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Development and Applications of Integrated Numerical Model and Artificial Intelligence Technology for Hot Spring Pool System

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ABSTRACT

With the successful development of the health industry, the construction of geothermal (hot springs) projects has been developed all over the country in China. Within the projects, hot springs designed as therapy baths in a garden-style landscape are an important supporting and promotional highlight of the system construction. Due to the significant environmental differences in climate in different regions where the hot spring projects are located, no industry standards can be referred to. Therefore, the engineering design of the projects is carried out from experience, resulting in significant deviations between the estimated project operation data and the actual one and directly increasing the costs related to the investment and operation. This paper addresses a numerical model to guide the project plan, engineering design, equipment selection, and system intelligent control to ensure low loss and high-efficiency operation of the project energy utilization.

The numerical model of the pool heat loss is highly feasible and practical by collecting a large amount of project data, verifying and validating the calculations, summarizing the key factors affecting the heat loss of hot spring pools, carrying out project validation, and obtaining a numerical model to solve this fundamental bottleneck problem plaguing the development of the industry. The model uses the Python language package as the simulation platform. By inputting environmental data, the model can get the heat loss of the hot spring pool hourly and automatically generate the energy consumption index, heat source configuration, electricity load, and daily water consumption. These outputs greatly facilitate the engineers to carry out design work, further optimize the process, and select the appropriate devices. The combination of model predictions and artificial intelligence (AI) technology makes it possible to integrate R&D and intelligent control of geothermal system equipment. It integrates heat control, data acquisition and transmission, associated APP link control, and intelligent system integration. It can reduce the energy consumption of the system, save the operation and maintenance costs, promote the effective and reasonable utilization of geothermal resources, and as well help the country achieve the grand goal of "carbon peak" and "carbon neutrality."

1. INTRODUCTION

The living standard of people in China has constantly been improving since the economic reform and opening, and more and more people have paid more attention to their leisure, entertainment, and health care. The spa industry, which integrates leisure tourism and recreation, occupies a prominent spot in the emerging sunrise industry. China's spa industry has been developed since the 1990s and is now diversifying, with mountain spas, rural spas, sea spas, cliff spas, garden spas, boat spas, canyon spas, health spas and so on flourishing. Because of the diversified development of health spas, their environment is complex, and the weather changes, it is not straightforward to accurately calculate the spring system's energy consumption and to result in energy wastage and high operating costs when the pool is at a constant temperature. Outdoor spas, in particular, are greatly affected by the weather, such as rain and sunny days, wind and no wind, and different altitudes and humidity, resulting in various unpredictable heat losses in the pool.

The calculation of constant temperature in the pool is usually based on the heat transfer calculation method of "Swimming Pool Water Supply and Drainage Engineering Technical Regulations," which mainly considers the evaporation loss of the pool water surface, the conduction heat loss of the pool bottom, pool wall, transportation pipes, and equipment, etc. In these losses, the wind speed is usually taken as 2.0-3.0 m/s for calculating the evaporation loss of the outdoor pool. Then, conduction heat loss is estimated to be about 20% of the pool water surface loss [1]. Environmental factors significantly influence diversified spa pools, such as cliff spa pools and mountain spring pools, where the wind speed often exceeds 3.0 m/s in the mountain areas. Using the conventional heat transfer theory, it is difficult to calculate the heat losses. In contrast, the traditional method cannot determine the proportion of single heat loss in the total losses; therefore impossible to apply it to the targeted energy-saving plan. Li Jinhai et al. studied a mathematical model for temperature control of the variation of hot spring water, leading to the water temperature being always kept within the permissible range [2]. Still, the mathematical model was built on the premise that weather and other unstable factors were not considered. However, the energy consumption of the spy pool can't be accurately calculated in this approach.

By establishing a set of "temperature loss numerical models" for the hot spring pools, our firm has tried to estimate the energy loss of various pools and the proportion of each energy consumption in the practical application. Then, artificial intelligence software emerged into the model to automatically adjust the replenishment water and water temperature, lowering energy consumption and operating costs. The model calculation can also make targeted energy-saving solutions according to the energy usage ratio, which sunshine spa enterprises in energy saving.

2. ESTABLISHMENT OF A NUMERICAL MODEL OF TEMPERATURE LOSS

Conventional calculation of spa pool temperature loss uses a reference method from swimming pool heat losses, divided into indoor and outdoor pools, and evaporative heat loss is the only portion of heat transfer calculation. Our temperature loss model of the spa pool uses a Python language package as the calculation platform, including a variety of spa pool types and location selections.

According to different themes of the spa pool design, diverse environmental spa locations and spa functions of the pool, and various influencing factors of separate presentation of the pools, the overall temperature loss of the spa system and the proportion of each heat transfer loss can accurately be calculated through the heat loss modeling approached in this study.

The proposed method includes a variety of potential heat losses, including pool wall and pool bottom heat conduction, surface evaporation, convection, radiation, pipeline transport, and overflow heat losses, shown in the schematic diagram of the heat loss model in **Figure 1**. The model also includes the potential effects of daytime sunlight exposure, dynamic perturbation of human beings in the pool, and meteorological conditions of the spa region.

Temperature loss model: $Q_{SP}= Q_{SPconv}+Q_{SPcond}+ Q_{SPeva}+ Q_{SPrad}+ Q_{SPren}+ Q_{SPspl}$.

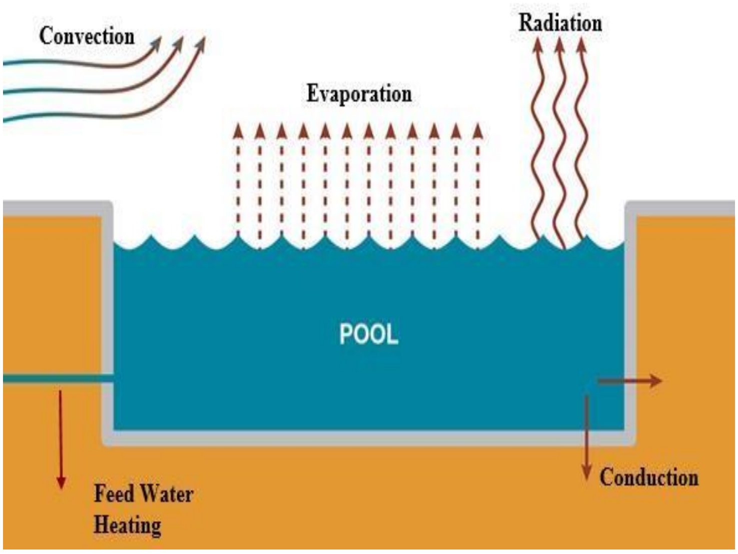

Figure 1: Schematic diagram of the heat loss model

2.1 Thermal conductivity loss via the wall and bottom of the pool

According to the characteristics of a hot spring water pool, an outdoor pool is usually built below the ground, and multiple layers of insulation are designed around the pool to minimize heat losses from the hot water to the surrounding soils. Therefore, the thermal conductivity loss through the wall and the bottom of the pool can be calculated based on the material and the thickness of each layer of the insulation. Detailed calculation equations are as follows:

$$Q_{SPcond}=Q_b+Q_d \tag{1}$$

$$Q_b = 0.001\lambda \bullet S_1(T_0 - T_{W1}) \tag{2}$$

$$Q_d = 0.001\lambda \bullet S_1(T_0 - T_{W1}) \tag{3}$$

$$\lambda = \frac{3\lambda_1\lambda_2\lambda_3}{b_1\lambda_2\lambda_3 + b_2\lambda_1\lambda_3 + b_3\lambda_1\lambda_2} \tag{4}$$

$$S1= 3.14\varphi H \tag{5}$$

$$T_{W1}=0.5(T_{land}+T_{air}) \tag{6}$$

Finally, thermal conductivity loss calculation model I of the final spa water pool wall and body is derived from equations (1), (2), (3), (4), (5) and (6) together as:

$$Q_{SPcond} = \frac{0.00942\varphi H\lambda_1\lambda_2\lambda_3(2T_0 - 0.5T_{air} - 1.5T_{land})}{b_1\lambda_2\lambda_3 + b_2\lambda_1\lambda_3 + b_3\lambda_1\lambda_2} \tag{7}$$

2.2 Water surface convection heat transfer of pool

Convective heat transfer between the air and the pool's surface is a vital part of the heat transfer in considering the temperature changes of the pool, mainly caused by airflow. The Nusselt number determines convective heat transfer, i.e., the larger the water surface area and the greater the wind speed, the more intense the convective heat transfer.

The temperature difference between the air and water is another factor affecting heat transfer. The more significant the air-water temperature difference, the faster the spa water temperature changes. The water surface convective heat transfer equation for a typical outdoor pool is as follows:

$$Q_{SPconv} = 0.00314(\frac{\varphi}{2})^2 F_1 h_x (T_0 - T_{air}) \tag{8}$$

F_1: perturbation factor.

$$h_x = \frac{(Nu)Ra}{\varphi} \tag{9}$$

If Re > 500000, $Nu = 0.644P_r^{\frac{1}{3}}R_e^{0.5}$, if Re ≤ 500000, $Nu = 0.037P_r^{\frac{1}{3}}R_e^{0.8}$, $R_e = \frac{V\varphi}{\upsilon}$.

According to equations (8) and (9), the water surface convection heat transfer loss:

$$Q_{SPconv} = 0.000785\varphi NuR_aF_1(T_0 - T_{air}) \tag{10}$$

2.3 Evaporation heat loss on the pool's surface

The surface evaporation heat loss of the hot water pool is the most significant part of pool heat losses due to the evaporation of surface water. The evaporation rate is affected by the partial pressure of water vapor of saturated air at the water surface, atmospheric pressure, ambient humidity, surface air flow rate and the degree of surface disturbance, etc. The typical pool surface evaporation heat loss model is:

$$Q_{SPeva}= SF_1(P_v-P_a) (B/B') (0.0782V+0.089) \tag{11}$$

$$P_v = 10^{(8.07131-\frac{1730.63}{T_0+233.426})}\beta$$

$$P_a = 10^{(6.07131-\frac{1730.63}{T_{air}+233.426})}\beta(RH)$$

$$B '= B[(1-0.1621)GD/ (6357+0.001GD)]^{5.256}$$

2.4 Radiative heat transfer loss of pool

According to Stefan-Boltz's law -- the quadratic law, the radiative heat of an object is only related to the temperature of the object; the higher the temperature, the greater the radiative heat loss, considering the hot spring pool as a black body, the radiative heat exchange loss model of the hot spring water is:

$$Q_{SPrad} = 10^{-3}S\varepsilon\theta_{rad}[(T_0 + 273)^4 - (T_{air} + 273)^4] \tag{12}$$

2.5 Circulating water piping heat loss

According to the "Equipment and pipeline insulation technology general rules" (GB4272-2008), pipeline and equipment heat dissipation with the pipeline's external surface temperature and contact area. When the outer surface temperature does not exceed 50 ℃, the maximum heat loss is estimated to be roughly 52 W/m^2 for perennial operation and 104 W/m^2 for seasonal operation, respectively. When the specific size of the pipeline is known, the heat loss model is as follows:

$$Q_{SPren} = 3.14\times10^{-3}Q_mL(d_f + d_b) \tag{13}$$

Qm: According to the standard, the annual operation is 52 W/m^2, and the seasonal operation is 104 W/m^2.

$SG= 3.14d_fL+ 3.14d_bL$

$d_f= (4\rho W_{cycle}/ (3600\times3.14\times V_2))\ 1/2$

$d_b= (4\rho W_{cycle}/ (3600\times3.14\times V_1))\ 1/2$

Note: d_b and d_f should be greater than the calculated values.

$W_{cycle}= 1.1W/ (1000n)$

2.6 Splash heat loss of pool

When there is artificial disturbance and overflow of water, the pool water surface can splash. The greater the perturbation, the greater the splash. When there is an air-water temperature difference, splash heat loss will increase from the strengthened heat exchange between air and pool. The splash heat dissipation model is calculated as follows:

$$Q_{SPspl}= W_yC (T_0-t_{air}) S/3600 \tag{14}$$

$$Wy= F_1Dy \tag{15}$$

According to equations (14) and (15), the heat dissipation of pool splashing is obtained:

$$Q_{SPspl}= 2.78 \times 10^{-4}D_yCSF_1(T_0-t_{air}) \tag{16}$$

2.7 Total temperature loss of pool

In summary, the total heat loss can be obtained by combining the abovementioned sub-heat losses. i.e.:

$$Q_{SP}=\frac{9.42\times10^{-3}\varphi H\lambda_1\lambda_2\lambda_3\ (2T_0-0.5T_{air}-1.5T_{land})}{b_1\lambda_2\lambda_3+b_2\lambda_1\lambda_3+b_3\lambda_1\lambda_2}+10^{-4}F_1(7.85\varphi NuR_a+2.78DyCS)(T_0-T_{air})+SF_1(P_V-P_a)$$
$$(B/B')(0.0782V+0.089)+10^{-3}S\varepsilon\bullet\theta_{rad}\left[(T_0+273)^4-(T_{air}+273)^4\right]+3.14\times10^{-3}Q_mL(d_f+d_b)$$

3. MODEL VALIDATION AND APPLICATION

In order to verify the accuracy of the model, we used temperature loss analysis for different locations and different spy pools through the model. We then evaluated the accuracy of the model predictions with tactual temperature changes from the natural pool. Finally, the system’s energy consumption was obtained from the heat balance combined with temperature change. Nanjing Jinwu spa pool is used as an example for actual verification in this study.

The above temperature loss model calculates the constant temperature replenishment of water and replenishment of heat through a heat transfer and loss, combined with an artificial intelligence platform, to achieve the automatic continuous temperature control of the spa pool. The application objects are Zhejiang Zhoushan hot spring pool and Chongqing Nanshan Yi Tang hot spring spa.

The relevant calculation formulas in detail are:

I. Heat calculation formula

$$Q = cm\Delta t \tag{17}$$

$Q=3600h_rQ_{SP}$

$m=W-Ds$

$\Delta t = t_0-t_s$ or t_0-t_d

II. Calculation of each heat loss proportion:

Surface evaporation loss: $\frac{Q_{SPeva}}{Q_{SP}}\times100\%$

Loss of circulation line: $\frac{Q_{SPren}}{Q_{SP}}\times100\%$

Splash heat loss: $\frac{Q_{SPspl}}{Q_{SP}}\times100\%$

Pool wall thermal conductivity loss: $\frac{Q_{SPcond}}{Q_{SP}}\times100\%$

Convection heat transfer loss: $\frac{Q_{SPconv}}{Q_{SP}}\times100\%$

Radiative heat transfer loss: $\frac{Q_{SPrad}}{Q_{SP}}\times100\%$

III. Calculation of constant temperature water supply and heat supply

When sunlight is available, the make-up of direct sunlight heat calculation:

Q_{sun}= 0.17445GS (G = 1 with sunlight, G = 0 without sunlight) (18)

$$Q_{cycle}= Q_{SP} + Q_{pipeline} + Q_{sun} \tag{19}$$

$$T_r=\frac{3.6(Q_{cycle}-Q_{sun})}{CW_{cycle}}+T_0 \tag{20}$$

3.1 Model verification

Experimental measurements were done in both dynamic and static (no human activities in the pool) conditions on the Jinwu landscape-type spa pool with a sea view. The circulating water multiplier (n) was set to 2.65h, and the pool temperature variation was calculated based on the detailed environmental conditions in **Table 1. Figure 2** shows the ratio of each heat loss to the total heat loss in percentage of various heat losses (see **Figure 2**). Then the accuracy of the temperature change calculation was verified by comparing it with the measured value, and the test results are shown in **Figure 3**.

Table 1 Basic conditions of the pool

The serial number	The name of the	Code name	unit	data
1	Pool types			Landscape type
2	Pool name			Spa Pool 1
3	Number of pool			4.00
4	Sunlight	G		1
5	Design pool temperature	T_0	℃	40
6	Outdoor air temperature	T_{air}	℃	15
7	Surface air wind speed	V	m/s	2.5
8	Altitude	GD	m	35
9	Ambient relative humidity	RH	%	60
10	Soil temperature around the pool	T_{land}	℃	20
11	Pool surface area	S	m^2	15.5
12	Pool depth	H	m	0.65

The heat loss of each model and the total temperature loss values were obtained from the overall heat losses based on the pool information in Table 1 as follows:

Q_{SPcond} = 0.64 kW

Q_{SPconv}= 3.37 kW

Q_{SPeva}= 33.71 kW

Q_{SPrad}= 2.39 kW

Q_{SPren}= 5.22 kW

Q_{SPspl}= 0.35 kW

Q_{SP}= 40.46 kW

Q_{sun}= 2.16 kW

Q_{cycle}= 45.68 kW

Tr= 48.97 ℃

It can be seen from **Figure 2** that the significant heat loss of the landscape-type pool is surface evaporation loss, accounting for 93.31% in the case examined, followed by convective heat transfer loss and radiative heat transfer loss, accounting for 8.32% and 5.92%, respectively. Splash heat loss and pool wall heat transfer loss are minor, accounting for 0.87% and 1.59%, respectively.

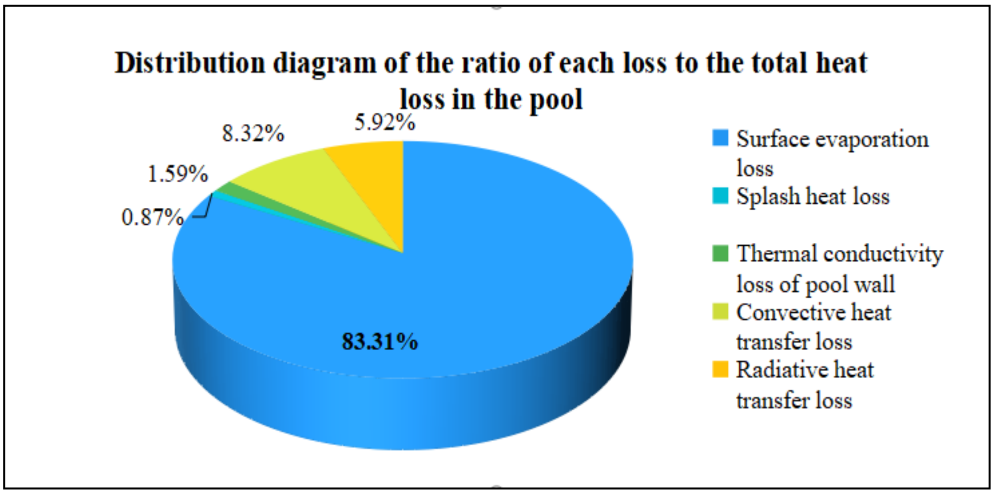

Figure. 2 Distribution of the ratio of heat loss to total heat loss in each model of a landscape soaking pool near the sea in Jinwu

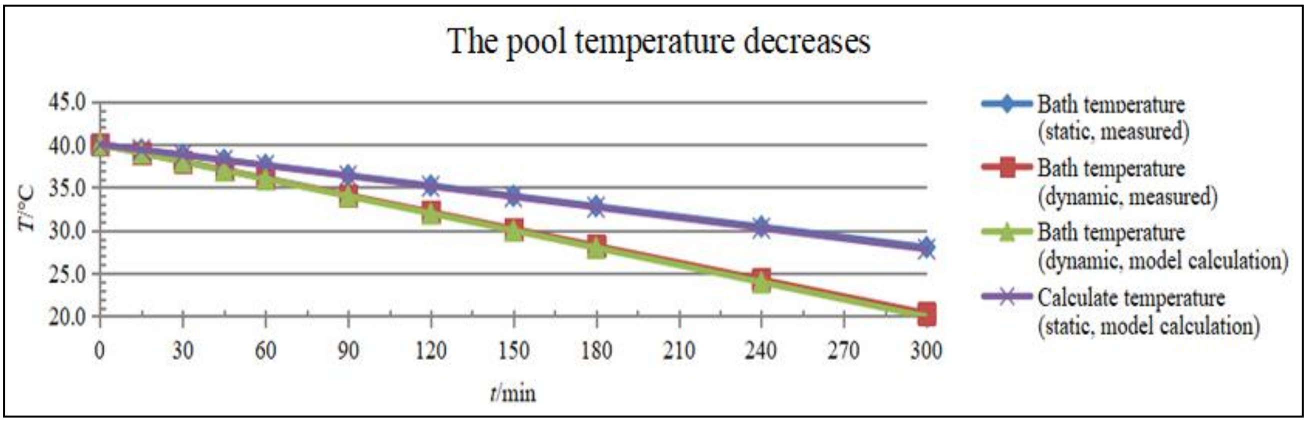

Figure. 3 Temperature variation of static and dynamic pools

Figure 3 shows the temperature change of the hot spring pool with time under static (i.e., no one is in the pool, the same as below) and dynamic (someone is in the pool); it can be seen that the temperature of the spa pool is gradually decreasing with time in the state of no water replenishment, and the temperature drops more under dynamic than under static, which indicates that the temperature loss is more when there is someone in the pool. It is happy to see that the model predictions of temperature at static and dynamic are almost the same as the measured temperature, which indicates that the model calculation is very reliable.

Using values measured after the 60 min and 120 min as examples, the calculated values at 60 min from heat calculation equation (17): t_{static} = 37.56°C and $t_{dynamic}$ = 36.3°C, respectively. The actual measured temperatures are t_s = 37.65°C and t_d = 35.99°C from Figure 3. Meanwhile, calculated values at 120 min are t_s = 35.12°C and t_d = 31.97°C, and the measured values according to **Figure 3** are t_s = 35.2°C and t_d = 32.1°C. In summary, the difference between the model calculation and measurement of the pool temperature loss after 1 hour and 2 hours was within 0.1°C, no matter whether the pool condition was in the static or dynamic mode.

3.2 Application of the model

3.2.1 Validation of temperature loss model for coastal beach-type spa pool in Zhoushan

In the experiments on the beach-type spa pool in Zhoushan Binhai, the data on the base conditions of the spy pool are given in **Table 2** for details. By applying the data to the model, the heat loss ratio distribution of each heat loss are following (see **Fig. 4** and **Fig. 5** for details):

Q_{SPcond}= 1.74 kW

Q_{SPconv}= 14.25 kW

Q_{SPeva}= 100.49 kW

Q_{SPrad}= 8.11 kW

Q_{SPren}= 8.49 kW

Q_{SPspl}= 1.25 kW

Q_{SP}= 125.85 kW

Q_{sun}= 5.37 kW

Q_{cycle}= 134.34 kW

Tr= 50.7 °C

Table 2 Basic condition table of Zhoushan coastal beach type bathing pool

The serial number	The name of the	Code name	unit	data
1	Pool types			Coastal beach-type
2	Pool name			Hot Spring Pool 1
3	Number of pool			6.00
4	Sunlight	G		1
5	Design pool temperature	T_0	°C	40
6	Outdoor air temperature	T_{air}	°C	4.0
7	Surface air wind speed	V	m/s	3.0
8	Altitude	GD	m	10
9	Ambient relative humidity	RH	%	80
10	Soil temperature around the pool	T_{land}	°C	15
11	Pool surface area	S	m^2	38.5
12	Pool depth	H	m	0.65

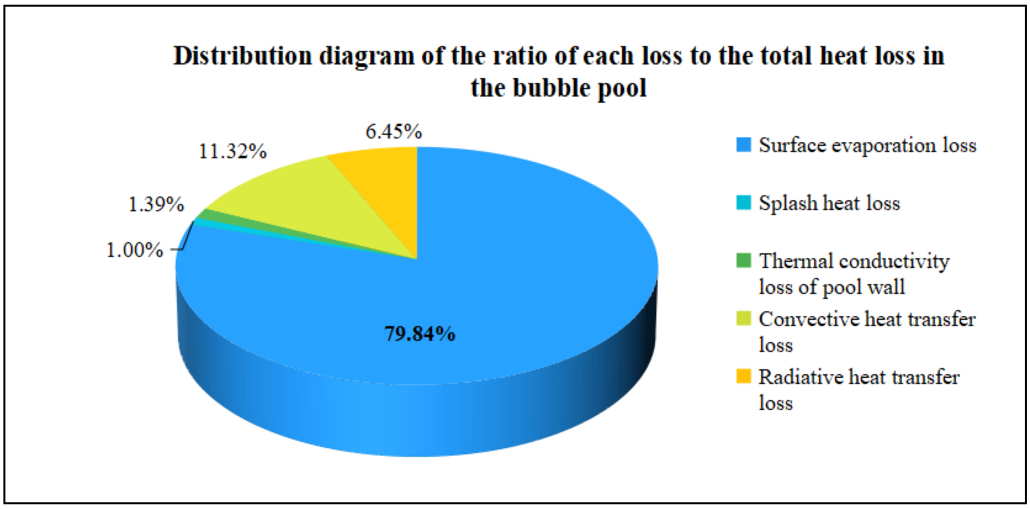

Figure 4. Ratio distribution of heat loss in the coastal beach-type bathing pool in Zhoushan

From **Figure 4**, the heat loss is mainly from surface evaporation loss, which accounts for 79.85% of the total heat losses. This is followed by convective heat transfer and radiation heat transfer losses, which account for 11.32% and 6.45% of the heat loss. Splash water heat loss and pool wall heat conduction loss accounted for only 0.93% and 1.35%, respectively.

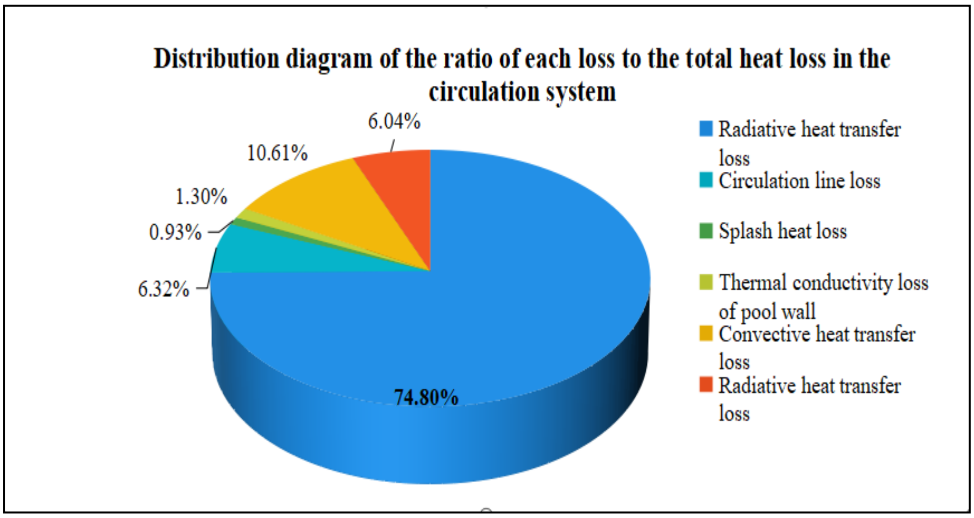

Figure 5. Ratio distribution of each heat loss in the circulation system of the coastal beach-type pool in Zhoushan

Figure 5 shows the situation of the addition of heat loss from the water circulation from the pool and the heating control center. Again, surface evaporation loss contributed to the major heat loss of the coastal beach-type pool in Zhoushan, reaching about 74.8%, followed by the heat losses from convection heat transfer, radiation heat exchange, circulating pipeline, pool wall heat conduction and splash water.

The circulating make-up water flow rate is calculated based on the total system heat loss, which is calculated by each heat loss sub-model and then subtracted from the sunlight heat under a natural environment. Finally, the circulating water temperature that needs to be configured under different circulating water amounts is calculated by equation (17), as detailed in **Figure 6**.

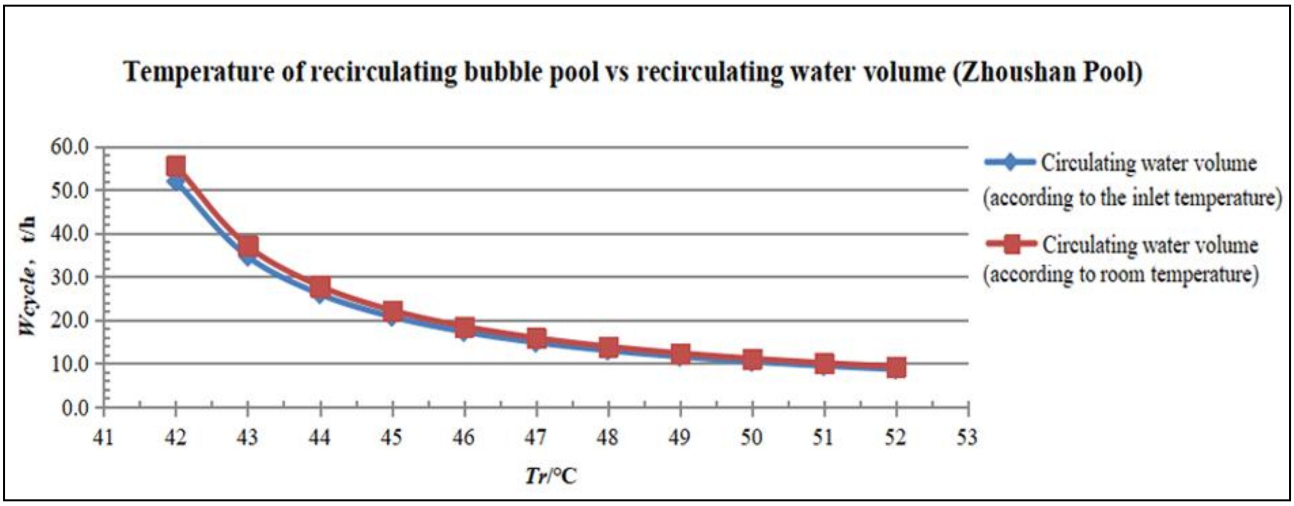

Figure 6. Comparison of circulating temperature and circulating water volume in Zhoushan coastal beach pool

3.2.2 Integration of pool temperature loss model and artificial intelligence (AI) technology

Taking Chongqing Nanshan Yitang hot spring pool as an example, the heat loss model is used as the basis for predictions of the temperature changes and the Python language is used as the software package to automatically calculate the water injection temperature and flow rate required for constant temperature of the pool. Under actual conditions, the AI intelligent platform control system is used to adjust the water injection temperature and flow rate by collecting the on-site data to achieve the overall goal of constant temperature and intelligent control of the spa pool. **Figure 7** shows the snapshot of the smart cloud platform control system, the on-site weather conditions, and as well the pool temperature of 43.6°C during the intelligent control.

Figure 8 shows the dynamic data changes of automatically thermostatic control process in real-time operation. It indicates that the wind speed and ambient air temperature are the main parameters for presenting the variable situations of the heat loss of the pool, especially the wind speed, which reaches up to 19 m/s. After adjustment by the AI automatic control platform, the temperature of the spa pool remains at 43°C, and the temperature fluctuates within 0.5°C.

Figure 7. Temperature loss model and AI control system

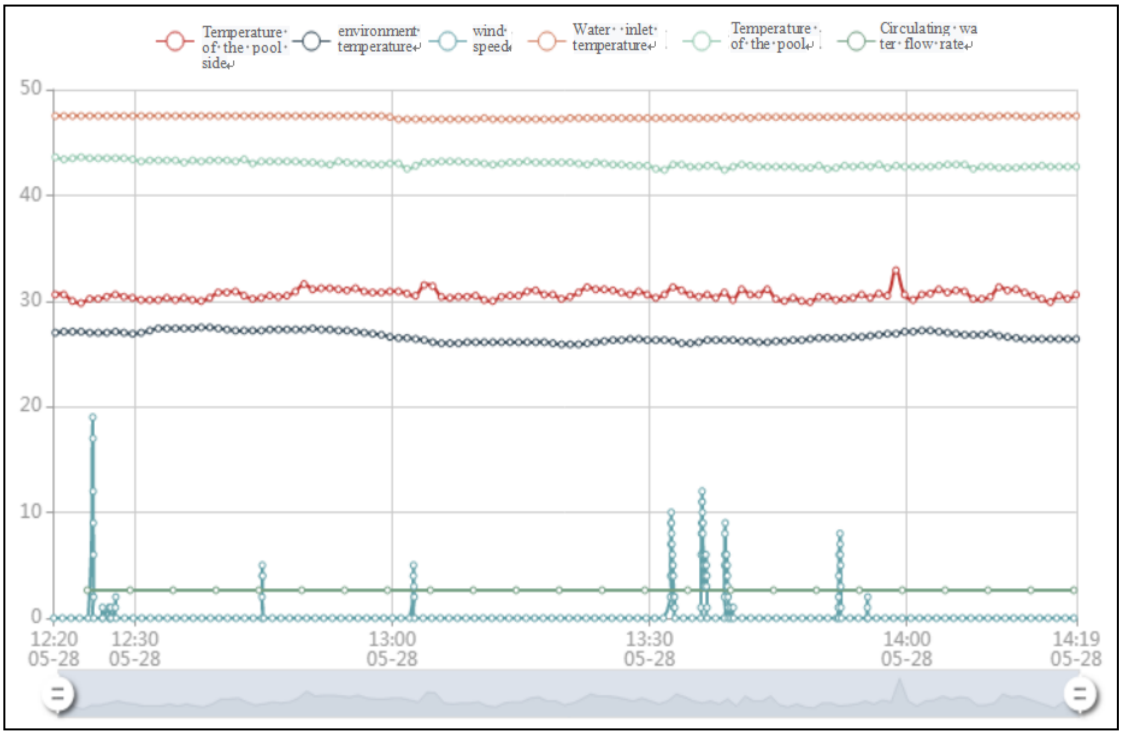

Figure 8. Trend graph of each data curve of Nanshan Yitang thermal spring intelligent control system

4. MODEL EVALUATION

The model for calculating heat loss of hot spring pools has the following advantages.

1. Adding dynamic coefficients to the calculation formula for real-time operations has improved the accuracy of the model predictions.

2. Some conditions, such as the pool surface wind speed, water temperature equal to the latent heat of evaporation of saturated steam, water temperature equal to the partial pressure of saturated air water vapor, and the ambient temperature of the pool equal to the partial pressure of water vapor, water density, standard atmospheric pressure and local atmospheric pressure, are the key factors must be included in the calculation model. In addition, human activities in the pool are also taken into account

when people enter the spa pool. Any activity generally perturbs the water pool; the more people, the more intense the apprehension.

3. Based on the spa pool function, the hot spring pool can be divided into indoor, outdoor, massage pool, landscape pool, hydrotherapy pool, warm-up pool, spa pool and other forms. According to the mode of water circulation, the pool can be divided into direct supply and discharge, a counter-current spa pool, a downstream spa pool, and a small hot spring pool. Because the pool heat dissipation ratio is different for the various pool type, the heat loss prediction in this study doesn't simply take the percentage of heat loss from evaporation directly, thus will not cause deviation from the measured value and will not mislead the selection of equipment.

4. Through the improvement of the existing spa water pool calculation method and equipment selection, combined with the four-season climate change and day and night temperature difference changes from real-time data monitoring, comprehensive analysis of environmental conditions, climate, sea level, spring temperature, pool structure, circulation system, constant temperature heating system, changes of operation mode for different energy consumption variables, this model gives the benchmark conditions of the evolution of calculations.

5. By integrating the model with the AI intelligent system, the pool system can save energy and reduce consumption by controlling the constant temperature of various hot spring spa pools.

5. CONCLUSIONS

From the perspective of the rapid development of the spa industry and the diversification of spa types, the proper calculation of heat loss of various hot spring pools is a primary issue for spa enterprises in China. This study of the temperature prediction model considers the influence of multiple factors covering the wide range of values of each influencing factor, resulting in better accuracy of the prediction model and facilitating hot spring enterprises to grasp the energy consumption of spa pools and systems. The construction of the temperature prediction model is also conducive to system equipment selection and regulation of the spa pool thermostat system in integration with artificial intelligence (AI) systems to achieve low energy consumption and low-cost operation for promoting the practical and rational use of geothermal resources. The main findings from this study are as follows.

1. The temperature loss of the spa water pool is mainly attributed to surface evaporation loss, accounting for 70-80% of the total heat loss. The rest of the heat losses account for the other 20-30 % (including convective and radiative heat losses, accounting for 15-25 %, and splash water heat loss and pool wall heat conduction loss, accounting for 1-3 %).

2. The temperature prediction model can calculate the heat losses more accurately by considering the influencing factors and taking into account both static and dynamic conditions. The temperature difference between the calculated and measured values on-site is within 0.1°C for the Jinwu coastal landscape-type spa water pool.

3. The model accurately predicts spa temperature change for small water pools by replacing the hot water in a period and for large water pools in the continuous water supply.

4. Through the integration of a heat loss predicting model and artificial intelligence, the spa system is able to be operated at real-time regulation of water circulating amount and temperature to achieve a constant temperature of the water pool.

Symbol Description:

G	Sun exposure intensity
T_0	Design pool water temperature, ℃
T_{air}	Outdoor air temperature, ℃
V	Water surface air speed, m/s
GD	Altitude, m
RH	Ambient relative humidity, %
T_{land}	The soil temperature around the pool, ℃
S	Pool surface area, m^2
H	Pool depth, m
F_0	Static disturbance coefficient
F_1	Actual disturbance coefficient
B	Standard atmospheric pressure, kPa
B'	Local atmospheric pressure, kPa
R_{air}	The density of air, Kg/m^3
R_a	Air thermal conductivity, W/m•K
υ	Motion viscosity coefficient, m^2/s

C	Specific heat of water, kJ/ kg.℃
ρ_{water}	Water density, kg/l
φ	Pool equivalent diameter, m
S_1	The surface area of the soaking pool wall, m^2
W	Total water in the soaking pool, kg
Q_{sun}	Sun exposure heat, kW
Q_{SP}	Total heat loss from the pool, kW
Q_{cycle}	Total heat loss of the cycling pool, kW
n	Circulating water ratio
W_{cycle}	Circulating water volume, t/h
Ds	The evaporation flow rate of pool water surface, kg/h
Q_{line}	Circulating water line loses heat, kW
W_y	Dynamic splash water, kg/h
Q_{SPcond}	Heat conduction of the wall and bottom of the pool loses, kW
V_1	Design pipe return water flow rate, m/s
d_f	Feed pipe diameter, m
L	Length of heat net, m
Q_m	Maximum allowable heat loss, W/m^2
t_D	Dynamic water temperature, ℃
Tr	The temperature of circulating water entering the pool, ℃
T_y	The temperature of circulating water in the control room, ℃
b_1	First layer insulation thickness, m
λ_1	Thermal conductivity of insulation layer, W/m•K
b_2	Second layer insulation thickness, m
λ_2	Thermal conductivity of insulation layer, W/m•K
b_3	Third layer insulation thickness, m
λ_3	Thermal conductivity of insulation layer, W/m•K
T_{W1}	Average pool wall temperature, ℃
d_1	Concrete layer outer diameter, m
d_2	Insulation brick layer outer diameter, m
d_3	Building transstory outer diameter, m
λ	Total thermal conductivity of the pool wall, W/m•K
Q_b	Heat loss from heat conduction of pool wall, kW
Q_d	Heat loss due to heat conduction at pool bottom, kW
R_e	Reynolds number
Pr	Prandtl number
N_u	Nusselt number
hx	Convective heat transfer coefficient, W/m•K
Q_{SPconv}	Water surface convection heat transfer loses heat, kW
θ_{rad}	Steffen-Boltzmann coefficient
Q_{rad}	Heat exchange between the pool and external radiation loss, kW
β	Pressure conversion factor, kPa
γ	Latent heat of vaporization, kJ/kg
P_v	The saturated steam partial pressure of water vapor, kPa
P_a	The partial pressure of water vapor, kPa
Q_{SPeva}	Evaporation heat loss of pool water surface, kW
D_y	Water splash per unit area, kg/m^2•h.
Q_{SPspl}	Pool splash heat loss, kW
ε	Radiation structural blackness
V_2	Design pipe feed flow rate, m/s

d_b	Backwater pipe diameter, m
S_G	Pipe surface area, m^2
t_S	Static water temperature, ℃
m	Weight of water in the pool, kg
Q	Heat loss per unit time, kJ
h_r	Heat dissipation time of the pool, h

References

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