HVAC SYSTEM ENERGY OPTIMIZATION IN INDOOR SWIMMING POOLS

E. Ribeiro[1,4], H. M. Jorge[2,4] and D.A. Quintela[3,5]
[1] School of Technology and Management, Polytechnic Institute of Leiria, Leiria, Portugal
[2] Department of Electrical Engineering and Computers, University of Coimbra, Coimbra, Portugal
[3] Department of Mechanical Engineering, University of Coimbra, Coimbra, Portugal
[4] Institute for Systems and Computers Engineering of Coimbra (INESCC), Coimbra, Portugal
[5] Association for the Development of Industrial Aerodynamics (ADAI), Coimbra, Portugal

ABSTRACT

Buildings with indoor swimming pools are recognised as a very high energy consumers, and presents a grate potential for energy savings. The management of indoor ambient conditions must act upon the most sensible parameters that affect the energy consumption. The energy is spent in several ways:

- → evaporation heat loss from the pool;
- → room temperature very high, typically 28ºC to 30ºC, to maintain the comfort of users and reduce the risk of condensation;
- → high rates of ventilation required, usually 4 to 10 air changes per hour, necessary to remove the excess humidity due to evaporation and indoor air quality guarantee.

Control Strategies adapted to the reality of each building is an important way to reduce energy consumption. This paper presents control strategies, that can be implemented in the building automation system and the HVAC system of an existing indoor swimming pool complex, in order to minimise energy consumption.

In the present case study, an appropriate control strategy, joint with pool cover at night, is a measure for the rational use of energy, that can lead to the reduction of 90 tep/year, which represents about 30.000€ in reduction in energy cost.

INTRODUCTION

In Portugal, the number of sport complexes with Indoor Swimming Pools (ISP), with an intensive use, has increased significantly during the last decade. The growing of such facilities has shown the necessity to promote the evaluation and control of the indoor environment in order to minimise the energy consumption, according to the measures proposed by the European Union Directive 2006/32/EC (EC, 2006) and national law 79/2006 (RSECE, 2006). In these directive, all buildings must be classified from an energy point of view, using de Energy Efficiency Index (EEI), and have to implement measures leading to the Rational Use of Energy (RUE).

Based on a case study analysis of energy consumption during the year 2006, the EEI obtained is 95.7 kgep/m2.year (Rodrigues, 2007). In this case the reference value for EEI corresponds to 35 kgep/m^2.year (RSECE, 2006). It is obvious that something has to be done in order to bring the actual EEI close to de reference value, a task that normally requires building thermal simulation techniques and further investments in equipment and control systems. A first approach is to implement optimised control strategies in conjunction with RUE measures such as cogeneration, renewable energy systems, recovery of energy in the rejected air and pool cover, in particular.

Figure 1 illustrates the primary energy distribution for the present case study.

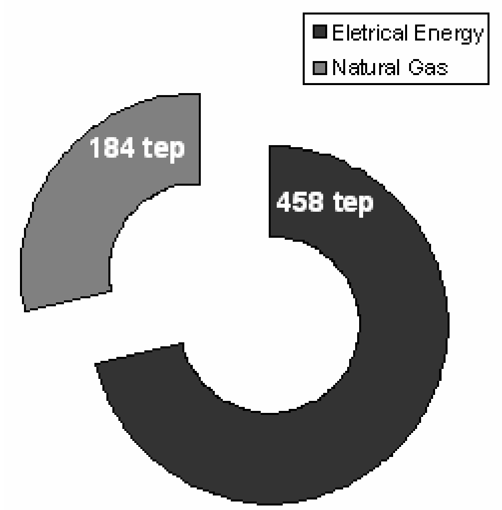

Figure 1 Primary energy distribution

We can identify five main energy topics in ISP that are responsible for 95% of the overall energy consumption:

- → HVAC system,
- → Pumping system,
- → Pool water treatment,
- → Water heating for baths,
- → Lighting.

In this work, we present an approach to control strategies of an HVAC system, coupled with a RUE measure that consists in covering the pool at night, which reduce significantly the energy consumption and the EEI.

PRINCIPLES, METHODS AN RESULTS

A. Case study

The building under analysis is a sports complex with 15.200 m^2, which incorporates an olympic pool of 50x25 m^2; a children pool of 25x12.5 m^2 and a multi-sports pavilion of 30x50 m^2.

In the olympic pool, the water temperature varies between 27ºC and 28ºC, and the room conditions have the following values: air temperature between 28ºC and 29ºC, relative humidity between 50% and 55%. In the children pool the water temperature varies between 29ºC and 30ºC, and the room conditions have the following values: air temperature between 30ºC and 31ºC, relative humidity between 60% and 65%.

An Air Handling Unit (AHU) ensures the HVAC system, at pool level, with dehumidifying and heating capacities.

A building automation system, using a network of direct digital controllers, controls all main process: HVAC system, pumping system, lighting and energy management.

B. Building Performance Simulation

Taking into account the complexity of the parameters involved in a feasibility study of measures to reduce the energy consumption of the building, the choice of energy simulation programs is actually the better way, either from both economical and time perspectives, to quantify the benefits that can be achieved by different control strategies (Pedrini et al., 2002.).

The energy simulation programs work with three main groups of variables, with a set of parameters that influence the building thermal performance (Clarke, 1997, 2001):

- → Climatic variables such as temperature, relative humidity, solar radiation, wind speed an direction, etc..
- → Design variables: internal geometry, thermo-physic properties, material properties, HVAC systems, passive and active solar systems, etc..
- → Use and occupancy variables: routines, internal thermal loads, equipment gains, etc..

There are several building energy simulation programs, used in research centres around the world, including in Portugal, such as ESP-r; ENERGYPLUS; TRNSYS and DOE, among others

ESP-r is an integrated modelling tool for the simulation of the thermal, visual and acoustic performance of buildings and the assessment of the energy use and gas emissions associated with the environmental control systems and constructional materials (ESRU,. 2002 and 2009). The ESP-r program was used throughout the present work.

The building of the present case study is represented within ESP-r according to the following figure (Lacerda, 2007).

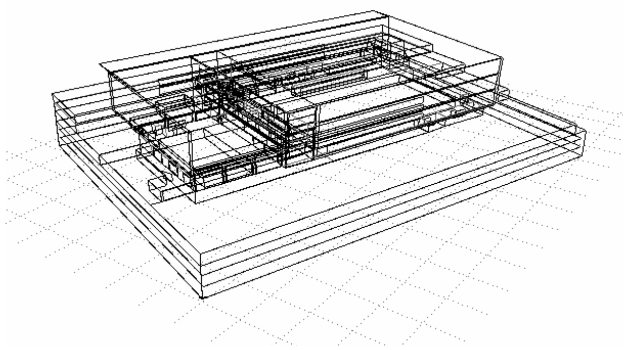

Figure 2 Model of the building case study

C. HVAC System Control Strategy

The use of AHU is necessary because the high evaporation in ISP complex, there are the largest source of energy losses, as can be observed in the Figure 3.

The environmental variables associated to AHU control, used in ESP-r Model, are in particular:

- → *Tap* - Pool water temperature (ºC),
- → *Tamb* - Ambient air temperature (ºC),
- → ϕ - Relative humidity (%),
- → *Qe* - Latent load associated with the evaporation from the pool (W).

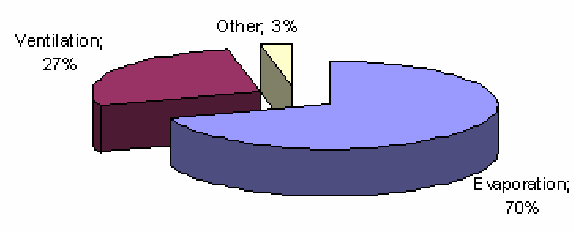

Figure 3 ISP energy balance (Department of Energy, 2009)

The latent load associated to pool evaporation is the must important variable of the process, therefore its estimation should be as rigorous as possible. The process of water evaporation occurs because of heat absorption by pool water, producing a reduction of the temperature of the water. Thus, if more vapour exists, more the water is cooled and more heating is required to maintain the comfort conditions.

The fundamental variable to quantify is the mass of evaporated water (m_e). Recent studies (Shah, 2003, 2004) identify an empirical formula that correlates the environmental variables and the influence of users. This influence is exerted at the free surface of the water, increasing the area of water in the pool by the movements of the users and the exposed wetted bodies.

$$m_e = A_{pool}\left[0{,}113-\frac{0{,}0000175\times A_{pool}}{N}+0{,}000059(P_s-P_a)\right] \quad (1)$$

Where:

- → A_{pool} - Pool area [m^2],
- → N – Number of users.
- → P_s - Saturation pressure of water vapour, at pool temperature [kPa],
- → P_a - Partial pressure of water vapour, at ambient temperature [kPa].

The correlation shall be valid only when:

$$\frac{A_{pool}}{N}<45 \quad (2)$$

Heat losses by water evaporation may be calculated knowing the mass of evaporated water (m_e) and the latent heat of vaporisation (Lv), at ambient temperature.

$$Q_e = m_e \times L_v \quad (3)$$

The latent heat of vaporisation (Lv) can be calculated, in the range of temperatures between 0 and 200ºC with an accuracy of 0.02%, by the empirical formula of *Regnault* (Donald & Gatley, 2004):

$$L_v = 705{,}62-0{,}81t \quad (4)$$

Thus, heat losses by water evaporation may be calculated according to the expression:

$$Q_e = A_{pool}\left[0{,}113-\frac{0{,}0000175\times A_{pool}}{N}+0{,}000059(P_s-P_a)\right]\times \times\left(705{,}62-0{,}81\times(T_{amb}-273{,}15)\right) \quad (5)$$

The saturation pressure of water vapour, at pool water temperature, is a function of absolute temperature and is given by (Ren, 2004) (Hyland et al., 1983):

$$P_s = e^{\left(\begin{array}{c}-5{,}8002206\times10^{3}\times T_{ap}{}^{-1}+\\ +1{,}3914993-\\ -4{,}8640239\times10^{-2}\times T_{ap}{}^{1}+\\ +4{,}1764768\times10^{-5}\times T_{ap}{}^{2}-\\ -1{,}4452093\times10^{-8}\times T_{ap}{}^{3}+\\ +6{,}5459673\ln(T_{ap})\end{array}\right)} \quad (6)$$

The partial pressure of water vapour at ambient temperature, is given by (Ren, 2004) (Hyland et al., 1983):

$$P_a = \frac{P_s|_{T_{amb}}\times\phi}{100} = \frac{\phi\times e^{\left(\begin{array}{l}-5{,}8002206\times10^{3}\times T_{amb}{}^{-1}+\\ +1{,}3914993-\\ -4{,}8640239\times10^{-2}\times T_{amb}{}^{1}+\\ +4{,}1764768\times10^{-5}\times T_{amb}{}^{2}-\\ -1{,}4452093\times10^{-8}\times T_{amb}{}^{3}+\\ +6{,}5459673\ln(T_{amb})\end{array}\right)}}{100} \quad (7)$$

In order to obtain reference values, to be compared later with the results of building energy simulations, a first run took place with the real environmental variables that were registered during 2006. The annual average values (daily means) are shown in Tables 1 and 2.

Table 1- Olympic pool: environmental variables

Variable	Value
Tap	27,5ºC
Tamb	28,3ºC
ϕ	52,3%
Qe	180.009W

Table 2- Children pool: environmental variables

Variable	Value
Tap	28,9ºC
Tamb	30,5ºC
ϕ	52,7%
Qe	45.168W

In these work we have considered an approach to control strategies based on the variation of the environmental variables at night (8PM to 8AM), which meets two distinct criteria:

- wet-bulb temperature,
- dew point temperature.

For the 1st criteria two simulations were made, taking into account different relative humidities, providing two control strategies (CS-1 and CS-3). In this case the environmental variables at night are:

Table 3- Olympic pool – 1st criteria

Variable \ CS	CS-1	CS-3
Tap	27,5ºC	27,5 ºC
Tamb	26,0 ºC	24,5 ºC
ϕ	65,0%	75,0%
Qe	171.765W	165.458W

Table 4- Children pool - 1 st criteria

Variable \ CS	CS-1	CS-3
Tap	28.9ºC	28.9 ºC
Tamb	28,0 ºC	26,5 ºC
ϕ	65,0%	75,0%
Qe	43.341W	41.660W

The same methodology was adopted for the 2nd criteria, resulting two control strategies (CS-2 and CS-4). In this case the environmental variables at night are:

Table 5- Olympic pool – 2nd criteria

Variable \ CS	CS-2	CS-4
Tap	27,5ºC	27,5 ºC
Tamb	25,0 ºC	22,5 ºC
ϕ	65,0%	75,0%
Qe	178.336W	179.632W

Table 6- TABLE I – Children pool - 2nd criteria

Variable \ CS	CS-2	CS-4
Tap	28.9ºC	28.9 ºC
Tamb	27,0 ºC	24,5 ºC
ϕ	65,0%	75,0%
Qe	45.152W	45.435W

D. Pool Cover simulation

The effects of a possible RUE measure, the use of pool covers for both pools, were analysed next. In this situation, two simulations took place considering two different control strategies:

- CS-5 – normal HVAC control at night.
- CS-6 – without HVAC control at night.

In this case the environmental variables at night are:

Table 7- Olympic pool with RUE measure

Variable \ CS	CS-5	CS-6
Tap	27,5ºC	27,5 ºC
Tamb	28,3 ºC	Free float
ϕ	52.3%	Free float
Qe	18.001W	18.001W

Table 8- Children pool with RUE measure

Variable \ CS	CS-5	CS-6
Tap	28.9ºC	28.9 ºC
Tamb	30,5 ºC	Free float
ϕ	52.7%	Free float
Qe	4.517W	4.517W

D. Results

Analysis of the results provided by the building thermal simulations highlights the three major losses in process:

- Building envelope losses to environment quantified by simulation, energy supplied by the HVAC system using thermal energy produced by natural gas boiler (Sensible Energy).
- Energy spent associated with the reduction of building latent load, quantified by simulation, which is to be ensured by the HVAC system using electricity (Latent Energy).
- Losses associated with energy heating water that is necessary to compensate evaporation, and calculated according to the amount of water evaporated in each simulation.

The total annual hourly sensible and latent energy is presente in the Figure 4 and Figure 5, respetely.

The quantification of the EEI and the energy used to heat restored water pool, for each control strategy, is presented in Table 9. The first line represents the real consumption during 2006.

Table 9- Consumption of Energy and EEI

	Electrical Energy (tep)	Natural Gas (tep)	EEI
Real	427,0	203,0	95,7
CS-1	420,3	195,5	93,5
CS-2	427,0	177,0	91,7
CS-3	414,2	174,6	89,4
CS-4	423,9	169,1	90,0
CS-5	392,5	202,2	90,3
CS-6	391,1	148,3	81,9

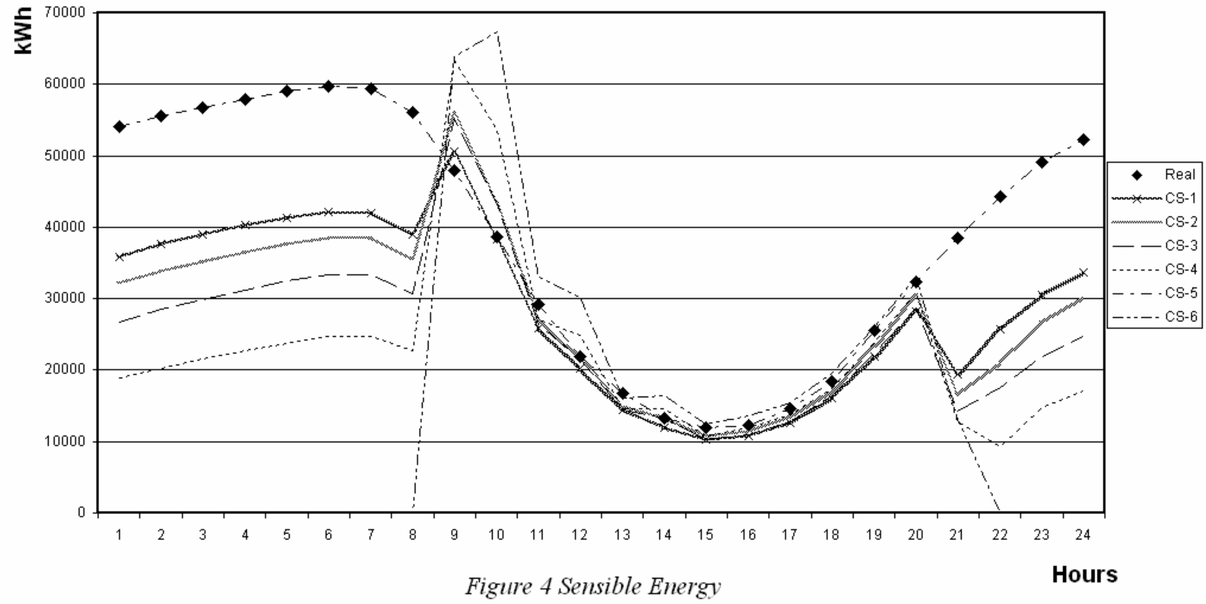

Figure 4 Sensible Energy

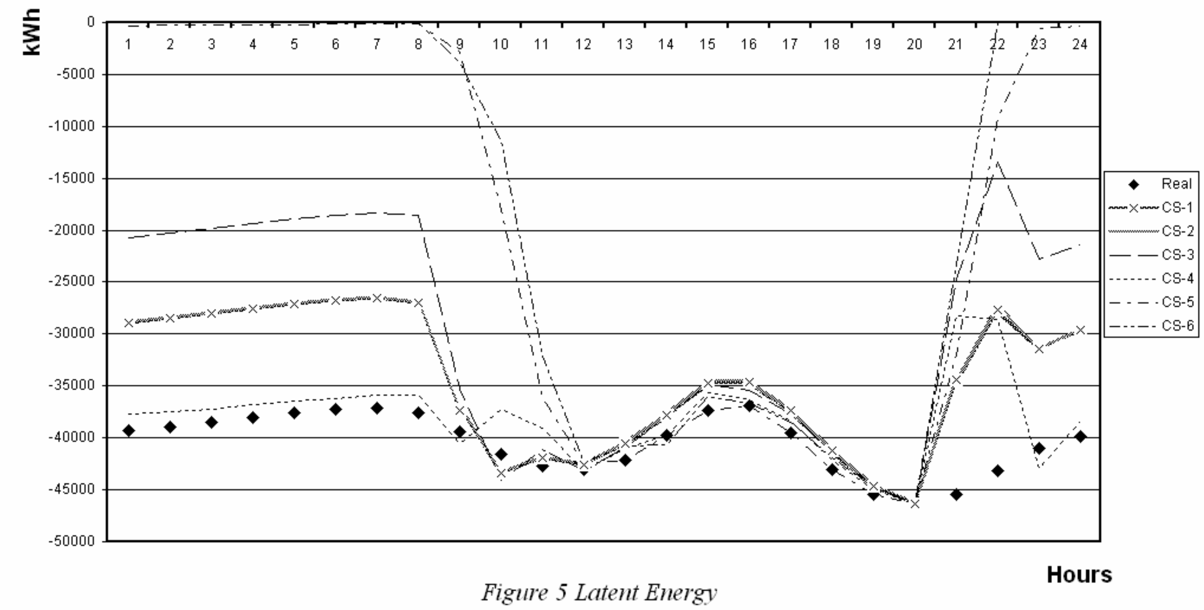

Figure 5 Latent Energy

CONCLUSION

The considerable reduction of sensible energy, obtained with control strategy CS-1, CS-2, CS-3 and CS-4, linked to the natural gas consumption, is due to lower room temperatures that reduce the building envelope losses to the environment.

Some reduction in latent energy, in control strategy CS-1, CS-2, CS-3 and CS-4, associated to the decrease of water evaporation, is caused by the increase of room relative humidity.

Significant reduction in latent energy, in control strategy CS-5, is to be related to the electrical energy consumption. This is a direct consequence of covering the pools and such measure of rational use of energy is seen to reduce significantly the water evaporation. In this case, the total reduction is 35,3tep that represents 5,6%.

Using the control strategy CS-6, in conjunction with pool cover at night, a reduction of 90,6 tep/year (14,4%) can be obtained, which represents 29.727€ in 2006 energy price (DGEG, 2010[A&B]) savings, with a four month of payback for pool cover.

Otherwise, the best control strategy with the minimum investment is the CS-3, with a reduction of 41,2 tep/year (6,5%), which represents 13.565€ in 2006 energy price (DGEG, 2010[A&B]) savings.

The authors believe that the present contribution underlines the importance of control strategies in the design of building automation and HVAC systems for energy savings in indoor swimming pools.

REFERENCES

Clarke, J.A. 1997. Environmental systems performance. PhD thesis, Universidad de Strathclyde, Glasgow, UK.

Clarke, J.A. 2001. Energy simulation in building design (2nd Edition). Butterworth-Heinemann. ISBN 0-750-65082-6. Oxford, UK, 2001.

DoE, 2009. Swimming Pool Cover. U.S.A.[http://www.energysavers.gov/your_home/water_heating/index.cfm/mytopic=13140, access in 26/04/2009].

DGEG, 2010A, Direcção Geral de Energia e Geologia. Preços Médios do Gás Natural no Sector Indústria. [http://www.dgge.pt?cr=8637, access in13/5/2010]

DGEG, 2010B, Direcção Geral de Energia e Geologia. Preços Médios de Energia Eléctrica no sector indústria. [http://www.dgge.pt?cr=8810, access in 13/5/2010]

Donald, P. Gatley, P.E. 2004. Psychrometric Chart Celebrates 100th Anniversary. ASHRAE Journal. [http://bookstore.ashrae.biz/journal/download.php?file=22915gatley.pdf, access in 21/4/2010]

EC, 2006. Directive 2006/32/EC on energy end-use efficiency and energy services, Directive 2006/32/EC of the European Parliament.

Energy efficiency in sports and recreation buildings: swimming pool covers; Case Study 76; Building Research Energy Conservation Support Unit; 2007.

ESRU, 2002. The ESP-r System for Building Energy Simulation: User Guide Version 10 Series. ESRU manual U02/1., University of Strathclyde, Glasgow, Scotland.

ESRU, 2009. *ESP-r Overview*. University of Strathclyde, Glasgow, Scotland. [http://www.esru.strath.ac.uk, access in 3/04/2009].

He-Sheng Ren, "Construction of a generalized psychrometric chart for different pressures", Journal of Mechanical Engineering Education, 2004.

Hyland, R.W. Wexler, J. 1983. Formulations for the thermodynamic properties of the saturated phases of H_2O from 173.15 K to 473.15 K., ASHRAE Transactions.

Lacerda, H. 2007. Previsão do Comportamento Térmico de um Complexo de Piscinas Interiores, Technical report.

RSECE, 2006. Ministry of Public Works, Transport and Communications. 2006. Sistemas Energéticos de Climatização em Edifícios (RSECE), Decreto-lei Nº 79/06.

Pedrini, F.S. Lamberts, R. 2002. A methodology for building energy modeling and calibration in warm climates. Building and Environment, Vol. 37, pp 903 – 912.

Ren, H.S. 2004. Construction of a generalized psychrometric chart for different pressures. Journal of Mechanical Engineering Education.

Rodrigues, P. 2007. Climatização de Recintos com Piscinas Interiores – Eficiência Energética", Technical report.

Shah, M.M. 2003. Prediction of evaporation from occupied indoor swimming pools. Energy and Buildings.

Shah, M.M. 2004. Calculating Evaporation From Indoor Water Pools. HPAC Engineering.