ECOPOOL+++: DEVELOPING A SUSTAINABLE OUTDOOR HEATED SWIMMING POOL

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ABSTRACT. The University of Algarve, in consortium with "Cristal Construções – Materiais e Obras de Construção Civil", "Itelmatis Control Systems" and "Itecons – Instituto de Investigação e Desenvolvimento Tecnológico para a Construção, Energia, Ambiente e Sustentabilidade", is developing a new concept of outdoor heated sustainable swimming pool, having a higher energy efficiency and lower environmental footprint. The main objective is to minimise energy and water consumptions, while assuring a comfortable temperature for the user, extending the utilization of the pool in the Algarve region, from the summer months, to at least 8 months of the year. In order to do it, different systems will be tested, including solar thermal and photovoltaic panels, inverted underfloor heating, heat accumulator exchanger with phase change materials and energy dissipating pipes. An innovative thermal insulation system will be included in the interior of the pool tank, together with a new system for the covering of the water plane. All these systems will be monitored and controlled by an industrial automation system that will communicate, via a programmable logic controller, using industry standard communication protocols, with a SMART platform, that will be in charge of the global operation's optimisation. This platform will support an intelligent and predictive control and monitoring module, that controls the automation system to maximize the energy usage of the renewable sources, while assuring the user preferences. One of the main outputs of this project is the construction of a smaller scale prototype of a swimming pool, with the characteristics mentioned above, in order to test and validate the proposed developments.

KEYWORDS: Outdoor heated swimming pool, solar energy, PCM heat accumulator, smart energy and water management system.

1. INTRODUCTION

Most existing swimming are largely inefficient due to heat and water losses, having a substantial impact in the associated environmental footprint. Tyler et al. [1] calculated the environmental impact of residential swimming pools in Arizona (USA) and other warmer regions, pointing out, as the main impacts per pool the following numbers: a water footprint from 45 to $185 \, m^3$/year; an energy footprint between $2\,400$ and $2\,800 \, kWh$/year; a carbon footprint of $1\,400 \pm 50 \, kg \, CO_2$e/year.

In terms of heat losses, outdoor heated pools require very high energy consumptions, due to:

(1.) evaporation of water into the surrounding air,

(2.) radiation to the sky;

(3.) convection near the surface of the water and

(4.) conduction through the walls and floor to the ground.

The water in swimming pools is an excellent medium for heat accumulation, which is the reason why, when there is greater availability of solar radiation, particularly in the summer period, the conditions for its use improve. Outside this period, the environmental conditions tend to no longer be favourable, causing lower free heat gains and simultaneously, greater thermal losses.

The large energy losses in outdoor swimming pools, as previously mentioned, are due to evaporation, radiation and convection, in descending order of importance. As the water surface is the pool area where the greatest heat exchanges take place, it is essential that it is efficiently and safely protected. A conventional roof with thermal insulation can reduce energy losses by between 50 % and 70 % [2]. Muleta [3] considers that it is possible to reduce evaporation by about 95 % using composite material coverings. By reducing, for example, the effect of evaporation, using an adequate coverage, benefits are not only associated with the

reduction of water replacement needs, but also in the subsequent reduction in the consumption of chemicals for water treatment.

Thermal losses due to conduction through the walls and floor are usually neglected. There are some thermal insulation solutions on the market for the swimming pool tank, which are based on the application of extruded polystyrene sheets on the outside of the tank, in contact with the ground [4], or on modular systems that integrate the structural and insulating function in the panel [5] or in the block [6]. This type of solution is, however, aimed at new pools, being difficult to implement or even impractical to apply in existing pools. Rose [7] proposes that the thermal insulation of the walls and floor in existing swimming pools is done from the inside of the tank, based on rigid phenolic panels (high pressure laminates) or cellular glass, together with a rigid waterproof mortar and PVC coating.

In addition to the innovative construction system for reducing thermal losses, highly efficient solutions from an energy point of view are required, such as heat storage systems. Systems integrating Phase Change Materials (PCM) were studied by Silva et al. [8] in building structures of brick masonry walls. The PCMs that have greater interest in buildings and civil construction in general, are well characterised in [9], where 150 of these materials are carefully described. Zsembinszki et al. [10] simulated the thermal behaviour of an outdoor swimming pool with $50\,\mathrm{m}^2$ and $1.65\,\mathrm{m}$ depth, in three locations in Spain using local climatic data such as temperature and relative humidity of the outdoor air, solar radiation and wind speed. The bottom and walls of the pool were composed of a heat exchanger, coated with $3\,\mathrm{cm}$ of PCM for heat accumulation, allowing the control of the water temperature in advance (about 20 hours) in relation to the foreseeable period of use of the pool. Salgueiro [11] presents a good characterisation of mortars based on light materials with PCM mixtures. It describes the methods used to determine the mechanical and thermal properties of different specimens, having different compositions of mortars.

The energy consumed in pumping water, for circulation through the filtering systems, is not negligible, even though it depends on the size of the pool. As suggested by Hunt and Easley [12] and Zhao et al. [13], the replacement, in swimming pools, of simple pumps that work only at nominal speed by pumps equipped with variable speed drives, which enable the motor to run at different speeds of rotation, can allow a 75–80 % energy reduction.

In terms of water losses, Severine [14] refers the importance of optimising the regeneration operations of swimming pool filtering systems to reduce water consumption. This author also highlights the possibility of reusing the water from washing filters for watering green spaces. Water losses also result from leaks in the hydraulic circuits. At this level, the most used detection method is the evaluation of pressure variation. Thus, the existence of an intelligent automatic control system for the detection of leaks in swimming pools is relevant, allowing the minimisation of human intervention, in similar way to what is already done in free surface drainage channels [15] or in fuel tanks [16].

Active measures can be used to reduce the impact of water losses and to increase the utilization of locally installed renewable energy sources, reducing the energy requirements of swimming pools. At this level, the best market practices point to the implementation of industrial automation systems, made-to-measure using programmable logic controllers for the supervision and control of equipment in an integrated manner for the interconnection of hydraulic systems, water treatment, and water heating systems. These systems already exist in some hotels pools and spas, normally integrated in building management systems, called BMS (Building Management System) through industrial communication buses. Complemented with alarmist software modules, they promote the optimisation of energy and water consumption as well as the reduction of response times in the detection and resolution of occurrences, with their advantages being widely recognised [17]. These intelligent control systems that allow the monitoring of parameters, imposing user-defined limits and generating alarms when they occur, are already used today in a wide variety of situations. For instance, in the context of swimming pools, the low-cost solution proposed in [18], aims to reduce the requirements of human intervention in the maintenance of the pool.

In terms of intelligent control algorithms, to improve the energy efficiency of indoor swimming pools, Marín in [19] proposes the use of predictive control in a hybrid control system that involves solar collectors and a boiler (possibly powered by biomass) for the thermal regulation of temperature. Using this methodology, it is possible to reduce the pool's energy demand significantly (in the order of 18.76 %) and consuming 42.64 % less fuel compared to a conventional Proportional Integral Derivative (PID) control. Still in the context of optimising energy efficiency and specifically with the aim of reducing response time, Machine Learning techniques such as Random Forest [20] or predictive control based on models [21, 22] can be considered.

2. ECOPOOL+++ PROJECT

The ECOPOOL+++ project aims to develop a new heated pool solution, more efficient, in terms of energy and water requirements, integrating an intelligent management of the various systems. The main system to be developed will consist of a thermal insulation solution inside the tank's envelope, which will reduce energy losses and, consequently, the heating needs. An attempt will also be made to develop a new system for covering the water surface, made up of multilayer panels of glass and air, which will reduce evaporation

losses, which are both heat and mass, as well as heat losses by convection and radiation. Regarding water heating needs, efforts will be made to ensure that these are fully met using solar energy, maximizing solar gains through the water plan and integrating solar energy capturing systems through the use of solar panels and a heat collector floor. The possibility of heat storage through the use of reserve tanks containing PCMs will also be analyzed. The possibility of "diverting" the excess heat from the water body of the tank for other purposes will also be analyzed, either directly for the production of domestic hot water or for the heating of the ventilation air of changing rooms, in periods when the water temperature exceeds comfort needs. Regarding water efficiency, systems will be studied and designed to contribute to the reduction of water consumption, either through the early detection of leaks, or through the minimization of water consumption in the regeneration operations of the filtration and eventual reuse of the resulting effluents. Finally, a control and monitoring system will be designed, with intelligent and predictive functions, capable of interconnecting the various technologies described above.

Through the comprehensive monitoring of all systems in operation in a real context, it will be possible to evaluate their respective performances (individual and in collective operation). This information will make it possible to decide which is the best operational set of recommended systems for each situation in view of its geographic location.

The main market objectives of this project, are:

(1.) to ensure the existence of an aggregated final solution, enhancing water and thermal savings, supporting with greater thermal comfort (water temperature with an adequate level of comfort for most of the year using only solar energy) and

(2.) provide the leading company's product portfolio with a disruptive pool solution.

Within the scope of this project, a small-scale prototype will be built, incorporating all the recommended solutions, in order to test and validate the intended developments, in the technical, environmental and economic aspects, allowing the final solution to be commercially valuable and with a potential to be exportable. The solutions developed, in part or in a whole, will be able to be applied in existing swimming pools, in order to improve their energy and water efficiency.

3. ECOPOOL+++ SYSTEMS

In the following a description is made of the developments occurring in the aim of ECOPOOL+++ project to implement the prototype of a sustainable swimming pool.

3.1. THERMAL INSULATION SYSTEM

The functions, requirements and properties of the new thermal insulation systems inside the pool were studied, and the main requirements that the layers of the system must meet have already been established. The system must ensure not only the limitation of heat losses by the interior lining, but also a good mechanical performance. The thermal insulation layer must not only have high thermal resistance but also have resistance to deformation. The base layer must present protection characteristics of the insulating material (impact resistance and deformation), waterproofing and support capacity of the coating, deformation capacity balanced with rigidity and resistance to blistering under negative pressure. The bonding mortar, which will support the final coating, must comply with good adhesion to the final coating (generally ceramic), high deformability (low susceptibility to cracking and chemical resistance (joint mortar).

3.2. PERFORMANCE REQUIREMENTS OF OTHER TECHNOLOGICAL SOLUTIONS

The technical specifications of the equipment to be installed will be defined, in order to obtain the performance output of the ECOPOOL+++ system and respective subsystems. A holistic analysis of the interaction between the different project specialties was already carried out.

For this purpose, the study was segmented into 4 different areas of expertise, namely:

(a) constructive solutions;

(b) hydraulic and thermal systems;

(c) electrical installation and industrial automation system; and

(d) the SMART platform.

In the following we describe each of these areas in more detail.

(a) Constructive solutions The constructive solutions encompass all the studies carried out in the definition of functional and performance requirements of construction materials and thus proceeded to validate the possibility of implementing the test bed. After validation by the University of Algarve of the test bed installation site, a summary specification of the constructive solutions was created, namely, with the definition of materials, dimensions of the pool and of the engine room. The first studies were also carried out to verify the hydraulic and thermal performance of the system, using the SOLIDWORKS software, based on the first draft of the architectural project.

(b) Hydraulic and thermal systems There are two different hydraulic systems, one dedicated to water filtration, common in every swimming pool, and another for the water heating purpose. The latter is schematically represented in Figure 1.
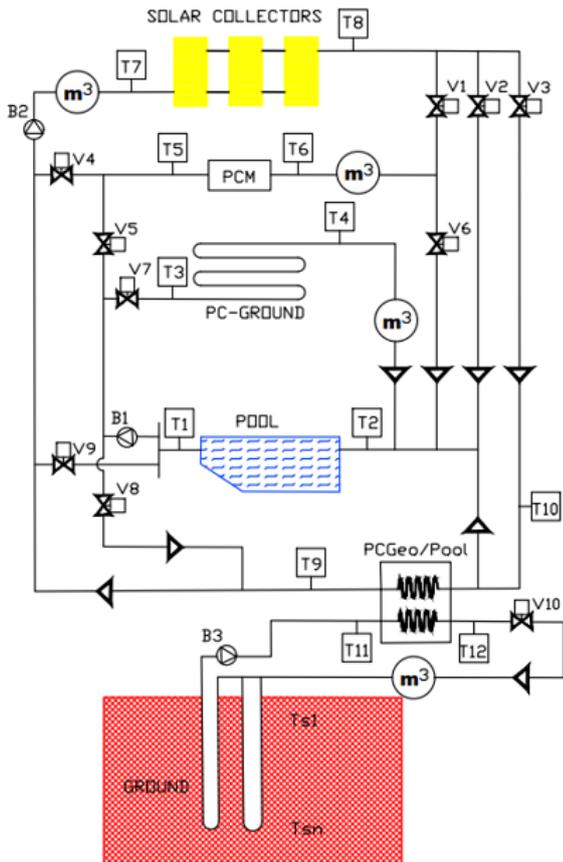
Figure 1. Solar heating based systems.

Although a common design option is to have only one circuit to perform both functions (filtration and heating), this solution is sometimes found in swimming pools. The choice for this singularity in the ECOPOOL+++ project comes mainly from the flexibility it allows in terms of individual control of each one of the heat recovering systems. This could be also done with one hydraulic circuit, but at expenses of more valves and controls.

Furthermore, the other reason for the choice is that the water flows are significantly different; those used in recirculation and filtration are much higher than those used in heating systems. Finally, the measurement of both flow rates and temperatures, in this way, makes monitoring of each heating sub-system easier.

The pool's heating systems focus on the use of solar energy as an energy source through solar collectors, collecting floors and heat accumulation in PCMs, whenever generation exceeds the needs, to keep the water temperature in comfortable values, i.e. between 24–26 °C. The storage in PCM materials allows shifting its use in periods when the water temperature drops, by known atmospheric reasons, as for example one or more days with a sky cloud's coverage or extreme heat losses at night. These solutions will be evaluated individually and their value verified in terms of contribution to the heating of the swimming pool, which will later be done in an integrated manner. Figure 1 presents the operating diagram. Currently, the

simulation has started and there is not yet any results of it that could be exhibited to show in a satisfactory way the performance of the outlined systems.

(c) Electrical installation and industrial automation system Several sensors will be integrated in the swimming pool, allowing the measurement of local variables such as the temperature at different points, the pH of the water and the chlorine level. It will also contain a set of devices, such as:

(1.) water pumps that will be automatically controlled,

(2.) electric valves in order to select if the water flows in the thermal production and retainment systems,

(3.) automatic compensation of water tank refilling according to hydrostatic level proves,

(4.) pressure sensors in different parts of the hydraulic circuit to check for pressure alarms and

(5.) automatic backwash systems according to differential pressure on the filters, among others to be determined during the project execution.

All the systems' controls will be made recurring to industrial PLC project, and all the digital/analogue system input/output will recur to low voltage and dry contact actuation on equipment and sensors, and all the analogue probes will communicate via generic 4–20 mA and 0–10 VDC, in order to simplify equipment's maintenance and replacement routines, according to the best practices of automation systems.

A local controller, called Swimming Pool Control and Monitoring System (SPMS) will be responsible for the communication with the set of sensors and actuators, including interfaces that will allow the integration with Internet Protocol (IP) sensors, but also Modbus or KNX automation devices. The controller will also be able to connect directly with the IP network of a local area network, in the house using Wi-Fi or Ethernet interfaces, or connect directly to the Internet using a separate access router. The architecture also considers the communication between the local controller and Internet based cloud services, through a WebSocket protocol or a Web Application Program Interfaces (Web API). The user will be able to select and configure its preferences using a web Human Machine Interface (Web HMI), made available at the local controller.

The draft of the "point map" of the automation system, will result from the P&ID draft and the generic specifications of the hydraulic, heat production and storage equipment. A study and definition of the architecture of communication protocols between the industrial automation system will be required, including the subsystems to be supervised and controlled, and the interconnection between the control devices and the SMART platform. As a final product the idea is that all the monitoring and controlling systems will be integrated in the local automation system, so
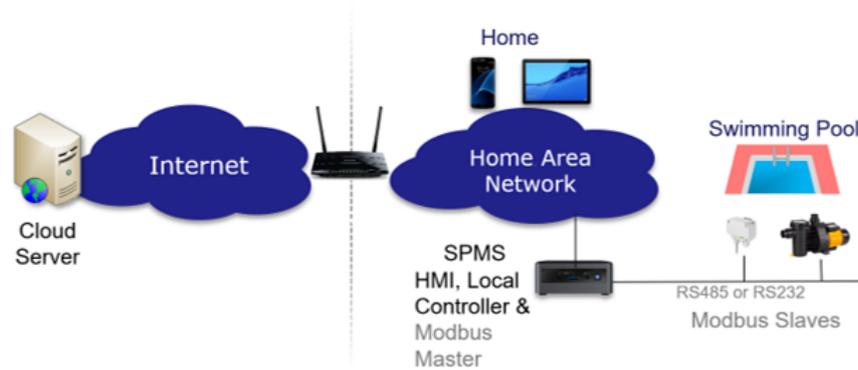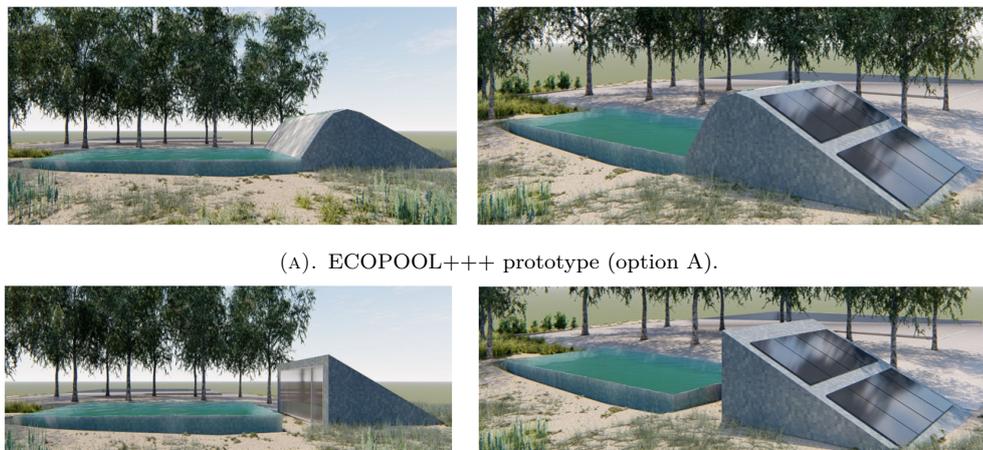
FIGURE 2. Intelligent monitoring and control system.

(A). ECOPOOL+++ prototype (option A).

(B). ECOPOOL+++ prototype (option B).

FIGURE 3. ECOPOOL+++ prototypes.

that all relevant data can be provided to the SMART Platform in order for it to run algorithms that allow the optimisation of water and energy consumption, while detecting malfunctions and water breaches.

(d) SMART platform   The integration of sensors, HMI and controllers enabling an intelligent control system is shown in Figure 2. It illustrates the optimised monitoring, activation and control architecture responsible for managing all pool equipment in order to reduce consumption and maximise the use of renewable energy sources. The system should place the user as a central element, preventing him from having to perform individual/detailed control functions. Thus, in addition to responding to the on/off request, the system should only require the specification of the value that the user wants for the water temperature. The control of all other parameters will be done automatically. The system must also learn from the users' actions, enabling an intelligent mode, adapting to the user's habits, minimising the need for entering parameters. The control and monitoring system will work autonomously using an external SMART server, placed on the Internet/Cloud, only when it is necessary to change usage patterns.

All measured variables will be sent to a cloud server, as represented in Figure 2. The local controller, represented in Figure 2 as SPMS, must collect the measurements from the sensors and Modbus devices, sending them later to the cloud server. The user will always have the possibility to access the local controller through a web interface, which allows him to control or monitor system data.

4. ECOPOOL+++ DESIGN

The prototype of the ECOPOOL+++ project will be located in the University of Algarve, at Campus da Penha, Faro, Portugal. It was established that the pool will be 10 m long by 5 m wide. The average depth should be 1.20 m with a maximum depth that can reach 1.40 m. The engine's room will be located on a wall adjoining the pool and must allow simultaneous access to several people, with a minimum area of approximately $10\,m^2$ and a minimum height of 2 m. The heat storage tank must have a minimum volume of 2.5 to 3.0 m3, with easy access, and must allow the replacement of all materials, if necessary.

Figures 3a and 3b illustrate 2 drafts of the prototype's architecture (still under discussion).

5. Conclusions

In the ECOPOOL+++ project, an innovative solution for heated outdoor pools is being developed with the aims of reducing thermal losses and integrating SMART water and energy management systems. The project started in 2021 and ends in June 2023. In this article, a bibliographical review was made about the various solutions that are being considered. A summary of the work already carried out was presented as well as some basic layouts already established, which will be developed in the next months. Specifically, the ongoing ECOPOOL+++ SYSTEMS as presented, includes a thermal insulation system, an hydraulic and thermal systems, electrical installation and industrial automation systems, together with a smart platform. Two solutions were also presented for the proposed prototype, which will be implemented at the University of Algarve and which will allow testing and validation of all the solutions developed. It will also constitute an excellent teaching model that can be used by students of this institution.

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