# Correlation between water consumption and the operating conditions of plumbing fixtures in public buildings

Felipe Gonçalves, Andreza Kalbusch and Elisa Henning


## ABSTRACT

Water resource management consists of planning and implementing measures to ensure sufficient and quality supply to activities requiring water usage, including the supply of plumbing systems in buildings. Major problems arise from mismanagement of water usage, such as the lack of proper upkeep practices and maintenance of plumbing fixtures in public buildings. The aim of this study is to analyze the existence of possible statistical correlations between water consumption data and operating conditions of plumbing fixtures in public administrative buildings. Ten public buildings were visited in Brazil while performing this research, in order to determine the per capita water consumption, flow rates, and operating conditions of plumbing fixtures. Flow rate data were obtained through field measurements by the gravimetric method and compared with the values set by Brazilian standards and environmental certifications. Consumption indicators were calculated, which showed variation from 16.6 to 69.3 L/user/day. The performed statistical analysis pointed out that there was significant correlation with variables related to construction and operating conditions of plumbing fixtures, such as the number of installed devices, number of leaks and defects found, in addition to devices with flow rate noncompliant to limits established by current legislation.


**Key words** | correlation, plumbing fixtures, public buildings, water consumption

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## INTRODUCTION

Any problems in plumbing systems may bring about negative impacts on a facility, as well as on its occupants, and on the environment. As cities develop, the challenge of providing water in order to supply users' needs without damaging nature becomes increasingly important (Brown *et al.* 2009). In countries such as Brazil, there is still a lack of organization and operational resources seeking more sustainable practices (da Silva *et al.* 2014). Thus, the operating condition diagnosis of plumbing fixtures in public buildings becomes important for highlighting the loss of water in these facilities and their likely causes. Thus, it is possible to correlate these data with the monthly consumption of buildings and understand the behavior of the involved variables.

Despite this, not all water is wasted by leakage. For example, as part of a daily and generally common practice, it is normal for users to forget to close manually operated taps after using them in public restrooms (da Silva *et al.* 2014). In addition, programs have proved that physical interventions and behavioral changes coupled with administrative actions are capable of reverting wasteful situations and effectively save water (Marinho *et al.* 2014). Water resource management is an aspect dependent on social, cultural, economic and technological factors and, additionally, mismanagement of water in buildings may even cause illness for their occupants (Brooks & Holtz 2009; WHO 2011).

The consumption indicator is the amount of water used by a consumer agent within a specified time period. This indicator displays values depending on the type and the use of each building. For example, administrative offices and elementary schools may generally display very similar

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indicators. This is because both are used only during business hours; their holiday periods are very similar during the year and only provide water consumption for toilets and eventual cleaning, among other common uses for these buildings (Farina *et al.* 2013). The indicator is also greatly impacted when water consumption is not controlled. Such situations deserve attention and care, since preventing water wastage may also prevent the pollution of water resources (Velazquez *et al.* 2013). Sustainable consumption of water may be more limited, considering conditions of the public authority in public buildings.

It is necessary to seek technology for achieving effective water savings, for example: by installing self-closing valves. A study by Demanboro *et al.* (2015) in a university campus pointed out that manual taps displayed longer operation time and, consequently, increased water consumption compared with automatic sensor taps, even if the latter are operated at a higher average flow rate.

However, technological actions alone will not be enough to reduce consumption, if water demand management is absent and users are not committed to conserving water. Therefore, the installation of saving technologies should always come accompanied by campaigns to increase users' awareness (da Silva *et al.* 2008). Users cannot be expected to acquire self-consciousness independently, but rather they should be adequately informed and educated on new technologies, the reason for deploying them and how they can achieve more sustainable consumption (Feldman 2011).

This study proposes to analyze all water consumption variables and operating conditions of plumbing fixtures, by means of field measurements in public administrative buildings in Joinville (Southern Brazil) and assess the existence of correlations comparing these two types of data.

## MATERIALS AND METHODS

The research was based on collected data from 10 public administrative buildings in Joinville, Brazil (26°18′14″S; 48°50′45″W) including all installed plumbing fixtures ($n = 418$). The flow rates were measured by means of the gravimetric method, which consists of collecting the flow using a beaker, and afterwards weighing the collected volume on a precision scale. Times were measured using a stopwatch.

All flow rates were measured three times and then the arithmetic averages were calculated from the water collections. Afterwards, the flow rates were compared with the standardized values to verify if they adhered to the established parameters. Reference values can be viewed in Table 1. *NBR* 10281 (ABNT 2015a) establishes minimum flow rate values, the *LEED* certification (USGBC 2011) and *AQUA* certification (AQUA-HQE 2014) establish maximum flow rate values, whereas *NBR* 5626 (ABNT 1998) and *NBR* 12483 (ABNT 2015b) contain only reference values. In addition to self-closing taps, operating times were also determined and compared with *NBR* 13713 (ABNT 2009), which establishes recommendations for plumbing fixtures with mechanical operation and plumbing fixtures with automatic closure cycles.

Other defects and the condition of plumbing fixtures were visually and operationally analyzed, such as the activation of toilet valves and deactivation time of self-closing taps. The identified leaks, when quantifiable, were also measured by the gravimetric method. In toilets and urinals, the pen method was used specifically, based on *NBR* 15097-1 (ABNT 2011), to check for leakage, such as trickling water, which are leaks classified as small water streams running through the inner walls of these devices. The method consists of flushing toilets and urinals and then measuring after a minimum delay of 30 minutes. After that, a circle is drawn on the ceramic parts, after being previously dried, using a water-soluble pen. If any part of the ink is dissolved, it means there are trickles (leaks) dripping through that space.

**Table 1** | Flow rate values established by standards and certifications

| | Taps | | | | | |
|---|---|---|---|---|---|---|
| | | | Cleaning | | | |
| Flow rate (L/s) | Lavatory | Kitchen | Tank | Garden | Drinking fountains | Showers |
| *NBR* 5626 | 0.15 | 0.25 | 0.25 | 0.20 | 0.10 | 0.10 |
| *NBR* 12483 | - | - | - | - | - | 0.05 |
| *NBR* 10281 | 0.04 | 0.04 | 0.05 | 0.05 | - | - |
| *LEED* | 0.14 | 0.14 | - | - | - | 0.16 |
| *AQUA* | 0.17 | - | - | - | - | 0.20 |

Additionally, other data were obtained, such as the year the building was constructed, the number of employees, and the monthly consumption of water during the course of 12 months, as well as the number of monthly working days in each building. The ages of the buildings were obtained by contacting the administration of each building that had the public documentation stating the respective year of construction.

It was possible to calculate the daily water consumption indicator as shown in Equation (1):

$$CI = \frac{Cm}{NA \times Dm} \times 1{,}000 \quad (1)$$

where:

*CI:* consumption indicator (L/user/day);
$Cm$: monthly water consumption ($m^3$);
$NA$: number of consumer agents (employees); and
$Dm$: number of working days in the month.

After performing the investigation, all collected data were inserted on a spreadsheet, sorted by type of plumbing fixtures, and their respective characteristics, defects and flow rates. The numbers of defects, leaks and plumbing fixtures were analyzed to verify the characteristics considered as discrete random data.

The observed defects included: the lack of aerators in kitchen and lavatory taps, excessive or insufficient flow rates, nonstandard flow rate times, excessive or irregular flow sprays, fixtures with no water flow, broken or missing parts in the device and leaks. The monthly consumption ($m^3$/month), consumption indicator (L/user/day) and flow rates ($m^3$/s) were considered regarding continuous random data. All discrete random data were transformed into percentages by dividing the gross number of each specific feature by their respective total overall amount found in the building; however, the continuous random data were maintained in their original format.

All data were imported and analyzed in the open-source *R* software (R CORE TEAM 2016) and the *RStudio* interface. The Pearson linear correlation coefficient was applied to verify the correlation between variables. Necessary assumptions were evaluated, such as normality and linearity. Mardia's test was used to verify the normality, present in the MSQC package (Santos-Fernandez 2016). The adopted significance level was $\alpha = 5\%$.

The only cases analyzed were $|r| \geq 0.8$ coefficients from the calculated correlations. This choice was made due to the power in the significance test as only these correlations were considered. This practice was followed as it is recommended for the test power to be high, even in small sample situations (SDW 2016). Thus, the sample size is $n = 10$ for this study and the selected correlations employ a minimum coefficient of $|r| = 0.8$, and the power of the *t*-test is at least 0.85 (85.0%), which was calculated aided by the *R* package *pwr* (Champely 2016).

It should be noted that the smaller the sample, the greater the Pearson correlation coefficient must be in order for the results to be significant. However, for large samples, smaller coefficients are needed, so the results can be significant. The correlation power scale used in this research was the same as proposed by Evans (1996) in Table 2.

After calculating the significant correlations, each result was contextually analyzed based on the investigated problem, including correlations that could be characterized as spurious. In spurious correlation, pairs of independent variables should not display any correlation ending up with high coefficients (Aldrich 1995). The sequence for the procedure is shown in Figure 1.

## RESULTS AND DISCUSSION

### Water consumption analysis

This study has shown consumption indicators ranging from 16.6 to 69.3 L/user/day. These results are comparable to those presented in a study conducted by Kammers &

**Table 2** | Correlation coefficients with their respective intensities

| Correlation coefficient | Correlation |
|---|---|
| $0.80 \leq \lvert r \rvert \leq 1.00$ | Very strong |
| $0.60 \leq \lvert r \rvert \leq 0.79$ | Strong |
| $0.40 \leq \lvert r \rvert \leq 0.59$ | Moderate |
| $0.20 \leq \lvert r \rvert \leq 0.39$ | Weak |
| $0.00 \leq \lvert r \rvert \leq 0.19$ | Very weak |

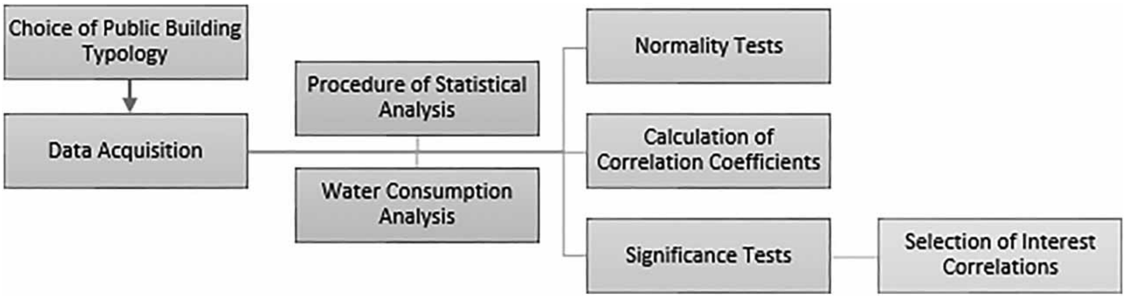


**Figure 1** | Sequence for the study procedure.

Ghisi (2006). The authors present indicators from 10 other buildings of the same typology, in a study that was also performed in Brazil, measuring average consumption indicators ranging from 18.3 to 67.2 L/user/day. The indicators were very similar to the maximum and minimum values found in this research when comparing these data.

Moreover, when considering the studies performed by Proença & Ghisi (2010) on 10 other offices, as well as Santana & Kiperstok (2010) on 14 public administrative buildings, all of them located in Brazil, the average obtained consumption values were 58.9 and 64.8 L/user/day, respectively. Those values are higher than the general average indicator of 39.6 L/user/day obtained in this survey. It shows how much water consumption indicators may vary, considering several factors.

For example, this can be seen on the boxplot graphs in Figure 2 as Building X displayed the lowest average *CI* values, noticeably below 25.0 L/user/day. Meanwhile, that building displayed the highest monthly water consumption average, around 250.0 $m^3$/month.

The lowest average consumption indicator was in Building X (16.6 L/user/day) when analyzing each building separately; precisely the same building, where all lavatory taps were self-closing, included a large number of aerators and operated at a very low flow rate (average 0.04 L/s). Meanwhile, Building V displayed the highest average

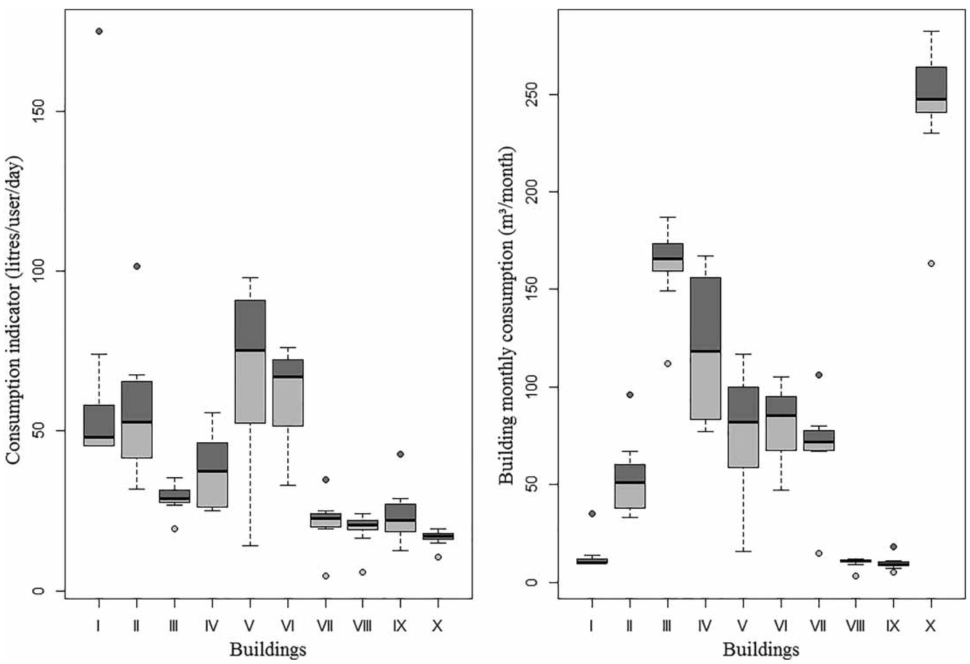


**Figure 2** | Comparison between consumption boxplots of 10 buildings.

consumption (69.3 L/user/day). Some of the most important collected data are shown in Table 3 displaying the respective analytics.

## Distribution of plumbing fixtures

Plumbing fixtures were sorted into their respective type and subdivided into classifications based on their uses or characteristics, according to the respective quantities in which they were found throughout the 10 buildings, as illustrated in Figure 3. It is important to note that there were very different densities in the buildings, not only when the number of employees is considered, but also when it comes to the number of installed plumbing fixtures. The buildings present well-diversified constructed areas, besides the difference between ages, when matched to one another. Therefore, there were not only considerable differences in consumption, but also diversified data related to the measured plumbing fixtures, making it become more understandable. There were a total of 418 plumbing fixtures measured.

## Correlation analyses

Among all the observed characteristics and conditions, flow rates were measured and problems were identified, and correlations were calculated based on those facts. A sample of imported software data can be seen in detail in Figure 4.

Consumption is directly proportional to the number of plumbing fixtures in the building ($r = 0.91$), as is true in the case of correlations involving the monthly building water consumption as observed on Table 4. Furthermore, the more water consumed, the more flaws will be found in devices ($r = 0.85$), which are mostly leaking defects ($r = 0.84$). This can be justified based on higher usage frequency in these devices, because there are increased chances of damaging them, due to increased handling.

As expected, the number of plumbing fixtures displays positive correlation with the number of defects and leaks found. In other words, because of the mere fact that generally there is a greater number of devices, there will also be an increasing number of unsolved problems generating an accumulation, all due to the lack of performance verification and maintenance.

The consumption was noted to increase according to the increasing number of lavatory taps with flow rate below the minimum as defined by the standard ($r = 0.85$) based on the results as shown on Table 5. Meanwhile, the monthly building consumption and leaks (especially in valves) in analyzed buildings were higher according to the number of devices

**Table 3** | Examples of spreadsheet data used to calculate correlations

| Building | Consumption indicator (litres/user/day) | Monthly building consumption (m³/month) | Plumbing fixtures (%) | Defects (%) | Average flow rate of plumbing fixtures (L/s) | Age of the building during measurements (years) |
|---|---|---|---|---|---|---|
| I | 61.74 | 12.75 | 6.46 | 3.32 | 0.1006875 | 50 |
| II | 54.78 | 52.58 | 4.07 | 3.83 | 0.0140000 | 50 |
| III | 29.04 | 163.17 | 13.64 | 8.16 | 0.1376471 | 16 |
| IV | 37.20 | 119.58 | 15.07 | 11.99 | 0.1438824 | 43 |
| V | 69.33 | 77.00 | 4.31 | 4.08 | 0.0205000 | 26 |
| VI | 61.41 | 81.50 | 6.94 | 9.18 | 0.1196620 | 15 |
| VII | 21.75 | 70.75 | 7.66 | 6.63 | 0.1065556 | 26 |
| VIII | 19.33 | 10.33 | 5.02 | 4.85 | 0.0852143 | 37 |
| IX | 24.36 | 10.25 | 2.63 | 1.79 | 0.1970250 | 30 |
| X | 16.59 | 245.83 | 34.21 | 46.17 | 0.0773448 | 19 |
| **Mean** | **39.55** | **84.37** | **10.00** | **10.00** | **0.1002519** | **31.2** |
| **Median** | **33.12** | **73.88** | **6.70** | **5.74** | **0.1036216** | **28** |
| **Variance** | **409.85** | **5,653.59** | **88.79** | **171.03** | **0.0030705** | **175.29** |
| **Std. dev.** | **20.24** | **75.19** | **9.42** | **13.08** | **0.0554119** | **13.24** |

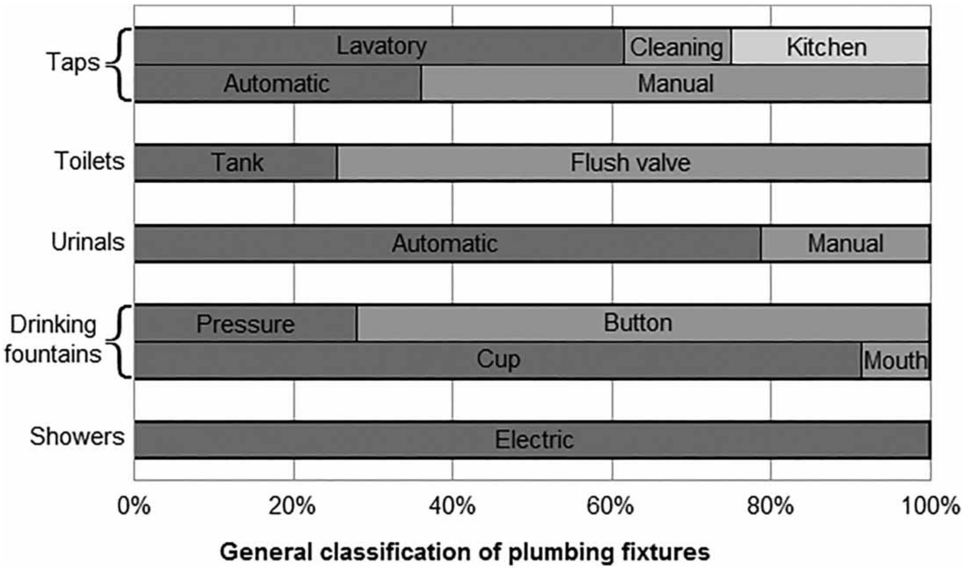


**Figure 3** | General data of plumbing fixtures in buildings.

equipped with water-saving technologies. It was interesting to note, there were not very strong or significant correlations involving water consumption and the overall number of taps and toilets, but only regarding water consumption and taps and toilets equipped with water-saving devices.

For those unexpected cases, there is a possible explanation of a third influential factor. Despite the reduced flow rate in lavatories and the deployment of water-saving technologies, such as automatic and dual flush valves in toilets, the lack of maintenance and the mismanagement of plumbing fixtures eventually annul the conditions supposed to achieve water saving. These circumstances adhere to the ideas of da Silva *et al.* (2008), who stated clarifications on the deployment of new technologies, which must be accompanied by the correct management and maintenance. Otherwise, such investments would be useless. An example of this situation is observed in correlations number 5 and 6 in Table 5 that identified all kinds of defects ($r = 0.89$), the highest indication being caused by leaking valves in self-closing taps ($r = 0.95$), which are supposedly water-saving devices.

Lack of maintenance can also generate a series of successive problems. That is, as there is no adequate correction or preventive maintenance on plumbing fixtures, it is expected that not only one type of tap is affected, but also all kinds of taps may malfunction. Similarly, if taps suffer consequences from incorrect management, other types of devices may display problems as well. This scenario can be better visualized in Figure 5, showing one of the main causes for the correlations involving problems in different types of devices, and this also illustrates how water consumption is affected. According to Balaras *et al.* (2005), the deterioration of installations and components of a building is a result of their own aging processes. However, this process can be greatly influenced by parameters such as the quality of materials used, the local climatic conditions, and the lack of maintenance.

There were a high number of occurrences of correlations between different types of defects. These are shown in Table 6 and emphasize this circumstance of problems linked to the same causes, even though indirectly. Additionally, there are cases, such as the correlation involving toilets with more than one defect and the amount of trickling (a slow leak) in urinals ($r = 0.87$). Regarding this, the greatest number of defects are found in drinking fountains, more toilets have broken valves ($r = 0.81$) and, similarly, the worse the drinking fountain conditions are, the more trickles will be proportionally present in the sample toilets ($r = 0.84$). These and other cases involving taps, toilets, and urinals can be observed in the table.

Likewise, there are a considerable number of results different from the expected behavior in Table 7, among so

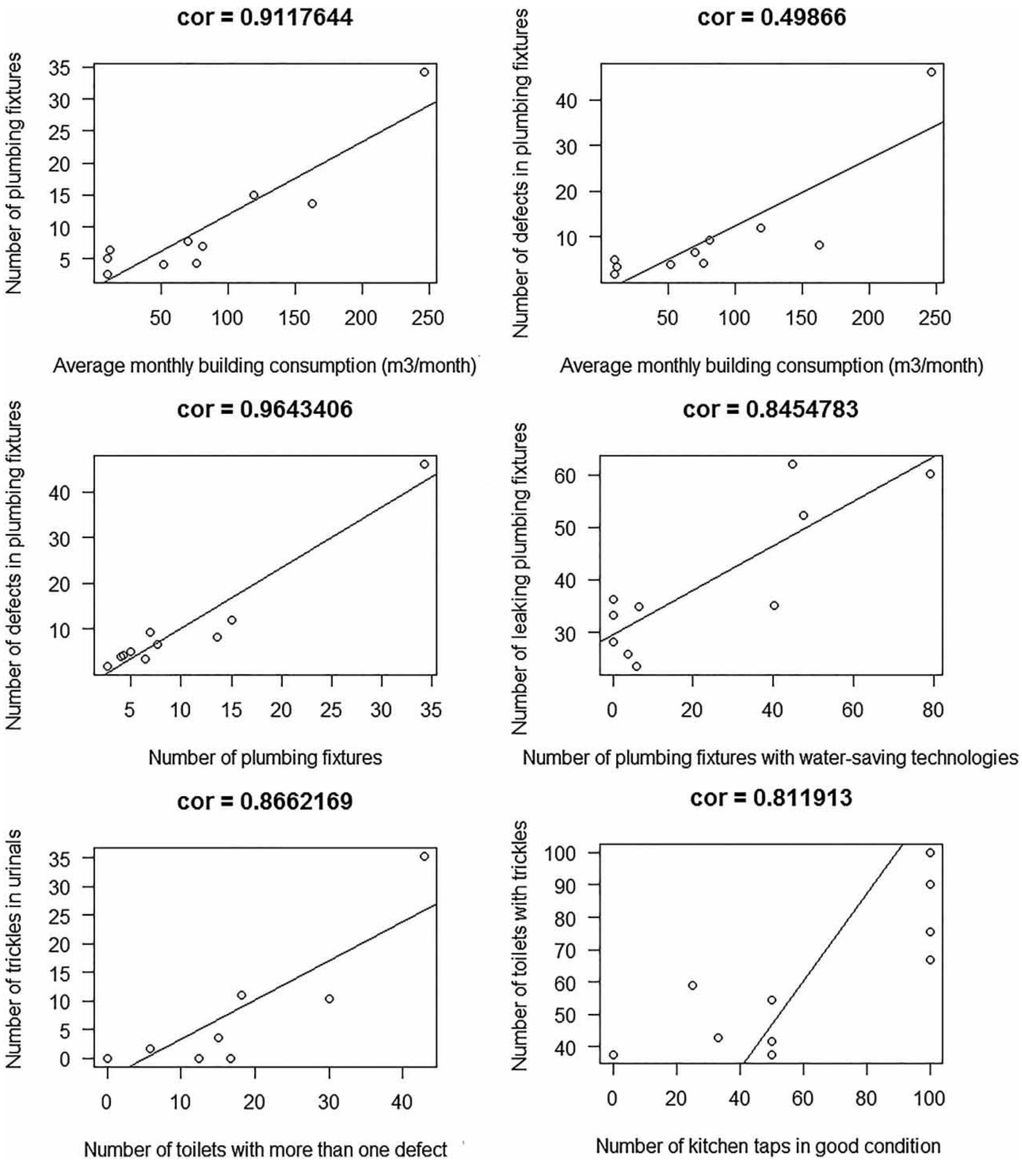


**Figure 4** | Detailed examples of some calculated correlations.

many expected phenomena. There are spurious correlations as found among the number of toilets where trickles are present and the number of kitchen taps that seem to be in good condition ($r = 0.81$). This is possibly explained, as maintenance is only performed when the problem is more evident, namely, taps that seem to be badly maintained in surroundings where food handling occurs daily. These are eventually more easily identified and, therefore, changed. In the case of water trickles, the same treatment is nonexistent, as these leaks are virtually invisible to users. Also, if users notice that a toilet is not in good operating condition, they can choose to use another one in the same bathroom. Thus, a toilet with problems will continue being defective, resulting in permanent and cumulative problems.

All these analyzed correlations show there is no guarantee of a sufficiently functional system even when the

**Table 4** | Correlations mainly involving water consumption and defects

| No. | Description of variables | Correlation coefficient | *p*-value |
|---|---|---|---|
| 1 | Average monthly building consumption ($m^3$/month), Number of plumbing fixtures | 0.91 | $2.39 \times 10^{-4}$ |
| 2 | Average monthly building consumption ($m^3$/month), Number of defects in plumbing fixtures | 0.85 | $1.84 \times 10^{-3}$ |
| 3 | Average monthly building consumption ($m^3$/month), Number of leaks in plumbing fixtures | 0.84 | $2.09 \times 10^{-3}$ |
| 4 | Number of plumbing fixtures, Number of defects in plumbing fixtures | 0.96 | $7.00 \times 10^{-6}$ |
| 5 | Number of plumbing fixtures, Number of leaks in plumbing fixtures | 0.97 | $2.00 \times 10^{-6}$ |

**Table 5** | Correlations mainly involving water-saving devices and defects

| No. | Description of variables | Correlation coefficient | *p*-value |
|---|---|---|---|
| 1 | Average monthly building consumption ($m^3$/month), Number of lavatory taps with flow rate below *NBR* 10281 | 0.85 | $1.83 \times 10^{-3}$ |
| 2 | Average monthly building consumption ($m^3$/month), Number of toilets with dual flush valve | 0.88 | $8.06 \times 10^{-4}$ |
| 3 | Number of plumbing fixtures with water-saving technologies, Number of leaking plumbing fixtures | 0.85 | $2.06 \times 10^{-3}$ |
| 4 | Number of plumbing fixtures with water-saving technologies, Number of plumbing fixtures with leaking valve | 0.84 | $2.36 \times 10^{-3}$ |
| 5 | Number of plumbing fixtures with water-saving technologies, Number of defects in self-closing taps | 0.89 | $6.09 \times 10^{-4}$ |
| 6 | Number of plumbing fixtures with water-saving technologies, Number of self-closing taps with leaking valve | 0.95 | $2.00 \times 10^{-5}$ |

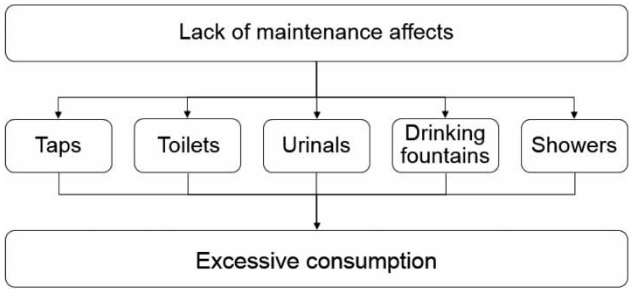


**Figure 5** | Organization chart on successive problems arising from the same cause.

**Table 6** | Correlations of successive problems arising from the same cause

| No. | Description of variables | Correlation coefficient | *p*-value |
|---|---|---|---|
| 1 | Number of garden taps in bad condition, Number of trickles in toilets with flush valves | 0.81 | $4.09 \times 10^{-3}$ |
| 2 | Number of toilets with trickles, Number of self-closing leaking taps | 0.85 | $2.00 \times 10^{-3}$ |
| 3 | Number of leaking urinals, Number of self-closing taps with nonstandard flow rate time | 0.92 | $1.55 \times 10^{-4}$ |
| 4 | Number of kitchen taps with defects, Number of manual leaking urinals | 0.83 | $3.05 \times 10^{-3}$ |
| 5 | Number of toilets with more than one defect, Number of trickles in urinals | 0.87 | $1.19 \times 10^{-3}$ |
| 6 | Number of defects in drinking fountains, Number of toilets with broken valve | 0.81 | $4.10 \times 10^{-3}$ |
| 7 | Number of drinking fountains in regular condition, Number of trickles in toilets with flush valve | 0.84 | $2.40 \times 10^{-3}$ |

plumbing fixtures are in good maintenance condition in the analyzed buildings.

There is a correlation between the increased number of leaking showers and increased flow rates in taps, especially in cleaning purpose taps ($r = 0.85$). This can be explained by the pipe pressure in building plumbing systems. Consequently, it will cause leaks in some existing plumbing fixtures.

**Table 7** | Correlations involving the age of building as well as spurious correlations

| No. | Description of variables | Correlation coefficient | *p*-value |
|---|---|---|---|
| 1 | Number of kitchen taps in good condition, Number of toilets with trickles | 0.81 | $4.34 \times 10^{-3}$ |
| 2 | Average flow rate of cleaning purpose taps, Number of leaking showers | 0.85 | $1.80 \times 10^{-3}$ |
| 3 | Average flow rate of taps, Number of leaking showers | 0.82 | $3.84 \times 10^{-3}$ |
| 4 | Age of the building, Number of toilets with flush tanks with other types of defects | 0.87 | $1.20 \times 10^{-3}$ |

Lastly, the age of the building displays positive association with the number of toilets with defective flush tanks ($r = 0.87$). This was an expected result, considering that toilets with flush tanks (especially those with higher tanks) are usually an older type of device. Therefore, the older the building is, the greater the problem index in these toilets will be, due to the installation time in buildings without proper maintenance care.

Thus, there is a vast amount of plumbing fixtures in regular or bad condition. Additionally, although most installed taps, toilets and urinals have been designed for saving water, many of these devices displayed malfunctions, with occurrences of various magnitudes of leaks. These circumstances may have contributed considerably to the diverse values of water consumption measured in the buildings included in the sample studied.

## CONCLUSIONS

This study was done by measuring 10 public buildings, by performing water consumption analyses and correlating obtained data, thus, it was possible to conclude the following from this research:

1. Low consumption indicators are not necessarily representative of low monthly water consumption in buildings.
2. There was considerable variability of consumption among the buildings, even though they are all the same type (public administrative buildings).
3. Monthly building water consumption is directly proportional to the number of plumbing fixtures in the building.
4. Water consumption in the building is also strongly correlated with the number of leaks and defects found in plumbing fixtures and with the flow rate in a number of noncompliant devices to the limits defined by current legislation. Large numbers of plumbing fixtures are in bad condition, displaying the absence of maintenance and the subsequent link to wasted water.
5. Deployment of saving technologies is inefficient when not accompanied by periodic inspections and corrections.
6. Well-maintained appearance of plumbing fixtures, linear jets and flow rates compliant with standards do not mean there cannot be considerable water wastage in these devices.
7. Campaigns related to water conservation are important strategies for generating water savings, since they involve users in the process and promote changes in water usage habits.
8. Proper management of water usage, doing away with bureaucratic excesses, encouraging users to use water more efficiently and abiding by performing indispensable maintenance are key points to solve the problems described in this research.
9. Oversized diameters and excessive installation of equipment should be avoided. Likewise, investment in specified materials and hydraulic designs, developed by skilled professionals, contribute to longer lifespan of systems and reduce water wastage.
10. Hydraulic design is decisive in water conservation, in addition to predictive maintenance that must be performed throughout the lifespan of the building. It is also important to provide easy and economical maintenance for the plumbing system.
11. Monitoring consumption, verification of the possibility of using alternative supply sources, and monitoring water wastage are indispensable issues when it comes to sustainability in the built environment.
12. Another interesting point is that public buildings should already be designed to provide adequate rainwater harvesting and disposal systems, which make a considerable impact in reducing consumption.

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