

Comparative analysis of water consumption in twinned indoor swimming pools in a Silesian Voivodeship of Poland

Analiza porównawcza zużycia wody w bliźniaczych krytych pływalniach w województwie śląskim, w Polsce

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Swimming pools, due to their specific nature, are sports facilities for which demand is highest for water of a quality subject to restrictive regulations. The objective of this study is to provide a detailed characterisation of the structure of water consumption in three 'twin' swimming pool facilities located in Poland, in the Silesian Voivodeship. Each of the analysed facilities includes a sports pool, a recreational pool with water attractions, a water slide, a whirlpool and a children's paddling pool. The findings of this study demonstrate a strong correlation between water consumption and the type of users and water management practices employed. In particular, it was found that recreational pools with water attractions (slides, whirlpools) used significantly more water than traditional sports pools. The findings of this case study offer a valuable foundation for the development of strategies aimed at enhancing the efficiency of water management in swimming pool facilities.

Keywords: swimming pools, water consumption, effective management, sustainability, technology optimisation.

Obiekty basenowe, ze względu na swoją specyfikę, są obiektami sportowymi o największym zapotrzebowaniu na wodę o jakości regulowanej restrykcyjnymi przepisami. Niniejsza praca ma na celu szczegółową charakterystykę struktury zużycia wody w trzech „bliźniaczych” obiektach basenowych zlokalizowanych w Polsce, w województwie śląskim. W każdym z analizowanych obiektów znajduje się basen sportowy, basen rekreacyjny z atrakcjami wodnymi, zjeżdżalnia wodna, wanna z hydromasażem i brodzik dla dzieci. Wyniki badań dowodzą, że istnieje silna korelacja między zużyciem wody a rodzajem użytkowników i stosowanymi praktykami zarządzania wodą. W szczególności dla basenów rekreacyjnych wyposażonych w atrakcje wodne (zjeżdżalnie, hydromasaże) wykazano znacznie wyższe zużycie wody w porównaniu z tradycyjnymi basenami typu sportowego. Wyniki niniejszego studium przypadku mogą zostać wykorzystane do opracowania strategii optymalizacji efektywnego zarządzania wodą w obiektach basenowych.

Słowa kluczowe: baseny, zużycie wody, efektywne zarządzanie, zrównoważony rozwój, optymalizacja technologii.

Introduction

The contemporary geopolitical landscape, coupled with an escalating water crisis marked by increasingly frequent droughts followed by severe floods and other natural disasters, requires urgent and comprehensive intervention from governments, facility managers, and urban planners. A central challenge in this context is the need to minimize the anthropogenic impacts

on ecosystems to preserve their integrity and stability [1–4].

Modern society is characterized by significant dynamism, evident in enhanced quality of life, escalating consumerism, and an increased reliance on non-renewable resources. Regrettably, these factors have led to a widening disparity between the essential requirements of the natural environment and the socio-economic demands of society. As consumer expectations rise, the strain on nat-

ural resources increases, underscoring the need for strategies that promote both economic development and environmental sustainability [5,6].

To address these complex issues, it is imperative to adopt a holistic sustainable development strategy that includes rational resource management, ecological education initiatives, and the promotion of conscious lifestyle changes among individuals and communities. By enhancing awareness of the

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importance of sustainability, it is possible to maintain a high standard of living while simultaneously mitigating adverse environmental impacts.

As social priorities evolve, there is a growing demand for a modern sports infrastructure, particularly in terms of physical activity and healthy living. However, many existing facilities, such as swimming pools and aqua parks, require substantial modernization, especially in terms of technical infrastructure, energy systems and effective water and wastewater management [7–9].

This work aims to provide a detailed analysis of water consumption patterns in three comparable swimming pool facilities in Poland. Despite the implementation of contemporary technological solutions, the levels of water consumption in these facilities remain high. A systematic comparison of this data with analogous facilities in other European countries will facilitate the identification of best practices and the development of innovative solutions aligned with sustainable development principles and closed-water circulation systems in the design of modern swimming pools in Poland [10, 11].

One critical issue is the irreversible loss of significant amounts of water that is discharged into sewage systems. Establishing legislative measures that impose strict limits on water and electricity consumption for investors, stakeholders from the public sector, and facility managers is essential [12]. Such regulations would encourage the adoption of advanced devices and technologies that improve resource management efficiency. By implementing these practices, facilities can maintain high-quality service delivery while significantly reducing the wastage of essential natural resources [13, 14].

The water used within swimming pools encompasses various activities, including the washing of filters, the operation of foot paddling pools, compensation for losses due to splashing and evaporation, and periodic replacement of water. Fortunately, these water sources can be effectively recycled through the appropriate systems. Advanced technologies, such as membrane filtration processes, ozonation systems, and advanced oxidation methods, facilitate the safe and efficient treatment of water, thereby allowing for its reuse in replenishing swimming pool basins or for sanitary purposes [15–18].

In addition, sports and swimming pool facilities typically feature large roof surfaces that present valuable opportunities for rainwater collection. Rainwater harvested can serve multiple applications, including irrigation of green spaces during summer months or as a resource for technological and sanitation processes. By analyzing data on water

consumption, user attendance patterns, and the specific characteristics of each facility, it is possible to establish clear and actionable principles aimed at optimizing water management practices. This analysis also enables user profiling, identifying potential risks, and the formulation of effective water conservation strategies [19].

In conclusion, the implementation of modern sustainable technologies in sports facilities not only contributes to environmental protection, but also advances the development of infrastructure according to global sustainable development objectives. By prioritizing sustainability within the sports and recreation sector, significant progress can be made towards the promotion of a healthier environment and the adoption of a more responsible approach to water resource management [20].

Materials and methods

Subject of the study

The objective of this study was to perform an analysis of water consumption in three sports facilities (P1, P2 and P3) located in the Silesian Voivodeship in Poland, which encompassed both a swimming pool area and a sports complex. All facilities were operated by a single management company, which facilitated the implementation of a uniform management system. Standardization of procedures, including the filter washing schedule, disinfection processes, and maintenance of water quality parameters, was an essential component of the research methodology. This approach ensured that data related to water consumption in the analysed facilities could be effectively compared.

Characteristics of the twin sports facilities

The analysed facilities (P1, P2 and P3) are divided into three functional zones.

The first zone is designated as the public area, which encompasses the entrance hall with a café, cash registers, changing rooms, and administrative offices. This area facilitates access to the changing rooms within the sports zone, the swimming pool, and the spectator stands.

The second zone is the large swimming pool hall. There is a sports pool (25 m × 16 m) that has been constructed in accordance with the requirements of the FINA to host competitive events, a pool designed for swimming instruction and recreational water activities. The recreational part incorporates a variety of water attractions, including neck massages, wall and water-air massages, an air geyser, a water mushroom, air benches, a jacuzzi, a paddling pool for young children, and a braking tub for water slides. Additionally, the facilities feature 80-meter-long slides, with portions extending outdoors, as well as a selection of hydromassage tubs and sauna zones.

The third zone is the 'dry' sports section which comprises a fitness zone and a gym, both of which are equipped with changing facilities and sanitary amenities accessible to people with disabilities. The main sports hall includes courts for volleyball and basketball. A separate reception area, intended as a customer service point, is equipped with a waiting room for patrons of the sports section.

The complete technical infrastructure for the facilities is situated in the sub-basin, thus ensuring efficient management of the operation and maintenance processes.

The swimming pool area (in each swimming pool facility) is equipped with four closed-water treatment circuits (systems): system I for sports pool (SP), system II for recreational pool with slide (RP), system III for whirlpool tubs (WT) and system IV for children's paddling pool.

Table 1 provides a comprehensive summary of the technical parameters associated with each system that operates as an independent water treatment plant. It is essential to emphasize that the water flow in the individual circuits is fully segregated, thus precluding any potential for cross-contamination.

Characteristic of the filtration process and water circulation systems

The facility employs two distinct filtration systems: under pressure filtration (system I and II) and pressure filtration (system III and IV). The under pressure filtration system is designed with an overflow pocket that has

Table 1. Technical data of swimming pool systems in p1, P2 and P3 facilities
Tabela 1. Parametry techniczne systemów basenowych w obiektach P1, P2 i P3

Parameter	System I (SP)	System II (RP)	System III (WT)	System IV (CP)
Internal dimensions of the pool [m]	25 × 16	irregular shape	Ø2.35	irregular shape
Water surface area [m ²]	400	205.8	4.0	28.8
Pool basin volume [m ³]	600	210	3.6	14.7
Temperature of water [°C]	28	30	34	32
Circulating water flow [m ³ /h]	178	260	72	28
Type of filtration	Under pressure		Pressure	
Number of filters [pcs]	2	3	1	1
Filter dimensions [m]	3.0 × 2.0 × 2.3	3.0 × 2.0 × 2.3	D=1.8m	D=1.2m
Media type	gravel and sand with a layer of activated carbon			

a significantly larger surface area, allowing more efficient washing while utilizing considerably less water. Consequently, this system is particularly advantageous for swimming pool applications that require substantial volume and filtration capacity.

In contrast to conventional closed rapid filters, under pressure filters separate the inflow of untreated water from the collection of filtered water, necessitating process automation. Water from the expansion tank is transferred to the filter via a pump that operates on an inverter system, which is controlled based on water level measurements obtained from a pressure transducer. This configuration ensures the maintenance of a constant water level within the filter.

Concurrently, water is extracted from the filter by another pump, also powered by an inverter, and regulated by measurements obtained from an electromagnetic flowmeter. This design guarantees consistent filtration efficacy, regardless of the level of contamination within the filtration bed.

Circuits III and IV utilize traditional pressure filtration methods, employing multilayer pressure filters containing activated carbon. Circulation pumps draw water from the expansion tank and are integrated with a pre-filter that captures larger impurities, thus protecting the rotors and other components of the installation from potential damage. The filtered water is subsequently pumped into the pressure filters located in the individual systems.

Before the filtration process, a coagulant is dosed to optimize filtration effectiveness. The appropriate dosage is determined based on the concentration of the active agent, Al^{3+} . According to the standard DIN 19643 [21], the minimum required dose of active coagulant is $0.5 \text{ g } Al^{3+}/m^3$. Following coagulant dosing, solid impurities are eliminated within the pressure filter, which features a multilayer sand-gravel bed containing activated carbon with a total height of 1.2 meters.

Backwashing of the filter is scheduled at least every three days [22] and is conducted when the pool is unavailable to users. The water used for washing is obtained from the expansion tank, ensuring that the process employs operational water.

Following the filtration process, the water is directed to the heat exchangers to achieve the desired temperature. Before heating, the water is disinfected by ultraviolet (UV) irradiation. The pH adjuster (sulphuric acid) and disinfectant (sodium hypochlorite) are then dosed (Fig. 1). Given the alkaline nature of sodium hypochlorite, it is imperative that the pH corrector possess an acidic reaction to maintain the pool water within the requisite pH range of 6.5 to 7.6 [23]. The dosing of both the pH corrector and the disinfectant,

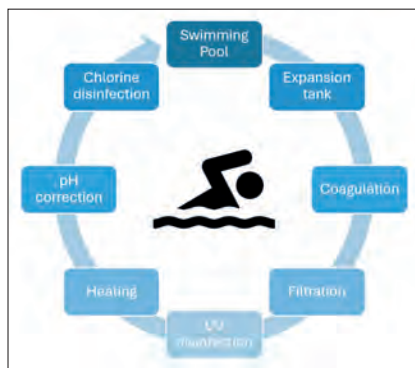


Figure 1.
Scheme of the pool water treatment
Rysunek 1. Schemat oczyszczania wody basenowej

together with the regulation of their respective concentrations in the pool water, is supervised by an automated control and measurement system that directly controls the dosing pumps. Subsequently, the treated pool water is transported to the pool basin through a system of bottom supply channels installed at the base, which incorporate hydromassage jets that are an essential component of the pool basin.

Characteristics of water consumption in facilities

The use of water in swimming pool facilities can be classified into two primary categories:

- Domestic and utility water – This category encompasses water utilized for the essential daily needs of facility users, including operations related to restrooms, showers, cleaning equipment, and catering services. This water is vital for ensuring user comfort and efficient functioning of the facility.
- Technological water – This category pertains to water employed in various technological processes, such as the backwashing of filters, operation of foot paddling pools, and the compensation for water losses resulting from evaporation and splashing in pool basins. Technological water is essential to maintain appropriate water quality parameters and ensure the effective operation of filtration systems.

In the context of analysing the use of water in swimming pool facilities, technological water is of particular significance, as it frequently serves as the primary source of wastewater generation. Water used in filtration processes and maintaining pool water quality is associated with substantial losses and corresponding operational costs. Thus, an in-depth understanding of technological water consumption is imperative for managing the operational expenses of the facility and optimizing the water treatment process-

es. Furthermore, it is crucial to continuously address water losses due to evaporation and splashing, as these factors significantly influence the overall water balance within the facility.

Methodology for measuring water demand

Water consumption in the three swimming pool facilities under analysis was systematically monitored utilizing data obtained from the Building Management System (BMS), which incorporated water meters equipped with M-Bus overlays. This system facilitates the direct transmission of water meter readings to the M-Bus wired network, thereby allowing for continuous and accurate monitoring of water usage. Furthermore, the readings from the water meters were regularly verified to rectify any potential measurement errors.

During the entire analysis period, the water quality consistently adhered to the relevant standards. The water utilized in the swimming pools was subjected to comprehensive testing to ensure compliance with quality benchmarks as stipulated in legal regulations, including the Regulation of the Minister of Health dated May 10, 2022 [23].

Managers of pool facilities are required to continuously oversee water quality through regular physicochemical and bacteriological assessments. This practice is imperative to ensure user safety and to maintain compliance with the applicable sanitary standards.

Results

From July 2023 to September 2024, a comprehensive evaluation was conducted on three twin swimming pool facilities (P1, P2 and P3) located in the Silesian Voivodeship in Poland, all operated by the same management company. The primary objectives of this research were to analyse the consumption of water for technological requirements and to assess the quality of the water. Throughout the evaluation period, the water quality in all the facilities examined consistently adhered to the rigorous standards stipulated in the Minister of Health Regulation for water intended for use in swimming pools [23].

Water consumption analysis – Sports Pool

Analysis of average monthly water consumption in the sports pools, illustrated in Figure 2a, revealed that the facility P1 exhibited the lowest consumption, averaging 166.63 m^3 per month. This figure was 51 m^3 , or 24%, lower than the consumption levels observed in facilities P2 and P3, which recorded average monthly consumptions of

217.23 m³ and 218.74 m³, respectively. The similarity in the consumption levels of facilities P2 and P3 indicates comparable operational characteristics; however, the P2 facility attracted a significantly higher number of users, which directly contributed to elevated water consumption.

Water consumption analysis – Recreational Pool

Regarding recreational pools, the assessment demonstrated relative stability in water consumption in all three facilities from July 2023 to May 2024. In particular, the months of June and July deviated from this trend, as the facility P3 was temporarily closed for technological maintenance, resulting in a significant decrease in its average monthly consumption, which fell to 303.38 m³. On the contrary, facility P1 maintained an average of 341.92 m³ per month, while facility P2 recorded an average of 347.75 m³ per month (Fig. 2b). The increase in consumption in facility P2 during this period, which

pared to the facility average of 122.90 m³ and is 40% higher than the facility average of 91.43 m³ (Fig. 2c). These differences in consumption levels are mainly due to factors such as increased water loss due to splashing, significant evaporation, and a greater need for frequent filter washing, all of which are exacerbated by the high frequency of use.

Water consumption analysis – Children’s Pool

Finally, the study of children’s pools revealed a strong correlation between water consumption, user attendance, and the frequency of swimming lessons. Facility P2 had the highest average monthly water consumption in this category, reaching 62.26 m³. This increased consumption can be attributed to the strategic location of the facility close to local schools, making it a preferred option for families and educational activities. In comparison, facility P1 recorded an average of 46.78 m³ per month, while facility P3 recorded an average of 44.82 m³ per month,

indicating that facility P2’s consumption was 33% higher than P1 and 39% higher than P3 (Fig. 2d). These data highlight the impact of demographics of users and geographical considerations on the effective management of water resources throughout the facilities.

The percentage share of water consumption of the analysed swimming pool facilities (P1, P2, P3), categorised by individual water systems, is shown in Figure 3. An analysis of the data shows that recreational pools account for the majority of water consumption. This predominance can be attributed to the specific operational characteristics of these pools, which have a number of water and air attractions, including water slides. Such features result in significant water losses due to evaporation, splashing and the operational demands of auxiliary systems.

Sports Pools – SP

Sports pools, which represent the largest capacity in terms of volume and surface area, rank second in terms of water consumption

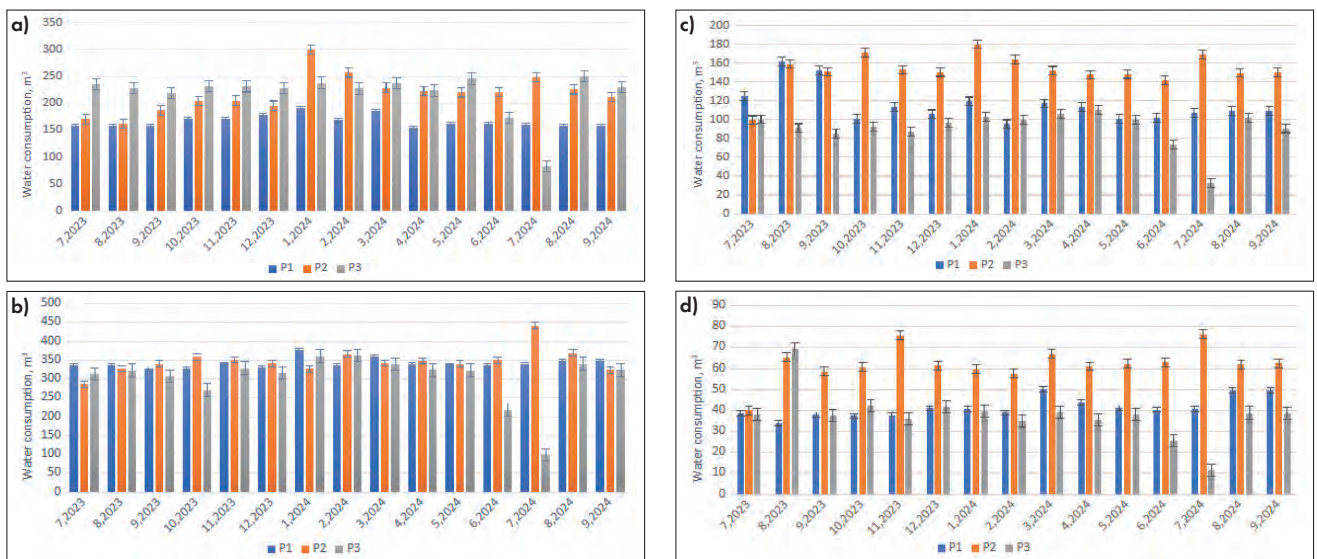


Figure 2. Water consumption for pool facilities (P1, P2, P3) depending on the type of pool basin
a) Sports pool (SP), b) Recreation pool (RP), c) Whirlpool Spa tubs (WT), d) Children’s paddling pool (CP)
Rysunek 2. Zużycie wody dla obiektów basenowych (P1, P2, P3) w zależności od rodzaju niecki basenowej a) Basen sportowy (SP), b) Basen rekreacyjny (RP), c) Wanny z hydromasażem (WT), d) Brodzik dla dzieci (CP)

reached a peak of 441.8 m³ per month, can be attributed to its obligation to accommodate users displaced from the inactive P3 facility, illustrating the interconnected nature of usage in the facilities.

Water consumption analysis – Whirlpool Tubs

The evaluation of the water consumption of the whirlpool tubs showed a high variability, closely related to the frequency of use. Facility P2, recognised for its popularity with customers, reported the highest average monthly water consumption at 152.57 m³. This figure represents an increase of 24% com-

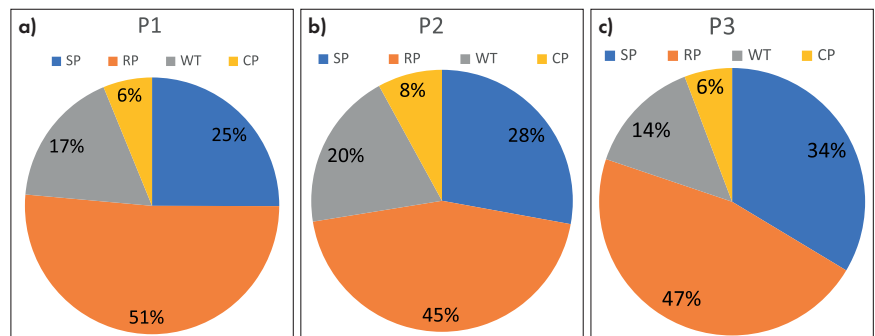


Figure 3. Average annual water consumption for individual types of swimming pools in the three analysed facilities a) P1, b) P2, c) P3
Rysunek 3. Średnie roczne zużycie wody dla poszczególnych rodzajów niecek basenowych w trzech analizowanych obiektach a) P1, b) P2, c) P3

distribution. Although these pools have relatively low levels of contamination and reduced spray losses, their significant volume has a significant impact on total water consumption. In facility P1, the sports pool is responsible for 25% of the total water consumption, which amounts to 116.6 m³ per month. Conversely, in facilities P2 and P3, the percentage is significantly higher at 28% (218 m³/month) and 34% (218 m³/month) respectively, indicating a more intensive use of these facilities.

Recreational Pool – RP

In facility P1, the recreational pool accounts for 51% of the total water consumption, corresponding to an average monthly consumption of 341.92 m³. Facility P2 shows a share of 45%, corresponding to a monthly consumption of 347.75 m³. In contrast, P3 shows that the recreational pool accounts for 47% of the total consumption, with a monthly figure of 303.38 m³. The higher percentage of water consumption in these pools is due to the high level of user engagement and the specialised nature of the additional equipment.

Whirlpool Spa Tubes – WT

Whirlpool Spa tubes are the third largest contributor to water consumption, despite their modest average volume of 3.6 m³. Significant water losses occur through evaporation and splashing by users. In facility P1, spas account for 17% of total water consumption, a significant figure given their limited capacity. In facility P2, the percentage rises to 20%, while facility P3 accounts for 14%. The variations in these percentages are due to differences in user load and the operational context of each facility.

Children's Paddling Pools – CP

Children's paddling pools have the lowest water losses of all the systems analysed. In facilities P1 and P3, the percentage is 6%, while in facility P2 it is slightly higher at 8%. The lower water consumption in paddling pools is mainly due to their limited volume and the comparatively lower number of users compared to other systems.

Discussion

Sports facilities, especially indoor swimming pools, consume considerable amounts of water for various technological, operational and hygienic purposes. This extensive water use results in the generation of significant amounts of wastewater, posing a challenge to effective water resource management and sustainability efforts [24-26]. A fundamental component of optimising water use in these facilities is the implementation of rational water management practices,

which include monitoring water use and identifying areas for improvement.

Effective management of water resources in swimming pools requires careful consideration of water reuse options, including the use of treated water in technological processes. It is also essential to minimise losses due to evaporation, splashing and inefficiencies resulting from operational failures or inappropriate use.

A study carried out by the authors on water consumption in three swimming pool facilities located in the Silesian Voivodeship of Poland revealed a significant correlation between water consumption levels and various facility parameters, functions, and number of users. Research conducted by Flora Silva et al. [7] on a swimming pool facility in Portugal, which featured both sports and recreational pools, indicated an annual water consumption of 8,440.8 m³. Most of this water was used for technological processes, such as filter washing and maintenance of pool basins. The facility's parameters included a water surface area of 591.6 m² and a total water volume of 1,050 m³, serving as a benchmark for comparative research.

The results obtained from the analysis of the three facilities in Silesia (P1, P2, and P3) revealed annual water consumption figures of 8,002.9 m³, 9,205.9 m³, and 8,130.1 m³, respectively. These figures are approximately consistent with the data collected by the Portuguese research team, indicating potential areas for knowledge exchange on effective water management practices in similar swimming pool facilities.

The research carried out by Kampel [27] in his dissertation focused on a swimming pool facility with a water surface area of 637.5 m², which resulted in an annual water consumption of 11,817 m³. This figure was found to be 22% higher than the highest recorded consumption of the facilities in the Silesian Voivodeship (P2) and 28.6% higher than the data obtained by the Portuguese research team [7].

Additional analyses by a Spanish research team indicate that the average annual water consumption is 2,017 m³ per swimming pool basin [28], largely due to the need for filter washing. The authors' results correlate closely with an average of 2,111.58 m³, further validating the accuracy of the data. With regard to filter rinsing technology, research by Doménech-Sánchez et al. [28] indicates an average water consumption of 5.53 m³ per filter rinse for a single swimming pool, which is in line with the results of this study of 5.57 m³.

A comparison of daily water consumption for filter rinsing between Portuguese studies and data from the Silesian Voivodeship reveals significant discrepancies. In Portu-

guese studies [7], daily consumption was determined to be 15.7 m³ for the sports pool and 7.7 m³ for the pool for swimming lessons. On the contrary, the average daily consumption of the sports pool in the facilities P1, P2, and P3 in Silesia was only 6.48 m³, representing approximately one-third of the figures observed in the Portuguese studies. A similar discrepancy emerged for the children's pool, where the average daily consumption was 1.52 m³, and for the recreational pool, where it was 10.67 m³. It is crucial to recognize that comparing water consumption between recreational pools and swimming lesson pools requires consideration of the differing roles these facilities play. The recreational pool, in addition to serving as a swimming training area, includes enhanced features such as an air-water massage zone and a water slide, both of which significantly contribute to increased water consumption.

The research conducted by Marco Maglionico and Irena Stojkov [29] on water consumption in a small pool (12 m × 5.5 m × 1.2 m) located in Bologna, Italy, showed a daily water consumption of 9.5 m³ on days designated for school and club classes. This figure is closely aligned with the daily consumption of 10.67 m³ recorded in a recreational pool in Poland. On days without classes, consumption decreased to 6 m³, with technological water usage for filter washing that was 4.03 m³ per day in this case.

Cardoso et al. [11] also conducted research in Portugal, comparing water consumption between various swimming pool facilities by analysing the consumption per m² of water surface area. Their findings demonstrated Environmental Performance Index (EPI) values of 17 m³/m² for a facility that covered 576 m² (resulting in an annual consumption of 9,792 m³) and 20 m³/m² for a facility with 746 m² (resulting in an annual consumption of 14,920 m³). The consistency of these values with those obtained from the Silesian Voivodeship, which reported water consumption indicators of 12.5 m³/m² (P1), 14.4 m³/m² (P2), and 12.7 m³/m² (P3), underscores the need to analyse water consumption indicators in the context of different types of swimming pool facilities.

Conclusions

A detailed investigation into water consumption was conducted in three different swimming pool facilities, encompassing both sports and recreational pools that feature water attractions such as water slides, hot tubs, and paddling pools for children. The findings of this research are summarised as follows:

- Average water consumption for swimming pool operations:

The mean annual water consumption was measured at 8,446.3 m³, which equates to an average monthly consumption of 703.9 m³. This figure represents the essential demand for water required to support the day-to-day operations of the swimming pool facilities. This includes compensating for water losses, conducting filter rinsing processes, and ensuring the maintenance of water quality.

- Correlation between water consumption and user attendance:

A robust correlation has been demonstrated between the number of users of recreational pools, water attractions, and instructional swimming pools, and the quantity of water consumed. An increase in the number of bathers has been shown to be directly correlated with increased water consumption. This is attributed to increased splashing, elevated levels of water contamination, and the need for more frequent filter washing.

- Stability of water consumption in sports pools:

Sports pools are distinguished by their stable water consumption patterns, which exhibit comparability in various facilities. This consistency can be attributed to two main factors. Firstly, there is the issue of standardised pool volumes. Secondly, there is the issue of the focused nature of user activity, which predominantly involves swimming as opposed to the utilisation of recreational amenities.

- Specific characteristics of hot tub water consumption:

Despite the relatively modest water volume and surface area occupied by hot tubs, they are associated with significant water consumption. The primary factors contributing to this high level of consumption include: water splashing induced by users and the operation of air bubble-generating devices, and high degrees of water pollution necessitating frequent filter washing and regular water replacement.

- Influence of swimming lessons on water consumption:

A near two-fold increase in water consumption is observed during intensive periods of swimming lessons for children in swimming pools. This increase can be attributed to two main factors: the increase in the number of participants and the intensified use of the associated infrastructure.

- Recreational pools as the preeminent water consumers:

The analysis showed that recreational pools have the highest average monthly water consumption, calculated at 331.02 m³. This volume is almost 40% higher than that of sports pools, despite the latter having three times the volume capacity. Such findings highlight the significant impact of user demographics and the presence of water attractions on overall water consumption levels.

In conclusion, the present analysis demonstrates that the structural characteristics

and specific usage patterns of swimming pool facilities are fundamentally important to determine the intensity of water consumption. The insights derived from this research can inform the development of optimisation strategies for effective water management within swimming pool facilities.

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REFERENCES

[1] S.C. Addanki and H. Venkataraman, Greening the economy: A review of urban sustainability measures for developing new cities, *Sustain Cities Soc.* 32 (2017) 1–8. <https://doi.org/10.1016/j.scs.2017.03.009>.

[2] A. Lewandowska and D. Szymańska, Ecologisation of Polish cities in the light of selected parameters of sustainable development, *Sustain Cities Soc.* 64 (2021) 102538. <https://doi.org/10.1016/j.scs.2020.102538>.

[3] R.F.M. Ameen and M. Mourshed, Urban sustainability assessment framework development: The ranking and weighting of sustainability indicators using analytic hierarchy process, *Sustain Cities Soc.* 44 (2019) 356–366 <https://doi.org/10.1016/j.scs.2018.10.020>.

[4] S. van Dijk, A.W. Lounsbury, A.Y. Hoekstra and R. Wang, Strategic design and finance of rainwater harvesting to cost-effectively meet large-scale urban water infrastructure needs, *Water Res.* 184 (2020) 116063. <https://doi.org/10.1016/j.watres.2020.116063>.

[5] M. Flörke, C. Schneider and R.I. McDonald, Water competition between cities and agriculture driven by climate change and urban growth, *Nat Sustain.* 1 (2018) 51–58. <https://doi.org/10.1038/s41893-017-0006-8>.

[6] M. Flörke, E. Kynast, I. Bärlund, S. Eisner, F. Wimmer and J. Alcamo, Domestic and industrial water uses of the past 60 years as a mirror of socio-economic development: A global simulation study, *Global Environmental Change.* 23 (2013) 144–156. <https://doi.org/10.1016/j.gloenvcha.2012.10.018>.

[7] F. Silva, A.M. Antão-Geraldes, C. Zavattieri, M.J. Afonso, F. Freire and A. Albuquerque, Improving Water Efficiency in a Municipal Indoor Swimming-Pool Complex: A Case Study, *Applied Sciences.* 11 (2021) 10530. <https://doi.org/10.3390/app112210530>.

[8] L. Fisher-Jeffes, G. Gertse and N. Armitage, Mitigating the impact of swimming pools on domestic water demand, *Water SA.* 41 (2016) 238. <https://doi.org/10.4314/wsa.v41i2.09>.

[9] C. Pimentel-Rodrigues and A. Silva-Afonso, Assessment of Measures to Increase Water Efficiency in Public Swimming Pools, *Sustainability.* 14 (2022) 14726. <https://doi.org/10.3390/su142214726>.

[10] K. Kubiak-Wójcicka, D. Domszy and S. Machula, Best Practices in Wastewater Management in Poland with Particular Emphasis on Swimming Pool Waters, in: *Cost-efficient Wastewater Treatment Technologies.* (2022) 485–504. https://doi.org/10.1007/698_2022_878.

[11] B.J. Cardoso, A.R. Gaspar, J.C. Góis and E. Rodrigues, Energy and water consumption characterization of Portuguese indoor swimming pools, in: *Proceedings of the CYTEF 2018 VII Congreso Ibérico, Ciencias Y Técnicas Del Frío, Valencia, Spain.* (2018). <https://doi.org/10.31224/osf.io/e8awk>.

[12] A. Piasecki, Water and Sewage Management Issues in Rural Poland, *Water (Basel).* 11 (2019) 625. <https://doi.org/10.3390/w11030625>.

[13] K. Kubiak-Wójcicka and M. Kielik, The State of Water and Sewage Management in Poland, in: *Quality of Water Resources in Poland.* (2021) 375–397. https://doi.org/10.1007/978-3-030-64892-3_16.

[14] P. Zawadzki and M. Wiesner-Sękala, Advanced wastewater reclamation – a response of the municipal sector to climate change and water scarcity, *INSTAL* 12 (2024) 65–74. <https://doi.org/10.36119/15.2024.12.12>.

[15] W. Studziński, W. Poćwiardowski and W. Osieńska, Application of the Swimming Pool Backwash Water Recovery System with the Use of Filter Tubes, *Molecules.* 26 (2021) 6620. <https://doi.org/10.3390/molecules26216620>.

[16] P. Pal, Introduction to membrane materials, processes, and modules, in: *Membrane-Based Technologies for Environmental Pollution Control,* Elsevier. (2020) 3–69. <https://doi.org/10.1016/B978-0-12-819455-3.00001-7>.

[17] M. Wolska and H. Urbańska-Kozłowska, Assessing the Possibilities of Backwash Water Reuse Filters in the Water Treatment System—Case Analysis, *Water (Basel).* 15 (2023) 2452. <https://doi.org/10.3390/w15132452>.

[18] A. Mika-Shalyha, J. Wyczarska-Kokot and A. Lempart-Rapacewicz, Membrane filtration in swimming pools – case study, *INSTAL* 9 (2024) 36–41. <https://doi.org/10.36119/15.2024.9.4>.

[19] E. Burszta-Adamiak and P. Sychalski, Water savings and reduction of costs through the use of a dual water supply system in a sports facility, *Sustain Cities Soc.* 66 (2021) 102620. <https://doi.org/10.1016/j.scs.2020.102620>.

[20] Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy (2020).

[21] DIN 19643:2023 Treatment of water of swimming pools and baths, Beuth-Verlag, Germany 2023 (in German).

[22] C. Sokółowski, Sanitary and Hygiene Requirements for Indoor Swimming Pools, Polish Association of Sanitary Engineers and Technicians, Ministry of Health and Social Welfare, Department of Public Health, Poland 1998 (in Polish).

[23] Decree of the Health Minister on the requirements for water in swimming pools, *Journal of Laws* 2022, item 1230 (in Polish).

[24] N.K. Arora and I. Mishra, Sustainable development goal 6: Global Water Security, *Environmental Sustainability.* 5 (2022) 271–275. <https://doi.org/10.1007/s42398-022-00246-5>.

[25] I.S. Marinopoulos and K.L. Katsifarakis, Optimization of Energy and Water Management of Swimming Pools. A Case Study in Thessaloniki, Greece, *Procedia Environ Sci.* 38 (2017) 773–780. <https://doi.org/10.1016/j.proenv.2017.03.161>.

[26] J. Wyczarska-Kokot and M. Dudziak, Reuse – Reduce – Recycle: water and wastewater management in swimming pool facilities, *Desalination Water Treat.* 275 (2022) 69–80. <https://doi.org/10.5004/dwt.2022.28756>.

[27] W. Kampel, Energy Efficiency in Swimming Facilities, Doctoral theses at NTNU (Norwegian University of Science and Technology), Trondheim 2015. https://www.godeidrettsanlegg.no/sites/default/files/bilder/PhD_Wolfgang_Kampel.pdf.

[28] A. Doménech-Sánchez, E. Laso and C.I. Berrocal, Water loss in swimming pool filter backwashing processes in the Balearic Islands (Spain), *Water Policy.* 23 (2021) 1314–1328. <https://doi.org/10.2166/wp.2021.217>.

[29] M. Maglionico and I. Stojkov, Water consumption in a public swimming pool, *Water Supply.* 15 (2015) 1304–1311. <https://doi.org/10.2166/ws.2015.095>.