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Proposal of a Water Consumption Efficiency Indicator for the Hotel Sector

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Abstract: This work proposes a novel indicator (HCWI) for evaluating water consumption efficiency in hotels. The indicator is built as a relative index that compares the current water consumption with an estimated minimum achievable value. To ensure the representativeness and applicability of the index, the evaluation of this water consumption baseline considers each water consumption micro-component individually and has been simplified, so it only requires fundamental characteristics of the hotel and those that are easy to identify and quantify. A value of the HCWI equal to one indicates the best water use efficiency that can be theoretically achieved with the technology available. On the contrary, larger values of the HWCI indicate high levels of water use inefficiency by the hotel. The applicability of the indicator is tested in six different hotels located in a touristic region in the north of Spain.

Keywords: hotel water consumption; efficiency; index; benchmarking

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1. Introduction

The constantly growing pressure on natural water resources has led to scarcity problems in many arid and semi-arid regions such as the Caribbean, Mediterranean, and the Middle East [1–3]. Water availability problems are also expanding to humid areas, where the amount of rain is progressively decreasing. It is expected that water-related issues will increase in the medium and long term due to the larger world population and activity associated with economic growth. In such a scenario, assessing what consequences will appear in tourism, business travel, and the hotel industry in general will be necessary.

The hotel industry is one of the foundations of the tourism and business travel sectors. Neglecting the transitory effect of the COVID-19 pandemic, the continuous economic progress during the last century, and the reduction of travel costs have led to a significant increase in the number of pleasure and business trips [4–9]. Travellers are demanding high-quality accommodation with added-value services at reasonable prices. This is a significant challenge for the hospitality industry, which needs to adapt to stricter quality requirements by offering additional and better services that require less water and energy.

Furthermore, the war in Ukraine has led to an extraordinary energy crisis. In this context, given the well-known connection between water and energy consumption, it is crucial to examine the efficiency of water use in hotels. This analysis is necessary to assess the hotel industry's impact on local water resources, especially in tourist areas, and to propose genuinely effective water conservation measures to help reduce the environmental footprint. The sustainability of the tourism sector strongly depends on the adaptation capability of the hotel industry to the upcoming environmental conditions and the severer legal regulations that will be in place in the future [10,11].

A bibliographic review on the topic may emphasize the exhaustive research conducted about hotel industry sustainability and, more specifically, regarding hotel water consumption from multiple perspectives and approaches [12]. The presented work includes a literature review (Supplementary Material) in which previous studies analysing water consumption in hotels are described and explored in detail. From this analysis exercise, a substantial heterogeneity of water consumption in hotels was identified. Even the unitary water volumes used by different hotels in the same area, expressed in terms of per room or per guest, significantly differ from each other. In most cases, the results of the studies are merely descriptive [13,14] and cannot be employed to produce consistent relationships between different cases or regions, forecast water consumption, or calculate water use efficiency indexes.

Currently, there is no simple, generic, and robust procedure to estimate an achievable minimum water consumption figure for a hotel based on its characteristics and that could be used as a baseline or reference. A water consumption indicator obtained from this baseline could be convenient for assessing the gross efficiency of a hotel's current water consumption and comparing hotels of different sizes and facilities characteristics either in the same region or from different areas. Such a benchmarking tool, kept at a reasonably low degree of complexity, would be helpful for public administrations and regulators, hotel corporations, or small rural hotels keen on improving their environmental efficiency.

This approach is already employed in other sectors to compare the water loss efficiency of different water distribution networks through a relative indicator. In fact, an efficiency index complying with these characteristics has been used by utilities and regulators since 2000 [15] and has been proposed by the new European Directive [16] as a tool to assess water losses management performance by water utilities. Similar to what happens in the hotel industry, where every hotel has its own specific characteristics, each water distribution network also has its own particularities. This heterogeneity does not allow for an easy comparison of water losses between different systems. However, the publication of the infrastructure leakage index (ILI), which considers essential characteristics of the network, provided a compromised solution to the problem. Since then, this practical but straightforward indicator (ILI) has become a common benchmark worldwide for quantifying a distribution network's water loss management efficiency. The calculation of the ILI involves an estimation of the minimum amount of volumetric losses that could be achieved based on the characteristics of the network. The ILI informs about how many times the actual losses are above that minimum achievable value.

This work proposes a new indicator for evaluating water consumption in hotels (HCWI) that is calculated following similar principles as those used for calculating the ILI. This new indicator estimates the minimum achievable water consumption in a hotel based on its characteristics and different water uses (micro-components) and informs about how many times the actual consumption of the hotel is with respect to this minimum achievable volume. In other words, this indicator shows the improvement margin for water consumption reduction for a particular hotel if different efficiency measures are implemented.

In summary, the HCWI is not only a benchmark indicator between different hotels but also between the current hotel's water consumption and the hotel's consumption if water-efficiency measures were implemented. Therefore, the results obtained for that improvement degree can be directly comparable between different hotels.

2. Understanding Water Consumption in Hotels

Total water consumption in a hotel depends on various activities related to providing services and accommodation to guests that use water in one form or another. Previous works, which will be analysed in the next section of the paper (Section 3), have identified potential sources of water consumption within the hotel industry. These activities are commonly known as micro-components of water consumption and constitute the fundamental components of the total water use. Given the variety of accommodation types within the hotel industry, not necessarily all micro-components are present in a specific establishment. The following list briefly describes the various micro-components that have been identified for water consumption in hotels (Section 3) and the primary factors affecting each one of them.

1. Rooms: Guests' water usage inside hotel rooms is constrained to sanitary uses. This water use is comparable to the indoor consumption of a household restroom as the water appliances are the same: tap, toilet, bidet, and shower or bathtub. As expected, water use inside guest rooms strongly correlates with the hotel occupation

rate. The main influential factors identified for this micro-component are the following: technical characteristics of the water appliances, dynamic water pressure available at the consumption points, and consumption habits of guests.

2. Kitchen: Water use in a hotel's kitchen is extremely similar to water consumption in a restaurant's kitchen. It comprises meals preparation, kitchenware washing, and cleaning activities. The magnitude of this micro-component depends not only on the hotel occupation rate but also on the possibility that the hotel restaurant is open to non-guests. In addition, the technical characteristics of the kitchen equipment (taps, dishwashers) are other influential factors.
3. Laundry: Water consumption associated with the laundry is required to wash towels, linen, and other clothes. Washing is typically done using industrial washing machines owned by the hotel or outsourcing laundry services to an external company. Water usage associated with this micro-component happens outside the hotel premises when this later situation occurs. Similar to water usage inside rooms, water laundry consumption directly depends on the hotel occupation rate. The main relevant factor that affects its magnitude is the technical characteristics of the washers used and the linen replacement policies followed by the hotel.
4. Pools: As in the previous item, the water amounts required by the regular use of swimming pools, spas, or other water attractions also depend significantly on the type of hotel. Hotel occupation rate has only an average influence on this micro-component because of the relatively high operation and maintenance flow rate in this type of installation. The main influential factors are the size of facilities and the hydraulic systems technology.
5. Irrigation: This micro-component accounts for the water required to maintain gardens and green areas. Irrigation depends hugely on the type of hotel: it may be negligible in urban business hotels, and conversely, it might demand significant amounts of water in the case of large holiday resorts. Hotel occupation rate does not significantly influence irrigation water or, at least, not in the same proportion as other factors such as the size of gardens, irrigation systems, plant species, or the climate itself.
6. Cooling and heating: This micro-component includes the water required by the hotel's air conditioning (AC) system. The amount of water used for cooling exhibits a medium dependence on the occupation rate of the hotel. The reason is that there are certain areas of the hotel, such as the reception, halls, corridors, the restaurant, or the gym, that need to be cooled independently of the hotel occupancy. However, other spaces, such as the guests' rooms, are only cooled if they are occupied. The main influential factor of this micro-component is related to the air conditioning system's technical characteristics and the climatic conditions at the hotel's location.

Following the previous description, Table 1 summarises the factors influencing the magnitude of each micro-component.

Table 1. Summary of characteristics of water consumption for each micro-component.

Micro-Component	Rooms	Kitchen	Laundry	Pools	Irrigation	Cooling and Heating
Aim of use	Sanitary	Meals preparation and cleaning	Clothes washing	Recreational	Garden watering	Air conditioning
Devices	Taps Toilets Bidets Baths Showers	Taps Dishwashers	Washers	Pools Spas Water attractions	Hoses Sprinklers Drippers	Cooling towers
Influencing factors	Technical features of devices	Technical features of devices	Technical features of devices	Climate and evaporation	Technical features of irrigation systems, type of plants, grass area	Technical characteristics of the AC system
Dependence on hotel's occupancy rate	High	High	High	Medium	Low	Medium

3. Literature Review and Conclusions

In order to set the context of this work, an extensive literature review was carried out. A total of 30 different specialised publications [17–46] were analysed from four different perspectives: year of publication, geographical location, number of hotels audited, and analysis methodologies used. The aim of this review was not only to determine reference figures for water consumption in hotels according to their characteristics but also to highlight how much dispersion there is in this type of data and how much variability, almost heterogeneity, can be found in the procedures behind it.

The detailed explanations and results of this review are included in the Supplementary Material. However, due to the variety of factors influencing water consumption and the dissimilarities between hotels, these reference values must be organised and presented from multiple perspectives.

It is unreasonable to compare hotels of different sizes directly, and their water consumption needs to be expressed using suitable relative indicators. Hence, water consumption from the various studies was recalculated with the information available to obtain relative consumption indicators. For this purpose, three essential characteristics of a hotel, which are easy to determine, were selected: floor area, number of rooms, and number of guests.

Relative daily total water consumption in hotels. Figure 1 presents the daily total water consumption from the 30 studies considered as a function of the selected three descriptive characteristics of the hotels. For each characteristic, a box-whisker chart shows the average value, median, maximum, minimum, and data dispersion of the compiled water consumption figures previously published.

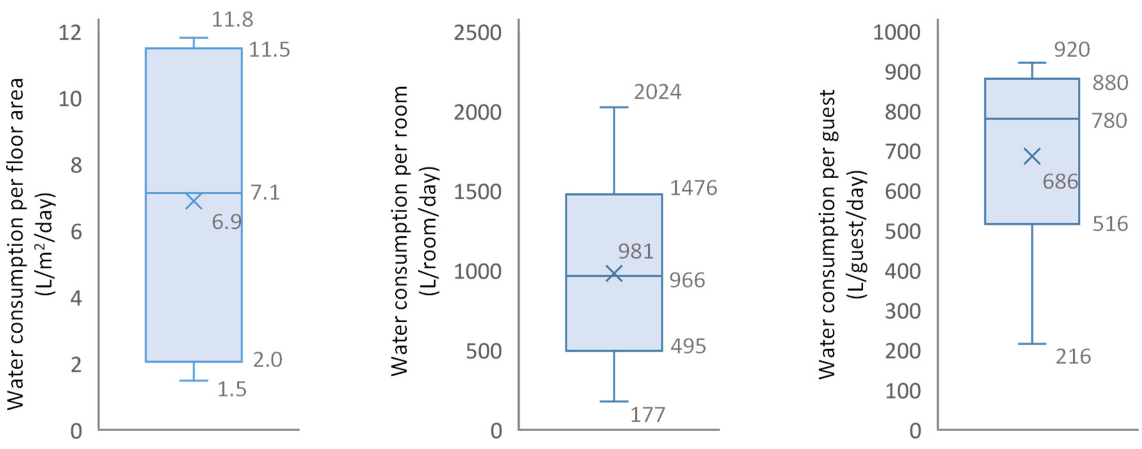


Figure 1. Box-whisker graphs for water consumption per floor area, room, and guest.

This chart shows a substantial dispersion of the total water consumption volumes independently of the relative indicator considered. In all cases, the relative standard deviation, calculated as the ratio between the standard deviation and the average, is above 25%, with the less dispersed water consumption indicator as the one calculated per guest (relative standard deviation of 5.0, 509 and 247 for consumption per floor area, per room and per guest, respectively).

The average figures obtained, considering all 30 studies, for each indicator are the following:

1. Water consumption per floor area: 6.9 L/(m^2·day)
2. Water consumption per room: 981 L/(room·day)
3. Water consumption per guest: 686 L/(guest·day)

Relative daily water consumption per individual micro-component. A second-level examination disaggregates daily water consumption into the identified micro-components described in Table 2. Again, similar to the analysis conducted with the total consumption, these figures are expressed relative to the selected hotel's characteristics (floor area, number of rooms, and number of guests). The box-whisker graphs for the relative water consumption of each micro-component and its contribution to the total water consumption are shown in Figures 2 and 3, respectively. It is to be noted that the contributions are expressed as a general percentage averaged from all the references reviewed. This means they should be understood as the average ones for an average hotel with all those facilities.

Table 2. Average daily water consumption for each micro-component.

Micro-Component	Rooms	Kitchen	Laundry	Pools	Irrigation	Cooling and Heating
Average consumption (L/room/day)	457	171	124	44	70	42
Contribution to total hotel consumption	35%	21%	15%	2%	18%	14%

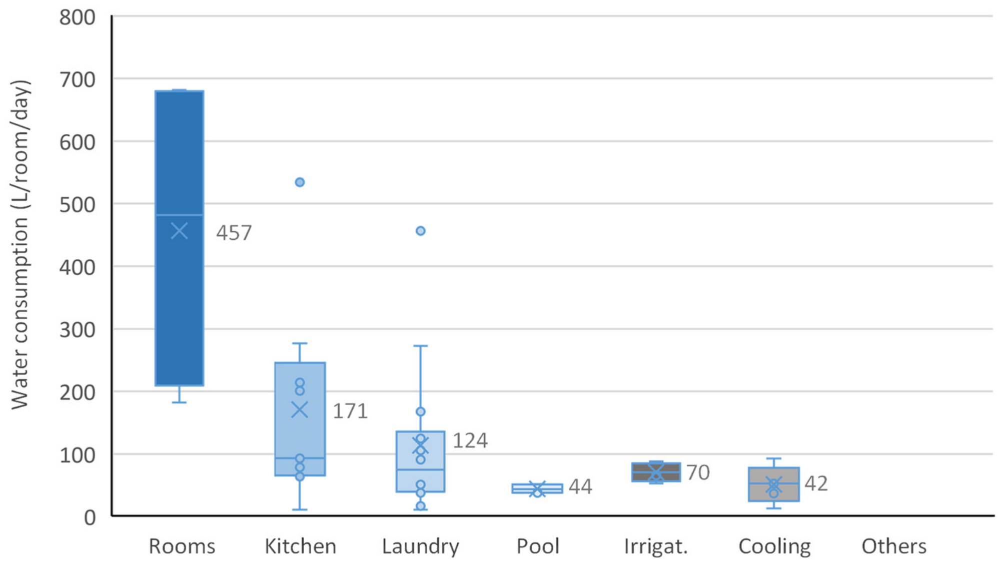


Figure 2. Distribution of daily relative water consumption per micro-component.

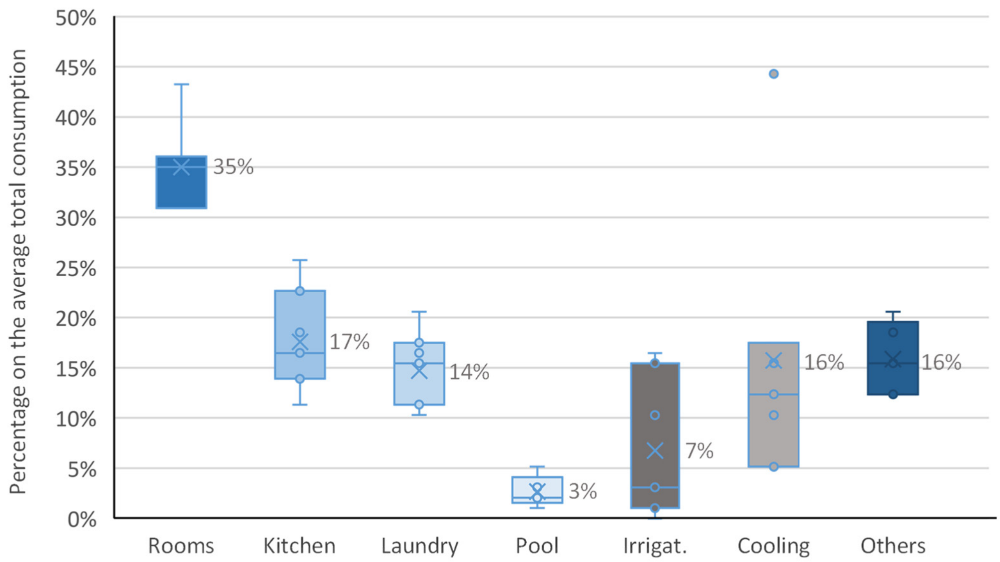


Figure 3. Contribution of each micro-component to daily water consumption.

4. Model for Water Consumption in Hotels

Given the variability found, the figures previously presented cannot accurately assess the consumption of a specific hotel or provide reliable information about how efficient water-related activities are. The contribution to the total water consumption of some micro-components can be estimated based on the entire surface area or the number of rooms. However, other components such as irrigation, cooling and heating, and the water use at a hotel's swimming pool strongly depend on specific characteristics of the establishment and the equipment installed that need to be considered in the calculations. In most cases, an average figure obtained from a literature review will not be helpful as a reference to estimate water consumption or to calculate an indicator for water efficiency performance.

For that reason, an accurate assessment of the hotel water usage and the potential efficiency improvements will require a detailed analysis of each micro-component. This approach might comprise complex multivariate regression calculations or equivalent statistical analysis methods (as followed by [14]).

The approach proposed in this paper aims to assess a hotel's water efficiency performance from a different perspective. It is similar to the methodology used to evaluate water losses in a distribution network and quantify its performance through a relative indicator [15]. The initial step is to build a simple consumption model for each water micro-component based on simple, measurable, and easily obtainable characteristics. Consequently, this model considers each hotel's specific features, local conditions, and environment that may affect its water consumption in a significant manner. Given its specific characteristics, this model allows the hotel administration to obtain a reference baseline figure for minimum achievable water consumption. Following the analysis, a second step compares the actual hotel water consumption with the calculated baseline figure. This comparison can be conducted globally or individually for each micro-component and will show the hotel's potential range of improvement for water reduction. In addition, it is possible to quantify the hotel's water efficiency and calculate a relative performance indicator. The following sections present the basic consumption model for each micro-component and, finally, the definition of the relative efficiency performance indicator.

4.1. Water Consumption in Rooms

Water consumption in rooms is, by far, the main component of the total water consumption in a hotel. At the same time, it is also the simplest one for analysis and modelling. Compared to other water micro-components, the type and variety of water uses within a hotel room are limited, and so are the factors affecting the amount of water used. In the literature, there is a general agreement about the following drivers for water consumption in hotel rooms:

1. The number of occupants in a hotel room is directly related to water consumption. An increase in the occupants' number implies a nearly proportional increase in water consumption.
2. The water consumption habits of the occupants affect the number of usages per day of the toilet and faucets or the running time of the showers and other faucets.
3. The number and type of water appliances can also influence the water volumes used inside guest rooms. Though hotel rooms tend to be comparable in number and type of appliances, the more sophisticated equipment in high-standard hotels (bidet, bathtub, rain showerheads, hydro-massage showers, etc.) can lead to higher water consumption.
4. The water efficiency of the appliances installed. Independently of the type of appliance considered, it should be analysed if the service can be provided more efficiently. The objective is to perform its function and satisfy the customer's needs using the lowest volume of water.

In a standard hotel room, water can be used only by the appliances in the bathroom. These appliances may fall within two types:

- Flow rate-based appliances (faucet, shower, bidet). The consumption volumes from these appliances depend on the discharge flow rate and the running time. In addition, the flow rate depends on the available dynamic pressure at the room. The consumption volumes made by hotel guests can be calculated based on the average duration of the usage events and the average flow rates provided by the appliances.

- Volume-based appliances (toilet, bathtub). These appliances can be characterised by an average usage volume defined, for example, by the toilet tank size or the bathtub capacity. The consumption volumes are determined by estimating the number of times the guests in the room may use these appliances every day.

The proposed water consumption model inside guest rooms considers each type of appliance separately:

$$WD_R(L/room/day) = N_G\left[\sum_i (Q_i \cdot t_i) + \sum_j (V_j \cdot n_j)\right] \quad (1)$$

where:

WD_R is the average water demand per room (L/room/day);

N_G is the average number of occupants per occupied room in the hotel. It is calculated by dividing the total number of hotel guests by the total number of occupied rooms. In general, it can also be considered as a characteristic parameter of the hotel. For example, in urban business hotels, N_G might range between 1 and 1.5, while in holiday resorts, it can be as high as 2.5 or 3;

i stands for each appliance of flow rate-based type;

Q_i is the average flowrate for each appliance i (L/min);

t_i is the average time each appliance i is used per day (min/guest/room/day);

j stands for each appliance of volume-based type;

V_j is the average volume per use for each appliance j (L/use);

n_j is the average number of uses per day for each appliance j (uses/guest/room/day).

It should be noted that, in Equation (1), the average time each appliance is used per day (t_i) and the number of uses per day (n_j) are defined as average values.

Reference values for standard and efficient appliances may vary according to the national standards applied in different countries. One of the best well-known references worldwide is the WaterSense programme [43] developed by the USEPA. That programme sets the technical specifications for the predominant water appliances, as shown in Table 3.

Table 3. Technical specifications for standard and efficient water use appliances.

Water Appliance	Units	Standard	Efficient
Faucets	gpm	2.20	1.50
	L/min	8.33	5.68
Showerheads	gpm	2.50	2.00
	L/min	9.46	7.57
Toilets	gpf	1.60	1.28
	L/flush	6.06	4.85

Until today, many studies have analysed water consumption habits in different sectors and, in particular, in the hotel industry. The conclusions are frequently derived from surveys and questionnaires answered by final consumers (see Supplementary Material 1), which result in a highly unreliable picture of water consumption. Using more detailed and sophisticated analysis techniques, refs. [47,48], summarised in Table 4, allow for a better modelling of water consumption characteristics. It is to be noticed that there is a significant difference between the results of both references. This is even though specific calculation and quantification work has been carried out in each case. The results presented only confirm that, although the expected variability of these figures is more or less limited, the real discrepancies between various situations can be very large.

Table 4. Average use-time (faucets and showerheads) and number of uses (toilets) per appliance.

Water Appliance	Variable (Unit)	[47]	[48]
Faucets	Time of use (min/guest/day)	1.6	4.8
Showerheads	Time of use (min/guest/day)	8.5	3.5
Toilets	flushes (flushes/guest/day)	4.0	3.5

To calculate a reference for the minimum average water consumption per room (WD_{RMin}), some minimum achievable figures for appliances and habits should be considered and applied to an average hotel room. The calculation has been conducted substituting the following values in Equation (1):

- Flowrates are the ones for efficient appliances in Table 3;
- Usage duration and number of flushes are selected from the ones within the range set by [47,48] in Table 4: 4.5 min/guest for faucets, 8 min/guest for showers, and 4 flushes/guest per toilets.

This way, the WD_{RMin} can be calculated as

$$WD_{R_{Min}}(L/room/day) = N_G\ [(5.68 \cdot 4.5 + 7.57 \cdot 8) + (4.85 \cdot 4)] = N_G \cdot 105.5 \quad (2)$$

The minimum consumption benchmark (MCB) associated with guests rooms (MCB_R) should also take into account the total number of hotel rooms (N_R) and the rooms occupancy rate (Occ_{Hotel}). The Occ_{Hotel} may vary significantly throughout the year depending on the type of hotel and customers and may follow a seasonal or weekly pattern. Consequently, to remove seasonality effects and conduct a more reliable assessment, extending the evaluation period of water consumption to a full year is recommended. Additionally, as litres are also translated into cubic meters, the constant 105.5 in Equation (2) turns into 38.5, and the MCB_R can be expressed:

$$MCB_R\left(m^3/year\right) = 38.5 \cdot N_G \cdot N_R \cdot Occ_{Hotel} \quad (3)$$

4.2. Water Consumption in Kitchens-Restaurants

Differences in kitchen water consumption between various hotels can be considerable. Parameters such as the size and number of restaurants, the type of cuisine, and the opening hours for customers significantly affect the total amount of water used in this activity. In consequence, the kitchen contribution to the entire hotel water consumption is hugely dependent on several factors:

- Factors affecting the number of meals served. These factors are related to size in general—the restaurant seating capacity, the working hours of the kitchen, or the number of meals shifts per day.
- Factors affecting the unitary water consumption per meal. These factors are either technical, such as the characteristics of appliances and machines used in the kitchen, or behavioural, such as the water consumption habits of employees. In addition, the type of cuisine may be relevant here. For instance, according to [49], Chinese kitchens may consume more significant amounts of water than others.

According to the previous factors, the proposed model for water consumption in a hotel each hotel kitchen can be expressed as

$$WD_K(L/restaurant/day) = C_{meal} \cdot N_{meals} \quad (4)$$

where:

WD_K is the average water demand per restaurant (L/restaurant/day);
C_{meal} is the average water consumption per meal served (L/meal);
N_{meals} is the total number of meals served (meals/restaurant/day).

Specific reference values for water consumption in hotels restaurants are not generally available. However, water consumption in single restaurants has been addressed in several studies [49–52], revealing a disparity of figures depending on various restaurant measurable features. The following list summarises the variation range of published results regarding the total water consumption in a restaurant kitchen as a function of different attributes:

Per surface area: 5.3 to 13.5 $m^3/m^2/year$;

Per meal served: 22.7 to 31.1 L/meal;

Per seat: 75.7 to 117.3 L/seat/day;

Per employee: 325.5 to 461.8 L/employee/day;

Restaurant figures could only be considered by taking into account two additional facts:

Unfortunately, water consumption in a restaurant is not the same as in a hotel kitchen. Some water uses (restrooms, cooling and heating, cleaning, etc.) considered when calculating the water consumption in a restaurant are not present or have a minimal presence in a hotel kitchen. According to [50], only 52% of the total water consumption in a restaurant occurs in the kitchen.

The references on restaurants cited above were focused on describing how and how much water is used but not on the potential reduction on water consumption if conservation measures were implemented. According to [53–55], the efficiency in a restaurant's kitchen could be improved up to an average figure of 35–40%.

From a conservative perspective, an efficient unitary water consumption per meal in single restaurants can be set at 23 L/meal. Considering the mentioned 52% to focus on kitchen consumption, a minimum value per meal results in 12 L/meal. Therefore, the minimum water demand for each hotel kitchen/restaurant can be calculated as

$$WD_{K_{Min}}(L/restaurant/day) = 12 \cdot N_{meals} \quad (5)$$

The number of daily meals served in a hotel depends on the number of guests staying (for clarity purposes, one restaurant will be assumed to be in the hotel). Secondly, it also depends on the time of the day, as most guests are likely to eat breakfast but not lunch. Thirdly, there is the possibility that hotel restaurants are open to non-guests. Thus, in the most popular restaurants, it may be the case that the number of dinners served is higher than the number of hotel guests. In order to relate the number of meals regularly served to the number of hotel guests, three coefficients have been considered: K_{break}, K_{lunch}, and K_{dinner}. For example, typically K_{break} will be equal to one in holiday hotels where virtually all guests eat breakfast in the morning, K_{lunch} will be significantly less than 1 in urban business hotels where guests often eat outside the hotel, and K_{dinner} will be greater than 1 in hotels where the restaurant is popular and receives external client for dinner. In conclusion, the number of meals can be parameterised as follows:

$$N_{meals}(meals/day) = N_G \cdot N_R \cdot Occ_{Hotel} \cdot (K_{break} + K_{lunch} + K_{dinner}) \quad (6)$$

where:

N_{meals} is the number of meals served per day;

N_G, N_R, and Occ_{Hotel} are the same variables already explained;

K_{break}, K_{lunch}, and K_{dinner} are the coefficients for breakfast, lunch, and dinner, respectively.

Therefore,

$$WD_{K_{Min}}(L/day) = 12 \cdot N_G \cdot N_R \cdot Occ_{Hotel} \cdot (K_{break} + K_{lunch} + K_{dinner}) \quad (7)$$

As all the calculations are extended throughout the year, and litres are converted to cubic meters, the MCB for the water consumption in kitchens (MCB_K) can be calculated as

$$MCB_K\left(m^3/year\right) = 4.38 \cdot N_G \cdot N_R \cdot Occ_{Hotel} \cdot (K_{break} + K_{lunch} + K_{dinner}) \quad (8)$$

4.3. Water Consumption in Outdoor Irrigation

From urban hotels to vacation resorts, the irrigated area and type of gardens are incredibly heterogeneous. Whereas a small indoor gravel area with cacti and other succulent plants may require minimum water and maintenance, large turf areas or landscapes with beautiful leafy plants will account for a significant part of the total water demand of the hotel. The type of plants is crucial to determining the water amounts required for irrigation of green areas, but it is not the only factor. The main drivers identified by other authors [56–62] are the following:

- Climate. The first factor to consider is the general weather that naturally exists at the hotel geographical location. The better adapted the plants are to the local climate, the lower their water consumption.
- Garden area. The second factor is the size of the area to irrigate—the larger the area, the higher the water demand.
- Types of plants. From great water-demanding types such as turf grass to arid and semi-arid types such as succulent plants, the water requirements largely depend on the plant species selected for landscaping. It is essential to highlight that the ornamental value of plants must not necessarily be related to their water requirements.
- Irrigation system. The efficiency of the different irrigation systems available in the market might be highly variable. They can range from the lowest one, such as simple sprinklers, to the highest ones, such as drip irrigation managed through an automatic system driven by the hour of the day and the weather conditions.
- Additional means might also be installed to reduce plants water demand. In some cases, specific techniques such as mulching may reduce the water needs for irrigation.

There is general agreement on the most appropriate variables to model each of the above factors. Climatic conditions are represented by evapotranspiration, i.e., the amount of water lost to the atmosphere from a planted area due to (i) soil evaporation and (ii) plant transpiration. For each geographical location, evapotranspiration can be calculated as a final value (ET_0) following a standard procedure on different climatic factors [63]: solar radiation, relative humidity, vapour pressure, air temperature, and average wind speed.

Similarly, the remaining determinants are generally represented by dimensionless efficiencies between 0 and 1. While there is a large consensus on the irrigation efficiency factor [59,60], approaches to model various plant types differ significantly. Some authors simplify it to a single element [59,61], while others include additional secondary components [62,64]. In summary, a basic calculation model for assessing the water demand for each garden area can be written as follows:

$$WD_I(L/garden/year) = ET_0 \cdot A \cdot PF \cdot \frac{1}{K_r} \cdot K_t \quad (9)$$

where:

WD_I is the irrigation water demand in a garden area (L/garden/year);
ET_0 is the evapotranspiration reference value at the geographical hotel location (mm/year);
A is the garden area (m^2);
PF is the plant factor for plant type;
Kt is the efficiency of gardening techniques;
Kr is the efficiency of the irrigation system.

Values for ET_0 can be available from meteorological institutions or even from the literature (for example [65]). Such values accurately depend on the geographical location, but as guidance, Table 5 shows some general examples for different climate types.

Table 5. General ET_0 ranges for different climate types.

Climate Type	ET_0 (mm/Year)
Cold tundra	0–400
Temperate regions	400–1000
Mild Mediterranean	1000–1500
Damp tropical regions	1500–2000
Arid zones	2000–2800

The plant factor (PF_i) is related to the water requirements of each plant. The higher the value of PF_i, the greater the amount of water the plant will need. Generic values of PF_i for different plants can be easily found in the literature (for example [59,61,62], Table 6).

Table 6. Examples of plant factors (PF_i) for some different plant types.

Plant Type	PF_i
Turf (cool season)	0.8
Herbaceous perennials, annual flowers, bedding plants	0.6
Turf (warm season)	0.6
Woody plants (humid)	0.7
Woody plants (arid)	0.5
Desert plants	0.3

Depending on the irrigation system, a fraction of the watering will not reach the plants' roots or will be lost in another way. That means a loss of efficiency of the irrigation system employed (Kr_i), which is consistently lower than one, that must be considered in the calculations (for example [59], Table 7).

Table 7. Examples of efficiencies (Kr_i) for different irrigation systems.

Irrigation System	Kr_i
Sprinkler	0.75
Diffuser	0.75
Drip	0.90
Manual hosing	0.95

Sometimes, specific gardening techniques are available to reduce the natural ground evaporation or plant evapotranspiration. These gardening strategies allow for a reduction in the water volumes used for irrigation. In those cases, the efficiency (Kt_i) provided by those techniques should be considered in the calculations (for example [59], Table 8).

Table 8. Examples of efficiencies (Kt_i) for different gardening techniques.

Gardening Technique	Kt_i
Irrigation stepping	0.95
Mycorrhizae	0.80
Mulching (textile + bark clippings)	0.80
Mulching (textile + gravel)	0.75

To determine the minimum reference value for irrigation water demand, it is necessary to review the component variables (Equation (9)) one by one. ET_0 is not eligible because it depends exclusively on the hotel's geographical location. The type of plant that minimises the irrigation demand should be the most suitable for the climate of the site; therefore, the PF_i is ultimately dependent on that. The area of the gardens, A_i, depends on the type and configuration of the hotel. However, the irrigation and gardening coefficients should correspond to the techniques with the highest efficiency compared to alternative methods. According to Tables 7 and 8, the maximum feasible value of K_{ri} and K_{ti} is 0.95 for both of them. In conclusion, the minimum value of water demand for irrigation can be delimited as

$$WD_{I_{Min}}(L/garden/year) = ET_0 \cdot A \cdot PF \quad (10)$$

Finally, the hotel's benchmark for irrigation water consumption must consider its geographical location. For each of the three major inhabited climatic areas, results for MCB_I are shown in Table 9, in which i stands for each of the garden areas in the hotel. It should be noted that the calculation of irrigation needs might be the most uncertain component of the hotel's MCB. The variability in meteorological conditions, characteristics of plant species, and the adaptability of the latter to the former can be much greater than that found for the other micro-components (attributes and use of taps, showers, washers, or even air conditioning systems). This should always be considered when performing these calculations and interpreting the results obtained.

Table 9. Values of MCB_I for different climate types and types of plants.

Climate Type	ET_0 (mm/Year)	PF_i	MCB_I (m^3/Year)	
Temperate regions	700	0.7	$0.490 \cdot \sum_i (A_i)$	(11)
Mild Mediterranean	1250	0.6	$0.750 \cdot \sum_i (A_i)$	(12)
Damp tropical regions	1750	0.5	$0.875 \cdot \sum_i (A_i)$	(13)

4.4. Water Consumption in the Laundry

Hotel laundry is responsible for washing sheets, pillowcases, duvet covers, towels, tablecloths and napkins, and staff and guest linen. It typically uses considerable amounts of water in different processes, such as the washing and rinsing cycles of clothes in washing machines and devices such as steam-heated dryers, steam ironing equipment, and the reclamation of dry solvent [34]. Previous studies addressing this water use concluded that the volume used in the laundry might vary according to the following:

- Procedures for the use of washers. Full washer loads are more efficient than partial loads [26]. This is generally related to sports activities and health centres and the level of textile dirt [30].
- Technical characteristics of washers. Depending on the technologies employed, water consumption could vary as much as 70%: front-loading vs. top-loading washers [66,67], continuous-batch washers [34], or water reclamation systems that allow associating successive wash cycles by using the rinse water of the last washer as the load water of the next one [23].
- Working habits of laundry employees [40] and incentives for guests to reuse towels and bed linens [45] may make a significant difference. In extreme cases, outsourcing laundry services directly impacts laundry water [24,68].
- Specific conservation measures. Though the impact of conservation strategies vary from one case to another, reports show that water reductions up to 50% can be achievable [68,69].

A water consumption model for laundry should comprise two main components. The first one is the water consumption rate of the washing machine, expressed in litres per kilogram of laundry. The second one is the weight of clothes to be washed regularly. Under this consideration, laundry water demand can be expressed as

$$WD_L(\text{L/laundry/day}) = C_W \cdot N_C \quad (14)$$

where:

WD_L is the laundry water demand (L/laundry/day);
C_W is the washer consumption factor (L/kg);
N_C is the amount of clothes per guest that should be washed daily (kg/laundry/day).

There are various alternatives to express the amount of water used by laundry washers. Manufacturers' most widely used indicator refers to the water volume used per load. Typical water consumption figures per load for standard washers range from 57 to 95 L/load [66], whereas high-efficiency front-loading machines may use less than 49 L/load [70]. However, while this indicator is helpful for domestic washing machines with similar load capacities, it is not practical for industrial equipment with an ample range of sizes.

For this reason, the most suitable indicator to define the efficiency of a washing machine is the water factor [71]. This parameter quantifies the water volume used, in litres, per kilogram of clothes washed. The most common type of laundry machine is a washer-extractor, which operates with a rotating drum that agitates the laundry during the washing and rinsing cycles. It then spins it at high speeds to extract water and use fresh water for each wash and rinse cycle [34]. This type of washer has a capacity of 88 to 100 kg/load and consumes around 21 to 29 L/kg [34] or 8.3 to 16.7 L/kg [23]. Technical improvements in industrial washing machines have lately allowed a reduction of water consumption to 8 L/kg, and some devices achieve figures as low as 7 L/kg [37]. However, the most efficient laundry consumes around 5 to 6 L/kg [72,73], which allows expressing the minimum laundry water demand as follows:

$$WD_{L_{Min}}(L/laundry/day) = 5 \cdot N_C \quad (15)$$

The weight of the clothes to be washed daily depends very much on the hotel type, category, and of course, occupancy rate. The clothes requiring washing are mainly used in the rooms and restaurants by guests and employees in their daily activities. The working clothes of the staff might alternatively be considered as well, but in general terms, they are much fewer in number and represent less weight than the clothes used by guests. Therefore, for simplicity purposes, the working clothes of the staff will be neglected in the calculation proposed although they could be included if needed. Table 10 shows the reference weight for each type of cloth piece.

Table 10. Reference weight of most common clothes used by hotel guests.

Cloth Type	Mass (g)
Towel—big	600
Towel—medium	250
Towel—small	100
Bed linen	600
Pillow cloth	100
Duvet	800
Tablecloth	600
Napkin	20

The amount of clothes (N_C) to be washed per day should be calculated separately for room clothes (N_{CR}) and restaurant/kitchen clothes (N_{CK}) since the clothes usage rates may differ significantly for each one. Then, considering the number of hotel guests and assuming that there is only one laundry in the hotel,

$$N_C\ (kg/day) = N_G \cdot N_R \cdot Occ_{Hotel} \cdot \left(N_{C_R} + N_{C_K}\right) \quad (16)$$

where:

N_G, N_R, and Occ_{Hotel} are the same variables already explained;

N_{CR} is the amount of clothes per guest in rooms (kg/guest/day);

N_{CK} is the amount of clothes per guest in kitchen-restaurant (kg/guest/day).

Table 11 shows the number of washes per day and guests expected for each room cloth type regularly, and Table 12 offers the washes per day and meal served in restaurants. Combining Tables 10 and 11 shows a global result of 1.46 kg/guest/day in rooms. In turn, the combination of Tables 10 and 12 yields 0.32 kg/meal/day in restaurants. As the meals per day has already been set above (N_{meals}, Equation (6)),

$$N_C\ (kg/day) = N_G \cdot N_R \cdot Occ_{Hotel} \cdot (1.46 + 0.32 \cdot (K_{break} + K_{lunch} + K_{dinner})) \quad (17)$$

Table 11. Average washes per guest and day for each cloth in rooms.

Cloth Type	Washes Per Guest and Day
Towel—big	1
Towel—medium	1
Towel—small	1
Bed linen	1/2
Pillow cloth	1/2
Duvet	1/5

Table 12. Average washes per meal and day for each cloth in restaurants.

Cloth Type	Washes Per Meal and Day
Tablecloth	1/2
Napkin	2

Therefore,

$$WD_{L_{Min}}(L/day) = 5 \cdot N_G \cdot N_R \cdot Occ_{Hotel} \cdot (1.46 + 0.32 \cdot (K_{break} + K_{lunch} + K_{dinner})) \quad (18)$$

The MCB for laundry water consumption (MCB_L) may finally be obtained by extending the calculations throughout the year and converting litres to cubic meters:

$$MCB_L\left(m^3/year\right) = N_G \cdot N_R \cdot Occ_{Hotel} \cdot (2.67 + 0.59 \cdot (K_{break} + K_{lunch} + K_{dinner})) \quad (19)$$

4.5. Water Consumption in Swimming-Pools

The contribution of swimming pools to the total hotel water consumption is highly dependent on multiple parameters that frequently are difficult to establish with sufficient accuracy. Among others, water consumption in a swimming pool depends on the type of hotel and clients' behaviours, the geographic location of the hotel, size and type of pool (indoor/outdoor), maintenance practices, local weather conditions, and the presence of leaks at the pipes and basin. Therefore, it is challenging to provide an exact figure of the lowest attainable water consumption without using complex equations and specific data of each swimming pool location and characteristic. The unavoidable water consumption in swimming pools is related to evaporation, backwashing of the filters, and often the legal obligation that applies in some countries to renew a certain percentage of the water of the swimming pool daily. Furthermore, splashing and showers can contribute significantly to total water consumption in swimming pools. While the first contributions depend on the hotel management, the lasts mainly rely on the behaviour of the users. Consequently, the control over this is more limited. To summarise, water consumption in swimming pools can be classified into the following categories:

- Evaporation. The amount of water lost depends on the temperature difference between the water and the surrounding air and other factors such as the relative humidity and the wind velocity over the pool [74].
- Maintenance tasks. Backwashing of the filters is a regular maintenance activity conducted periodically. The required frequency of backwashing depends on the number of swimmers and the dirt they introduce into the water. Even if proper maintenance is carried out, part of the water needs to be regularly renewed to adjust and correct the presence of chemicals and reduce the concentration of chloramines.
- Swimmers' activity. It is compulsory to shower for hygienic reasons before diving into a swimming pool. In addition, after taking a bath, it is highly advisable to take a shower to remove chlorine, bacteria, fungus, dead skin cells, hair, and other people's body fluids. Depending on several factors, splashing could be a significant component. It can be reduced by giving the proper slope to the wet deck and installing gutters around the pool's edge to collect most of the water splashed out.

Consequently, the model for water demand in swimming pools can be set as

$$WD_P = WD_{Evap} + WD_{Maint} + WD_{Swimmers} \quad (20)$$

where:

WD_P is the swimming pool's total water demand;
WD_{Evap} is the water losses evaporation in a swimming pool;
WD_{Maint} is the water used in filters backwashing;
$WD_{Swimmers}$ is the water consumption due to swimmers' activity.

When totalling the volume of water used in pools, many authors only add the water losses caused by evaporation and splashing. For these subcomponents, their magnitude depends on the free surface area of the swimming pool, the water temperature and the air velocity above the pool, the relative humidity, and the average ambient temperature at the pool's location. There are significant differences between indoor [75] and outdoor [74] swimming pools concerning evaporated volumes. Ambient conditions at indoor swimming pools are typically well-controlled to maintain the users' comfort and can be estimated much more accurately, as they are kept stable throughout the year. In fact, indoor air ambient conditions should meet legal requirements in terms of relative humidity and temperature in most countries. Water consumption in outdoor pools caused by evaporation is less predictable, as it can significantly vary depending on the changing weather conditions.

A literature review on the topic can provide different methods of various complexities for estimating water losses due to evaporation and the type of use of the swimming pool. One of the most widely used methods for estimating evaporation losses is the one proposed by [76]:

$$\mathrm{WD_{Evap}(L/pool/day)} = 15{\cdot}24{\cdot}\ \mathrm{A_p{\cdot}F_a{\cdot}(p_w - p_a)} \tag{21}$$

where:

A_p is the pool surface area (m^2);

F_a is the activity factor, which depends on the type of pool;

P_w is the saturation vapour pressure taken at the temperature of water at its surface (bar);

p_a is the saturation pressure at ambient air dew point (bar).

Some countries require that part of the water volume be renewed daily regarding regular maintenance tasks. However, the new treatment technologies make this unnecessary, and this practice will reduce its contribution to the total water consumption in pools in the future. Therefore, as confirmed by [77], the everyday backwashing of the swimming pool filters is the most demanding operation. The frequency of backwashing and the time needed to clean the filters depend on the type of use, the concentration of hair and other organic materials, and other factors such as users coming to the swimming pool after going to a nearby beach. In summary [77], the backwash water totals about four times the pool volume per year.

$$\mathrm{WD_{Maint}(L/pool/day)} = \frac{4{\cdot}1000}{365}{\cdot}\mathrm{V_p} = 11{\cdot}\mathrm{V_p} \tag{22}$$

where:

V_p is the pool volume (m^3).

As mentioned above, the proper design of the swimming pool may nearly eliminate the splashing losses so that the primary water consumption by swimmers is the use of showers. Habits, pressure, and technical characteristic of showers have an influence, but in any case, it can be modelled using a unitary consumption of water per swimmer:

$$\mathrm{WD_{Swimmers}(L/pool/day)} = \mathrm{C_s{\cdot}N_s} \tag{23}$$

where:

C_s is unitary water consumption per swimmer (L/day/swimmer);

N_s is the number of swimmers in the swimming pool.

Apart from the pool's features, all the other variables need to be quantified to assess the minimum achievable water consumption in a hotel swimming pool (WD_{PMin}). Typical values for the parameters p_w, p_a, and F_a in Equation (21) can be found in the literature (for example [75]), and are presented in Table 13, Table 14, and Table 15, respectively.

Table 13. Saturation vapour pressure p_w.

T (°C)	p_w (bar)	p_w (kPa)
15	0.0170	1.70
20	0.0234	2.34
25	0.0317	3.17
30	0.0425	4.25
35	0.0563	5.63
40	0.0738	7.38

Table 14. Saturation pressure at ambient air dew point p_a.

T (°C)	40% Relative Humidity		50% Relative Humidity		60% Relative Humidity	
	p_a (bar)	p_a (kPa)	p_a (bar)	p_a (kPa)	p_a (bar)	p_a (kPa)
20	0.0094	0.94	0.0117	1.17	0.0140	1.40
25	0.0127	1.27	0.0158	1.58	0.0190	1.90
30	0.0170	1.70	0.0212	2.12	0.0255	2.55

Table 15. Typical activity factors.

Type of Pool	F_a
Residential pool	0.50
Condominium	0.65
Therapy	0.65
Hotel	0.80
Public, schools	1.00
Whirlpools, spas	1.00
Wave pools, slides	>1.5

For outdoor pools working with a dry bulb air temperature below 0 °C, the value is 0.0061 bar for p_a. Alternatively, figures from Table 14 can be taken depending on the specific working conditions. Using this calculation methodology, in a worst-case scenario, an outdoor swimming pool in a hotel (with an activity factor of 0.8), taking p_a as 0.0061 bar, with a saturation vapour pressure at 25 °C of 0.0317 bar, will lose 7.4 L/m^2/day. Following an equivalent calculation, the evaporation loss for an indoor pool is about 4 L/m^2/day.

Rather than its capacity, the surface area is the main and most variable dimension of a swimming pool. Besides that, particularly in hotels, the depth can be simplified to 1.5 m on average.

According to [78,79], the average water used per swimmer ranges from 40 to 60 L/day/swimmer. In conclusion, the minimum water demand per day for an outdoor swimming pool may be estimated:

$$WD_{P_{Min}}(\mathrm{L/pool/day}) = 7.4 \cdot A_p + 11 \cdot 1.5 \cdot A_p + 40 \cdot N_s \quad (24)$$

In the case of bulk estimations, for which the number of swimmers, N_s, could not be easily available, it could be taken into account that official standards generally regulate the maximum bathing load through the pool area. For example, [80,81] set an average ratio of 2 m^2/swimmer.

To extend the calculation of WD_{PMin} to a full year and obtain the MCB_P, the number of days the pool is open has to be taken into account. Here, it will be better considered as the percentage of open days over 365 days ($Pool_{Open}$):

$$MCB_P\left(\mathrm{m^3/year}\right) = 0.365 \cdot \left(23.9 \cdot A_p + 40 \cdot N_s\right) \cdot Pool_{Open} \quad (25)$$

4.6. Water Consumption in Air Conditioning

Various types of heating, ventilation, and air conditioning (HVAC) require cooling towers to work. A cooling tower transfers waste heat to the atmosphere from a coolant, typically water, that evaporates when it circulates through an airstream [33]. The volume of water evaporated in the cooling tower implies that a portion of the water used in the cooling process is lost by misting and drifting away. Because of this, cooling towers are considered one significant cause of the increase in water consumption in the commercial and industrial sectors [33]. The quantity of water used by this type of system depends on several factors:

- The system technology and design. The water demand in an open-loop cooling tower is much greater than that for a closed-loop device. Not only that, but closed-loop devices have shown significant advantages and better overall efficiencies than the alternative open-loop system [27]. Equally, feasible modifications on existing systems such as eliminating single-pass cooling, increasing the tower's cycles of concentration, or improving total operational management have reported significant reductions in water consumed [82]. Finally, other aspects such as the design loads performance [83] and the maintenance level [34] have shown an evident influence on water consumption.

- Characteristics of the building. The size of the building and, more particularly, the space being cooled and heated is the main factor for the water consumption of the cooling system [51]. Other features such as the building design criteria and the average and maximum occupancy [51] should also be considered.

A full-detail model to calculate the expected water demand of a hotel cooling system should be based on the system's technical characteristics, the local weather conditions, and the total space (volume) of the building to be cooled. However, from a practical point of view, such an approach cannot be easily implemented and integrated into a model in which the main drivers are the number of rooms, number of guests, and other quantifiable variables. For simplification purposes, a model based on the hotel's public (shared) spaces and the number of occupied rooms is proposed:

$$WD_{AC} = WD_{AC_{\text{Occupied rooms}}} + WD_{AC_{\text{Common areas}}} \quad (26)$$

The water requirements for the air conditioning of occupied rooms depend on the water consumption of the air conditioning system per room and the number of occupied rooms:

$$WD_{AC_{\text{Occupied rooms}}}(\text{L/AC system/day}) = C_{AC} \cdot N_R \cdot Occ_{Hotel} \quad (27)$$

where:

$WD_{AC\ \text{Occupied Rooms}}$ is the water consumption of the air conditioning system for occupied rooms (L/AC system/day);

C_{AC} is the unit water consumption per room of the air conditioning system (L/room/day);

N_R and Occ_{Hotel} are the same explained above.

Assessing the water requirements for the air conditioning of the hotel common areas (lobby, corridors, restaurants, etc.) involves a more significant number of uncertainties. On the one hand, common areas are constantly air-conditioned, whereas the system may be switched off in rooms while their occupants are away. On the other hand, the size of the common areas can be much more variable and challenging to assess than in rooms. To keep a straightforward approach, this component will be set as a constant value after applying a given percentage, 15%, on the total water requirements to air conditioning all the hotel rooms, no matter the particular occupancy rate at any moment:

$$WD_{AC_{\text{Common areas}}}(\text{L/AC system/day}) = 0.15 \cdot C_{AC} \cdot N_R \quad (28)$$

In summary, and assuming one AC system in the hotel,

$$WD_{AC}(\text{L/day}) = C_{AC} \cdot N_R \cdot (Occ_{Hotel} + 0.15) \quad (29)$$

References on water consumption rates for air conditioning systems range significantly from 274 L/room/day in [18] to 27–53 L/room/day in [27]. From a conservative perspective, the minimum efficient consumption could be set at

$$WD_{AC_{Min}}(\text{L/day}) = 25 \cdot N_R \cdot (Occ_{Hotel} + 0.15) \quad (30)$$

If the hotel occupancy rate is considered, and water consumption is calculated for a whole year, the MCB for air conditioning (MCB_{AC}) is obtained as

$$MCB_{AC}\left(\text{m}^3/\text{year}\right) = 9.13 \cdot N_R \cdot (Occ_{Hotel} + 0.15) \quad (31)$$

5. The Indicator: Hotel Water Consumption Index (HWCI)

All the MCB presented above can be easily calculated for any hotel since they rely on a few essential characteristics: number of rooms (N_R), number of seats in the restaurant (N_S), number of meals served per day (N_M), geographical location, garden area (A_i), swimming pool area (A_p), average number of swimmers (N), restaurant occupancy rate (ResReat), and room occupancy rate (OcRate). By adding all the MCB obtained, the total minimum consumption benchmark for the whole hotel can be calculated:

$$MCB\left(m^3/year\right) = MCB_R + MCB_K + MCB_I + MCB_L + MCB_P + MCB_{AC} \quad (32)$$

The MCB obtained represents a minimum reference value for the hotel's total annual water consumption. The hotel water consumption index (HWCI) is now defined as the ratio between the current hotel annual water consumption and the MCB:

$$HWCI = \frac{\text{Current annual water consumption}\left(m^3/year\right)}{MCB\left(m^3/year\right)} \quad (33)$$

In conclusion, the HWCI shows a direct comparison between the current water consumption in a hotel and the minimum water consumption that could be still achievable in practical terms. In other words, the indicator shows the number of times the current consumption is greater than it could be under the most efficient reference conditions.

6. Case Study

The HWCI was calculated for six hotels. All of them are located in a touristic region in the north of Spain (temperate, relatively humid European area with cold winters and moderate summers).

For confidentiality purposes, the hotels will be named only as H1 to H6. However, all their main characteristics, used in the calculations, are depicted in Table 16. The hotels vary from a small high-standard historic urban hotel (H2) to a large business and touristic urban hotel (H5) or a small countryside hotel (H4). The individual occupation rate for each hotel was not directly available, so general data on average hotel occupation for each year (Table 17) were obtained from the official tourism organism in the region [84] and applied equally for all six hotels. Because of the same reason, the average room occupancy (N_G) was kept to one. Actual monthly water consumption for each hotel was provided from year 2017 to year 2020 (Figure 4). Total consumption for each year is presented in Table 17. It is to be noticed that hotels H5 and H6 stopped all activity during the COVID-19 pandemic in 2020.

Table 16. Hotels' main features.

Hotel ID		H1	H2	H3	H4	H5	H6
Hotel Style		**Rural Business**	**Urban Luxury**	**Urban Budget**	**Rural Small**	**Urban Business**	**Urban Luxury**
Number of Rooms		114	36	76	42	200	145
Restaurant's coefficients	Breakfast	1	1	1	1	1	1
	Lunch	0.5	0	0.3	0.7	0.7	0.5
	Dinner	1.2	0	0.5	1.5	1	1.2
Garden area (m^2)		12,500	0	0	3000	465	0
Swimming Pool	Area (m^2)	0	0	0	100	175	0
	% Open	0	0	0	0.25	0.25	0
	Swimmers/day	0	0	0	15	30	0

Table 17. Hotels' water consumption during the later years and average occupation rate.

	Actual Water Consumption for Each Hotel (m^3)						Average Occupation Rate Per Year
Hotel ID	**H1**	**H2**	**H3**	**H4**	**H5**	**H6**	
2017	30,783	3972	4827	3349	44,462	17,798	65.4%
2018	34,226	4371	4491	3430	44,946	18,013	67.5%
2019	45,834	4488	4314	3289	43,642	17,403	68.4%
2020	38,013	3058	2674	1417	-	-	41.0%

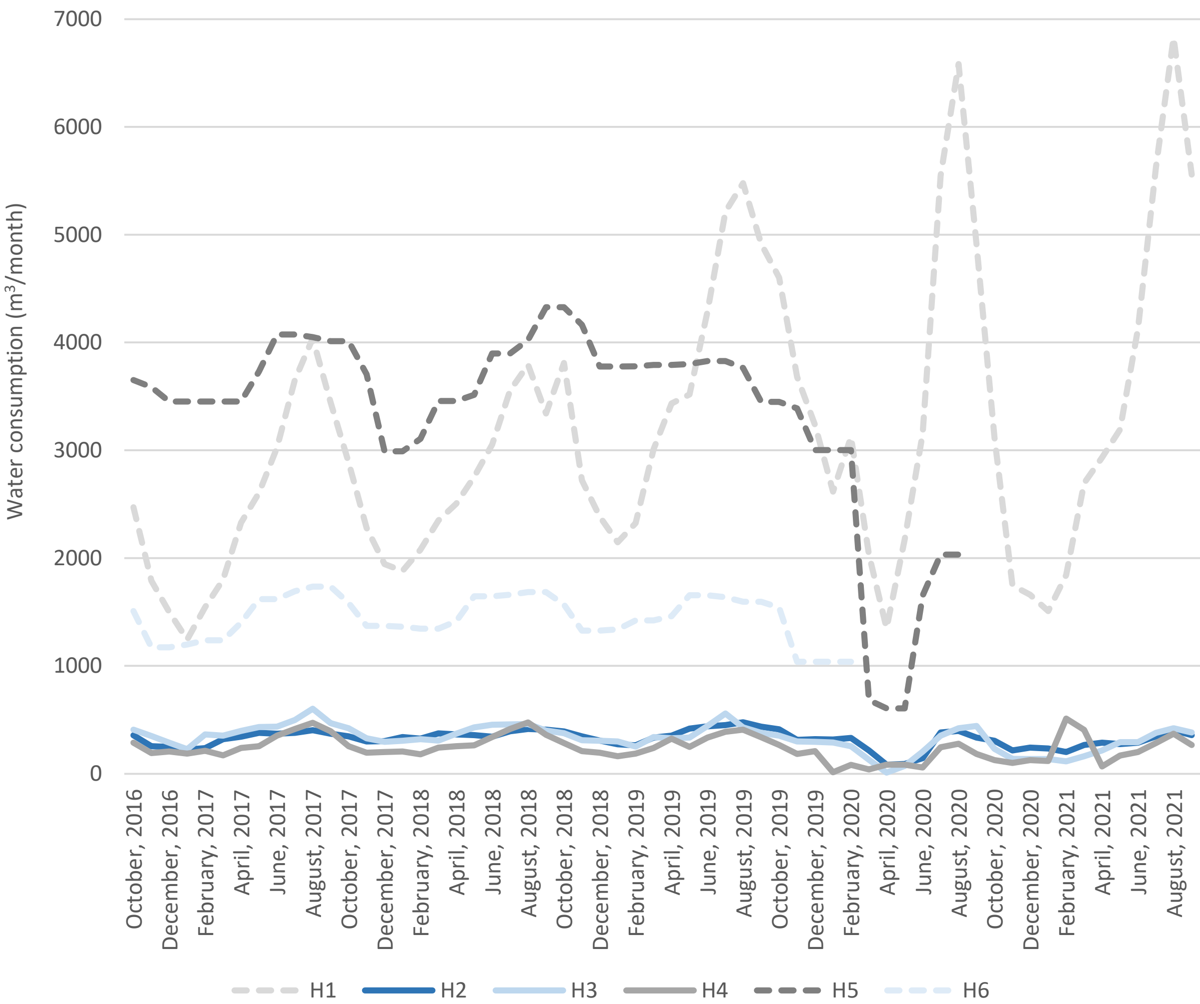
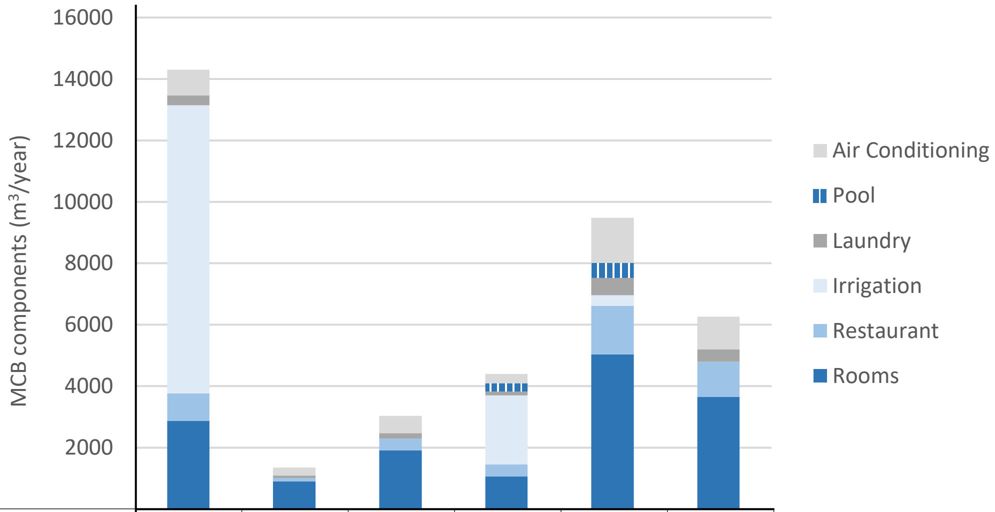


Figure 4. Water consumption per hotel and month.

The MCB can be obtained, component by component (Equations (3), (8), (11)–(13), (19), (25), and (31)). Figure 5 shows the particular results for each hotel in the year 2017 (65.4% occupation rate).

In Figure 5, the weight of the different characteristics of each hotel on its total MCB can be better appreciated, for example, the importance of garden irrigation versus the low number of rooms in H1 and H4 or also,, conversely the high number of rooms in H3 and H5 given their eminently urban character.



m³/year	Hotel ID	H1	H2	H3	H4	H5	H6
	Rooms	2872	907	1914	1058	5038	3652
	Restaurant	898	103	381	391	1575	1142
	Irrigation	9375	0	0	2250	349	0
	Laundry	318	76	183	125	559	405
	Pool	0	0	0	273	491	0
	Air Cond.	836	264	558	308	1467	1064
	Total MCB	**14,299**	**1351**	**3036**	**4405**	**9479**	**6263**

Figure 5. Micro-components for the calculation of MCB for all six hotels in year 2017.

The same calculations were then performed to obtain the MCB for each hotel from 2017 to 2020, and the final value of HWCI for each hotel and year was obtained (Table 18). A general review of HWCI revealed that the most efficient hotel in water consumption is H4. In all the years, its HWCI falls below one. In principle, this is a strange result because it means that the actual water consumption in that hotel is lower than the ideal, most efficient one. However, as it is the case of the ILI for water losses [85], the HWCI is also an estimation based on experience and literature; therefore, cases like this one are not common but may be possible. One more aspect not to be neglected is that H4 is the second hotel with the largest green area. As explained in Section 4.3, the uncertainty behind the calculation of irrigation needs could influence the particular result for H4. Hotel H3 remains at water consumption levels very close to its minimum efficiency (HWCI ≈ 1.5). Hotels H1, H2, and H6 would be in the next tier of water inefficiency (HWCI ≈ 3.0), and finally, H5 would be the most inefficient hotel in water consumption (HWCI > 4.5).

Table 18. HWCI results for all six hotels from 2017 until 2020.

Year	Avg. Occ. Rate		H1	H2	H3	H4	H5	H6
2017	65.4%	Actual consump. (m^3/year)	30,783	3972	4827	3349	44,462	17,798
		MCB (m^3/year)	14,299	1351	3036	4405	9479	6263
		HWCI	2.2	2.9	1.6	0.8	4.7	2.8
2018	67.5%	Actual consump. (m^3/year)	34,226	4371	4491	3430	44,946	18,013
		MCB (m^3/year)	14,452	1392	3130	4464	9748	6458
		HWCI	2.4	3.1	1.4	0.8	4.6	2.8
2019	68.4%	Actual consump. (m^3/year)	45,834	4488	4314	3289	43,642	17,403
		MCB (m^3/year)	14,518	1410	3171	4489	9863	6542
		HWCI	3.2	3.2	1.4	0.7	4.4	2.7
2020	41.0%	Actual consump. (m^3/year)	38,013	3058	2674	1417	-	-
		MCB (m^3/year)	12,520	865	1942	3724	6358	4001
		HWCI	3.0	3.5	1.4	0.4	-	-

The evolution of the HWCI for each hotel during these four years is shown in Figure 6. H1 and H2 show an upward trend in HWCI during the four years. This means that their actual water consumption grew more than their MCB, revealing a decline in water efficiency during those years. Conversely, the other hotels, H3 to H6, show a reduction in HWCI, which means an increase in water consumption efficiency. In any case, Figure 6 shows that the special conditions of the pandemic in 2020 did not significantly change the water efficiency trend each hotel had during the previous years.

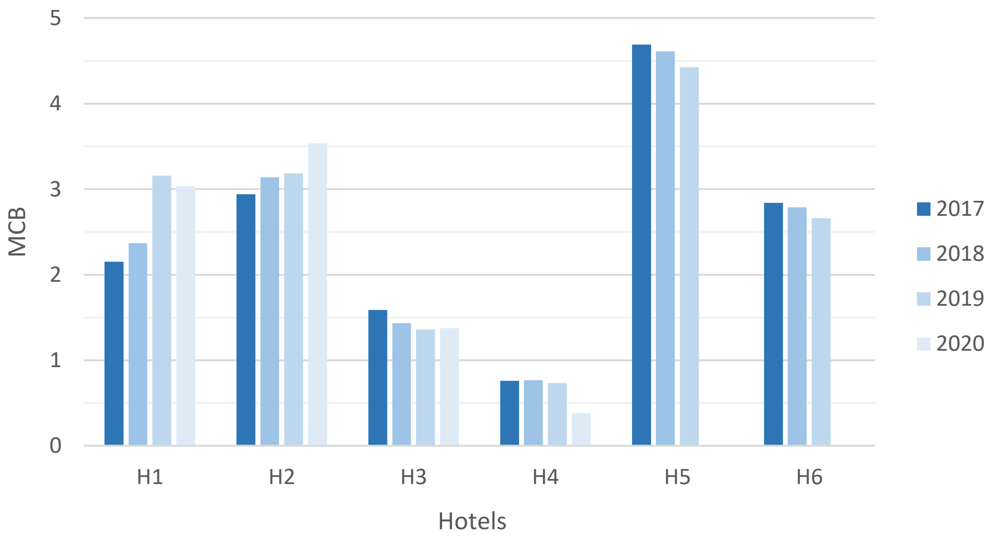


Figure 6. HWCI results for all six hotels from 2017 until 2020.

7. Discussion

By its very definition, the function of the HWCI is to assess the efficiency of a hotel's current water consumption or, in other words, the ability of a hotel to reduce it while maintaining an adequate level of satisfaction of its guests. It is important to distinguish between this function of the HWCI and other possible yet different environmental assessments that can also be made on a hotel's operation.

For example, the HWCI outcome is independent of the possible different water sources a hotel can use. Water reuse can be of great importance [86–88], as it reduces the hotel's impact on water resources. However, such reuse can involve significant costs (energy, reagents), so the positive impact on the resource could be overshadowed by such increased costs. To be aware of this, and to avoid it as much as possible, it is necessary to ensure that final water consumption itself is kept at a low level, and this is precisely the function of the HWCI.

Desalination of seawater or brackish water has also been studied [89–92]. Again, these cases involve a variation in the hotel's water balance (public distribution network versus own resources), but their environmental impact could be negative due to a possible lack of control (overexploitation of aquifers), not to mention the increase in energy these options imply. Again, ensuring that end-use consumption is close to its technical minimum (HWCI) is a necessary condition for an adequate exploitation of these resources.

Other approaches from a broader perspective, such as emissions or life cycle analysis [93–95], are more distant from the present work, but still, they ultimately depend on the overall level of resources consumption of the hotel, and water is a basic component of it.

Thus, the HWCI proves to be an essential indicator that can contribute to the different types of studies mentioned above. Moreover, for all of them, it is necessary to go deeper into the particularities of each hotel, which complicates each individual analysis and prevents broad comparisons. Precisely, the potential of the HWCI lies in fully assessing water use in a way that is consistent and supported by the current state of the art and simple enough in terms of calculations and data to make it extensible to benchmarking work. This is the main aim of the HWCI, but in addition, we can list the following additional advantages:

- The HWCI efficiency indicator takes into account and evaluates all the existing water consumption micro-components in any hotel separately. The minimum achievable water consumption in a hotel is calculated by summing the minimum water consumption achievable in each micro-component, considering the hotel's characteristics.

This structure allows the HWCI to be easily adapted to any hotel. For example, if a hotel does not have a swimming pool or if it has outsourced a service such as laundry, those components can be eliminated from the final calculation of the HWCI. From a global perspective, an outsourced service does consume water, and it should be taken into account in externalities or life cycle analyses, but they are outside the strict management of the hotel's scope, which is the HWCI.

- The figures obtained for the HWCI are independent of the local conditions, hotel style, or other factors that may influence water consumption. The HWCI considers and reduces the dependence on these and other hotel characteristics related to water consumption components. This way, the HWCI figures can be used for a more reliable comparison of the efficiency performance of different accommodation establishments;
- Regardless of the above, the HWCI has been designed to have a simple calculation procedure, and the parameters needed can be directly obtained and verified by external auditors. The HWCI calculation only requires eight primary hotel attributes. The proposed figures for the parameters used in the calculation are justified according to the current state of the art and previous publications. The operations to be performed are neither mathematically nor statistically complex;
- The HWCI is easy to understand, and it can be directly compared to a reference value: one. The greater the HWCI, the less efficient hotel's water use is. The HWCI is a non-dimensional index that reflects the inefficiencies related to water consumption and how many times above the minimum achievable amount the current consumption of the hotel is. It also reflects how much room is available to implement water efficiency measures, quantifying the magnitude of the attainable savings and providing indication where to apply them.

The authors also would like to highlight the main drawbacks of using the proposed indicator:

- The HWCI is based on figures representative of current conditions. As such conditions might change in the future, the HWCI calculations should be updated accordingly. This may be especially relevant for the case of new technologies in consumer devices that may be developed and thus reduce the minimum achievable consumption in some microcomponents. Likewise, ET_0 values can be updated as climate change studies confirm them;
- The calculation of the HWCI has been proposed on an annual basis because it is intended for long-term analysis, and the usual reports on occupancy, consumption, and even climatic parameters are all prepared on an annual basis. However, this does not prevent the HWCI from being used for the analysis of shorter time periods. In the case of hotels with a highly seasonal occupancy that may also be located in climates with very distinct seasons (such as the Mediterranean climate), an annual average may not represent properly the hotel operation. Alternatively, the hotel management may want to know in more detail the water efficiency consumption in each season since the maximum occupancy and water consumption normally match the highest temperatures. In such cases, calculating the HWCI for a period of three months (or any other duration) is not a problem. It is sufficient to know the value of all the calculation parameters for that period of time. Although some of them will be constant (flow rates or consumption times), it will be the most critical ones (occupancy, temperatures, rainfall) that will make the difference;
- The HWCI relies on the previous calculation of the MCB. It is essential to highlight that the MCB is solely a reference for the hotel's minimum achievable water consumption. The MCB does not provide a figure for the actual minimum achievable water con-

sumption for the specific conditions of the establishment analysed. This way, values of HWCI below one should not be frequent but are not impossible (as in the case of H4 in the previous section). HWCI below one should be interpreted as belonging to hotels with fully efficient water consumption. HWCI above one should not be considered an unacceptable result without a detailed analysis;

- There is a risk of manipulating the parameters used to calculate the minimum achievable consumption to obtain lower values for the HWCI. Consequently, a complete understanding of the indicator requires that the report also includes a comprehensive justification of the parameters used in the calculation.

8. Conclusions

As shown in the case study, the HWCI contributes to a better understanding of the potential sources of water inefficiencies and the selection and design of mitigation measures.

When properly used, this indicator provides much more information than a single index and facilitates the comparison of hotels of various characteristics located in different geographical areas. This way, the HWCI could become a valuable analysis tool at different levels. At the level of a single hotel management, the HWCI allows not only to identify options for improvement in water use but, above all, to carry out continuous efficiency monitoring over time in a consistent manner and to evaluate the results of the various actions that are being implemented. At the hotel chain management level, the HWCI, being a relative indicator, is helpful for benchmarking exercises—either considering different hotels at the same time or tracking the outcome of possible water efficiency policies in various hotels along time. Finally, at the public policymakers level, the HWCI could help to identify efficiency gaps in the water consumption of the hotel sector or even set the standard that could be required in the future.

As experience has shown for the case of ILI in the management of water distribution networks, the advantages of HWCI for assessing the efficiency of water consumption in hotels clearly exceed its disadvantages for a better environmental performance.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/w14233828/s1; Two files have been prepared and are attached separately as supplementary material: "Supplementary material 1—Literature review" contains the literature review. A summary of the results is presented according to four key aspects of each paper: year of publication, geographical location, number of hotels audited, and audit techniques used. "Supplementary material 2—Summary of equations" exclusively contains the ordered and consecutive compilation of all the equations that make up the water consumption model. As it does not contain the justifications for each numerical value, the direct view and understanding of the model is easier.

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