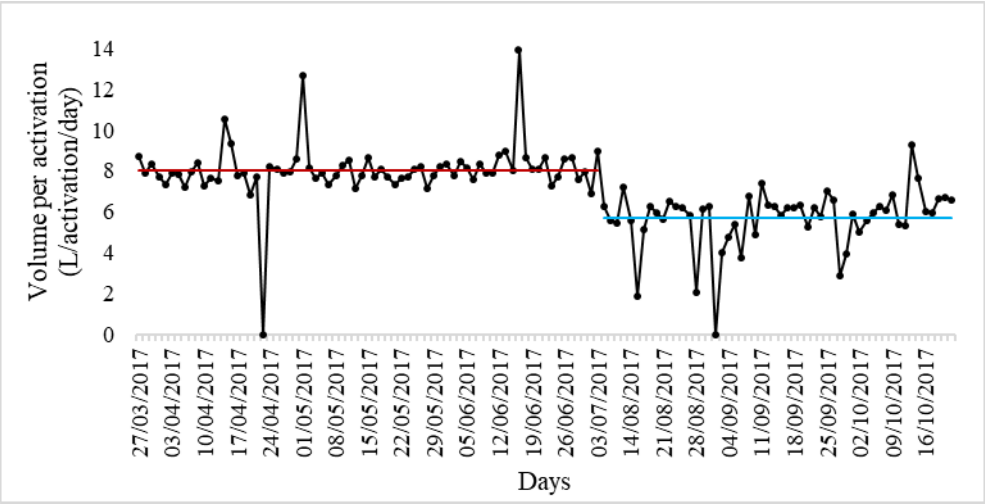
This result is corroborated by the Wilcoxon-Mann-Whitney Test, with p-value = 0.9146 for the women's toilets and p-value = 0.4868 for the men's toilets. The mean number of activations in the women's toilets (WT) was 116 per day (s = 43 activations/day) in the first measurement period and 118 activations/day (s = 38 activations/day) in the second period. The mean number of activations in the men's toilets (WT) was 70 per day (s = 26 activations/day) and 66 per day (s = 27 activations/day) in the first and second measurement periods, respectively. Figure 5 shows the mean daily consumption per toilet activation in the women's bathrooms. Water consumption on holidays is equal to zero. The consumption per activation is lower in the second measurement period when the toilets are equipped with dual-flush devices.

Figure 5: Daily consumption per activation of the toilets of the women's bathrooms, with mean values in red and blue for periods 1 and 2, respectively.



The consumption per activation was also lower in the toilets of the men's bathrooms when the dual-flush devices were installed (Figure 6). There were a few flushes to the men's toilets on some holidays, which may indicate use by members of the University's property security team.

Figure 6: Daily consumption per activation of the toilets of the men's bathrooms, with mean values in red and blue for periods 1 and 2, respectively.



Considering the two analysis periods, the mean reduction in volume per activation was 22.86% in women's bathrooms and 29.39% in men's bathrooms. The volume reduction by activation was verified using the Wilcoxon-Mann-Whitney Test in the women's (p-value < 0.001) and men's bathrooms (p-value < 0.001).

3.2. Water consumption in lavatory taps

Figures 7 and 8 present the daily consumption for the eight lavatory taps installed in the women's bathrooms and the six lavatory taps installed in the men's bathrooms in the two measurement periods. It is important to emphasize that, unlike what occurred with the toilets, the taps were not replaced throughout the two measurement periods.

Figure 7: Daily water consumption of lavatory taps installed in women's bathrooms, with mean values in red and blue for periods 1 and 2, respectively.

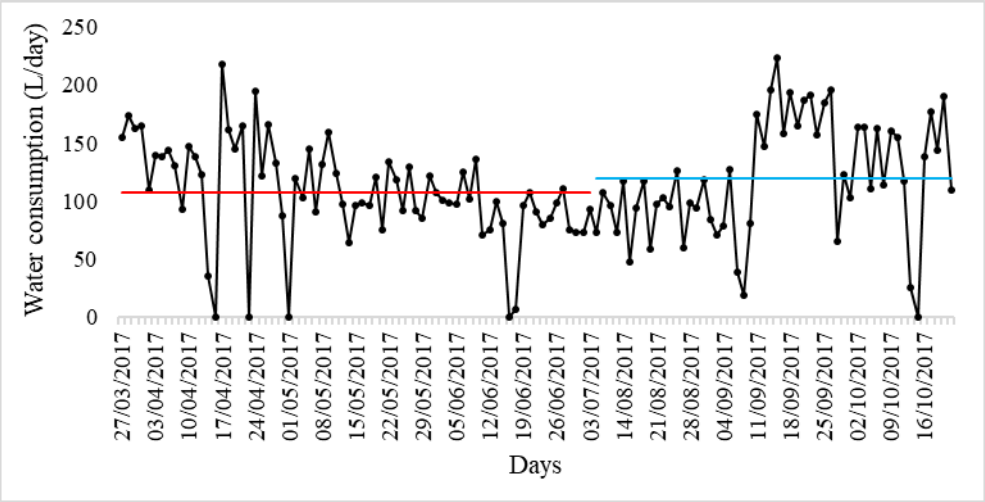
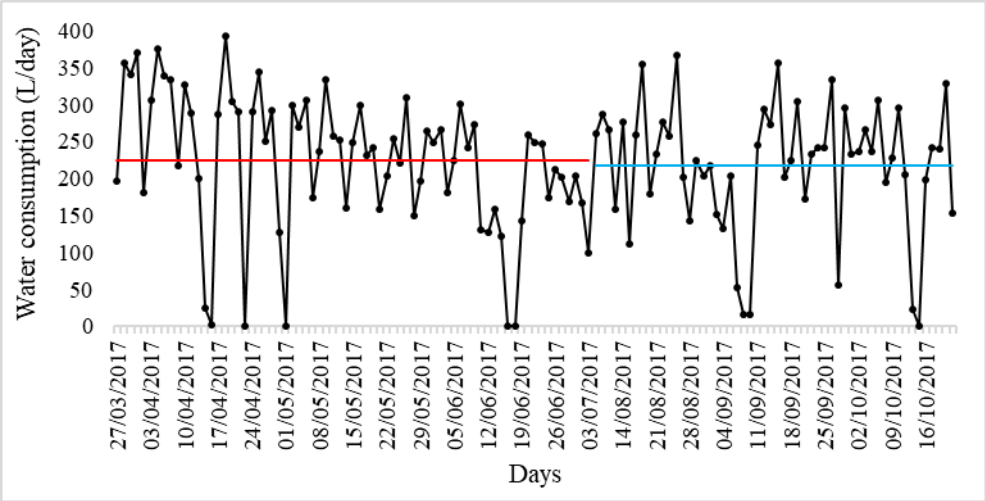


Figure 8: Daily water consumption of lavatory taps installed in men's bathrooms, with mean values in red and blue for periods 1 and 2, respectively.



The mean values found for the taps installed in the lavatories of the women's bathrooms in the initial and final measurement periods were 107.328 L/day (s = 43.846 L/day) and 119.827 L/day (s = 51.227 L/day), respectively. The mean values found for the taps of the lavatories of the men's bathrooms were 224.147 L/day (s = 95.080 L/day) for the initial period and 216.988 L/day (s = 87.931 L/day) for the second measurement period. Figure 9 shows the mean daily consumption per activation of the lavatory taps in women's bathrooms. Consumption per activation showed slight variation in the two analyzed periods, and it is equal to zero in the holidays.

Figure 9: Daily consumption per activation in the lavatory taps of women's bathrooms, with mean values in red and blue for periods 1 and 2, respectively.

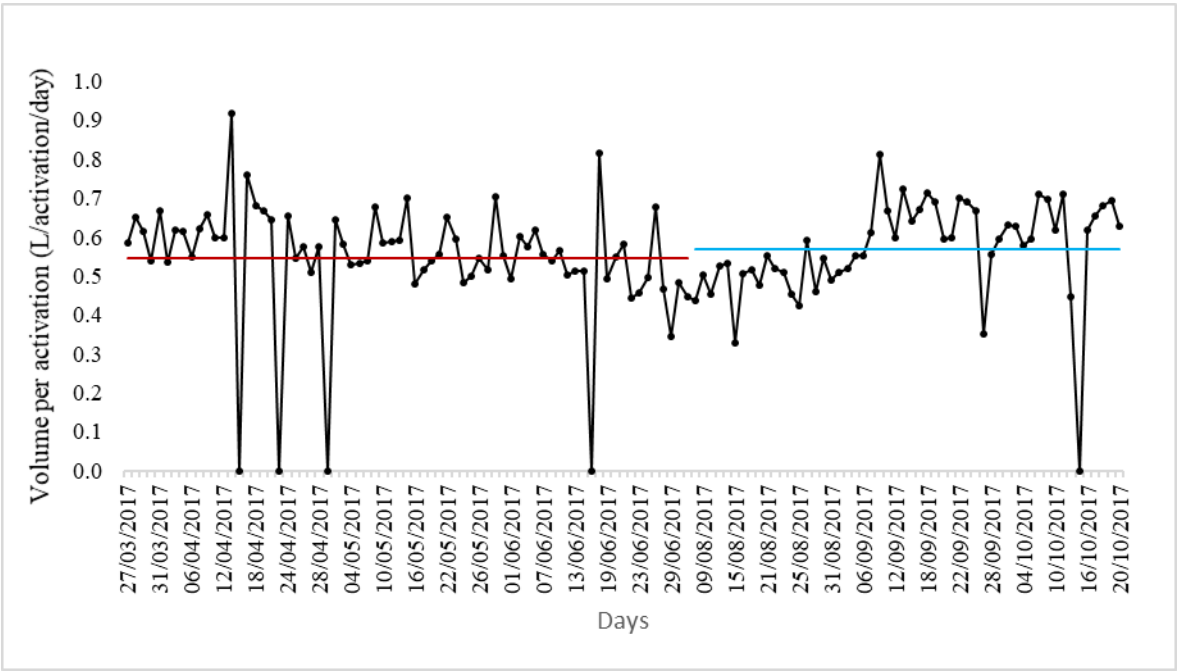


Figure 10 shows the daily consumption per activation in the lavatory taps of the men's bathrooms in both measurement periods.

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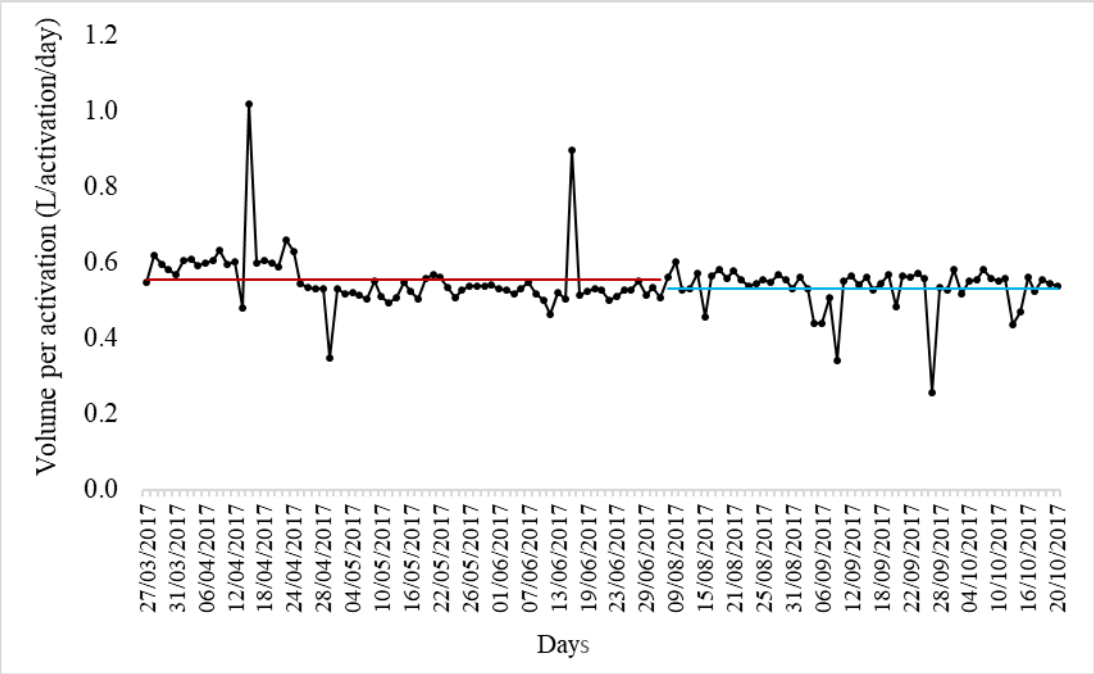
Figure 10: Daily consumption per activation of lavatory taps in men's bathrooms, with mean values in red and blue for periods 1 and 2, respectively.



The volume per activation varied slightly during the two measurement periods in the lavatory taps of the men's and women's bathrooms, as verified by the Wilcoxon-Mann-Whitney Test in the women's (p-value = 0.372) and men's bathrooms (p-value = 0.636). This result was expected since the taps were not replaced.

3.3. Number of activations in toilets and lavatory taps

Figure 11 shows the number of activations in toilets and lavatory taps in the women's bathrooms. The mean number of daily activations in the toilets and lavatory taps of the women's bathrooms in the first period of measurements are 116 and 188, respectively. The toilets of the women's bathrooms were activated, on average, 118 times a day, and the lavatory taps, 203 times a day in the second measurement period.

Figure 12 shows the number of activations in toilets and lavatory taps in the men's bathrooms. The toilets were activated, on average, 70 times per day in the first measurement period, while the lavatory taps were activated 408 times per day. The mean number of daily activations was 66 in the toilets and 398 in the lavatory taps in the second measurement period.

The difference in the number of activations in toilets and lavatory taps in the men's bathroom is justified by the presence of urinals. One of the limitations of this research was the impossibility of installing water consumption meters in urinals due to the characteristics of the plumbing system and other constructive elements of the building.

The difference in the number of activations in lavatory taps of the women's and men's bathrooms follows the number of students who use the building. Students who identified themselves as male and female represented 68.6% and 31.4% of the students enrolled in subjects taught in the building during the analysis period. There were 74,792 activations in lavatory taps in this period. Of this number, 67.5% occurred in men's and 32.5% in women's bathrooms. The total number of toilet activations in the analysis

period was 23,161. In this case, 63.1% of the activations occurred in women's and 36.9% in men's bathrooms. This may be due to the presence of urinals in men's bathrooms.

Figure 11: Number of activations of the toilets and lavatory taps in the women's bathrooms in each analyzed period

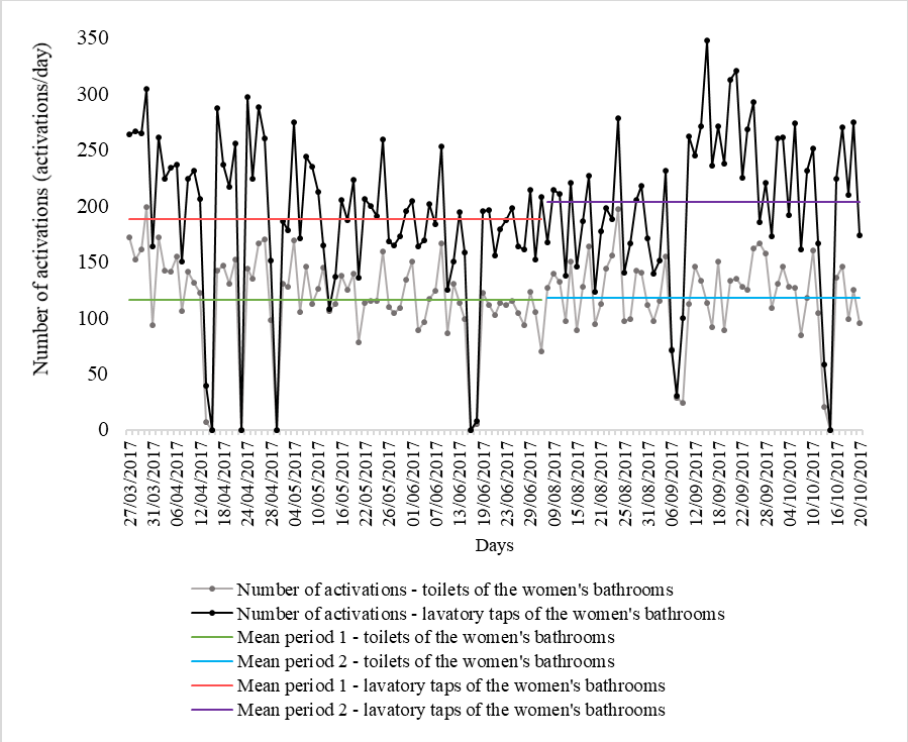
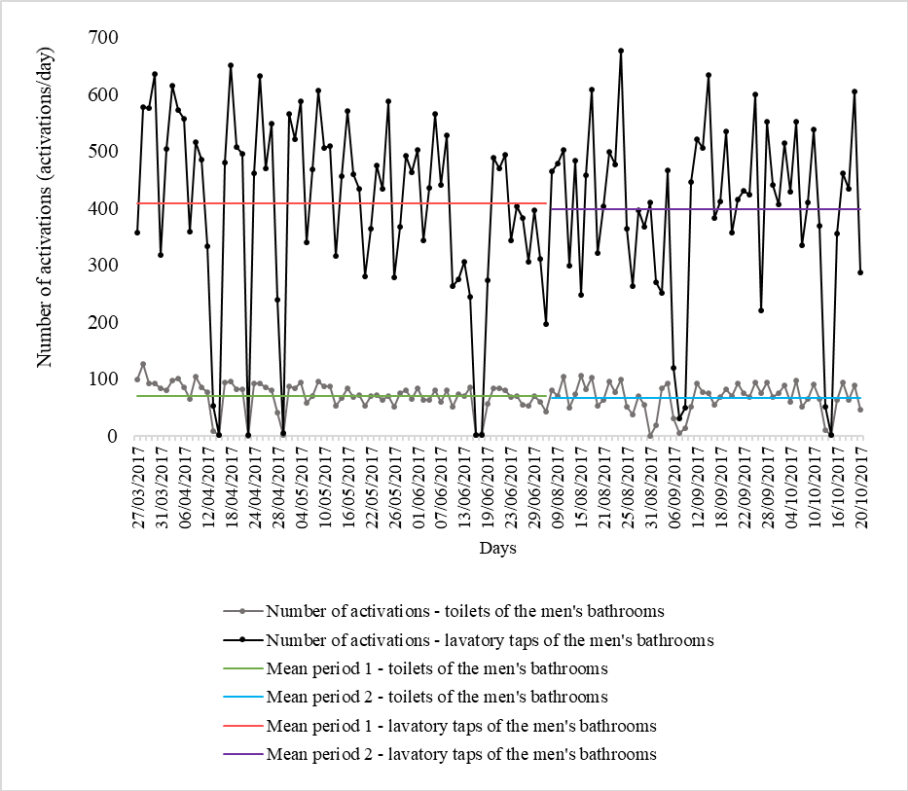


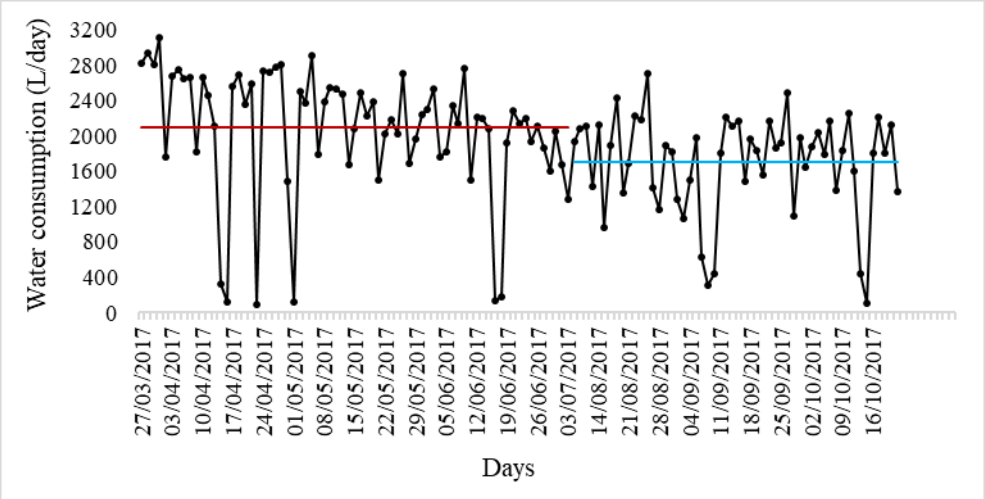
Figure 12: Number of activations of the toilets and lavatory taps in the men's bathrooms in each analyzed period



3.4. Water consumption in the building

Figure 13 shows the building's total water consumption (in liters/day), including all plumbing equipment installed in the men's and women's bathrooms in the two measurement periods. The highest recorded water consumption was 3,112.568 liters/day. The mean consumption of all equipment installed in the classroom building was 2,089.338 liters/day (*s* = 715.612 liters/day) for the initial period and 1,699.485 liters/day (*s* = 562.778 liters/day) in the final measurement period, excluding weekends in both periods. The lowest consumptions in Figure 13 represent the holidays throughout the measurement period.

Figure 13: Total daily water consumption of the building, with mean values in red and blue for periods 1 and 2, respectively.



The water consumption in the initial measurement period was 22.94% higher than that determined in the second period. Table 3 presents the descriptive statistics of water consumption data in the building. The decrease in building water consumption was significant according to the Wilcoxon-Mann-Whitney test (p-value < 0.001).

Table 3: Summary measurements for the water consumption (L/day) of the building in the two measurement periods

Period	Median	Mean	*s*	Min	Max	p-value
1	2,214.193	2,089.338	715.612	96.725	3,112.568	< 0.001
2	1,837.110	1,699.485	562.778	111.631	2,705.178	

The decrease in water consumption in the building can be explained by adopting water-saving devices (dual-flush mechanisms) in the second measurement period, according to the analysis presented in section 3.1. Some studies show that toilets are responsible for a significant portion of water consumption in different building typologies (ODURO-KWARTENG *et al.*, 2009; FASOLA *et al.*, 2011; GATO-TRINIDAD *et al.*, 2011). Barbosa *et al.* (2018), who characterized the final uses of water in higher education buildings at the Darcy Ribeiro University Campus of Universidade de Brasília, found that the toilets presented the largest share of building consumption in most of the buildings evaluated.

According to Marinho *et al.* (2014), one of the factors affecting water consumption in university buildings is the quality of plumbing systems and their maintenance. For the authors, this factor does not depend on the user but on institutional decisions. In other words, the better the quality of the devices and maintenance system, the lower the water losses. Fuentes et al. (2018) state that water consumption patterns differ between building typologies. Therefore, the detailed characterization of a building's water use profile is important for planning demand management strategies.

4. Conclusions

This study analyzed the water consumption of a classroom building located on a university campus before and after installing dual-flush devices in toilets. The dual-flush devices considerably reduced the building's water consumption. The total water consumption in the building in the initial measuring period was, on average, 22.94% higher than the water consumption in the second period. The mean reduction was 24.63% in women's toilets and 31.56% in men's toilets. Despite the decrease in consumption, the number of toilet uses did not change, reinforcing the dual-flush mechanism's performance in reducing water consumption. Water consumption in lavatory taps did not show significant changes in the two periods analyzed. This result was expected since the taps installed in the building were not replaced or regulated during the study and did not undergo routine maintenance.

This work demonstrated that replacing single with dual-flush devices in toilets reduced water consumption in a university building. The analysis also showed that, although consumption decreased, the number of toilet activations did not change significantly. This indicates that replacing the flush devices did not considerably change the equipment use habits. The knowledge of existing plumbing systems, the identification of consumption profiles, and the measurement of the performance of water-saving equipment allow planning to promote water conservation. Water conservation in buildings requires a plural approach involving technological and social aspects. The integrated implementation of these strategies can effectively contribute to water conservation in the urban environment.

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