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Published in:
IOP Conference Series: Earth and Environmental Science

Published: 01/01/2019

Document Version:
Final Published version, also known as Publisher's PDF, Publisher's Final version or Version of Record

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Publication record in CityU Scholars:
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Published version (DOI):
10.1088/1755-1315/238/1/012001

Publication details:
Li, Y., & Huang, G. (2019). Temperature control of a PCM integrated open-air swimming pool in cold season: a numerical and experimental study. *IOP Conference Series: Earth and Environmental Science*, *238*(Conference 1), [012001]. https://doi.org/10.1088/1755-1315/238/1/012001

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IOP Conference Series: Earth and Environmental Science

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To cite this article: Y Li and G Huang 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **238** 012001

Temperature control of a PCM integrated open-air swimming pool in cold season: a numerical and experimental study

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Abstract. In a conventional swimming pool temperature control, the return water temperature is considered as the representative temperature of the swimming tool rather than the average temperature although the latter is more representative regarding to thermal comfort. This is because the average temperature is difficult to measure. This paper uses field data to identify a relationship between the average and the return water temperature and develops a temperature control method based on this relationship. This control method is applied to an open-air swimming pool, for which the heat is supplied from a PCM storage tank. Numerical study, which is resorted to a simulation platform constructed using TRNSYS and MATLAB, is used to analyze the control performance of the new method and demonstrate its effectiveness by comparing with the conventional control.

1. Introduction

Most open-air swimming pools in many countries are closed in cold seasons, because a heavy energy demand is required for maintaining the pool water within the comfortable temperature range. If the traditional heating approaches (e.g. electrical or gas boilers) are used to provide heat for the swimming pools, the cost will be very high [1]. Therefore, a variety of techniques are proposed by researchers to extend the available time of the open-air swimming pools in cold seasons. For instance, Yadav and Tiwari [2] simulated the water temperature variation of an Australian swimming pool with thermal insulation cover. It was reported that the heat losses of the pool could be effectively reduced when the thermal insulation cover was used. Rakopoulos and Vazeos [3] numerically and experimentally investigated the performance of the open-air swimming pool heating system with solar collector. The thermodynamic models of the system were solved, and the numerical data was compared with the measured data in an Athens Olympic swimming pool. The good agreement between the numerical and experimental results validated the reliability of the mathematical models. Buonomano et al. [4] used the PV thermal collector to heat an outdoor swimming pool with a volume of 1260m^3. The TRNSYS software was utilized to simulate the operation of the swimming pool heating system.

One of the most popular heating technologies for the open-air swimming pool is using PCM storage tank. In our previous study [5], the PCM storage tank was applied to shift electricity consumed during the on-peak period to off-peak period, which brought the considerable economic benefits. Although the control strategy of the PCM storage tank integrated open-air swimming pool was presented, the assumption that the open-air swimming pool temperature T_{pool} was equal to the outlet temperature of the swimming pool T_{out} was used in the swimming pool model. However, actually the value of T_{pool} should not be determined only by the value Tout. In the real swimming environment (when people are swimming), only the inlet and outlet temperature of the swimming pool can be measured by the sensors, and thus the Tout is usually considered as the T_{pool} to perform the control strategy. However, this traditional method will lead to the control delays of the real T_{pool} (i.e. average swimming pool temperature $T_{average}$), and thus it will be out of the permissible thermal comfortable zone (e.g. 27°C to 29°C).

To overcome this problem, this study therefore proposes a new approach for the temperature control of a PCM integrated open-air swimming pool. In order to illustrate the proposed method, the case study of using the PCM storage tank to provide heat for a simulative open-air swimming pool is presented. Three sensors are placed inside the simulative swimming pool to acquire the $T_{average}$, and lots of field measurement data are used to identify the relationship $T_{average} = f\,(T_{out})$. On this basis, the simulation platform of the system will be constructed using the TRNSYS and MATLAB. The experimental setup will be established to validate the correctness of the simulation platform. Finally, the temperature control of the PCM integrated open-air swimming pool will be conducted using the on/off control strategy. The control performance of the proposed method will be compared with that of the traditional method to demonstrate its effectiveness.

2. Methodology

The methodology for temperature control of a PCM integrated open-air swimming pool is presented in Fig. 1. Firstly, large amounts of filed measurement data should be collected and used to identify the relationship $T_{average} = f\,(T_{out})$. Then the open-air swimming pool model will be refined by the new relationship. Secondly, the simulation platform of the heating system will be constructed using the new swimming pool model. The experimental setup should be establised to validate the reliability of the simulation platform. Finally, The on/off control strategy will be added into the validated simulation platform. The real control temperature range of T_{out} will be determined according to the relationship $T_{average} = f\,(T_{out})$. The control performance of the proposed method will be analyzed and compared with that of the traditional method by observing the $T_{average}$.

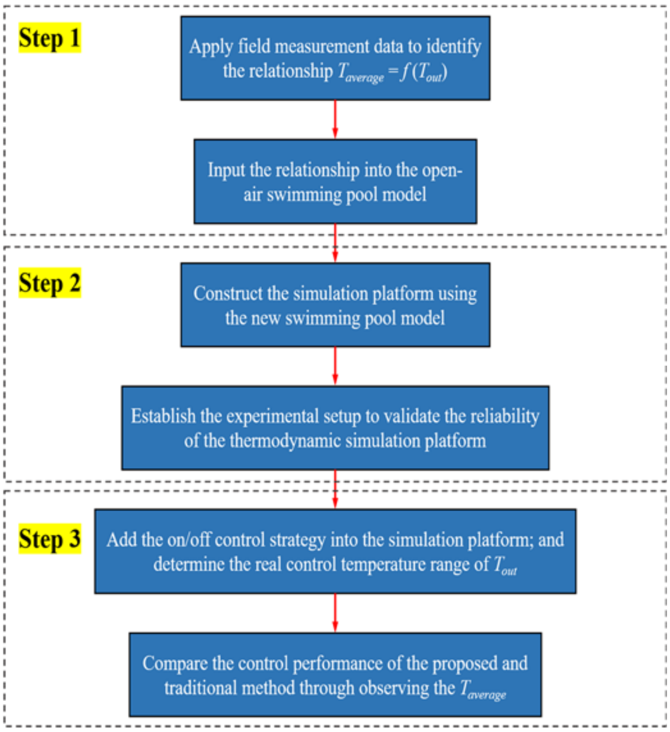

Figure 1. Methodology for temperature control of a PCM integrated open-air swimming pool.

3. Case study

The simulative open-air swimming pool integrated with PCM storage tank was constructed to illustrate the proposed temperature control approach. The schematic diagram of the constructed experimental setup was shown in Fig. 2. It mainly included the simulative open-air swimming pool, PCM storage tank, computer, solar irradiation recorder, solar irradiation instrument, meteorological translator, data logger, temperature/RH probe, ultrasonic anemometer, pump, valves and temperature sensors, etc.

The temperature sensor distribution in the simulative open-air swimming pool was presented in Fig. 3. The size of the simulative swimming pool was 150cm × 100cm × 80cm. As shown in Fig. 3 (b), the water depth in this study was 60cm. Three temperature sensors were placed in the middle of the swimming pool. The vertical distance between the temperature sensors and water surface was same with the distance between the sensors and pool bottom, which was equal to 30cm.

The simulation platform that was established in TRNSYS 17 was used to perform the temperature control of the open-air swimming pool. Type 654 in the TRNSYS is selected as the pump model. The PCM storage tank and open-air swimming pool model are built through the MATLAB codes, which is linked to TRNSYS 17 using the MATLAB interface Type 155. The models of the main components in the system are shown as follows.

- Open-air swimming pool model

$$\rho_{water} cp_{water} V_{pool} \frac{dT_{pool}}{dt} = q_{total} \tag{1}$$

where ρ_{water} and cp_{water} are the density and specific heat, respectively. V_{pool} is the swimming pool volume; and q_{total} is the total heat flux of the swimming pool.

- PCM storage tank model

$$\rho_{water} cp_{water} \varepsilon_{water} \left(\frac{\partial T_{water}}{\partial t} + v_{water} \frac{\partial T_{water}}{\partial x}\right) = k_{water} \varepsilon_{water} \frac{\partial^2 T_{water}}{\partial^2 x} + \frac{h_{total} A_{PCM} (T_{PCM} - T_{water})}{V_s} \tag{2}$$

where v_{water} is the mean velocity of the HTF; T_{water} is the temperature of the water; k_{water} is the thermal conductivity of the HTF; t is the time; ε_{water} is the water fraction in the energy storage tank; h_{total} is the effective convective heat transfer coefficient between the HTF and the PCM; A_{PCM} is the heat transfer area of the tube wall; T_{PCM} is the temperature of the PCM; V_s is the volume of one element; and x is the distance. The heat transfer process of the PCM is determined as the following equation:

$$\rho_{PCM} (1 - \varepsilon_{water}) \frac{\partial H_{PCM}}{\partial t} = k_{water} (1 - \varepsilon_{water}) \frac{\partial^2 T_{PCM}}{\partial^2 x} + \frac{h_{total} A_{PCM} (T_{PCM} - T_{water})}{V_s} \tag{3}$$

where ρ_{PCM} is the density of the PCM; and H_{PCM} is the enthalpy of the PCM. It should be noted that the assumptions and solution method were presented in our previous study [6].

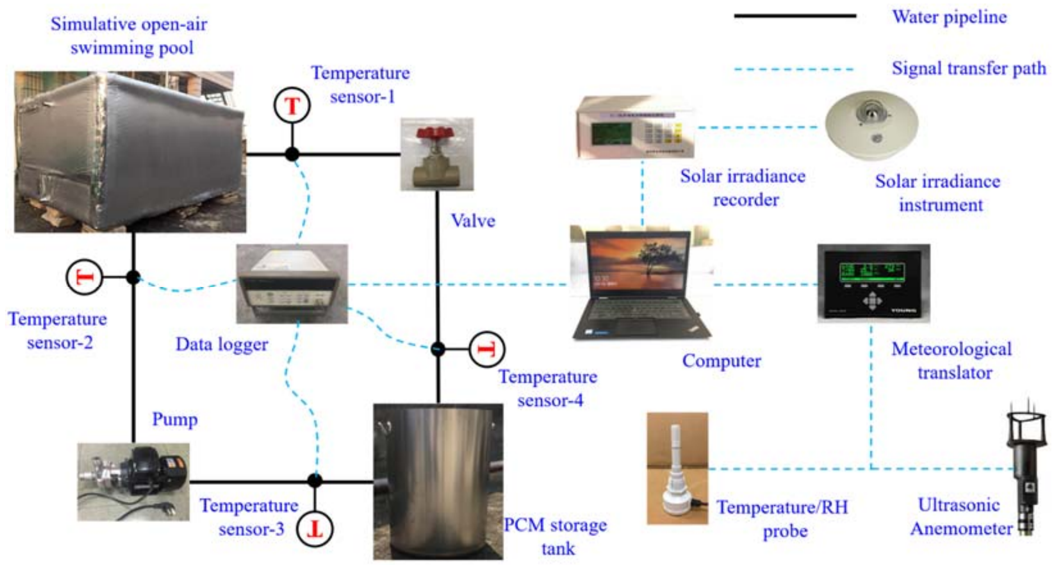

Figure 2. Schematic diagram of the constructed experimental setup.

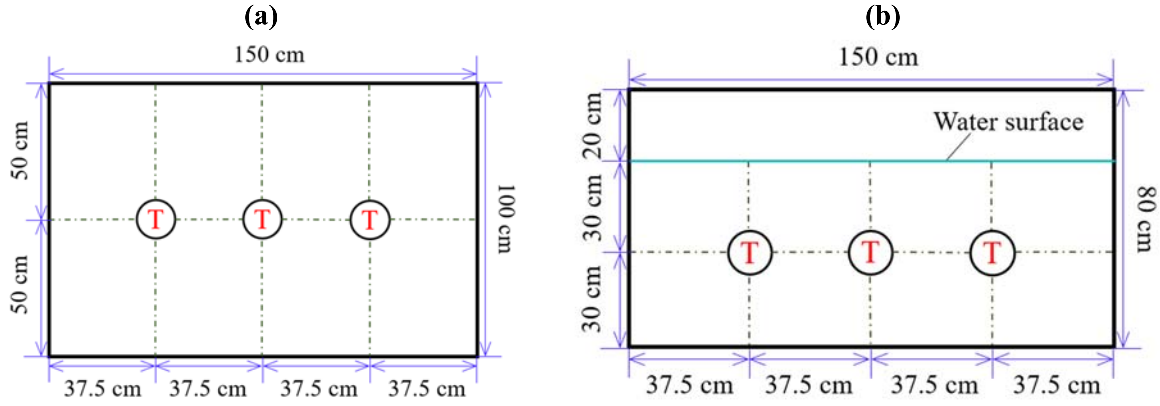

Figure 3. Temperature sensor distribution in the simulative open-air swimming pool: (a) plan view; and (b) front view.

4. Results and analysis

The field measurement data which was obtained by the experiments conducted in April 2018, was used to identify the relationship between the $T_{average}$ and T_{out}. The fitting curve between the $T_{average}$ and T_{out} was shown in Fig. 4, which was presented as the following equation:

$$T_{average} = 1.0011 T_{out} + 0.6132 \tag{4}$$

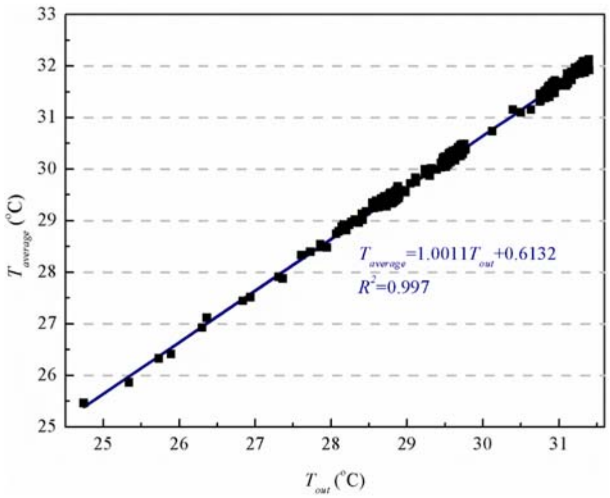

Figure 4. The Relationship between the $T_{average}$ and T_{out}.

To validate the reliablity of the constructed simulation platform, the experiment was conducted in 14th April, 2018 (from 17:30 to 19:00). The comparison of the swimming pool outlet temperature and heat flux between the experimental and numerical were presented in Fig. 4. It was observed that there was a good agreement between the experimental and numerical results, which indicated that the established simulation platform was reliable and correct.

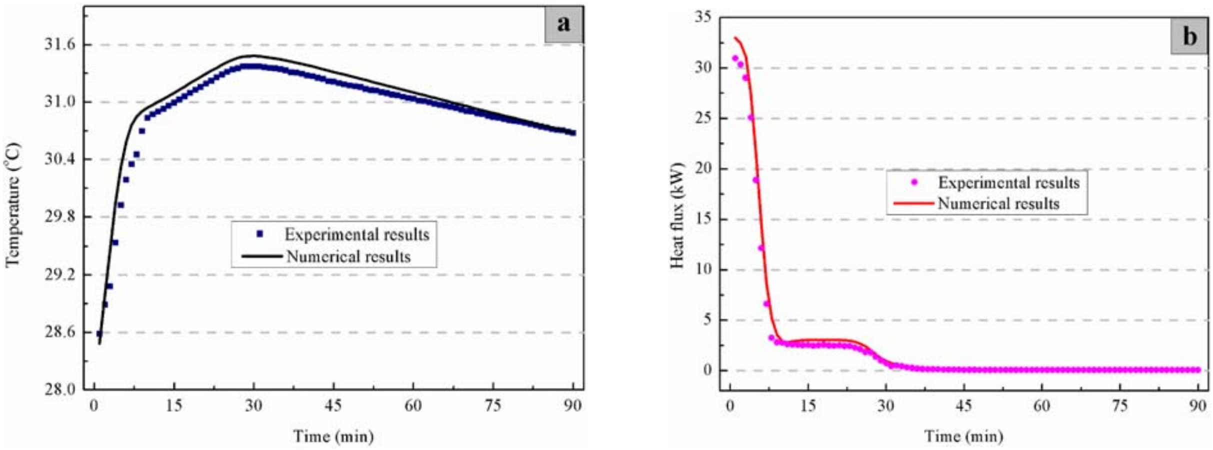

Figure 5. Comparison between the numercial and experimental results: (a) swimming pool outlet temperature; and (b) heat flux.

To verify the reliablity of the proposed method, the control performance between the proposed and traditional method is compared, shown in Fig. 6. During the traditional method, the set control temperature range of the T_{out} is from 27.9°C to 28.1°C; during the proposed method, the set control temperature range of the $T_{average}$ is from 27.9°C to 28.1°C, and thus according to the Equation (4) that of the T_{out} is from 27.26°C to 27.46°C. It can be seen that the $T_{average}$ fluctuates between 27.6°C and 28.4°C when the proposed method is used, which suggests that the swimming pool temperature can be fully maintained within the comfortable range (27°C to 29°C); the $T_{average}$ fluctuates between 27.6°C and 29.7°C when the traditional method is used, which suggests that the swimming pool temperature cannot be maintained within the comfortable range. Therefore, the poposed method is more advantegeous than the trational method for satisfying the comfortable temperature requirement of the swimming pool.

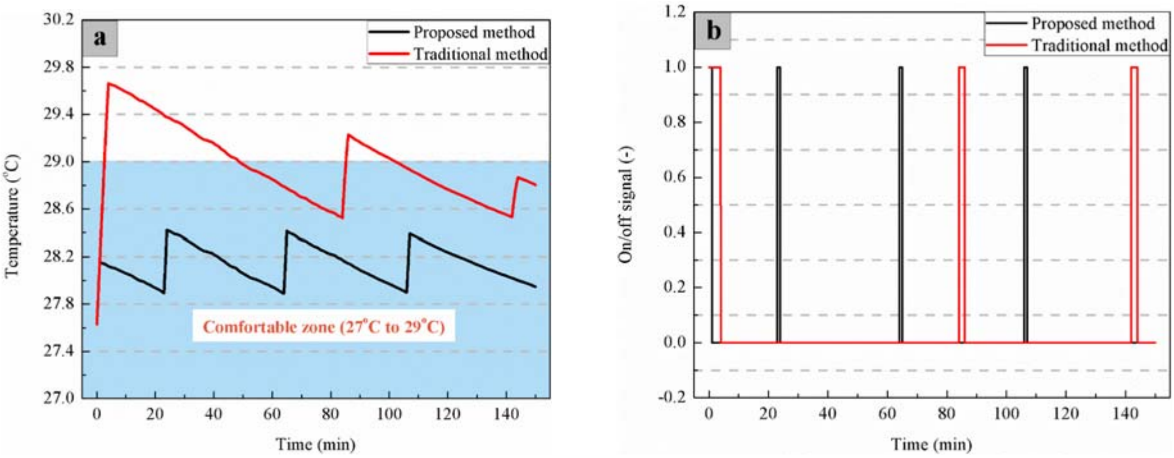

Figure 6. Comparison between the proposed and traditional control method: (a) $T_{average}$ and (b) on/off signal of the pump.

5. Conclusions

A new method for the temperature control of a PCM integrated open-air swimming pool was presented in this study. The case study of using the PCM storage tank to provide heat for a simulative open-air swimming pool was conducted to illustrate the proposed approach. A few of sensors are placed inside the simulative swimming pool to acquire the $T_{average}$, and the relationship $T_{average} = f\ (T_{out})$ was identified by lots of field measurement data. Based on this relationship, the simulation platform of the system was constructed using TRNSYS and MATLAB. The experimental setup was established in order to validate the reliability of the simulation platform. The system control performance indicated that the $T_{average}$ could be maintained within the comfortable range. Therefore, the proposed method provided a guideline for the temperature control of the PCM integrated open-air swimming pool.

Acknowledgements

The work described in this paper was supported by Guangdong Basic and Applied Basic Research Fund (No. 2015A030313814) and Guangdong-Hong Kong Collaboration Scheme – Research Project of Guangdong Province No.2017A050506058.

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