Systematic review of indicators for the assessment of water consumption rates at hospitals

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ABSTRACT

This study reviews the pertinent literature and summarizes water consumption indicators (CI) for hospitals. To facilitate comparison, two consistent metrics are highlighted, namely the annual water usage per bed (m^3/bed/year) and per built area (m^3/m^2/year) for the different locations. Overall, the review reveals a wide variation among water consumption indicators. Hospitals in Italy have a reported use of 458 m^3/bed/year, the highest indicator reported; the lowest CI among the reviewed articles was for German public hospitals at 103 m^3/bed/year. Not surprisingly, higher water tariffs tend to reduce consumption, while higher per capita income increases consumption. Yet overall CI values tended to reflect a variety of causes, including activity level, laundry arrangements, water costs, the application of sustainable practices, environmental certification and other considerations. Given the high indicator values identified for Brazilian hospitals, future research might consider a more detailed study of how their water consumption might be better managed.

Key words | consumption indicator, green hospitals, health hospitals, water consumption

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INTRODUCTION

Water is a limited resource. Important measures can be taken to improve the management of this limited resource, such as the measurement, comparison and sharing of consumption data (Negri & Kubota 2006). Ilha *et al.* (2006) emphasize the importance of indicators that make it possible to compare the consumption of water among buildings of similar typology using a standard methodology, thereby avoiding inadequate interpretations.

In this context, among the buildings that have a very high level of water consumption, either because of the activities performed there or by the high degree of waste associated with their realization, hospitals deserve special mention. Hospitals are large consumers of water, mainly because of equipment that requires intensive use of water to operate, such as boilers, chillers, cooling towers, sterilizers, air conditioning, laundry, sanitation and other processes (SABESP 2010).

The consumption indicator is the amount of water used by a consumer agent within a specified period of time. In hospitals, the water consumption indicator varies depending on the type (public or private), size (number of beds, built area), geographic location, equipment complexity and practices such as participation in rational water-use programs. The consumption indicator is strongly impacted when water usage is not controlled (Gomes *et al.* 2016; Gonçalves *et al.* 2018).

The determining factors for water consumption in hospitals are usually the number of beds, the size of the built area and the number of employees, so it is common to estimate the consumption indicator as a function of these variables.

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The consumption indicator allows for analysis and comparison of hospital performance with regard to water use, and is generally determined according to the built area, number of beds, or number of employees.

The Department of Health and Human Services (2015) states that measuring water consumption per square foot is best suited to monitor the individual performance of a hospital from year to year. However, due to a high degree of variability, water consumption per m^2 is less useful for comparing performance among different hospitals.

According to the Canadian Water and Wastewater Association (2009), the monitoring of annual consumption by number of beds is fundamental for the design of new units or for hospital enlargements. In Canada, the m^3/bed indicator is appropriate for comparative analysis of water consumption in hospital buildings.

Hospitals that have successfully conducted conservation and rational water-use programs have been able to reduce their consumption by up to 30%. Based on these data, health centers that have implemented water conservation changes can expect a return on investment in the range of 25–40% (AWWA 2008; Calza *et al.* 2012).

Environmental standards and certifications, such as the 'Global Green and Healthy Hospitals community', LEED ('Leadership in Energy and Environmental Design') and EMAS ('Eco-Management and Audit Scheme'), are also important tools for reducing water consumption and applying sustainable practices at hospitals.

The 'Global Green and Healthy Hospitals community' has 1,035 members in 54 countries who use innovation, engineering and investment to transform the health sector and promote a healthy future for people and for the planet (GGHH 2018).

The LEED certification is awarded for sustainable constructions that meet the criteria for resource rationalization (e.g. energy and water). The EMAS seal is a tool developed by the European Commission and other organizations to assess, inform and improve their environmental performance (Green Building Facts 2018).

In this context, the main objective of the current study is to present water consumption indicators for hospitals and to analyze the perspectives and limitations of each article reviewed.

METHODOLOGY

Research strategy

This systematic review was based on guidelines from the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-analyses) model (Liberati *et al.* 2009). The articles selected for review were identified through database searches in the Periodical Portal of Capes and Scopus (CAPES 2018; Elsevier 2018). Only one of the included articles was selected from other sources. The keywords used were 'healthy hospitals', 'hospital', 'water consumption', 'consumption indicator' and 'green hospitals', combined with the Boolean descriptors 'AND' and 'OR' with the synonyms 'healthcare', 'water use' and 'sustainability'. The filters 'Hospitals', 'Engineering', 'Sustainability', 'Sustainable Development', 'Health Care Industry', 'Water Resources and Supplies' and 'Water Conservation' were applied to the selection of articles.

Inclusion criteria

Articles in English, Portuguese and Spanish were included that conducted studies on the consumption of water in hospitals, were published between 2000 and 2018, and which provided water consumption indicators for this type of building.

Exclusion criteria

Articles that presented preliminary studies, those that only indicated the main uses of water in hospitals, those that determined the consumption of water for a specific use, such as hemodialysis, maintenance of equipment temperature, or for climate control were excluded. Studies that did not measure water consumption in relation to any of the commonly used parameters (area, number of beds, or number of workers) were also excluded.

Selection of studies

The articles were initially selected based on their titles and a reading of the abstracts, following which, the full articles

were reviewed. The data included in the systematic review were extracted independently and then compared and discussed. Information on authorship, data collection period, number of hospitals analyzed, nature (public or private), place of study, area, number of beds and employees and average annual water consumption were extracted.

RESULTS

Using the PRISMA research strategy, 1,678 articles were initially identified from Capes ($n = 844$), Scopus ($n = 882$), and other sources ($n = 1$). Applying the inclusion and exclusion resulted in 392 relevant articles that could be included in the analysis. The combination of keywords chosen resulted in many irrelevant articles, mainly on the use of water in hospital treatments, and only 60 articles met the inclusion criteria. From the 60 articles, only 12 were included in the qualitative synthesis. The selection process is illustrated in Figure 1.

The water consumption indicators for hospitals can be obtained according to the following factors: (a) *capacity*: representing the volume consumed per constructed area (m^3/m^2) and serving as a measure of efficiency, (b) *number of beds* (m^3/no. of operational beds), and (c) *number of workers* (m^3/no. of workers) for a given period. The factors are not always determined according to the same criteria, which explains why some authors do not define all the characteristics of the hospitals under review, presenting only those that will be used to determine the consumption indicator.

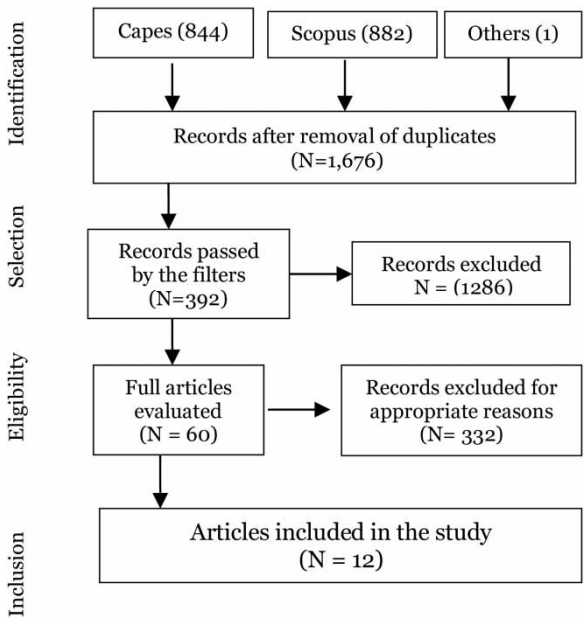

Figure 1 | Flowchart of article selection process.

Table 1 describes the characteristics of the selected articles used in the review of water consumption indicators for hospitals. Data were obtained from 322 hospitals in different countries. This total contains 225 public hospitals, ten private hospitals and 53 teaching hospitals. Public hospitals have been found to have the largest number of workers and beds and to have larger built areas.

Table 2 summarizes the results obtained by the authors from the articles reviewed regarding the water consumption indicators for hospitals. These indicators are important references for the strategic and sustainable management of water resources in hospitals, as it is essential to know the quantity and proportional uses of water in order to promote its conservation.

DISCUSSION

The present study showed that water consumption indicators for hospitals in different countries displayed a considerable degree of heterogeneity among the reviewed articles. The CIs identified were determined in relation to the built area, number of beds and number of workers, allowing for a comparison of the identified indicators and an analysis of the determining factors of water consumption described by the respective authors.

To determine the CI, the authors considered the volume of water in relation to the number of beds, the built area and the number of workers, the latter being the least commonly used. The advantage of using the built area and number of beds in the determination of water consumption is that the identified parameters (built area and number of beds) aid in the design of new units or expansions, reducing investment and maintenance costs. The parameters also make it possible to monitor the performance of hospitals on an annual basis, making it easier to compare hospitals of the same type or to verify that the values are in accordance with best practices. The consumption indicator in relation

Table 1 | Characteristics of the selected articles used in the review of water consumption indicators for hospitals

No.	Author	Location	Study period	Hospitals analyzed				
				Type	No.	Area (m^2)	No. of beds	No. of workers
1	González *et al.* (2016)	Spain	2005–2012	Public Private	10 10	7,077–175,000 7,330–33,989	48–1,075 39–200	300–5,811 237–643
2	García-Sanz-Calcedo *et al.* (2017)	Spain	2010–2014	Public Private	13 –	13,300–66,326 –	43–508 –	– –
3	Gomes *et al.* (2016)	Brazil	2013	Teaching hospitals	49	–	77–1,200	–
4	González *et al.* (2018)	Germany	2005–2015	Public Private	19 –	3,000–151,000 –	45–1,003 –	51–2,793 –
5	Mohee (2005)	Mauritius	2005–2015	Public Private	1 –	– –	435 –	– –
6	Calza *et al.* (2012)	Brazil	2006–2007	Teaching hospital	1	17,369	200	–
7	Dettenkofer *et al.* (2000)	Germany	2000	Teaching hospital	1	352,679	1,709	5,493
8	Rajagopalan & Elkadi (2014)	Australia	2011	Public Private	1 –	1,996 –	– –	– –
9	D'Alessandro *et al.* (2016)	Italy	2013	Public Private	179 –	– –	17–1,530 –	– –
10	Mohammadi *et al.* (2014)	Iran	2007–2013	Teaching hospital	1	–	–	–
11	Collet *et al.* (2016)	India	2016	Public	1	–	183	–
12	Oliveira (2018)	Brazil	2015–2016	Teaching hospital	1	31,006	442	–

Table 2 | Water consumption indicators for hospitals

No.	Author	Hospital type	Annual consumption			Determining factors of consumption	
			$m^3/m^2/yr$	$m^3/bed/yr$	$m^3/wkr/yr$	Economizing	Increasing
1	González *et al.* (2016)	Public and Private	1.59	195.85	53.69	–	–
2	García-Sanz-Calcedo *et al.* (2017)	Public	1.65	262.82	–	–	–
3	Gomes *et al.* (2016)	Teaching hospital	2.60	378.95	–	–	–
4	González *et al.* (2018)	Public	1.20	103.40	62.92	EMAS seal	–
5	Mohee (2005)	Public	–	235.24	–	–	–
6	Calza *et al.* (2012)	Teaching hospital	–	453.70	–	–	Laundry waste = 22.4% pathologies and leaks
7	Dettenkofer *et al.* (2000)	Teaching hospital	–	144.00	–	Rainwater storage	–
8	Rajagopalan & Elkadi (2014)	Public	1.38	–	–	–	Renal dialysis
9	D'Alessandro *et al.* (2016)	Public	–	458.40	–	–	Awareness-raising initiatives at only 10% of hospitals
10	Mohammadi *et al.* (2014)	Teaching hospital	2.28	210.97	–	Water management	–
11	Collet *et al.* (2016)	Public	–	405.55	–	–	Heating, ventilation, and air conditioning systems
12	Oliveira (2018)	Teaching hospital	3.62	257.48	–	–	–

to the number of beds is the most commonly used by the authors of the surveyed articles. Only two authors considered the number of workers (González *et al.* 2016, 2018), and they concluded that this parameter is not statistically correlated to water consumption.

García-Sanz-Calcedo *et al.* (2017) studied small and large hospitals, noting that smaller hospitals consume more water per bed and per built area than larger hospitals. Gomes *et al.* (2016) observed that the teaching hospitals perform well, since the water consumption indicators obtained as m^3/m^2, m^3/bed, and m^3/patient/day, when compared against international data, are within the mean.

González *et al.* (2018) conducted an analytical study at 19 German public hospitals and found the lowest consumption indicator among the studies at 103.4 m^3/bed/year. The reviewed German hospitals stand out with regard to sustainable consumption of water and all have the EMAS seal, a factor that demonstrates the importance of environmental certifications for implementing sustainable practices in buildings. The authors also concluded that the average annual water consumption depends on the number of beds, making this an indispensable factor for the design of new hospital facilities, adapting the distribution and different water uses of this type of installation.

Mohee (2005) studied the water consumption at a public hospital with 435 beds on a small island in the Indian Ocean. The hospital consumed 235.24 m^3/bed/year and did not perform any water conservation activities. It was demonstrated that, at this hospital, the lowest water consumption occurred during the daytime period.

Calza *et al.* (2012) studied the University Hospital of West Paraná (HUOP), which has 200 beds and a consumption indicator of 453.7 m^3/bed/year, representing one of the highest indicators among the results reviewed. Based on this consumption index, the authors justified the need for an institutional water conservation program. The wastage rate was approximately 23% and half of the water used by the hospital was for laundry, with an estimated consumption of between 35 and 40 liters of water for each kilo of laundry, in individual loads.

Dettenkofer *et al.* (2000) determined the water CI for a teaching hospital representative of Germany's public services sector, where 30% of the water consumption occurs at the hospital's own power plant. The hospital also has a rainwater harvesting system, used for non-potable purposes, resulting in a consumption indicator of only 144 m^3/bed/year, one of the lowest among those analyzed.

Rajagopalan & Elkadi (2014) studied a medium-sized public sector clinic in Australia, which operates only 5 days a week, during the daytime. Given the operational pattern, the clinic should have the lowest CI among those analyzed, the rest of which are open around the clock. However, water consumption in this building is affected by renal dialysis, which uses reverse osmosis and discards 30–50% of the original network water used. As a solution to reduce water consumption, the authors suggest that the water discarded by the dialysis apparatus be transferred to a reservoir and used to generate steam for sterilization units, for plant irrigation and for sanitation systems.

In the study by D'Alessandro *et al.* (2016), the average number of beds and the average annual consumption at 179 public hospitals in Italy were reported, allowing for the calculation of a consumption indicator of 458.4 m^3/bed/year, the highest indicator obtained in this review. The authors analyzed a large number of hospitals, which may make the results of the consumption indicator less representative, since small hospitals or those that do not perform consumption-intensifying activities can mask the results. The authors state that the lack of attention to the problem of high water consumption can result from the low cost of the water supply in Italy, as well as in other European countries.

The results obtained by D'Alessandro *et al.* (2016) have confirmed the results of many empirical studies on water consumption in European countries. That is, the tariff applied to water use has a strong negative effect on water consumption (water consumption decreases when the tariff increases), while per capita income has a positive effect on water consumption. According to Dalhuisen & Nijkamp (2002), tariffs are often used as a tool to improve water economy. The implementation of efficient water pricing practices that promote equity, efficiency and sustainability in the water sector is probably the simplest conceptual tool, but possibly the most difficult to implement politically (Romano *et al.* 2014).

Low water tariffs and inefficient pricing support the idea that public water utilities (and the politicians involved in their management) may be more interested than the private

sector in meeting citizens' water needs and at the same time lowering water tariffs, despite the negative effect this has on water sustainability and environmental preservation. Indeed, public enterprises could be more interested in meeting the goals of politicians, who are associated with securing election success and long-term retention through the provision of benefits such as low-cost goods and services, such as water (Romano *et al.* 2014; Romano & Guerrini 2014).

Mohammadi *et al.* (2014) studied the energy consumption of the Sanandaj Tohid Teaching Hospital in Iran for 7 years (2007–2013). The average water consumption indicator over the 7-year period was 210.97 m^3/bed/year and 2.28 m^3/m^2. In the last year of the study, the hospital reached indicators of 144.9 m^3/bed/year and 1.62 m^3/m^2. This reduction occurred after corrective measures were taken at the facilities, the establishment of an energy committee and the appointment of experts to monitor energy consumption and train employees.

Collet *et al.* (2016) conducted a study at the 183-bed Tata Medical Center Cancer Hospital in India. The hospital faces limitations on the use of raw water from the main supply sources (two deep wells and water supplied by the government) as they have high total hardness, high iron content, and a significant number of total and fecal coliforms. The highlighted water quality properties make the water unsuitable for cooking, hand washing, cleaning, or air conditioning. The listed water-use activities require a total of 200,000 liters of water per day. Reverse osmosis (RO) filtered water is used to meet them.

Given the high demand for RO filtered water, Collet *et al.* (2016) reported that the cost of water became highly sensitive to the cost of electricity. As an alternative, the authors calculated the rainwater capture potential of the hospital, with 4,409.20 L for the period from July to October (the rainy season in the region). The CI obtained was 405.55 m^3/bed/year. Heating, ventilation and air conditioning systems were identified as responsible for the excess water consumption, as they consume 72,000 L/day (36% of all water used by the hospital).

Sanandaj Tohid Hospital (CI = 210.97 m^3/bed/year) and Tata Medical Center (CI = 405.55 m^3/bed/year), from different regions of Asia, showed a high variation in their consumption indicators. While at the Iranian Sanandaj Todid Hospital, measures are being taken to reduce water consumption and improve management, at Tata Medical Center it is necessary to focus primarily on the quality of water provided and seek alternative sources of supply. These differences reflect Indian cultural and governmental aspects. The variation demonstrates how the quality of water provided by the public supply influences hospital water and resource management.

Oliveira (2018) studied the Hospital Getúlio Vargas (HGV), located in the city of Recife, Brazil, a public teaching hospital founded in 1953. The CI in relation to the built area of 3.62 m^3/m^2 found for the HGV is the highest among those surveyed in this study. According to information gathered by the author, the HGV does not currently have any educational campaign on the theme of 'water'. In addition, only 14 of the hospital's 385 faucets make use of economizing equipment. This represents only 2.18% of all sanitary appliances. There is also a high leakage rate at the hospital and it is estimated that 5,393 L/day is wasted.

It can be seen that studies carried out at hospitals in Brazil stand out because of their high consumption rates mostly caused by high rates of leakage. It is possible to identify the difference between the CIs obtained for Brazilian hospitals compared with those from other countries in the graphs found in Figures 2 and 3.

Alternatives have been developed at hospitals to reduce the consumption of treated water, based on the use of either rainwater or wastewater. Table 3 presents some examples of these alternatives, which are presented in the Saúde Sem Dano (2014) report of the Green and Healthy Hospitals Network, demonstrating concrete actions performed at hospitals that can serve as examples for use in other buildings of the same typology.

However, technological actions alone will not be sufficient to achieve sustainable consumption if water demand management is absent and users are not committed to conservation. The installation of economizing technologies should always be accompanied by campaigns to increase user awareness. Users should not be expected to acquire self-awareness independently, but should be adequately informed and educated to use innovative technologies, to understand how they can achieve sustainable consumption and the reason for their implementation (Feldman 2011; Gonçalves *et al.* 2018).

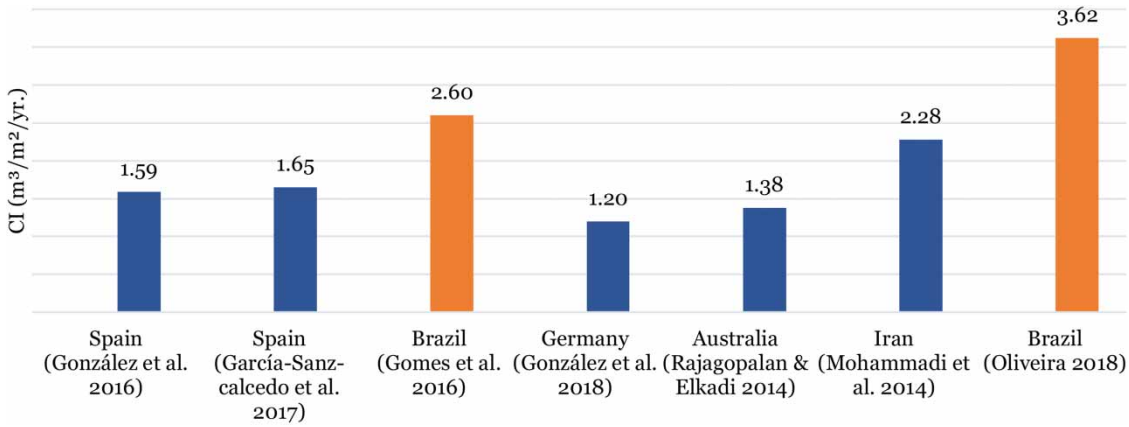

Figure 2 | Water consumption indicators as m^3/m^2/year.

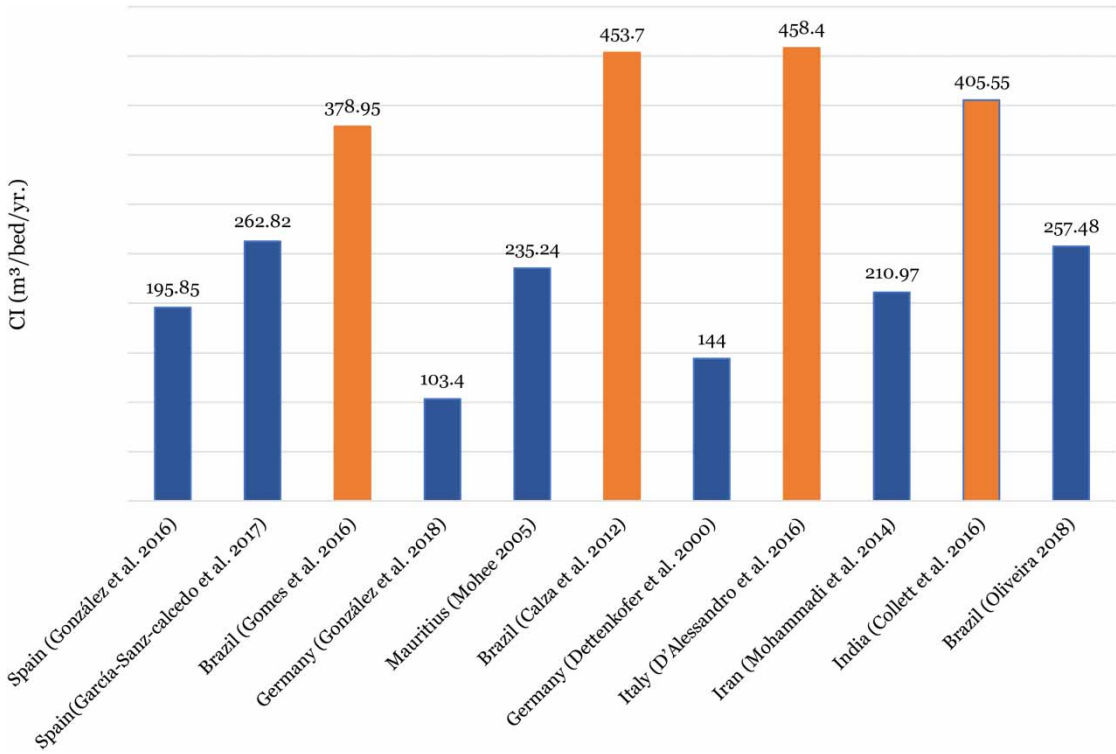

Figure 3 | Water consumption indicators as m^3/bed/year.

It is also important that the results of the campaigns be evaluated. For example, understanding information, pamphlets and other educational materials distributed to users, and the effectiveness of the campaign, making it possible to determine which aspects work well and which need to be changed, identifying the habits and perceptions of users that can change, as well as those that have not changed (Hoy & Stelli 2016).

Given the results obtained, it is clear that public-sector water management must implement efficient water pricing practices that promote equity, efficiency and sustainability, because water consumption decreases as water tariffs

Table 3 | Alternative measures for reducing water consumption in hospitals

Location	Hospital	Action performed
Mumbai, India	Koohinor Hospital, 100 beds, with LEED Platinum international certification	Rainwater collection system and wastewater treatment, resulting in water savings of 40%
Mirebalais, Haiti	Mirebalais Teaching Hospital	Black water treatment system
Butaro, Rwanda	Butaro Hospital	Rainwater storage for use in flush toilets
Singapore	Khoo Teck Puat Hospital	Uses recycled municipal water and rainwater drawn from a large adjacent retention tank for irrigation of gardens
Waitakere, New Zealand	Waitakere Hospital	Employs a vast rainwater collection system, channeled through valves and infiltration basins (rain gardens), for irrigation and flushing

Source: Adapted from Saúde Sem Dano (2014).

increase. In hospitals, where users are not directly affected by bill increases when water is wasted, it is essential that management develop actions that help to implement sustainable practices, such as obtaining environmental certifications, making use of rainwater, reusing water from hospital medical processes and regular equipment maintenance.

CONCLUSION

The analysis of the presented data shows that a great variation exists in the water CI among the hospitals studied. Several reasons may explain the variation, such as: age of the building, state of conservation of the units, degree of user perception about rational use of water, activities developed, presence of laundry and leakage rates, among others. To determine the CI, it is important to highlight the characteristics of the hospital structure, operation and geographical location, as they directly influence the value of the CI obtained and allow hospital efficiency to be compared. In most of the reviewed articles, the parameters used to determine the CI are the number of beds and the built area. The number of workers is the least used, and the two studies that applied it found that it is not sufficiently consistent for a proper determination of the CI.

Therefore, prevention of excessive consumption or waste of water, systematic monitoring of consumption and research carried out at educational institutions are fundamental for identifying atypical consumption and obtaining best practices in the management of a hospital's water resources.

The two review articles that reported the application of sustainable practices in the hospitals had the lowest water consumption indicators, making clear the importance of sustainable practices in water consumption at hospitals.

Determining the consumption indicator is the first step in the analysis of water consumption at hospitals. In addition to the hospitals' specific characteristics, it is important that consumption is analyzed in a general way, investigating the effects of water tariffs, climatic conditions and geographic or demographic characteristics. An adequate understanding of the listed factors is essential for developing and implementing appropriate policies for this type of study.

The principal results obtained from the systematic review are the identification of the number of beds as the parameter most used by authors to determine the CI and the high level of performance of German public hospitals with regard to water use, with the lowest consumption indicator among the reviewed articles, at 103.4 m^3/bed/year. The largest CI found in this review belongs to Italian hospitals, with 458.4 m^3/bed/year. It has also been observed that the tariff applied to water use has a strong negative effect on consumption (water consumption decreases when the tariff increases).

Analysis of the factors responsible for the low or high water performance of hospitals makes it possible to conclude that by combining the best practices of the public sector and of hospital management with regard to water supply and management, low consumption indicators can be achieved.

Future research should consider a detailed study on water consumption at hospitals in the state of Pernambuco,

Brazil, which would include a combination of measures to reduce water consumption and verify the most appropriate actions to be taken in each situation, as well as analyze the feasibility of using water from alternative sources.

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