ENERGY MODEL VALIDATION OF HEATED OUTDOOR SWIMMING POOLS IN COLD WEATHER

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ABSTRACT
Outdoor swimming pools are becoming commonly exploited even in wintertime as they represent a good attraction in the hotel industry to compete with geothermal pools available only in some countries. The present study proposes a numerical model for outdoor swimming pools based on the energy balance methodology. Conduction to the ground, convection and evaporation at the pool’s surface are taken into account in the formulation among with other heat loss sources and gains. The model is validated with experimental data from a pool exploited in a real hotel. The simulation shows that by adequately operating the pool with optimizing pool-cover time and backwash ratio, energy savings in exploitation can be achieved. Some modifications on the pool design are proposed to reduce energy consumption.

INTRODUCTION
Swimming in cool season is a real pleasant activity that many people cannot afford at home. For this reason, many entertaining businesses like hotels, companies in tourism puts many resources to build outside swimming pools and spas that can operate in wintertime. However, these types of equipment induce important energy consumption for water heating. For comfort reasons, water rated temperature should be higher than that in use in summer time. Thus, the need of energy is huge. In some part of the world, this energy is produced by a natural geothermal source, but in most cases, fossil or electrical energy sources are used. Designing pools should therefore include reducing energy consumption.

Therefore, specific research should be performed in order to evaluate the heating energy of the pools in Nordic climate and to assess different designs, which optimize heating needs.

Heat loss from an exposed water reservoir is composed of conduction through the ground, radiation with the sky, convection and evaporation to surrounding air. Many studies have proposed models to evaluate this heat transfer. For evaporation, early investigation of Carrier (1918) or Rohwer (1931) proposed equation to estimate evaporative rate. Other studies (Smith, et al., 1994, Rasmussen et al., 1995, Asdrubali, 2009) showed that evaporation heat transfer depends mainly on the wind speed and vapour pressure difference between surrounding air and water. Bowen (1946) studied the relation between evaporative and convective heat transfer. For heated swimming pools, there is some heat gained by the water other than the one from solar incident radiation. Ruiz et al (2010) developed a TRNSYS model of an outdoor swimming pool with neglected conduction through the ground as recommended by ASHRAE (2003). The results of their model could adequately be compared to the experimental ones. However, they applied the model only for the summer time. The number of swimmers of the pool is not taken in account. Another model for unoccupied outdoor swimming pool was elaborated by Almanza et al (1994). They use mathematical formulation of each heat transfer mod. The results could adequately correspond to those of the literature. However, the model was applied to simulate a swimming pool in Mexico where average winter temperature is not very low, as compared to Nordic climate.

The existing models of swimming pools are mostly developed for indoor utilization. Those for that could be applied on outdoor swimming pool are used to study pool in warmer time. Moreover, the effect of the number of swimmers, air bubbling jet, snow or rain, backwash and other phenomena are usually neglected. The aim of this study is to validate a model of an outdoor swimming pool with real data of a pool exploited in wintertime and to evaluate the energy saving of some specific design modifications.

SWIMMING POOLS DESCRIPTION
Pool instrumented for the model validation is an outdoor pool of a hotel in Mont Tremblant, Canada. This pool is a therapeutic bath with 19 air bubbling jets. The pool has a volume of 32m³ and a surface of 30m² dug directly inside the ground. Rated temperature for winter use is 36.7°C controlled by an electronic thermostat. Two electrical heaters of 30kW are used for water heating. There is no temperature reset. However, the pool is covered at night, from 10PM to 7AM, by a plastic paper of 0.3cm thickness and an estimated thermal conductivity of 0.2W/mK. Air bubbling jet in the therapeutic bath is generated by a 2.5HP blower with a nominal flow rate of
360 m³/hr. Each air injector has 5.1 cm of diameter. Air is blown from surrounding environment, i.e. at outside air temperature. Mean rate of energy consumed during the data acquisition period is 41.6 kW for the therapeutic bath.

The following data have been collected on the pool from 19 February to 24 March 2011:

- all heaters power;
- air blower power;
- pool’s number of swimmers;
- backwash and water draining.

Operation data are presented in Table 1.

**Table 1: Data from pool operation**

<table>
<thead>
<tr>
<th>Date</th>
<th>Backwash</th>
<th>Draining</th>
<th>Number of swimmers</th>
</tr>
</thead>
<tbody>
<tr>
<td>19-Feb</td>
<td>1</td>
<td>0</td>
<td>79</td>
</tr>
<tr>
<td>20-Feb</td>
<td>1</td>
<td>0</td>
<td>89</td>
</tr>
<tr>
<td>21-Feb</td>
<td>0</td>
<td>0</td>
<td>71</td>
</tr>
<tr>
<td>22-Feb</td>
<td>1</td>
<td>0</td>
<td>55</td>
</tr>
<tr>
<td>23-Feb</td>
<td>0</td>
<td>0</td>
<td>57</td>
</tr>
<tr>
<td>24-Feb</td>
<td>0</td>
<td>0</td>
<td>77</td>
</tr>
<tr>
<td>25-Feb</td>
<td>1</td>
<td>0</td>
<td>49</td>
</tr>
<tr>
<td>26-Feb</td>
<td>1</td>
<td>0</td>
<td>75</td>
</tr>
<tr>
<td>27-Feb</td>
<td>1</td>
<td>0</td>
<td>87</td>
</tr>
<tr>
<td>28-Feb</td>
<td>1</td>
<td>0</td>
<td>30</td>
</tr>
<tr>
<td>01-mar</td>
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<td>0</td>
<td>63</td>
</tr>
<tr>
<td>02-mar</td>
<td>1</td>
<td>0</td>
<td>40</td>
</tr>
<tr>
<td>03-mar</td>
<td>0</td>
<td>0</td>
<td>29</td>
</tr>
<tr>
<td>04-mar</td>
<td>1</td>
<td>0</td>
<td>32</td>
</tr>
<tr>
<td>05-mar</td>
<td>1</td>
<td>0</td>
<td>25</td>
</tr>
<tr>
<td>06-mar</td>
<td>0</td>
<td>0</td>
<td>26</td>
</tr>
<tr>
<td>07-mar</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>08-mar</td>
<td>1</td>
<td>0</td>
<td>35</td>
</tr>
<tr>
<td>09-mar</td>
<td>0</td>
<td>0</td>
<td>37</td>
</tr>
<tr>
<td>10-mar</td>
<td>0</td>
<td>0</td>
<td>25</td>
</tr>
<tr>
<td>11-mar</td>
<td>1</td>
<td>0</td>
<td>39</td>
</tr>
<tr>
<td>12-mar</td>
<td>0</td>
<td>0</td>
<td>75</td>
</tr>
<tr>
<td>13-mar</td>
<td>0</td>
<td>1</td>
<td>74</td>
</tr>
<tr>
<td>14-mar</td>
<td>0</td>
<td>0</td>
<td>99</td>
</tr>
<tr>
<td>15-mar</td>
<td>1</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>16-mar</td>
<td>2</td>
<td>0</td>
<td>90</td>
</tr>
<tr>
<td>17-mar</td>
<td>1</td>
<td>0</td>
<td>94</td>
</tr>
<tr>
<td>18-mar</td>
<td>1</td>
<td>0</td>
<td>72</td>
</tr>
<tr>
<td>19-mar</td>
<td>1</td>
<td>0</td>
<td>64</td>
</tr>
<tr>
<td>20-mar</td>
<td>1</td>
<td>0</td>
<td>35</td>
</tr>
<tr>
<td>21-mar</td>
<td>1</td>
<td>0</td>
<td>26</td>
</tr>
<tr>
<td>22-mar</td>
<td>0</td>
<td>0</td>
<td>32</td>
</tr>
<tr>
<td>23-mar</td>
<td>1</td>
<td>0</td>
<td>27</td>
</tr>
<tr>
<td>24-mar</td>
<td>0</td>
<td>0</td>
<td>24</td>
</tr>
</tbody>
</table>

Backwash is decided by the operator and occurs for about 30 minutes. The backwash ratio is the percentage of the pool volume with is replaced by fresh water from town water distribution during the backwash. In this case, 10% of pool’s water is replaced. Draining lasts for about one hour. Aqueduct water temperature is round about 8°C during the data acquisition period. Weather station is located in St-Jovite, 5 km far from the position of the swimming pool. The required data are:

- outside air temperature;
- outside air relative humidity;
- wind velocity;
- total horizontal radiation.

**SIMULATION MODEL OF SWIMMING POOL**

The model of a swimming pool is developed as a TRNSYS TYPE to take advantage of previously developed models in this program.

The energy balance in pool water is described by the following equation:

\[
\rho V C \frac{\partial T}{\partial t} = \sum q_{\text{gain}} - \sum q_{\text{loss}} \quad \text{Eq 1}
\]

Heat gained by the swimming pool water originates from heaters, bodies of swimmers and solar radiation. Moreover, heat is lost to the environment by conduction through the ground, convection and evaporation to the surrounding air, radiation with the sky. An amount of energy is consumed to heat snow or rain fallen in the pool and recharged water after backwash or draining.

The gain from the swimmers is evaluated using the following formulation:

\[
q_{\text{ac}} = N q_0 \quad \text{Eq 2}
\]

where \(q_0\) represent the rate of sensible heat gain from an occupant. This value is estimated in ISO7730 (1994) as 150 W for athletic activities.

Pool water collects a part of incident solar radiation. Energy is absorbed by the pool wall surface and transferred to water. The water directly absorbs another part of energy. The overall pool solar absorbance \(\gamma\) determines the heat gained as follows:

\[
q_s = A \gamma H \quad \text{Eq 3}
\]

ISOTC180 (1995) recommends to use 0.85 as overall pool solar absorbance.

The most important gain comes from the heaters. Its value is calculated with another TYPE in TRNSYS and considered as an input in the swimming pool model.

Overall heat gained by the pool water equals:

\[
\sum q_{\text{gain}} = q_h + q_s + q_{\text{ac}} \quad \text{Eq 4}
\]

Evaporation represents the most important part of the heat loss by the pool water.
Equation frequently used to describe evaporation of following type is:
\[ q_e = A(a + bu)(pV_{sat} - pV_a) \] Eq 5

Heated water evaporates to surrounding air resulting in a decrease of water volume in the pool. However, frequent backwash and draining of the pool replace lost water. Therefore, the model calculates only the energy consumption to heat the evaporated water. Water volume remains constant in the simulation.

To consider the pool’s number of swimmers, Mohamed Shah (2004) developed a model, which depends on the ratio of the number of swimmers over the pool surface.

Convection heat transfer is calculated based on the evaporation. Bowen’s (1926) equation for ratio of evaporative heat loss over convective heat loss is:
\[ \frac{q_e}{q_c} = \frac{C_v}{1000} \frac{(T_p - T_a)}{(pV_{sat} - pV_a)} P_a \] Eq 6

where \( C_v \) is a coefficient with a value between 0.6 and 0.66.

When the pool is covered, the convection heat transfer is composed of natural and forced convection. Forced convection heat transfer is evaluated using correlations proposed by Bejan (2003) for heat transfer on an isothermal flat plate with laminar or turbulent flow.

For \( Re > 5 \times 10^5 \):
\[ Nu_{d,Re} = 0.029 Re^{0.8} G \] Eq 7

where
\[ G = \frac{Pr}{(0.029/Re_d)^{1/3} \left( 0.5 Pr + 5 \ln (1 + 5 Pr) / 6 \right)^{1/3}} \]

For \( Re < 5 \times 10^5 \):
\[ Nu_{d,Re} = 0.332 Re^{1/2} Pr^{1/3} \] Eq 8

\( Re_d \) depends on the wind velocity. \( d \) is a fictive length of a square with a surface equal to that of the pool. This approximation allows considering the variation of wind direction on the pool surface.

The natural convection heat transfer is calculated using the correlation for isothermal horizontal surface facing upward (Bejan, 2003):

For \( Ra > 10^7 \):
\[ Nu_{d,Ra} = 0.54 Ra^{1/4} \] Eq 9

For \( Ra < 10^7 \):
\[ Nu_{d,Ra} = 0.15 Ra^{1/4} \] Eq 10

The overall Nusselt number, \( Nu_d \), results in summing the two calculated values. The convection heat transfer is calculated as follows:
\[ q_c = \frac{h_d U_{cv} A(T_p - T_a)}{h_d + U_{cv}} \] Eq 11

where
\[ h_d = \frac{Nu_d k}{d} \]

To evaluate the conduction heat loss through the ground, the following assumptions are made:

- soil temperature \( T_{cd} \) at 5m under the pool’s surface is considered constant and equals 8.6°C;
- ground thermal conductivity equals 2.3W/mK;
- \( A_g \) represents constant area of contact between water and the soil.

Equation describing the heat loss by conduction is formulated as follows:
\[ q_{cd} = U_{cd} A_g (T_p - T_{cd}) \] Eq 12

Radiative heat loss is calculated from the following expression:
\[ q_r = \varepsilon A (T_{cv}^4 - T_{sky}^4) \] Eq 13

where \( T_{sky} \) is the sky temperature, \( T_{cv} \) and \( \varepsilon \) represents the cover or water temperature and emissivity, respectively.

For each backwash, 10% of total water is renewed. In the case of draining, 100% of this volume is replaced. One hour is considered as the time that all this water is reheated to reach the rated temperature. Therefore, the rate of heat required to this operation is calculated as follows:
\[ q_b = \frac{\rho C V n_b P_b}{3600} (T_p - T_b) \] Eq 14

where \( n_b \) equals the number of daily backwash and 1 for draining and \( P_b \) is 0.1 for backwash and 1 for draining.

The energy to heat snow is also taken into account. The amount of snowfall is collected hourly in the weather station as a correspondent quantity of water. The following formulation calculates the rate of energy needed to heat this water:
\[ q_s = \rho V q w \] Eq 15

where \( qw \) equals 333.7kJ/kg and represents the latent heat of fusion for water.

Air injection in the pool for bubbling effect is a well-studied phenomenon. Ghazi (1991) has developed an experimental correlation between the Nusselt number based on heat transfer from air to water by direct contact and the Reynolds number depending on air speed and jet orifice diameter.
The overall heat lost is calculated as follows:

\[ \sum q_{\text{loss}} = \left[ q_e + q_r + q_{cd} + q_s + q_n + q_j \right] \text{.} \tag{16} \]

**TRNSYS ENTIRE SIMULATION MODEL**

Besides the TRNSYS TYPE developed for the swimming pool, some standard TRNSYS components are added to the whole system simulation. The weather data are introduced into the model by the means of an EPW file from the weather station. A differential controller controls the heaters. However, the hysteresis temperature difference is set at 1°C to reproduce an electronic thermostat.

**VALIDATION**

The purpose of the validation is to define the value of correlation coefficient for evaporation \((a, b)\) and the coefficient \(C_v\) for the ratio between the evaporative and the convective heat loss. This choice is made because evaporation and convection represent the most important part of the heat loss.

To validate the model, the power of heaters measured on the pool is compared to the simulation results. The measurements are registered at 15 minutes interval. However, different operations on the swimming pool such as backwash or draining are registered just as a value per day. The number of occupancy is also register per day. Therefore, an hourly comparison between the simulation and the measurements is not correct. Hence, the daily energy consumption of heaters is compared. A genetic algorithm is used for the optimization. The first 5 days of simulation are used as warm-up and not included in the optimisation. The objective function is to minimize the square of difference between the simulation results and the measurements. The constraints for parameters are as follows:

- \(a\) – from 0.01 to 0.1;
- \(b\) – from 0.01 to 0.1
- \(C_v\) – from 0.6 to 0.66

The constraints for \(a\) and \(b\) are chosen according to different set correlations found in the literature. The interval of \(C_v\) is given by Bowen (1926).

To assess the multi solution possibility, 10 simulations are executed. The results are presented in Table 2. Mean %, Max % and \(\Sigma(\%)^2\) represent the mean value of percentage difference of daily energy consumption, the maximum value over the simulation time and the sum of square of all values, respectively.

<table>
<thead>
<tr>
<th>a</th>
<th>b</th>
<th>Cv</th>
<th>Mean %</th>
<th>Max %</th>
<th>(\Sigma(%)^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.096</td>
<td>0.031</td>
<td>0.635</td>
<td>11.26</td>
<td>31.68</td>
<td>5484.4</td>
</tr>
<tr>
<td>0.100</td>
<td>0.027</td>
<td>0.634</td>
<td>11.27</td>
<td>32.66</td>
<td>5563.2</td>
</tr>
<tr>
<td>0.099</td>
<td>0.034</td>
<td>0.630</td>
<td>11.31</td>
<td>33.65</td>
<td>5621.5</td>
</tr>
<tr>
<td>0.097</td>
<td>0.034</td>
<td>0.630</td>
<td>11.23</td>
<td>31.68</td>
<td>5543.1</td>
</tr>
<tr>
<td>0.096</td>
<td>0.031</td>
<td>0.614</td>
<td>11.41</td>
<td>31.68</td>
<td>5551.3</td>
</tr>
<tr>
<td>0.099</td>
<td>0.031</td>
<td>0.645</td>
<td>11.03</td>
<td>31.68</td>
<td>5508.3</td>
</tr>
<tr>
<td>0.099</td>
<td>0.033</td>
<td>0.645</td>
<td>11.00</td>
<td>31.68</td>
<td>5479.9</td>
</tr>
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<td>0.099</td>
<td>0.029</td>
<td>0.650</td>
<td>11.07</td>
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</tr>
<tr>
<td>0.096</td>
<td>0.033</td>
<td>0.631</td>
<td>11.19</td>
<td>32.66</td>
<td>5544.2</td>
</tr>
</tbody>
</table>

It can be observed that the optimum parameters are calculated as the difference between the maximum and the minimum value of \(a\), \(b\) and \(C_v\) which are 4.3, 20.8 and 5.6%, respectively. It demonstrates a probable unicity of the optimum set of values and that the results of this simulation are close to this optimum set.

Retained set of parameters is as follows:

- \(a = 0.098571\)
- \(b = 0.032857\)
- \(C_v = 0.64476\)

The difference between the simulated daily energy consumption and the measured one is presented in Figure 1. However, the difference between the overall energy consumption over the 30 days of acquisition data and the simulation results is 1.5%.

With this set of parameters, convection and evaporation heat losses are about 75% of the overall heat loss. This result justifies the choice of \(a\), \(b\) and \(C_v\) as optimization parameters.
DISCUSSION AND RESULT ANALYSIS

The validated model is used to study the different design and operation modifications that could help reduce the energy usage of the swimming pool. In the operation behaviour, two modifications can be studied.

The effect of replacing water during backwash and draining is assessed. The operator of the pool renews about 10% of water at each backwash. This operation occurs at least once a day. The simulation shows that it represents about 9% of the energy generated by the heaters.

During the 30 days of study period, one draining was performed. The calculation shows that it is about 2.5% of the spent energy. It results that more than 10% of the energy is spent to renew the water in the pool and Figure 3 shows that it varies linearly with the backwash ratio. It is therefore important to develop the backwash and draining procedures that will optimize the backwash ratio according to the heat saving and the water cleaning.

The percentage difference of the total consumed energy is shown. The effect of this operation is important. Increasing the pool-covered time significantly reduces the need for heating. From 9 to 12 hours of covered time, the consumption of energy decreases slowly. However, for higher values of covered time, it decreases more rapidly. This is due to the passive solar heat effect gained on the cover. Of course, it is not possible to cover the pool for 23 hours per day. Nevertheless, this result shows that managing the pool requires to organise the operation so that it is covered for the maximum of time. Covering in daytime helps to benefit from the supplemental solar heat gain.

This idea was pushed to the maximum by simulating a two-reservoir pool instead of covering the pool during the night. The water is relocated in another reservoir with only heat loss by conduction to the ground. Even for this case, only 11% of the total energy is saved. However, if this construction is combined with an increase of the pool-cover time from 9 to 12 hours, the saving reaches up to 20%.

Another studied design modification is the origin of air for bubbling air jets. The air is drawn up from ambient environment. The effect of taking this air from a controlled zone area is studied. For this purpose, different inlet air temperatures are studied and presented in Table 4. It can be observed that if the air is taken from a normally conditioned space at 20 °C, savings are about 4%. It doubles if the air is taken from heated equipment like laundry.

Some modifications in the design of the swimming pool are studied to assess their impact on the heat consumption.

The cover used has an evaluated heat coefficient of 66W/m²K. The simulations are performed in order to study the impact of reducing this value on the heat consumption. As presented in Table 3, the impact of the cover heat coefficient is significant but not very high. An isolated cover gives less than 10% difference on the total heat consumption.
Table 3

<table>
<thead>
<tr>
<th>U (W/m²K)</th>
<th>Energy savings (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>66</td>
<td>0.00</td>
</tr>
<tr>
<td>30</td>
<td>1.27</td>
</tr>
<tr>
<td>15</td>
<td>2.75</td>
</tr>
<tr>
<td>7</td>
<td>4.83</td>
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<tr>
<td>3</td>
<td>6.77</td>
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<tr>
<td>1</td>
<td>8.41</td>
</tr>
<tr>
<td>0.1</td>
<td>9.94</td>
</tr>
</tbody>
</table>

Table 4

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Energy savings (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>3.24</td>
</tr>
<tr>
<td>20</td>
<td>3.93</td>
</tr>
<tr>
<td>25</td>
<td>5.08</td>
</tr>
<tr>
<td>30</td>
<td>6.47</td>
</tr>
<tr>
<td>35</td>
<td>8.78</td>
</tr>
</tbody>
</table>

The saved energy in this case should just be a waste from the other heated spaces; otherwise, this heat has to be produced. Higher rated temperature in this type of pool is due to the discomfort effect of cold air from jet bubbling. Heating this inlet air could imply reducing the rated temperature with more important saving of energy.

**CONCLUSION**

The present study has proposed a method to build a model for an outdoor swimming pool. This model is used to evaluate the energy saving obtained by different modifications on the pool operation and design.

A wise operation such as the optimization of the backwash ratio and draining, good utilization of the pool cover as long as possible can result in reducing the heat consumption. It was also found that using more isolate cover slightly decreases the heat consumption. By exploiting hot air from another building space as the inlet air for bubbling jet, savings could reach up to 10% of the heating energy.

**NOMENCLATURE**

- A: pool area, m²
- C: water specific heat, J/kgK
- h: convection coefficient, W/m²K
- H: total horizontal radiation, W/m²
- k: air conductivity, W/mK
- N: number of occupant
- Nu: Nusselt number
- Pa: atmospheric pressure, Pa
- Pr: Prandtl number
- pv: vapour pressure, Pa
- q: rate of heat transfer, W
- Ra: Rayleigh Number
- Re: Reynolds number
- u: wind velocity, m/s
- U: heat transfer coefficient, W/m²K
- V: Volume of water

**Greek**

- γ: overall pool solar absorbance
- ρ: water density
- σ: Stefan–Boltzmann constant

**Subscript**

- a: ambient
- b: backwash
- c: convection
- cd: conduction
- cv: cover
- e: evaporation
- h: heater
- n: snow
- oc: number of swimmers
- p: pool
- r: radiation
- s: solar
- sat: saturation

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