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Hybrid thermal model for swimming pools based on artificial neural networks for southeast region of Brazil

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ABSTRACT

Nowadays, the usage of systems based on solar energy have been largely stimulated. The correct designing and efficiency of these systems are highly dependent of the seasonal climatic characteristics of the regions where they will be installed. In this work, we propose a hybrid structure to simulate the thermodynamic behavior of pools, which uses neural computational models to incorporate the climatic information of the regions being analyzed. The neural models have as input variables data of geographic position such as: elevation, latitude and longitude, what permits to delineate the climatic profile of the region being considered. The human activity is another factor that directly influences the thermodynamic behavior of pools and, therefore, is also considered. In this work, changes of volume are estimated in order to track losses due to the human activity.

1. Introduction

Within the current scenery of energy consumption and the population growth, it is expected that conventional systems for energy generation may not be enough to meet future world demand. The usage of alternative energy to attend this demand is already a reality. In developing countries like Brazil, the usage of solar energy systems as heaters is being highly stimulated specially in regions with low wage indexes.

Swimming pool systems that use the solar energy as source for the heating of water can have an important social role. If a swimming pool and its solar heating system are properly dimensioned, taking into consideration the region weather conditions where the systems will be installed can produce a significant reduction in the conventional energy consumption that would be spent to heat it.

It is known that the systems efficiency based on solar energy is highly dependent of the seasonal climatic characteristics of the region where the system will be installed. In order to know the thermal behavior of the pools, specify their dimensions correct, define the quantity of heaters or standardize their configurations it is necessary to know the climatic characteristics of the regions where the systems will be installed. Thus, it is necessary to count on mathematical models depending of the geographic position and of climatic conditions of each region. The development of these models and its simulations would permit a better use of devices and resources and a more efficient installation of the solar heaters in urban as well as in rural areas. This can be a challenge when considering large territorial extensions due to the lack of meteorological stations to collect data. The territory considered for the simulation in this work corresponds to the State of Minas Gerais, Brazil, which has a large territory of 586,528 km^2 and is located between the latitudes 22°54′00″S to 14°13′58″S and the longitudes 39°51′32″W to 51°02′35″W.

Considering the heating of pools based on solar energy, climatic variables such as average ambient temperature, maximum ambient temperature, air relative humidity, dew point temperature and sky temperature influence directly in the pool temperature. Because of the large territorial area and the geographic diversity of region considered, the obtaining of the climatic profile for all the main locations is not viable through the installing of the meteorological stations due to high cost involved what justify the usage of alternative computational models based, for example, in neural networks. The territory considered has only 28 meteorological stations for which the data considered for the neural representation were collected during 10 years. From this work, the procedures adopted to obtain the neural representation of the climate for the state of Minas Gerais–Brazil could be applied and extended to other regions and countries.

The human activity is another factor that directly influences the thermodynamic behavior of pools and, therefore, must be also considered. The human activity corresponds to usage of pools by visitors, which withdraw water of the pool by means body and activity in the pool. The loss of water by human activity diminishes the vol-

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Nomenclature

A_p	area of the pool (m^2)
A_s	surface area of the pool–soil interface (m^2)
c	proportionality constant for evaporative heat loss (°C/kPa)
C_p	specific heat of water (kJ/kgK)
$I_{(t)}$	time dependent insolation per unit time per unit area (W/m^2)
I_b	direct component of the incident solar intensity
I_d	diffuse component of the incident solar intensity
P_a	water vapor pressure (kPa)
P_w	saturation vapor pressure of the water in air temperature (kPa)
R	longwave radiative loss to the sky (W/m^2)
$T_p(t)$	time dependent pool temperature (°C)
$T_s(t)$	soil temperature (°C)
$T_a(t)$	time-dependent ambient temperature (°C)
$\overline{T}_a$	average value of ambient temperature (°C)
T_{sky}	time-dependent sky temperature (°C)
T_{dw}	dew point temperature (°C)
$\overline{T}_{dw}$	average value of dew point temperature (°C)
T_r	correspond to the amplitude of the annual, monthly, daily or hourly variations of the ambient temperature considered for simulation (°C)
$T_{\max}$	maximum ambient temperature (°C)
$T_{\min}$	minimum ambient temperature (°C)
T_{9h}	ambient temperature at 9 a.m. (°C)
T_{15h}	ambient temperature at 3 p.m. (°C)
T_{21h}	ambient temperature at 9 p.m. (°C)
T_{dw9h}	dew point temperature at 9 a.m. (°C)
T_{dw15h}	dew point temperature at 3 p.m. (°C)
T_{dw21h}	dew point temperature at 9 p.m. (°C)
E_l	elevation (m)
l_t	latitude
l_o	longitude
U_c	coefficient of convective heat loss ($W/m^2 {}^\circ C$)
U_r	coefficient of heat loss by radiation ($W/m^2 {}^\circ C$)
U_s	coefficient of heat loss by contact with the soil ($W/m^2 {}^\circ C$)
V_p	volume of pool (m^3)
$V(t)$	corresponds to the variation of the volume of pool (m^3)
$\overline{\tau\alpha}$	annual average effective transmittance-absorptance product for the pool
ε	emissivity of the water
ρ_p	specific density of water (kg/m^3)
β_1	conversion factor of units
$\overline{RH}$	corresponds to the average air relative humidity
ω	hourly angular frequency
T_y	period of the year in appropriate units
ϕ_{Ta}	phase angle for ambient temperature
h	integration period (hours)
k	corresponds to time-step
$\bar{\mu}$	average value
σ	standard deviation
L_n	normalized value
L_o	value to normalize
$L_{\min}$	minimum value of the process variable to normalize
$L_{\max}$	maximum value of the process variable to normalize
$L_{imiteInf}$	minimum value of the process variables of the original data set
$L_{imiteSup}$	maximum value of the process variables of the original data set

ume and influences the thermodynamic behavior of the pool. In this work, changes of volume were matched to typical mathematical functions i.e. step, ramp and exponential. The volume was estimated in order to track losses due to human activity. The variation in the pool volume is determined by parametric estimation of the thermal model through the least squares method.

In this work, we propose a hybrid structure to simulate the thermal behavior of pools influenced by regional climatic conditions. The proposed simulation structure integrates a thermodynamic model for pools and artificial neural networks (ANN) to incorporate the climatic information of the regions where the pool will be installed. The neural computational models presented use as part of the input variables the geographic position (elevation, latitude and longitude) and takes advantage of the generalization capacity of the neural networks (NN) to obtain climatic information of regions, into of representativeness domains of the neural models.

This work is divided in seven sections. In the second section, a literature review is given. In third section, the thermal model for pool considered in this work is presented. In the fourth section, the hybrid structure of simulation is proposed. In the fifth section, the procedures adopted in the preparation and neural representation of climatic data are described and implemented. In the last section, simulations with the hybrid structure proposed are presented. Finally, the conclusions and future works are presented.

2. Literature Review

The literature has proposed several thermal models for pool systems which take into consideration different losses, inclusive the human activity (Almanza & Lara, 1994; Croy & Peuser, 1994; Govaer & Zarmi, 1981; Haaf & Luboschik, 1994; Hahne & Kübler, 1944; Molineaux, Lachal, & Guisan, 1994a, Molineaux, Lachal, & Guisan, 1994b; Sartori, 2000; Smith, Löf, & Jones, 1994). The studies of Smith et al. (1994) detach that the main factor that affect the thermodynamic behavior of a pool is the energy loss. The authors highlight the evaporation as responsible for 56% of the losses, the radiation for 26% and the convection for 18%. In Sartori (2000), the energy losses were also analyzed. Therefore, the efforts were concentrated in the evaporation problem, once it is the predominant effect.

In Haaf and Luboschik (1994), the identification of a thermal model based in experimental data was described. During three years, the authors monitored several pools, collecting data for model validation. In Hahne and Kübler (1944), a model for simulation of heated pools, considering the wind velocity as catalyser of the process of losses by evaporation, was discussed. In Molineaux et al. (1994a, 1994b), a model of heated pool that uses as source of heating solar collectors was proposed.

Croy and Peuser (1994) studied the behavior of visitors to swimming pools conventionally heated and solely solar-heated. According to the authors, the number of people together in the pool as well as the pool temperature varies in accordance with the ambient temperature. From a case study, the authors observed that the number of visitors is not influenced by the artificial heating of the pool. Experience with other pools showed that conventional open air pools are generally also poorly visited in periods of bad weather, thus, the heating of pools does not appear to be justified. Notice that, the temperature of a solely solar-heated pool vary with the ambient temperature. Therefore, one of the factors responsible for the thermodynamics behavior of pools is a change in the volume of water of the pool, which can vary due to human activity, in other words, due to the withdrawal of water by body