Research Paper

Water consumption in public schools: a case study

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ABSTRACT

The objective of this study is to define a consumption indicator (CI) for water that can be used as a reference for developing water conservation plans at public schools. The methodology followed consists of a historical water consumption data survey of all schools in Recife, Brazil, a registration survey of school buildings, the calculation of consumption indicators for the period 2012–2015, and finally, the calculation of reference indicators. The results obtained indicated a reference range for the CI of 13.0 ± 2.0 L/student/day for water considering the set of all school typologies, with a 95% confidence level. The analysis of the schools in groups, classified into four typologies, led to the following reference ranges: 11.5 ± 2.0 L/student/day for regular schools, 13.5 ± 3.5 L/student/day for extended period schools, 22.0 ± 6.0 L/student/day for full period schools, and 18.5 ± 6.5 L/student/day for technical schools. Through the use of a consumption indicator, schools with a limited supply of potable or above average water can be identified and specific actions can be developed to achieve a sustainable use of water in the school environment.

Key words | public schools, water conservation, water consumption indicators

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INTRODUCTION

Population growth, increased urbanization, and industrialization have led to an increase in the demand for drinking water, while also contributing to the degradation of natural resources and compromising the availability and quality of freshwater sources, especially when occurring without planning or organization. Water must therefore be consumed efficiently and sustainably to ensure its availability for both present and future generations (Kanakoudis 2002; Kanakoudis *et al.* 2011; Kanakoudis & Gonelas 2014; Makki *et al.* 2015).

Water conservation planning is normally created so that the population can use water in a rationed manner, either through voluntary or non-voluntary measures, many times as a result of an imminent water crisis (Mini *et al.* 2014; Haque *et al.* 2015; Kanakoudis & Gonelas 2015; Perren & Yang 2015; Parandvash & Chang 2016). However, public buildings frequently fail to receive the same incentive, especially in developing countries. Water consumption in the urban environment is concentrated in residences, commercial buildings, and industries, therefore, the majority of water conservation plans focus mainly on these types of buildings. To make matters worse, many public buildings are old. In Recife, for example, some of the buildings are over 100 years old. In developing countries, in general, it is difficult to carry out projects that guarantee the maintenance and upkeep of these buildings.

Brazilian public schools, in this context, are highlighted by the inadequate use of water in addition to the poorly

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conserved conditions of their sanitation systems, leading to a high degree of water loss. These factors derive from many causes, including the lack of consumer awareness regarding environmental conservation, as well as the absence or inefficiency of a maintenance system (Kanakoudis 2002; Cheng & Hong 2004; Gonçalves *et al.* 2005; Farina *et al.* 2011; Roccaro *et al.* 2011; Kanakoudis & Gonelas 2014, 2015; Melo *et al.* 2014; Kanakoudis *et al.* 2016; Soares *et al.* 2017; Nunes *et al.* 2018). The school becomes a key point for the discussion on water use, as it is an institution responsible for the education of citizens, including environmental education.

The state of Pernambuco in northeastern Brazil has the lowest water availability per capita among all of the Brazilian states (ANA 2012, 2017; Silva *et al.* 2017). With a large part of its territory located in a semiarid region, it suffers drought events in the countryside and rationing in the Recife Metropolitan Area (RMA). Recife is the most populous city in the state of Pernambuco and the ninth most populous in Brazil (IBGE 2016). It also has the greatest number of state public schools, approximately 140. Some neighborhoods in the RMA are not supplied every day by the local water supplier, causing what is known as supply rotation. For this reason, buildings often have water reservoirs or use an alternative supply source, such as groundwater from wells. Even when faced with this scenario, water conservation techniques are only apprehensively exploited by the population, such as the use of rainwater, the reuse of gray water, and even the use of water-conserving equipment.

Soares *et al.* (2017) analyzed water consumption at two public state schools in Recife and found that, although the per capita consumption indicator (CI) was relatively low (less than 5 L/student/day), water losses due to leaks were high and the schools did not use water-economizing equipment. These results have aroused interest in understanding the pattern of water consumption in public schools across the region.

This study presents a tool to characterize the water consumption pattern at public schools through the quantification of the Consumption Index. With it, one can identify schools with a limited supply of drinking water or those that are above average, for example. Both cases require attention in the search for the sustainable use of water in the school environment.

WATER CONSUMPTION INDICATORS

In order to meet the guidelines of a Water Conservation Program (WCP), priority must be given to knowing the characteristics that influence water consumption in buildings (typology, construction process, leaks, population, and climate conditions), and the definition of a consumption profile for a consumer agent – the CI (Makki *et al.* 2015). The CI is a tool to characterize and monitor water consumption in buildings, and is very useful for setting targets and implementing water conservation measures.

The consumption of water in buildings is normally estimated through a CI expressed as a volume of water divided by the number of consumer agents, which is the most representative variable of water consumption in the system. The CI is therefore obtained according to the typology of the building, such as L/person/day in a residential building or an office building, L/bed/day at hospitals, and L/student/day at schools. These values can be used as references when assessing the impact of the reduction of water consumption on the implementation of a WCP (Cheng & Hong 2004; Gonçalves *et al.* 2005; Farina *et al.* 2011; Kanakoudis *et al.* 2011, 2013, 2015).

In the literature, CI values for projects can be found, which are indicators adopted to develop cold water building installations that assure the proper functioning of the sanitary equipment. These CI values can be found in textbooks or government regulations. However, the actual water consumption of a building should be measured and the actual CI may be calculated by relating the volume of water consumed within a certain period of time to the number of consumer agents. A value that represents the real consumption of a building can be obtained, reflecting its particular characteristics as well as the consumption patterns of its population. Through the identification of the actual CI, it is possible to create benchmarks that characterize an ideal consumption situation. Generally, to achieve the benchmark, water conservation plans must be laid out that take into account, among other measures, the use of water-conserving equipment and user consumption habits. Table 1 lists the water consumption indicators for schools from around the world.

UNICEF (2012), in its standards for water, sanitation, and hygiene (WASH) in schools, considers that sufficient

Table 1 | Water consumption indicators for schools worldwide

Category	Value	Unit	Locality	Origin
Daytime school[a]	15 to 25	L/person/day	UNICEF	UNICEF (2012)
School – boarding school[a]	35 to 60	L/person/day	UNICEF	UNICEF (2012)
Primary schools[a]	11 to 18	L/student/day	UK	United Kingdom Department for Education and Skills (2002)
Secondary schools[a]	14 to 21	L/student/day	UK	United Kingdom Department for Education and Skills (2002)
Daytime school[a]	45	L/person/day	India	Bureau of Indian Standards (2010)
School – boarding school[a]	135	L/person/day	India	Bureau of Indian Standards (2010)
Daytime school[a]	20	L/student/day	USA	Mays (2001)
School – boarding school[a]	25	L/student/day	USA	Mays (2001)
Pre-school buildings	30 to 70	L/student/day	Italy	Farina *et al.* (2011)
Elementary schools	10 to 30	L/student/day	Italy	Farina *et al.* (2011)
Primary schools	30	L/person/day	Taiwan	Cheng & Hong (2004)
School – semi-boarding[a]	50	L/student/day	Brazil	Creder (2006)
School – boarding school[a]	150	L/student/day	Brazil	Creder (2006)
State public schools	25	L/student/day	São Paulo	State Ordinance 45.805
Early childhood education	18.85 to 55.60	L/student/day	Campinas/SP	Gonçalves *et al.* (2005)
Elementary school	21.33	L/student/day	Campinas/SP	Gonçalves *et al.* (2005)
High schools	10.68	L/student/day	Campinas/SP	Gonçalves *et al.* (2005)
State schools from 1st and 2nd degrees	4.5 to 81.1	L/student/day	São Paulo	Oliveira & Gonçalves (1999)
State elementary and high schools	6.42 to 62.82	L/student/day	Triângulo Mineiro/MG	Melo *et al.* (2014)
State elementary and high schools	3.9	L/student/day	Recife/PE	Nunes (2015)
State elementary schools	4.9	L/student/day	Recife/PE	Soares *et al.* (2017)
State elementary and high schools	3.9 to 16.9	L/student/day	Recife/PE	Nunes *et al.* (2018)
Elementary and high schools	3 to 9	L/student/day	Sydney/Australia	Sydney Water (2017)

Source: adapted from Nunes (2018).
[a]CI for projects.

water must be available at all times for drinking and personal hygiene, and, when applicable, for food preparation, cleaning, and laundry, considering an indicator of 5 L/person/day for all school children and staff at day schools, and 15–20 L/person/day for boarding schools. In addition, water for flushing toilets must be considered as follows: flushing toilets 10–20 L/person/day for conventional flush toilets; 1.5–3 L/person/day for pour-flush toilets; and 1–2 L/person/day for bidets. These quantities are for day schools and should be doubled for boarding schools. The UNICEF indicators do not consider the use of water conservation equipment or technology; therefore, they are not a benchmark for the rational use of water in schools. They are a CI for school building projects in developing countries.

The city of Sydney, Australia, has already set benchmarks for primary schools based on the use of water conservation techniques. They indicate a range of 3–9 L/student/day to be normal consumption. Indicators below this reference range are considered to be very low consumption, and values above need to be investigated (Sydney Water 2017).

METHODOLOGY

The methodology employed in this study is subdivided according to the following topics: (a) survey of historical data; (b) calculation of drinking water consumption statistics; (c) calculation of the water CI; (d) calculation of reference indicators; and (e) analysis of the data obtained.

Historical data survey

The State Education Secretariat of Pernambuco (SEE-PE) provided a listing of school buildings under the responsibility of the State Government of Pernambuco and respective locations. From this point on, the buildings in the city of Recife, the state capital, were selected, numbering 180 buildings.

According to the classification by the SEE-PE, the schools can be characterized as follows: regular, schools of reference in high school (EREM), or technical schools. The schools of type EREM are subdivided into extended EREM and full-period EREM. For the analysis of water consumption data according to school typology, the classification for the year 2015 was considered.

Regular schools are those in which the student body studies during only a single shift, whether in elementary school or high school. Some regular schools may serve the *Educação de Jovens e Adultos* (EJA – Education of Youngsters and Adults), in this case operating in three shifts.

Schools of type full period EREM have exclusively high school students, who remain at the school during two shifts for all of the days of the week. Most of these schools have been subjected to recent renovations, such as the construction of science labs, computer labs, locker rooms, and lunchrooms, and it is considered that all of them must have laboratories, a kitchen, and an infrastructure adequate to attend to students daily, which requires a better infrastructure than the remaining school typologies.

Schools of type extended EREM are those which, theoretically, should have only high school students; however, in practice, they are currently in a transition process between regular schools and full time EREM. Therefore, this typology presents both high school and elementary school students, with the former group remaining for 3 days of the week during two shifts (morning and afternoon), while the latter has classes during only one shift. The functioning hours can be up to three shifts and the infrastructure is also similar to the schools belonging to the full period EREM.

Finally, technical schools are those which provide professional training courses, such as technical courses for management, construction, and network systems, among others. Their structure includes laboratories and other facilities that meet the particular needs of each course. The students are able to study during one or two shifts. Each building has very specific working hours, which can involve from two to three shifts per day.

A preliminary analysis was necessary regarding the consistency of data provided by SEE-PE and, following this, 137 buildings remained corresponding to the school typology. Four buildings did not have information on the school type but had records of consumption and population and were included in the group of regular schools for the general analysis. However, these schools were not included in the detailed study regarding this group. Therefore, at the end of the selection process, 140 buildings had data on water consumption and their respective number of students.

SEE-PE also provided school censuses showing the number of students properly enrolled in the schools between the years 2012 and 2015. The local water company provided the data related to the monthly historical water consumption of the aforementioned schools. These data were analyzed in order to understand the historical consumption habit of the schools, considering that some of them are in transition, with regard to their operating model. It allowed the analysis of a greater amount of data and the detection of behavioral or structural changes in the buildings. Other relevant factors were the unavailability of data on school population for previous years and the fact that data from the local water utility and the Department of Education were deficient for some years at some schools.

Calculation of drinking water consumption statistics

The historical water consumption data for the period from 2012 to 2015, obtained from the local concessionaire, were organized into an Excel spreadsheet for analysis. Each building received a code from 01 to 180. As was done in other studies carried out across many cities, including Recife, the atypical months corresponding to the periods of vacations were disregarded in this calculation (January, June, July, and December).

The consumption of drinking water is considered here only from the water supplied by the local water company. In the case of the existence of any alternative supply source such as a well or water trucks, this additional availability was not taken into account. However, the service of water trucks is very uncommon within the city of Recife due to the associated high costs. Regarding supply from wells, no monitoring is generally carried out for the values captured, making it impracticable to obtain data related to water consumption from wells.

For each year analyzed (2012, 2013, 2014, and 2015), the annual measurements of monthly water consumption were calculated for each school. Therefore, each building analyzed can represent up to four samples.

Calculation of water consumption indicator

The CI in L/student/day was calculated according to Equation (1), which related the water consumption in the building to the consumer agents for a given time period.

$$IC = \frac{Cm \times 1000}{NA \times Dm} \quad (1)$$

where *Cm* is the mean consumption in m^3/month, calculated for each year; *NA* is the number of consumer agents; and *Dm* is the number of weekdays per month.

For the number of consumer agents (*NA*), the number of students was used, and the period in which these students were present at school was analyzed. The teachers and remaining employees were not considered since the CI is a reference of consumption as function of a specific agent. In schools, the reference normally used is the number of students. For the number of weekdays, an average of 22 per month was considered.

As previously mentioned, the students can attend the school at different hours. This study balanced all of the students by considering them to all have studied during a single shift, doubling them in cases where they remained in the school for two shifts, according to the criterion adopted by Nunes (2015).

Therefore, using this criterion, the number of high school students at a full-period EREM is multiplied by a factor of 2, since they remain at school for two shifts; while those at extended EREMs are multiplied by factor of 1.6, because they study for two shifts during 3 weekdays. The students belonging to the technical schools must be analyzed according to each specific case, while those from the regular type of schools do not have an adjustment factor.

For each school, up to four CIs were obtained, corresponding to each of the years studied (2012–2015). This methodology was adopted since physical characteristics of the school buildings may vary from year to year, such as number of students and employees, presence of leaks, or change in the administrative attitude of the school, among various other factors.

For example, a school that has consumption data from 2012, 2013, 2014, and 2015 will have four indicators, considered as four values in the statistical analysis. Some schools did not have historical water consumption data due to several factors (absence of water meter, impossibility of reading meter, among others); therefore, it was not possible to calculate the four indicators for every school.

Calculation of the reference indicators

The search for a reference CI for the state public schools in Recife took into consideration all of the CIs calculated for all of the schools during the period studied and was organized in such a way that each indicator could be treated as an independent value. Subsequently, the mean CI was calculated as well as the respective standard deviation in order to calculate the reference range of the samples. The limits of the reference range were defined as the mean CI plus or minus a confidence interval of 95%.

The data obtained are plotted in Figure 1 relating the school code (01 to 180) and the respective CI(s) in L/student/day. A general reference range was thereby obtained as a set of all of the samples.

In addition to the general analysis of the CI dataset, a second analysis was carried out that took school typology into consideration. In order to consider the particularities of the distinct school types, the samples were divided into four subgroups: full-time EREM, extended EREM, technical school, and regular school. Reference ranges for the CIs for each of these school types were established, using the data from each subgroup separately.

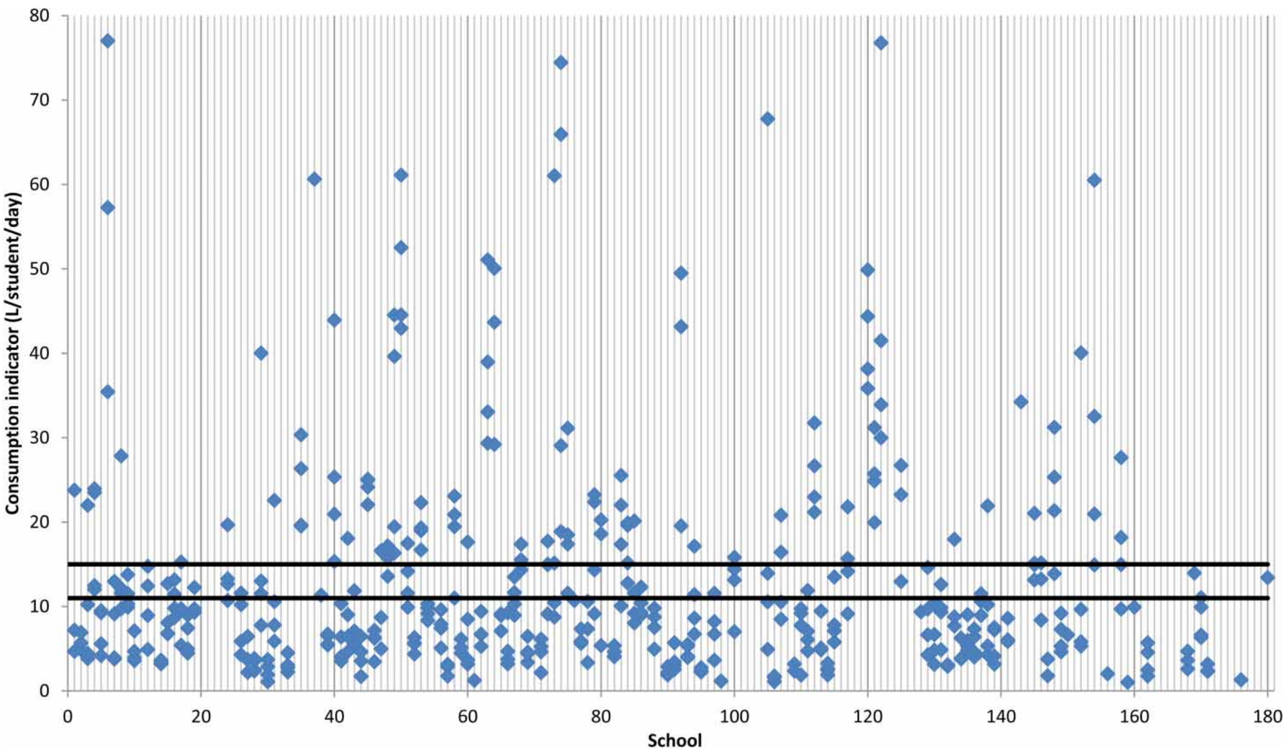

Figure 1 | Consumption indicator (L/student/day) for all public schools in Recife between 2012 and 2015.

RESULTS AND DISCUSSION

The water CI for the total set of schools varied from a low of 1.0 L/student/day at School 159 to a high of 103.5 L/student/day at School 06. The reference range for the water CI calculated for the set of all school typologies in Recife was 13.0 ± 2.0 L/student/day, with 95% confidence, using data from 140 schools.

Values above 200 L/student/day and below 1 L/student/day were not considered in the study because they are likely to not represent an atypical situation and should be thoroughly investigated on a case-by-case basis. These consumptions may have occurred because of water meter measurement errors, the presence of alternative water supply sources, or even the occurrence of large leaks. Figure 1 displays the CI values for the schools and identifies the limits of the reference range.

Out of the 455 total samples, 279 had a CI below the lower limit of the reference range, which can be explained in several possible ways, such as bad hygiene habits of the student body, insufficiency of the water supply in some areas of the city, lack or absence of sanitary equipment at schools, difficulty on the part of the student body to access water, or alternative water supply source(s) in addition to the local water company, e.g., capture from wells.

The 122 CI values above the higher limit may represent a lack of equipment maintenance and consequent presence of leaks in sanitary installations that generate high water consumption associated with losses. Nunes (2015) recorded losses of up to 62% of water consumption at one school in Recife included in this research (School 28). Other issues were also listed by many authors, such as the lack of consumer awareness regarding environmental conservation and the absence of direct responsibility for the payment of the water bill (Gonçalves *et al.* 2005; Melo *et al.* 2014; Nunes 2015). In addition, Nunes (2018) visited 59 of the 140 schools analyzed in this study and discovered that more than 54% of them had no hydraulic equipment with water-conserving technology.

Out of the sample universe, 54 were found to be within the calculated reference range. Among the 140 buildings studied, none of them presented a CI within the reference range for all of the years studied.

Among the particularities, School 100 is located in a rented building, where all the sanitary installations for student use are in a precarious condition, jeopardizing water supply. In contrast, a family home exists on the school building grounds that is supplied by the same distribution branch as the school, meaning that all consumption in the residence is counted as part of the school's consumption. This information was obtained in the field in 2014, illustrating the 5% error expected in this study.

Other schools, such as School 68, presented an indicator within the reference range during only one of the four years. This unit is part of the technical school subgroup, which has a daily routine similar to an EREM, where students study full time. Another difference is that the institution is provided with private support and consequently receives preventive maintenance, effectively correcting any leaks discovered.

Soares *et al.* (2017) studied School 28 in detail during 2014 and raised a hypothesis to explain the low consumption that considered the difficulty students had in accessing restrooms, which required authorization by the monitor, who would have to open two access bars. In addition, the students were not allowed to shower at the school, even though some of the students were there full time, as it is an extended EREM.

Soares *et al.* (2017) also present results for School 33, for the year 2014. In this building, only teachers and employees had access to the water from the local concessionaire. The sanitary facilities allowed to the student body were supplied from the capture of well water, masking the true water consumption by the institution. Other schools that presented a very low consumption might also fall into this group. Being supplied by alternative sources not considered in this study, their CIs may not correspond to reality.

Melo *et al.* (2014) performed a study at public schools in the state of Minas Gerais, Brazil, and assumed that CI values for elementary schools and high schools above 10 L/(consumer agent)/day may be a consequence of waste associated with different factors.

Simultaneously, analyses were carried out for each school subgroup, shown in Table 2.

The analysis of the group of regular schools led to a reference range for the CI of 11.0 ± 2.0 L/student/day. Out of the total 313 CI values analyzed, 181 samples were below the lower limit and 76 samples were above the higher limit. For this typology, none of the schools had all four years within the reference range.

Table 2 | CI reference values at public schools in Recife

School building type	CI – reference range (L/student/day)	No. of schools	Sample size[a]
All schools	13.0 ± 2.0	140	455
Regular school	11.0 ± 2.0	93	313
EREM Extended	13.5 ± 3.5	18	53
EREM Full period	22.0 ± 6.0	19	59
Technical school	18.5 ± 6.5	7	24

[a]Each school may have up to four samples.

By comparing the reference range obtained for the total set of schools, we can observe that the consumption habits at regular schools make sense with this lower indicator, since at regular schools, students are normally not provided with lunch. In addition, the student body remains at school for only one shift, making the use of showers unnecessary. Some schools do not even have this type of equipment.

The group of schools from the extended EREM and full period EREM types showed results very similar to those of the regular schools. The reference range of the CI for extended EREM schools was 13.5 ± 3.5 L/student/day, with 14 CIs above the higher limit and 26 below the lower limit out of the total of 53. The reference range for the full period EREM schools was 22.0 ± 7.0 L/student/day, with a universe composed of 59 samples, where 15 fell above the higher limit and 30 below the lower limit.

The CIs of EREM type schools, both full period and extended, showed that most of the schools have very similar behavior, with slight variations according to the year. The CIs of these subgroups are higher than the overall average, as expected, since these schools have some distinct aspects, considering that they are regarded as model schools for the city. Among the main differences, the presence of pantries that serve up to five meals per day and the presence of laboratories can be highlighted, both of which influence the consumption of water at the school.

The technical schools presented a reference range of consumption of 18.5 ± 6.5 L/student/day. Different from the other subgroups, one school had CIs for all four years within the reference range (School 68).

Among all the types of school, the technical type presented the highest range of CI variation, which may be justified by the fact that these schools involve diverse courses and distinct necessities. Among the courses at School 148, for example, is oral health, which demands a consumption of water higher than other courses, such as the telecommunication course at School 68. School 148 is located in a low-income area of the city and suffers from theft by the local community, compromising the functioning of its sanitary installations, such as when the water pump was stolen. School 68 is located in a wealthy area of the city and has a public–private partnership that handles the preventive maintenance of the sanitary installations at the school.

In this study, it is concluded that many of the schools studied had water consumption levels above the theoretical value used for the development of hydraulic projects in Brazil, whose reference is 50 L/student/day for semi-boarding schools (Creder 2006).

Gonçalves *et al.* (2005), who monitored seven schools in Campinas (SP), including three elementary schools and four state schools, found a mean CI of 21.33 L/student/day for elementary schools and 10.68 L/student/day for state schools. Melo *et al.* (2014) studied schools in the Triângulo Mineiro (MG) and found consumption indicators varying from 6.42 L/student/day to 62.82 L/student/day. Farina *et al.* (2011) investigated 600 school buildings in Bologna (Italy), including kindergartens and elementary schools, finding a CI for elementary schools within a range of 10–30 L/student/day. Cheng & Hong (2004) studied around 300 schools in Taiwan and obtained a mean CI of 30 L/student/day.

When comparing schools investigated in this study with schools from other developing locations, it can be seen that the reference ranges are similar. However, when comparing against results from developed sites or those that have implemented rational water use programs, there is a great disparity.

CONCLUSIONS

The focus of this study was the quantitative assessment of drinking water consumption at the different types of state public schools in Recife, restricting the analysis to historical data from the past few years. Qualitative aspects of water use were not considered. The criterion used to analyze schools (according to the typology) allowed for the consideration of a few important factors for water consumption, such as amount of functioning shifts at the school, period of time students spend in the school, and the preparation of meals.

This study obtained reference values for water consumption at public state schools located in the city of Recife, categorized by the type of school building. It is an important contribution to assessing the general scenario of the city as well as to represent a parameter for the surrounding municipalities or those with similar physical, cultural, social, and economic characteristics.

The reference ranges should not be considered as benchmarks, but as a representation of the actual current scenario in the public schools. These data should be used to prioritize water conservation actions at schools to achieve rational and sustainable water use in these buildings and to ensure that the minimum health requirements are being considered.

For the schools that consumed water above the reference range limit, actions to manage water demand should be considered, such as replacement of conventional equipment by water economizing equipment, and the use of alternative sources such as rainwater and gray water reuse. The consumption of water below the reference range limit at schools should also be investigated. One of the possible factors for low water consumption values is restriction of the school's water supply. In these situations, the study of possible solutions to increase the water supply from other alternative supply sources is recommended, such as capture of rainwater and/or well water.

This research should continue and further studies should assess other indicators, especially indicators regarding leaks and losses, as well as assessment of consumer perception regarding water consumption in schools, since consumer behavior reflects directly on consumption. It is also important to develop extension activities along with the school community, seeking to create awareness for this target public (students, teachers, and employees) regarding the importance of conscious behavior with respect to water conservation, consumption, and basic hygiene. In addition to educational campaigns, other actions to manage water demand in buildings need to be developed, such as preventive maintenance of hydro-sanitary equipment and systems, development of studies for the use of new alternative water supply sources such as the harvesting of rainwater, and development of feasibility studies for the replacement of conventional hydro-sanitary equipment with water-economizing models. It would then be possible to elaborate and implement propositions for water conservation planning at public schools.

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