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Quantitative Determination of Potable Cold Water Consumption in German Hospitals

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Abstract: A hospital's water installations are critical for its function, but the environmental cost is high. This study quantifies the mean potable cold water consumption (PCWC) in 19 hospitals belonging to the German Public Health System. The hospital floor area ranges from 3000 to 151,000 m^2 and the number of beds from 45 to 1003 beds. To this end, 60 Eco-Management and Audit Scheme statements were analyzed corresponding to the period 2005–2015 in accordance with their geographic location, heating-degree-days per year, cold-degree-days per year, hospital category depending on the number of beds, floor area, and number of workers. It was found that PCWC is greater in hospitals located in areas with greater heating-degree-days per year. The potential mean annual savings estimated were 8,600,000 m^3 of water equivalent to 15,000,000 euros, 4000 MWh energy, and 30,000 tons of CO_2 emissions. It was concluded that, to determine the mean annual water consumption, it is preferable to use the number of beds as reference indicator, and the value of the consumption as reference indicator was proposed as 103 m^3 per bed per year.

Keywords: healthcare center; environmental quality; hospital; water consumption; healthcare engineering

1. Introduction

Hospitals' high water consumption and their need for this water in order to provide proper care mean that the water supply is one of their critical supplying [1]. The hospital industry uses significant amounts of water for both technical equipment (X-ray machines, sterilizers, vacuum pumps, etc.) and the services it offers [2]. Given this situation, there needs to be a change in current consumption trends towards saving water, optimizing its management, and towards respect and awareness of it as a resource, its equitable distribution [3], and its value as an ecological and social asset [4].

A study was carried out during the period from March to July 2012 of German organizations that have the Eco-Management and Audit Scheme (EMAS) seal. EMAS are European Union standards for organizations that have implemented an EMS (Environmental Management System) [5] and acquired a commitment to continual improvement, as verified by independent audits [6]. This is a management tool developed by the European Commission for firms and other organizations to assess, inform, and improve their environmental performance. The results of the study conducted in Germany in 2012 were included in a report entitled "EMAS in Germany—Evaluation 2012" [7]. It found that the states with most EMAS records were North Rhine-Westphalia with 10%, Bavaria with 20%, and Baden Württemberg (the most representative) with 32% of the total number of EMAS records in Germany.

Urban water consumption in Germany is about 4554 hm^3 per year, 13.8% of the country's total water consumption [8]. The mean daily per capita consumption is 121 L at a cost that ranges from 1.23 €/m^3 to 2.17 €/m^3 depending on the different regions of the country [9,10].

The ratios commonly used in European hospitals indicate a mean consumption of 500–1000 L/day/bed [11], but these data fluctuate widely depending on the place studied, type of establishment, date of construction, user volume, workers, green areas, and services offered. The data for the US are in the range 300–550 L/day/bed [12], and for Germany 300–611 L/day/bed [13]. For hospitals in Spain, González et al. (2016) determined a mean consumption of 534 L/day/bed [14].

Similar recommendations are those used by the Mexican Institute of Water Technology, with a value of 800 L/day/bed and the Pan American Health Organization of 450 L/day/bed [15,16]. More recent Canadian studies indicate even higher ratios of 900–1800 L/day/bed [17].

Water consumption is also high in other countries. For example, in an Indian hospital the total potable cold water consumption (PCWC) was 1110 L/day/bed [18], and in a hospital in Mauritius water consumption was estimated at 238.71 m^3 per patient per year [19].

The usual key points of consumption in a hospital are the following: sanitary use, sanitary hot water (SHW), potable cold water (PCW), irrigation of green areas, cooling towers/air conditioning, laundry, air conditioning, kitchens, sluicing, and therapeutic pools [20].

In Germany, the potential savings that might derive from water management in hospitals has yet to be systematically studied [21], even though the real prospects for savings are high given that in 2016 there were 1951 operational hospitals with a total of 498,718 beds [22]. Nonetheless, the growing interest on this subject is leading to an increasing number of studies on the implementation of environmental audits, such as that carried out by Dettenkofer et al. (2000) [23].

The sparse amount of research carried out so far has been with small samples of buildings, and therefore with low statistical significance. The aim of the present study was to analyze and quantify the mean PCWC of hospitals in Germany based on different variables or factors and to determine indicators of consumption that might be used as referents to optimize its management.

2. Materials and Methods

An analytical study was carried out from 2005 to 2015 in 19 German hospitals that had been built or reformed between 1980 and 2005, and that belonged to the States of Bavaria, Baden-Württemberg, Lower Saxony, Bremen, and North Rhine-Westphalia. The mean annual water consumption of each of these hospitals was analyzed.

The data for analysis were extracted from the EMAS Regulations [24] and specifically, from the annual reports for the EMAS certificate, and calculated by each hospital during the period of years analyzed in this study. In total, 60 German hospital EMAS statements have been analyzed [25]. Table 1 identifies the hospitals analyzed, indicating the useful area, number of workers, and number of beds.

The Kliniken Landkreis Heidenheim hospital was excluded from the final analysis because there were no data about its built surface area, as also was the Klinikum Harlaching hospital since the EMAS studied detected a serious leakage problem in the water supply.

The numbers of beds and workers were obtained from the annual data published by the German Hospital Federation [26]. In both cases, the values were taken as the averages of the corresponding interval of years. When calculating the floor area of the hospital, only the area for healthcare use, expressed in square meters (m^2), was taken into account.

To perform the statistical analysis, a two-way ANOVA test was carried out to decide whether or not the random samples of k populations had the same mean. To this end, three indicators of water consumption were used based on the area, number of workers, and number of beds. These indicators were chosen because they are the ones that are usually used in hospital analytical accounting and appear in the scientific literature. Besides, they are the ones the governments typically use to carry out water efficiency assessments. The ANOVA test requires the samples to be normally distributed, and have the same variance. Levene's test was used to verify it [27]. The analyses showed that there was a statistically significant influence of a variable on the valuations obtained when the confidence interval was taken to be 95%. Table 2 gives the details of the experiments carried out. These factors were chosen over other potential factors because they were found to generate the most significant differences in the identification of water consumption ratios since they correspond to exogenous variables that do not depend on the internal management of a hospital but on the thermo-hygrometric conditions of the location and size of the hospital.

Table 1. List of hospitals analyzed.

State	Hospital	Floor Area (m^2)	n° Workers	n° Beds
Bavaria	Bezirkskrankenhaus-Kaufbeuren	27,076	626	414
	KlinikImmenstadt	8847	334	161
	KlinikSonthofen	3187	51	45
	KlinikOberstdorf	5150	112	70
	KH Rotthalmünster	22,941	385	193
	KH Vilshofen	16,474	385	182
	KH Wegscheid	7500	159	60
	KlinikumBogenhausen	86,000	1480	951
	KlinikumHarlaching	73,604	1099	749
	KlinikumNeuperlach	39,260	776	545
	KlinikumSchwabing	125,238	1327	953
	KlinikThalkirchenStrasse	12,600	105	131
Baden-Württemberg	KlinikenLandkreisHeidenheim	-	1566	568
Lower Saxony	Klinikum Oldenburg	62,494	2560	814
	KRHPsychiatrieLangenhagen	6600	200	184
Bremen	Klinikum Bremen-Mitte	150,993	2793	1003
North Rhine-Westphalia	LWL-KlinikMünster	48,783	646	376
	LVR-Klinikums Düsseldorf	73,864	1181	522
	LWL-KlinikLengerich	59,870	556	396

Table 2. Factors considered for the study and their grouping in different intervals.

Factors	Geographic Location (GL)	Heating Degree-Days Year (HDDY)	Cold Degree-Days Year (CDDY)	Hospital Category Depending on the Number of Beds (HCNB)
Distribution regarding factors	Bavaria	HDDY1: 1000 to 1250 °C	CDDY1: ≤100 °C	HCNB 1: <200 beds
	Lower Saxony	HDDY 2: 1200 to 1500 °C	CDDY 2: 100 to 200 °C	HCNB2: 200 to 500 beds
	North Rhine-Westphalia	HDDY 3: 1500 to 1750 °C	CDDY 3: 200 to 300 °C	HCNB 3: 500 to 1000 beds
		HDDY 4: 1750 to 2000 °C	CDDY 3: 300 to 400 °C	HCNB4: >1000 beds
		HDDY 5: 2000 to 2250 °C	CDDY 4: >400 °C	
		HDDY 6: 2250 to 2500 °C		
		HDDY 7: >2500 °C		

CDDY and HDDY factors are used to study the influence of geographical conditions, such as latitude, longitude and elevation on water consumption, and because they are typical parameters in this field of research, as stated in the works of Rachida Idchabani et al. [28] and Shanmugapriya and Migadlaska [29].

The heating-degree-days per year (HDDY) parameter is defined as the sum, considering all the days of a period, of the difference between a base temperature (TBc) taken as referent and the mean temperature of the day when that temperature was lower than the base temperature [30]. The base temperature taken as reference was 15 °C.

$$HDDY\ = \sum_{i=1}^{n} (TBc - \tfrac{T_{max}+T_{min}}{2})\cdot X_c \tag{1}$$

with T_{max} being the maximum daily temperature, T_{min} the minimum daily temperature, and X_c a binary coefficient with the value of 1 when the daily mean temperature is lower than TB_c and 0 when it is higher.

The parameter cold-degree-days per year (CDDY) is defined as the sum of all the daily mean temperature values below 0 °C during a period of months:

$$\text{CDDY}\ = \sum_{i=1}^{n} (\sum_{j=1}^{p} \frac{|T_{ij}|}{p}) \tag{2}$$

with T_{ij} being each of the temperatures that during a given day are lower than 0 °C, n the number of days in the period from November to March, and p the total number of measurements made on that given day.

The harshness of a winter is usually classified according to the value of the CDDY parameter. Thus, it is considered a very mild winter when this value is less than 100 °C, normal when the value is between 100 °C and 200 °C, moderately severe when the value is between 201 °C and 300 °C, severe when the value is between 301 °C and 400 °C, and very severe when it is greater than 400 °C.

3. Results

In the following, we present the results of applying the aforementioned statistical methods. First, we shall analyze the correlations between the mean annual water consumption and the three indicators used in the study—the floor area (Indicator 1), number of workers (Indicator 2), and number of beds (Indicator 3). Then we shall present the results of the climate analysis, and finally discuss the results of the two-way ANOVA tests according to the classification factors listed in Table 2.

3.1. Relationship between the Mean Annual PCWC and Floor Area, Number of Workers, and Number of Beds

The sample data sets used to perform the correlation analysis were selected considering the mean water consumption of the 19 hospitals studied during the period 2005–2015. Outliers were excluded from the final analysis (in particular, the data relating to the Klinikum Bremen-Mitte hospital had no statistical relevance). All data outside the interval $\mu \pm 3\sigma$ have been considered outliers. Figure 1 shows the three correlations in relation to PCWC. The area, number of workers, and number of beds that correspond to the data of the three variables are represented along the axis of abscissae on a logarithmic scale, and the mean annual PCWC values along the axis of ordinates. The correlation observed between the mean annual PCWC and hospital floor area is weak (R^2 = 0.6612).

Equation (3) defines the relationship between the mean annual PCWC and the floor area of each hospital.

$$\text{PCWC} = 1.01S_x + 7693 \tag{3}$$

where PCWC is the mean annual consumption of cold water expressed in m^3, and S_x is the hospital's floor area expressed in m^2.

Figure 1 also shows the correlation between PCWC and the number of workers in a hospital. One observes that this correlation is again weak (R^2 = 0.6990). This is indicative of there being no relationship of dependency between the number of workers and the mean annual water consumption. Equation (4) defines the relationship between the mean annual PCWC and the number of workers in each hospital.

$$\text{PCWC} = 51.97T_x + 9013 \tag{4}$$

where PCWC is the mean annual consumption of cold water expressed in m^3, and T_x is the number of workers in the hospital's annual records.

Equation (5) defines the relationship between the mean annual PCWC and the number of beds in each hospital.

$$\mathrm{PCWC} = 127.01C_x + 4580 \quad (5)$$

where PCWC is the mean annual consumption of cold water expressed in m^3, and C_x is the number of beds in the hospital's annual records.

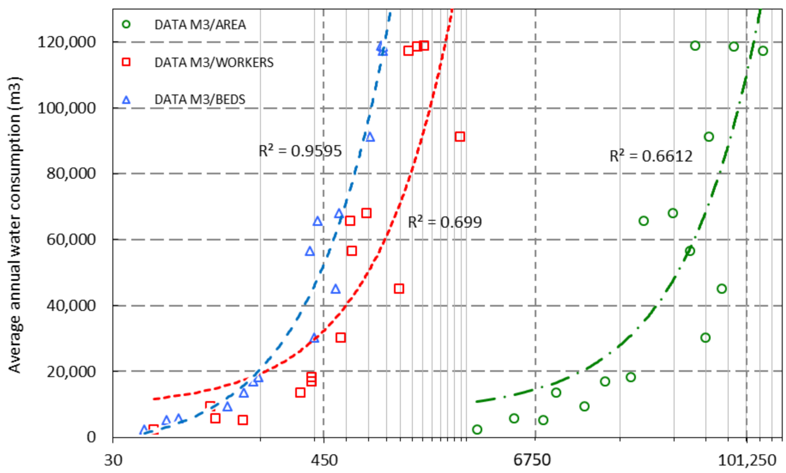

Figure 1. Relationship between mean annual PCWC and the floor area of each hospital, number of workers, and number of beds.

Figure 1 also shows the correlation between PCWC and the number of beds in a hospital. One observes that this correlation is strong (R^2 = 0.9595). It can be concluded that the mean annual water consumption has a relationship of dependency on the number of beds. This result is valid for sizing the installations of new hospitals [31], adapting the different pumping, distribution, and accumulation elements to the actual consumption, avoiding the usual oversizing of this type of installation, which entails significant investment and maintenance costs.

The relatively low linear correlation between the water consumption of hospitals in relation to surface area and the number of workers does not imply that the average consumption of water in hospitals with a similar surface area or the number of workers necessarily has to be different. Therefore, the following is an analysis of the variance of the average water consumption of a group of hospitals grouped in relation to factors considered significant in relation to the consumption of this supply.

In the following, we present the factorial models of the analysis of variance that was performed. The studies carried out were to compare the geographic location (GL) factor with the other factors in Table 2. It should be noted that the proposed models correspond to unbalanced data, since the number of data grouped by factor is different, for example, the number of hospitals (number of data) in the study is different for each location, in particular, the number of hospitals in Bavaria is 11, in North Rhine-Westphalia is 3 and in Lower Saxony is 2. These models were solved using SPSS (Type I sums of squares). To validate the proposed models, we studied whether the basic hypotheses of each model contradict the observed data, i.e., whether or not the model assumptions (normality, independence, and homoscedasticity) are satisfied. To this end, we used graphical and analytical procedures. Once the hypotheses of the model had been verified, we interpreted the factorial models of the analysis of variance that had been carried out. Table 3 presents the *p*-values obtained from the analyses of variance with respect to the statistical indicators.

Table 3. Results for the *p*-value corresponding to the ANOVA for the average annual water consumption for a 0.05 level of significance.

Experiments	Consumption Ratios		
	Indicator 1	Indicator 2	Indicator 3
	$\frac{m^3 \text{ mean water consumption}}{m^2 \text{ built surface area}}$	$\frac{m^3 \text{ mean water consumption}}{\text{number of employees}}$	$\frac{m^3 \text{ mean water consumption}}{\text{number of beds}}$
	p Values		
Geographic location—Hospital category depending on the number of beds			
Geographic location	0.03 *	0.70	0.44
Hospital category depending on the number of beds	0.02 *	0.01 *	0.00 *
R-squared	0.661	0.598	0.684
Geographic location—Total heating degree-days year			
Geographic location	0.16	0.79	0.61
Total heating degree-days year	0.08	0.08	0.04 *
R-squared	0.559	0.380	0.465
Geographic location—Total cold degree-days year			
Geographic location	0.08	0.80	0.69
Total cold degree-days year	0.15	0.05	0.15
R-squared	0.420	0.294	0.206

* At the 0.05 level, the population means are significantly different.

In the two-factor analysis performed between GL and the classification of the hospitals by category, analyzing consumption with respect to Indicator 1, significant differences were found (Table 3) in consumption depending on GL (p = 0.03) and on size (p = 0.02). In the different studies carried out, no analysis was made of the interaction between factors. In the following subsections, we shall analyze in greater depth the results of the different models studied.

3.2. Study of Water Consumption According to Location and Hospital Category (HCNB)

3.2.1. Indicator 1: Mean Water Consumption (M^3) Depending on the Hospital's Floor Area (M^2)

The analysis of variance (two-way ANOVA) considering location and classification by category (see Table 2) with respect to Indicator 1 showed significant differences in both cases. For the present study, the factor with the greatest statistical significance was the number of beds per hospital, at a significance level of 0.05 with a statistic of 5.79 and a p-value of 0.02.

In view of the p-values, all of which were less than 0.05, it is possible to affirm that all the effects are significant. The analysis shows that both the hospitals' size and their GL influence the water consumption per m^2 floor area.

Given the existence of these significant differences, a multiple comparison (post-hoc test) was carried out using the Tukey test together with the corresponding study of homogeneous subsets associated with the said test, the objective being to analyze exhaustively the existing differences. Tables 4 and 5 shows the results for the Indicator 1.

Table 4. Tukey test of indicator 1 for comparison of the means at a 0.05 significance level.

Geographic Location—Hospital Category Depending on the Number of Beds							
Indicator 1							
Geographic location	Mean Diff	SEM	t Value	Prob.	Sig.	LCL	UCL
Lower Saxony—Bavaria	0.67	0.30	3.19	0.11	0	−0.13	0.13
North Rhine-Westphalia—Bavaria	−0.44	0.25	2.47	0.23	0	−1.13	0.24
North Rhine-Westphalia—Lower Saxony	−1.12	0.36	4.45	0.02	1	−2.08	−0.15
Hospital category depending on the number of beds	Mean Diff	SEM	t Value	Prob.	Sig.	LCL	UCL
HCNB 1–HCNB 2	−0.40	0.27	2.12	0.33	0	−1.13	0.32
HCNB2–HCNB 3	0.04	0.28	0.20	0.99	0	−0.71	0.78
HCNB 3–HCNB 1	0.44	0.22	2.88	0.15	0	−0.14	1.03

Table 5. Homogeneous subsets associated with the Tukey test of indicator 1.

Geographic Location—Hospital Category Depending on the Number of Beds						
Indicator 1						
Geographic location	***n***	**Subsets**		**Hospital Category Depending on the Number of Beds**	***n***	**Subsets**
		1	**2**			**1**
North Rhine-Westphalia	3	0.7567		HCNB 1: <200 beds	7	0.9600
Bavaria	11	1.2000	1.2000	HCNB 2: 200 to 500 beds	3	1.3633
Lower Saxony	2		1.8750	HCNB 3: 500 to 1000 beds	6	1.4017
Sig.		0.350	0.113	Sig.		0.237

Table 5 presents the results. The subsets with equal means are shown by columns. The first is formed by the States North Rhine-Westphalia and Bavaria and indicates that there are no significant differences between them. The second homogeneous subset is formed by the States of Bavaria and Lower Saxony, also indicating that there are no significant differences between these two States. Therefore, two groups can be established with similar characteristics of mean water consumption. As one sees in the table, the p-value associated with the first GL group (North Rhine-Westphalia and

Bavaria) is 0.350, greater than 0.05, indicating that the hypothesis of equality in mean consumption can not be rejected for this subset.

The case is analogous for the other subset formed, with a *p*-value equal to 0.113. The subsets were found to differ from each other—the mean consumptions of the first group being different from those of the second. It was also observed that the greatest mean consumption (1.875 m^3 per m^2 of floor area) corresponded to the State of Lower Saxony, and the lowest (0.7567 m^3 per m^2 of floor area) to North Rhine-Westphalia. In the analysis carried out to identify different subsets with regard to the hospital category depending on the number of beds (HCNB), no differentiated subsets were found. The HCNB-3 group was that with the greatest mean water consumption—1.402 m^3 per m^2 of area (Table 5).

3.2.2. Indicator 2: Mean Water Consumption (M^3) Depending on Number of Workers

Regarding Indicator 2, the factorial analysis of variance showed significant differences in one of the two factors used, specifically in the factor relating to HCNB, where significant differences of $F = 7.82$; $p = 0.01$ ($p < 0.05$) were observed. In the subsequent multiple comparison (post-hoc) analysis using the Tukey test (Table 4), we found no significant differences according to the location of the hospitals. This contrasts with the number of beds factor for which no significant differences were identified between the different groups of hospitals by only a very small margin ($p = 0.06$).

In the analysis carried out to identify different subsets with respect to GL, although no differentiated subsets were obtained, it was possible to determine that hospitals located in Bavaria were those with the greatest mean water consumption, this being 65.26 m^3 per worker. This contrasts with the study carried out for the factor HCNB in which two subsets were established with similar mean water consumption characteristics. In the case analyzed the HCNB-3 group (500 to 1000 beds) was the one with the highest mean water consumption, with a consumption of 89.29 m^3 per worker.

3.2.3. Indicator 3: Mean Water Consumption (M^3) Depending on the Number of Beds

The results obtained for Indicator 3 are similar to those analyzed above for Indicator 2. In this case, significant differences at a significance level of 0.05 were obtained for the factor related to HCNB, with a statistic of 11.45 and a *p*-value of 0.00.

In order to analyze in greater depth the existing differences, a multiple comparison (post-hoc) analysis was performed using the Tukey test (Table 4). It was possible to verify that there were no significant differences with respect to the GL factor, but that there were such differences with respect to HCNB.

From the results with respect to the GL factor, we could find no differentiated groups, with the hospitals located in Lower Saxony having the greatest mean water consumption, this being 119.65 m^3 per bed. In the case of the HCNB factor, it was deduced that the mean consumption was similar in the subset formed by the group HCNB-1 and in the subset formed by the groups HCNB-2 and HCNB-3. Therefore, two groups can be established with similar characteristics of mean water consumption. The category with greatest water consumption was that corresponding to the HCNB-3 group, in which the mean consumption was 128.48 m^3 per bed.

3.3. Study of the Water Consumption According to Location and Heating-Degree-Days per Year (HDDY)

The results obtained with the factors that studied location and HDDY showed significant differences in one of the three indicators used with respect to the HDDY factor, specifically that relating to the mean water consumption by number of beds (p_{Beds} 0.04). This is consistent with the Tukey test result which also indicates the existence of statistically significant differences between the HDDY-4 (1750 to 2000 °C) and HDDY-5 (2000 to 2250 °C) groups. It can be concluded that there is a direct relationship between HDDY and water consumption based on the number of beds in the hospital, but not on the area or number of workers.

3.4. Study of the Water Consumption According to Location and Cold-Degree-Days per Year (CDDY)

With the factors location and CDDY, the result of the two-way ANOVA did not show significant differences in any of the three indicators (p_{Area} 0.08 and 0.15; $p_{Workers}$ 0.80 and 0.05, p_{Beds} 0.69 and 0.15), i.e., no direct relationship was identified between CDDY and water consumption by floor area, number of workers, or number of beds in a hospital.

The average annual water consumption per available bed was calculated as being 103.40 m^3/year/bed. Table 6 presents the classification according to the percentiles and the type of statistical indicator

Table 6. Classifications according to percentiles and type of statistics indicators of mean annual water consumption.

Indicator	Percentiles					
	10%	25%	50%	75%	90%	Average
$\frac{m^3 \text{ mean water consumption}}{m^2 \text{ built surface area}}$	0.65	0.77	1.08	1.48	2.01	1.20
$\frac{m^3 \text{ mean water consumption}}{\text{number of employees}}$	36.94	42.96	53.32	87.59	89.59	62.92
$\frac{m^3 \text{ mean water consumption}}{\text{number of beds}}$	74.41	84.04	93.80	124.80	132.77	103.40

Table 7 lists the indicators of mean annual consumption based on the number of beds in a hospital. These indicators were obtained by analyzing the means from the EMAS of the hospitals listed in Table 1.

Table 7. Mean annual PCWC.

Indicator	n° Beds	m^3/Bed
$\frac{\text{annual average water consumption } (m^3)}{\text{number of beds}}$	<200	100
	200 to 500	105
	500 to 1000	108
	>1000	110

Based on the water consumption values analyzed, we estimated that mean annual savings of 8,600,000 m^3 of water are possible in Germany. When performing this calculation, it was estimated that with minimal investment and awareness policies it is possible to reduce the average expenditure of each hospital by 16.5% over a period of two years. This would represent annual savings of approximately €15,000,000, considering an average water cost of 1.75 €/m^3.

It would also be possible to save 4000 MWh, and avoid the emission into the atmosphere of 30,000 tons of CO_2 per year.

4. Discussion

The information about the environmental efficiency of German hospitals registered in EMAS is sufficient, but there are certain deficiencies in the indicators (floor area, number of beds, and number of workers) that make it difficult to carry out a comparative evaluation. This is because the indicators chosen are not always used with the same criteria, and therefore do not adequately quantify the parameter analyzed. This is likely due to a poorly chosen indicator. There are studies that point to such deficiencies according to the indicators used, an example being the EVER study [32].

Any measure to improve the efficiency of a hospital must take into account the climate, social, and operational conditions pertinent for the functioning of healthcare buildings [33]. Therefore, as regards the investments made in hospitals to improve their efficiency, priority should be given to improvements in DHW production, storage and distribution systems, since these are the ones that generate the greatest energy expenditure. Production support systems that use renewable energies, preferably solar thermal, geothermal or biomass are, therefore, recommended.

Efforts should also be made for the operation, piping and recovery of cooling/condensation water towers and for the installation of electronic metres to monitor consumption rates and possible leaks.

Rainwater can also be used, collecting it from the roof and the urbanisation, and using it to irrigate green areas. This is an option that would reduce the consumption of PWHC and its environmental impact. Rainwater harvesting (RWH) or the use of grey water (GW) is not recommended in healthcare buildings because it may increase the risk of bacterial contamination [34].

Concerning gardening, savings of around 25–30% can be achieved through the technical improvement of facilities, the selection of native species and the use of efficient and programmable irrigation systems.

The installation of atomisers in the hospital's distribution network is also recommended. Atomisers are specific saving devices for taps and showers, which inject air into the flow of water to increase its speed and thus reduce the flow between 30% and 50%.

Concerning the water used for cleaning walls, it is recommended to replace traditional systems with microfibre-based cleaning systems, which absorb much more dirt due to the magnet effect produced during scrubbing. This improves the hygiene and overall appearance of the surface and reduces water consumption, task execution time and the amount of chemicals required.

Other effective measures include the use of timers with programmed disconnection for DHW system production by means of water heaters or storage tanks, to interrupt operation when there is no activity [35]. The installation of low consumption taps and tanks with double push button can also be installed to reduce PWHC consumption.

Flushing the facility's water systems can contribute to reducing the risk of proliferation of such bacteria as Legionella pneumophila. However, this considerably increases water consumption [36].

A large part of water savings in a hospital is directly related to its everyday management [37], for which it is possible to act directly through the personnel. It is advisable to make staff and users aware of the importance of saving water through sensitisation and training campaigns, and to seek to maintain comfort in the hospital through the rational use of water [38]. An interesting strategy is the installation of partial water and energy metres in the water facilities, which would allow a detailed control of consumption and obtaining the necessary data for an adequate distribution of costs between the different services of the hospital.

The investment required to reduce water consumption in a hospital is directly related to the type and age of its facilities. In hospitals of more than 20 years old, pipes often suffer from corrosion problems, which depend mainly on the environment in which they are placed, the material used in their manufacture and the operating regime. In these cases, priority should be given to replacing the water supply system by choosing a suitable material for Legionella pneumophila treatments.

The improvement of the pumping network, by means of variable flow distribution with hydraulic balancing and electronic control, is another measure that increases the performance of the installation, reducing its energy consumption, pressure losses and the flow of water driven, contributing to the sustainability of the hospital.

Another interesting strategy is the reuse of condensed water from HVAC chillers by combining air conditioning and water extraction from the air [39].

It was found that water consumption is greater in hospitals located in areas with higher HDDY, and that it is aggravated by greater numbers of beds. Here, we would note that it is paradoxical that hospitals in the HDDY-5 group which has the greatest accumulation of HDDY consume less water—92.475 m^3—than the rest of the groups, with a consumption of 101.9688 m^3 in HDDY-3 and of 141.88 m^3 in HDDY-4. In this case again, of the 6 hospitals analyzed, 2 are in Lower Saxony and 4 in Bavaria, which is one of the States with the greatest implantation of EMAS.

The results of this research have been provided to the health authorities so that they can be applied in the management of hospital facilities in the future.

5. Conclusions

Based on the results, one concludes that in the hospitals analyzed there exists a direct relationship between the annual water consumption and floor area, number of workers, and number of beds, rather than with the factors GL and the category of the hospital. To determine the mean annual consumption of a hospital, the indicator which was observed to be most strongly correlated was the number of beds, so that this should be used as the indicator of reference.

The mean annual consumption is 103.40 m^3/bed (283 L/bed/day), lower than studies which have set it at between 300 and 600 L/day/bed [11]. This may be the effect of applying the EMAS systematics, and of greater sensitivity and interest in reducing consumption.

It was estimated that annual mean savings of 8,600,000 m^3 of water is possible. This would represent an annual saving of 15,000,000 euros taking a water cost of 1.75 €/m^3. It is also possible to save 4000 MWh and avoid the emission into the atmosphere of 30,000 tons of CO_2 per year.

It was shown that there is a trend towards greater water consumption in hospitals with more beds. Indeed, there is a difference of more than 40 m^3 between those in group HCNB-1 with a consumption of 81.47 m^3 and those in group HCNB-3 with 128.48 m^3. The former group of hospitals are located in Bavaria, one of the States that has most hospitals with EMAS in Germany.

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