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Analysis of the sustainability of swimming pools: Water and energy cycles

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ABSTRACT

The objective of this article is to conduct a literature review aimed at analyzing recent research conducted between 2018 and March 2023 concerning the water and energy cycles in swimming pools. This review aims to provide updated information by considering the impact of the COVID-19 pandemic on the sector. Additionally, it serves as a complementary review to a previous study that encompassed research up until 2018. Four challenges that the review seeks to analyze and investigate are identified: water balance, energy balance, chemical balance, water treatment, and diverse legislation. Regarding the water balance, the importance of reducing evaporation from swimming pools is highlighted, especially in Mediterranean climates with prolonged drought periods. Various solutions to improve the water balance are analyzed, such as the use of solar covers and the optimization of the water recirculation and filtration system. In relation to the energy balance, it is recognized that the use of pumps and filters consumes a lot of energy. The review emphasizes the importance of optimizing the water recirculation and filtration system, and various ways to improve the energy efficiency of pool heating and air conditioning are examined. In addition, the use of renewable energy technologies, such as solar panels, to reduce the energy demand of pools is considered.

In summary, this review updates previous research on the water and energy cycles in swimming pools, with a focus on water and energy balance. The review identifies challenges and solutions to improve the sustainability of pools and highlights the importance of addressing the complexity of applicable legislation. The results of this

review are expected to be useful for future research and to promote more sustainable management of swimming pools.

KEYWORDS

Swimming pools, Environmental impact, Water, Energy, Sustainability, Climate control, Evaporation, Filtration.

1. Introduction

Efficient energy and water consumption in swimming pools is a challenge in achieving more efficient and sustainable pools. Energy and water consumption must be optimized to enhance sustainability in the swimming pool sector.

Optimizing the sizing, design, and operation of pools is also necessary to facilitate the reduction of environmental impact, particularly in terms of water footprint, CO2 emissions, non-renewable energy consumption, and the use of chemicals.

This academic literature review builds upon a previous review that encompassed articles up to 2018. Its aim is to analyze new research conducted between the years 2018 to March 2023, updating the results also to the immediate pre-COVID pandemic era, through the COVID pandemic, to the current post-COVID era.

In swimming pools several different cycles can be identified which combined represent the operation of the pool:

- Water cycle
- Energy cycle
- Chemical cycle

In this literature review, which highlights the above-mentioned reality, the water and energy cycles are analyzed, leaving the chemical cycle for further research.

In more detail, four challenges have been identified in the world of swimming pools that this literature review seeks to analyze and investigate:

- Water balance in swimming pools. Within this challenge there is an issue that, in the current and future era, expected due to climate change, becomes more important, especially in Mediterranean climates with long, and increasingly persistent, periods of drought. This is the evaporation of water from swimming pools.
- Energy balance of swimming pools
- Chemical balance and water treatment of swimming pools. As previously mentioned, this challenge will be left for subsequent lines of research.
- Diverse legislation. There is a great variety of applicable legislation at different levels that complicates the legal situation of the swimming pools, in Spain this

regulation exists at national level as well as by autonomous communities, even there are diverse municipal regulations.

With respect to the water balance, a prominent problem is water evaporation (Shah, 2002, 2012, 2012, 2014; Smith et al., 1999). On evaporation, there are investigations referring to occupied and unoccupied pools, with notable differences in the results at the level of evaporation rate (Shah, 2012, 2018). Specifically, when the activity performed in the pool involves increasing the air-water exchange surface area the evaporation rate is higher in occupied pools (Shah, 2002, 2012). In 2009, a research published a scale model supporting Shah's studies (Asdrubali, 2009).

In studies after the initial literature review regarding the evaporation rate, research has been conducted on the artificial neural network and finite element simulations. These studies demonstrate that with the use of new technologies, it is possible to simulate and predict the evaporation rate of a pool, where the variables are multiple and difficult to analyze since they are all interrelated, variables such as indoor air temperature, relative humidity, water temperature, pool occupancy, inflow currents and many other parameters (Aldarabseh & Merati, 2022; Ciuman & Lipska, 2018; Foncubierta Blázquez et al., 2018, 2023; Gallero et al., 2020; Liew et al., 2018; Shah, 2022, 2023; O. O. Smedegård et al., 2022)..

Regarding studies related to swimming pool filtration, the hydraulic efficiency and filtration of swimming pools during recirculation and disinfection are investigated, which are necessary to maintain the healthiness and cleanliness parameters of swimming pools. One key focus is on avoiding dead zones where water components can be retained for long periods creating hygiene problem areas in addition to reducing the hydraulic efficiency of swimming pools (Alansari et al., 2018). There are also studies where the large water losses during the filter washing process are analyzed, and how to improve it (Doménech-Sánchez et al., 2021; Wyczarska-Kokot, 2016)..

In recent studies, the focus has been on analyzing how to recover the water from the filter washing processes (Chen et al., 2014; Poćwiardowski, 2023; Studziński et al., 2021; Wyczarska-Kokot & Lempart, 2018).. Furthermore, during this last analyzed period there are several studies that model with new technologies the hydrodynamic circuits of swimming pools and evaluate in this way the design of swimming pools also (Dougha et al., 2018; Golbaz et al., 2019; Orlov et al., 2018; Zhang et al., 2018)..

Lastly, concerning the energy cycle of swimming pools, the most significant elements include energy consumption for water heating, as well as air conditioning and dehumidification of the building. Several measures can be implemented to improve energy efficiency and reduce the environmental impact of swimming pools. For instance, a high-efficiency heating system such as heat pumps can contribute to the sustainability of the swimming pool sector, since a heat pump is an element that uses heat from the air or water to transfer it to the air or water element being heated, thus enhancing energy efficiency (Chow et al., 2012).

Other research in the field focuses on energy simulation models that take human activity into account (Santos et al., 2013). Some studies incorporate neural networks to adapt the model to other locations with environmental data based on artificial intelligence for the calculation of energy demand (Mančić et al., 2014). Additionally, researchers focus on better pool energy and water management, seeking solutions in thermal energy for energy savings, and consequent economic savings, brought about by optimization measures (Marinopoulos & Katsifarakis, 2017).

Studies in the recent period have focus on optimizing the efficient operation of swimming pools based on consumption forecasting to achieve fuel savings (Delgado Marín et al., 2019).. There are also studies, as in the previous cases, where computation and analysis of mathematical and neural models are used for the improvement of the energy cycle of swimming pools (Calise et al., 2018; Lau et al., 2020; Limane et al., 2018; Marin & Garcia-Cuscales, 2020; O. Ø. Smedegård et al., 2021).

Another significant topic of the latest investigations refers to the use of renewable energy sources, as is the case of solar energy for swimming pools heating (Delgado Marín et al., 2019; Ilgaz & Yumrutas, 2022; Lugo et al., 2019; Pérez-Carramiñana et al., 2022; Pop & Pop, 2018; Singh et al., 2020; Wache et al., 2020; Zhao et al., 2018).

2. Methodology

As previously mentioned, there is a review of previous academic literature that encompasses technical and engineering aspects of simulation in swimming pools, aiming to achieve more efficient pools. This review includes articles up until the year 2018.

Both systematic literature reviews begin with a comprehensive general search using the same keywords as below:

- Artificial AND Neural AND Network AND "Swimming Pool".
- "Digital Twin" AND "Swimming Pool".
- Disinfection AND Model AND "Swimming Pool".
- Filtration AND Model AND "Swimming Pool".
- Rain AND Simulation AND "Swimming Pool".
- Shadows AND Simulation AND "Swimming Pool".
- Simulation AND "Swimming Pool" AND Cover
- "Swimming Pool AND Operation
- Water AND Evaporation AND "Swimming Pool".
- "Water treatment" AND "Swimming Pool".

For this second academic literature review, the databases Scopus, and Web of Science (WoS) were also utilized.

Scopus is a multidisciplinary bibliographic database produced by Elsevier. It contains information on scientific journal articles, conference proceedings, books, and book chapters. It is one of the largest and most comprehensive databases worldwide in terms of scientific, technical, and medical content, with over 75 million records from 1823 to the present. Scopus is widely used by researchers, scholars, librarians, and information professionals around the world for bibliographic searches, citation analysis, trend identification, and scientific research evaluation.

Similarly, Web of Science (WoS) is a multidisciplinary bibliographic database produced by Clarivate Analytics. It encompasses information on scientific journal articles, conference proceedings, books, and book chapters. WoS is also one of the most significant databases in the realm of scientific research. It includes information on articles from high-quality journals, selected based on their impact in the research field and editorial quality. WoS serves as a valuable resource for researchers, providing access to influential scholarly literature and facilitating citation analysis and research evaluation.

In the initial review, after collecting the references based to the keywords, a systematic filtering process is conducted using criteria such as title, author, year, and language. This process initially yields a total of 40,056 bibliographic references, including journal articles and proceedings in the English-language, the reference language in the field of the study. Duplicates and irrelevant articles are then eliminated, filtering by reading the title, summary of the work and selection of keywords. This filtering process results in a sample of 284 articles.

Subsequently, the documents are downloaded and undergo a preliminary reading, then they are labeled in categories and subcategories with a reference management program, where all these references are collected. Finally, after this analysis process, a total of 55 documents remains identified as the focus of the study.

The aim of this second systematic review is to update the data with new research conducted from 2018 to 2023, thus also aiming to see if during the COVID pandemic era there has been the same academic production or other topics that were not previously of academic or social interest have been addressed.

This new temporal update of the literature review has been carried out following a bibliographic method for information collection, processing, and presentation of results (Codina, 2020c, 2020b, 2020a; Lic. Reinaldo Rivera Oliva et al., 2010; Munn et al., 2018).

3. Results

The results and phases of the literature review followed during this process are described below:

Phase 1 (Identification). Identification of information sources. In this phase, the documents to be examined were selected. As mentioned earlier, the sources used were Scopus and Web of Science (WoS). After inputting the keywords and applying temporal filters from 2018 to 2023, a total of 370 records were obtained from Scopus. Similarly, a search was conducted in WoS using the same parameters, resulting in 262 records. In total, 632 records were identified.

Phase 2 (Review). Process of analysis of the information for the elimination of duplicate records, a total of 166 records, also proceeding to the systematic review to filter the total number of records. This systematic review phase is conducted by the technique of content analysis, which makes it possible to find the theoretical elements that allow statements to be made and interpretations to be made about the object of study in order to subsequently form the results section. Specifically, the title of the article, keywords, number of citations, and abstract of the article are examined. Following this method 422 records are excluded, leaving 44 remaining records. Additionally, the snowball methodology (Agichtein Eugene & Gravano Luis, 2000; Biernacki & Waldorf, 1981) is applied to add

other relevant references, resulting a total of 10 records. Thus, the final selection consists of 54 articles for eligibility and classification.

Phase 3 (Eligibility). Once the articles have been selected for their readability, the complete contents are analyzed and classified according to their research topic and linked to the challenges to achieve a more efficient and sustainable swimming pool. The selected topics are the following:

- Water. There are a total of 30 articles that address elements related to the water cycle.
    - Evaporation (8 articles). Evaporation in swimming pools is a key factor in the water balance. Its calculation depends on temperature, relative humidity, wind speed, solar radiation, and pool surface. Improvements can include covers to reduce evaporation and the use of recycling and water treatment technologies to minimize water loss.
    - Filtration (6 items). Water filtration and recirculation in swimming pools are essential to maintain water quality and minimize energy consumption. Improving efficiency in these systems is important to save energy and reduce costs. Improvements can include the use of recycling and water treatment technologies, proper selection of filtration equipment, and optimization of the filtration system to minimize freshwater loss and reduce chemical use. Improved efficiency can also reduce the amount of time and energy needed to keep the pool clean and maintained.
    - Water reuse (2 articles). One of the topics that emerged during the COVID pandemic period and should be explored in future research. Relating it to climate change and future scenarios, improving the environmental impact of swimming pools, is the reuse of swimming pool water for other purposes, such as its use again in the pool, garden irrigation, WC, cleaning, ... it is important to save water and reduce the environmental impact of swimming pools. During times of drought, the reuse of pool water can be crucial to reduce the demand for fresh water.
    - Chemical / Disinfection (26 items). The topic of disinfection and chemical treatment of swimming pools is complex and there are many points of view and variables to consider. A potential line of research to improve the

environmental impact and sustainability of swimming pools could focus on the evaluation and enhancement of the chemicals used for water treatment. More environmentally friendly alternatives could also be studied, such as the use of ozone systems, ionization, or biological filters. Additionally, the optimization of the use of chemicals could be investigated to reduce their environmental impact and to evaluate the impact of chemical waste on the environment. Due to the complexity of this topic, it is not addressed in this article, leaving it open for future research.

- Energy. Elements related to the energy cycle there are a total of 30 articles that address this topic.
    - Energy (30 articles). The energy balance of swimming pools includes energy consumption for water heating, air conditioning and dehumidification of the building. To improve energy efficiency and reduce the environmental impact of swimming pools, several measures can be implemented. For example, a high-efficiency heating system, such as condensing boilers, and heat recovery systems can be used. In addition, solar covers can be used to heat the pool water and reduce energy consumption. Optimization of air conditioning and dehumidification systems is also important, including proper selection of equipment and scheduling of its use. Renewable energy technologies, such as solar panels or geothermal, can be implemented to reduce the pool's energy demand. By improving the energy balance of swimming pools, their environmental impact can be reduced, and their sustainability increased. The overall management of the pool as a system is also an important issue to consider in improving the energy balance.
    - Heating (6 articles). Articles focused on the heating and air conditioning systems of the swimming pool and its spaces to increase the efficiency and reduce the consumption and impact of the same.
- Modelling (12 articles). There are several scientific articles that propose the use of simulation, finite element modeling, neural networks, and new technologies to improve the environmental impact of swimming pools. For example, simulation models have been used to optimize the hydraulic design of water circulation

systems and reduce energy consumption. In addition, neural networks have been used to predict energy consumption and reduce the costs associated with pool heating and cooling. Other technologies, such as the use of sensors and control systems, have also been investigated to improve energy efficiency and reduce the environmental impact of swimming pools.

In addition to these topics related to the water and energy balance of swimming pools, also 9 articles identified and related to solar systems to reduce the consumption of non-renewable resources and improve the sustainability of swimming pools. Furthermore, 5 articles that examine the carbon footprint and its relationship with tourism and swimming pools. These articles will be analyzed for future research directions related to swimming pools and their sustainability.

Finally, the research included for in-depth analysis is 53. It is important to note that some of these studies may cover multiple topics mentioned earlier.

Figure 1 shows graphically how this new temporal update of the literature review was carried out following the method explained above.

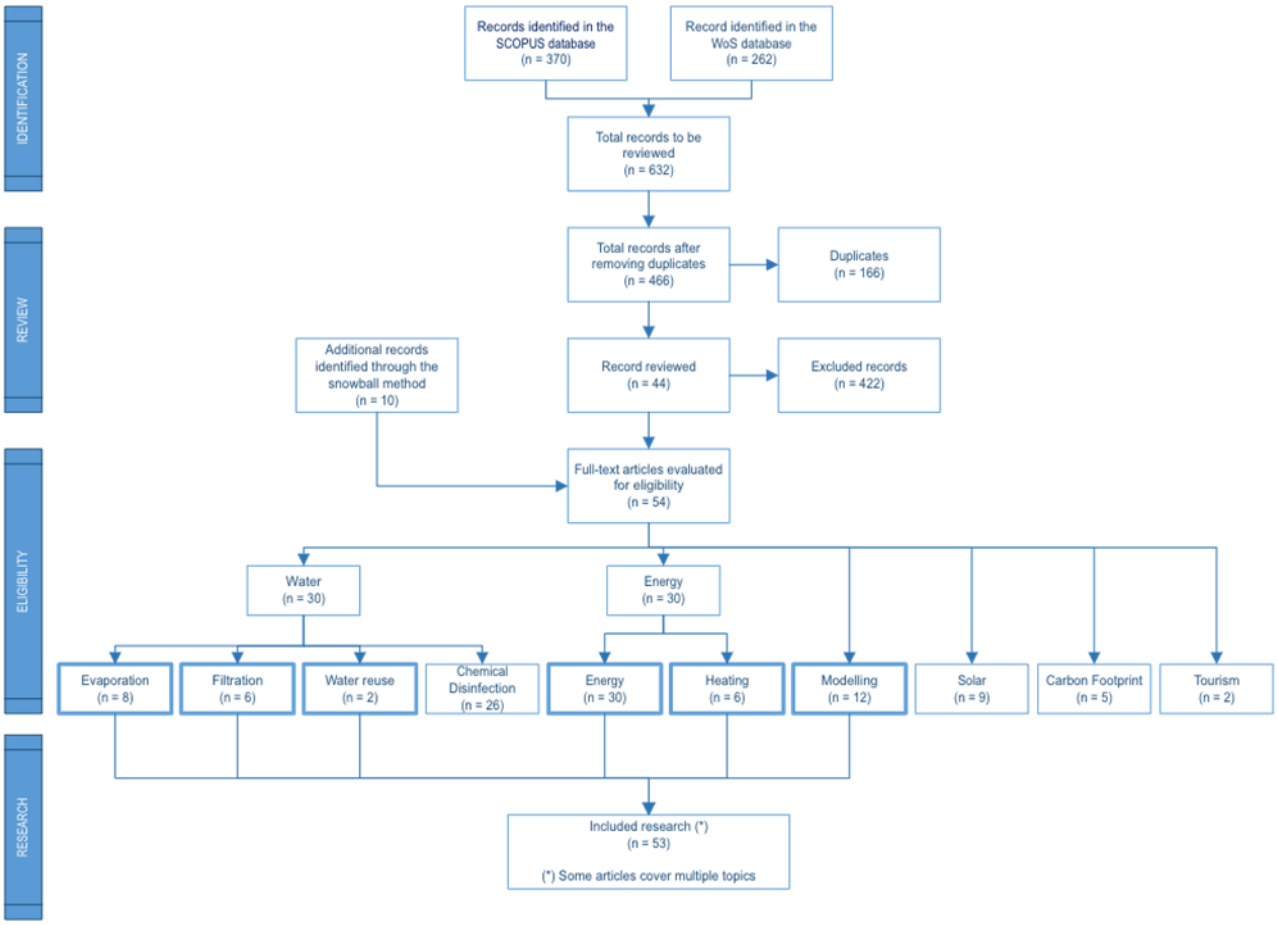

Figure 1. Outline of the literature review.

Finally, as mentioned earlier, 53 articles have been selected and are listed in Table 1, indicating the concepts addressed in each article. However, if we look at the total number of articles by topic, it adds up to 64 articles. This is because, as shown in Table 1, there are several articles that cover multiple topics.

Title	Authors	Citations	Year Published	Water			Energy		Modelling
				Evaporation	Filtration	Water reuse	Energy	Heating	
Optimal design of PCM thermal storage tank and its application for winter available open-air swimming pool	Li, Yantong et al.	55	2018				X		
Multi-objective optimization of a solar-assisted heat pump for swimming pool heating using genetic algorithm	Starke, Allan R et al.	31	2018				X		
Experimental validation of the numerical model of air, heat and moisture flow in an indoor swimming pool	Ciuman, Piotr et al.	26	2018				X	X	X
Energy consumption analysis of residential swimming pools for peak load shaving	Song, Chunhe et al.	25	2018				X		
Use of a predictive control to improve the energy efficiency in indoor swimming pools using solar thermal energy	Delgado Marín, J. P. et al.	22	2019				X		
Energy and Economic Analysis of Energy Savings Measures in a Swimming Pool Centre by Means of Dynamic Simulations	Calise, Francesco et al.	20	2018				X		
Experimental test for the estimation of the evaporation rate in indoor swimming pools: Validation of a new CFD-based simulation methodology	Foncubierta Blázquez, Juan Luis et al.	19	2018	X					X
Three-dimensional OpenFOAM simulation to evaluate the thermal comfort of occupants, indoor air quality and heat losses inside an indoor swimming pool	Limane, A et al.	19	2018					X	X
A multi-objective optimal design method for thermal energy storage systems with PCM: A case study for outdoor swimming pool heating application	Li, Yantong et al.	19	2020						

Title	Authors	Citations	Year Published	Water			Energy		Modelling
				Evaporation	Filtration	Water reuse	Energy	Heating	
Feasibility study of a geothermal energy system for indoor swimming pool in Campi Flegrei area	Barbato, M et al.	16	2018				X		
An ANN-based optimization approach of building energy systems: Case study of swimming pool	Li, Yantong et al.	15	2020				X		
Energy and Water Consumption and Carbon Footprint in Tourist Pools Supplied by Desalination Plants: Case Study, the Canary Islands	Díaz Pérez, Francisco Javier et al.	14	2018				X		
Swimming Pool Evaporative Water Loss and Water Use in the Balearic Islands (Spain)	Hof, A et al.	13	2018	X					
Improved model for calculation of evaporation from water pools	Shah, Mirza Mohammed	13	2018	X					
Comparative study of carbon footprint of energy and water in hotels of Canary Islands regarding mainland Spain	Díaz Pérez, Francisco Javier et al.	12	2019				X		
Numerical simulation and experimental validation of an outdoor-swimming-pool solar heating system in warm climates	Lugo, S. et al.	11	2019				X		
Thermal performance prediction of outdoor swimming pools	Lovell, D. et al.	11	2019				X		
Heating energy-saving potentials in HVAC system of swimming halls: A review.	Yuan, Xiaolei et al.	10	2021				X		
Swimming pool heating technology: A state-of-the-art review	Li, Yantong et al.	9	2021				X	X	

Title	Authors	Citations	Year Published	Water			Energy		Modelling
				Evaporation	Filtration	Water reuse	Energy	Heating	
Improving Ventilation Efficiency for a Highly Energy Efficient Indoor Swimming Pool Using CFD Simulations	Rojas, G et al.	9	2018				X		
An innovative swimming pool water quality index (SPWQI) to monitor and evaluate the pools: design and compilation of computational model	Golbaz, Somayeh et al.	8	2019						X
THE INFLUENCE OF THE FILTRATION BED TYPE IN THE POOL WATER TREATMENT SYSTEM ON WASHINGS QUALITY	Wyczarska-Kokot, J et al.	8	2019		X				
HVAC SYSTEM ENERGY OPTIMIZATION IN INDOOR SWIMMING POOLS	Ribeiro, E et al.	8	2019				X		
Dynamic simulation model and empirical validation for estimating thermal energy demand in indoor swimming pools	Marin, J P D et al.	7	2020				X		X
A numerical study on various heating options applied to swimming pool for energy saving	Jordaan, Matthys et al.	7	2019				X		
The Use of a Heat Pump in a Ventilation Unit as an Economical and Ecological Source of Heat for the Ventilation System of an Indoor Swimming Pool Facility	Ratajczak, K et al.	7	2020					X	
Economic feasibility of heating source conversion of the swimming pools	Al-Falahat, Ala'a et al.	7	2022				X		
A quantitative analysis of swimming pool recirculation system efficiency	Alansari, Amir et al.	6	2018		X				
Systematic and data-driven literature review of the energy and indoor environmental performance of swimming facilities	Smedegård, Ole Øiene et al.	5	2021				X		

Title	Authors	Citations	Year Published	Water			Energy		Modelling
				Evaporation	Filtration	Water reuse	Energy	Heating	
Computational fluid dynamics analysis of the hydraulic (filtration) efficiency of a residential swimming pool	Zhang, J. et al.	4	2018		X				X
Numerical Analysis of the Energy Consumption of Ventilation Processes in the School Swimming Pool	Ciuman, Piotr et al.	4	2021				X		
Enhanced CFD-based approach to calculate the evaporation rate in swimming pools	Gallero, F.J.G. et al.	3	2020	X					X
Mathematical modelling of water exchange in public swimming pools	Orlov, Vladimir et al.	3	2018						X
Assessment of factors influencing the energy and water performance of aquatic centres	Duverge, Jean Jonathan et al.	3	2020				X		
Design and fabrication of an intelligent management and control system to optimize energy consumption in indoor swimming pools	Mahmoudi, Rahim et al.	3	2021				X		
Application of the swimming pool backwash water recovery system with the use of filter tubes	Studziński, Waldemar et al.	3	2021		X				
Evaluation of methods for prediction of evaporation from water pools	Shah, Mirza Mohammed	3	2022	X					
Socio-technical modeling of smart energy systems: a co-simulation design for domestic energy demand	Barsanti, Matteo et al.	2	2021				X		
Water loss in swimming pool filter backwashing processes in the Balearic Islands (Spain)	Doménech-Sánchez, Antonio et al.	2	2021		X				

Title	Authors	Citations	Year Published	Water			Energy		Modelling
				Evaporation	Filtration	Water reuse	Energy	Heating	
Introduction: Energy Systems Modeling for a Sustainable World	Labriet, Maryse	1	2018				X		
Modelling and optimization of the heat pump system for the usage of swimming pool	Lau, M.J. et al.	1	2020						X
Measurement and Analysis of Evaporation in Indoor Swimming Pools: Comparison with the ASHRAE' s Activity Factor	Smedegård, Ole Øiene et al.	1	2022	X					
Optimal heating of an indoor swimming pool	Wolfmayr, Monika	0	2020				X	X	
Reuse - Reduce - Recycle: water and wastewater management in swimming pool facilities	Wyczarska-Kokot, J et al.	0	2022		X	X			
Experimental adjustment of the turbulent Schmidt number to model the evaporation rate of swimming pools in CFD programmes	Foncubierta Blázquez, Juan Luis et al.	0	2023	X					X
Effect of air parameters, water temperature, and number of pool occupants on moisture gains	Garnysz-Rachtan, A. et al.	0	2018					X	
Analysis of numerical simulation of the hydrodynamics in swimming pools, in terms of water quality	Dougha, Mostefa et al.	0	2018						X
SPOOLS: SUSTAINABLE POOLS - MAIN DEVELOPMENTS OF THE PROJECT	Oliveira, Miguel José et al.	0	2018				X		
Sensitivity analysis of an outdoor swimming pool under dynamic conditions ScienceDirect 2nd International Conference on Sustainable Materials Processing and Manufacturing Sensitivity analysis	Bernhard, Maïté et al.	0	2019				X		

Title	Authors	Citations	Year Published	Water			Energy		Modelling
				Evaporation	Filtration	Water reuse	Energy	Heating	
of an outdoor swimming pool under dynamic conditions									
A Methodology of Energy Optimization in Indoor Swimming Pool	Natali, Alessia et al.	0	2020				X		
Intelligent water treatment management system for swimming pools	Vologdin, S.V. et al.	0	2021						X
The potential of swimming pool rinsing water for irrigation of green areas: a case study	Poćwiardowski, W.	0	2023			X			
Further development and verification of the model for evaporation from pools	Shah, Mirza Mohammed	0	2023	X					

Table 1. List of selected articles by subject and concepts.

4. Discussion of results

This research explores the many challenges to improving the sustainability of swimming pools. It focuses on the critical aspects of water and energy management. The literature review highlights the changing dynamics of sustainability, particularly given climate change and the pressing need for efficient use of resources. One of the key findings relates to the important impact of evaporation control on the water balance. The use of innovative technologies to predict and mitigate evaporative water loss illustrates the commitment of the academic community to address sustainability in practical terms.

The study of filtration efficiency not only highlights technological advances in the maintenance of pool cleaning and sanitation, but also points to a broader implication in water conservation. The introduction of methods to recover water from filter washing processes is an important step towards reuse and sustainability, reinforcing the critical intersection between technology and environmental management.

Energy efficiency, particularly using renewable energy sources such as solar panels to heat swimming pools, is emerging as a key area of focus. This transition not only helps to reduce the carbon footprint of swimming pools, but also provides an example of the practical application of renewable energy in everyday facilities. Consideration of high-efficiency heating systems, such as heat pumps, further illustrates the potential for both significant energy savings and environmental benefits.

The integration of advanced simulation models and neural networks to optimize swimming pool operations highlights the importance of predictive analytics in achieving sustainability goals. These technological advances provide a more fine-grained understanding of pool dynamics, enabling targeted interventions that can significantly reduce both water and energy consumption.

5. Conclusions

The literature review provides evidence that the sustainability of swimming pools is an important subject undergoing significant changes, which will affect residential pools and the tourism sector, among others. Furthermore, with climate change, there is a need for more efficient use of resources such as energy and water in swimming pools.

Several research articles on the sustainability of swimming pools, in line with the Sustainable Development Goals (SDGs), address similar topics in both pre-COVID and

post-COVID periods, although the post-COVID academic literature is more advanced. Moreover, the industrial sector associated with swimming pools faces significant technological, process, and product challenges to transform the current pool infrastructure into a more environmentally friendly and sustainable one, particularly in the case of the hotel industry.

The challenges identified in this research are the water and energy balance in swimming pools, while also considering the complexity of applicable legislation. The review highlights actions and measures to achieve more sustainable pools with reduced environmental impact. These include the use of renewable energy technologies, optimization of water recirculation and filtration systems, and the application of computational simulation using mathematical models and neural networks. These approaches aim to develop more efficient facilities and products with reduced water and energy consumption.

Elements focused on disinfection and chemical treatment of pool water, as well as systems and mechanisms for reusing filter backwash water, are left for future research lines. Additionally, the impact of climate change on the pool sector necessitates the adaptation of current and future facilities to this new reality.

Furthermore, the new 2023 Directive on Corporate Sustainability Reporting will standardize the provisions of the European Green Deal and the 2030 Agenda at the European level, and the hotel sector will be required to comply with it, with direct implications for pools. This first set of European Sustainability Reporting Standards (ESRS) establishes the basis for a standardized common European language for sustainability issues throughout Europe. There are a total of 12 standards with different indicators: 2 cross-cutting standards (ESRS1 General Requirements; ESRS2 General Disclosures), 5 environmental standards (ESRS E1 Climate Change; ESRS E2 Pollution; ESRS E3 Water and Marine Resources; ESRS E4 Biodiversity and Ecosystems; ESRS E5 Resource Use and Circular Economy), 4 social standards (ESRS S1 Own Workers; ESRS S2 Workers in the Value Chain; ESRS S3 Affected Communities; ESRS S4 Consumers and End Users), and 1 governance standard (ESRS G1 Business Conduct). This new scenario will require sustainable pools to comply with these standards.

The study has the limitation of not including a bibliometric review regarding the chemical balance of pools, water treatment in pools, and diverse legislation at the national, regional, and local levels.

Conflict of Interest Statement

The authors have declared no conflict of interest in relation to the research, authorship and/or publication of this article.

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