Energetic performance of gas and heat pump systems for swimming pool heating

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Abstract

The use of heating systems for swimming pools has suffered a fast increase in Brazil. The aim of this research is to investigate the energetic performance of two distinct kinds of swimming pool heating systems: gas-fired and electric heat pump. A practical instrumentation research was prepared and installed in two indoor swimming pools, placed in the same ambient. During a period of about three months, measures of air and water temperature, wind speed, relative humidity, water flow, gas and electric energy consumption were collected. Data was treated and analyzed and, as a result of this work, it was found that the average coefficient of performance - COP of the heat pumps studied is 4.0. For the natural gas-fired system, the global efficiency factor was found to be 76%. The efficiency of the heaters isolated was found to be 82%. This research showed that the COP of heat pump systems has strong correlation with the air temperature. The lower the air temperature, the lower the COP. Temperature has also strong influence on the consumption of energy. Some characteristics of the investigated swimming pools, as well as details of its operational procedures, have also been discussed.

Keywords

Swimming pool, water heating systems, energetic efficiency.

1. Introduction

In Brazil, swimming pool heating systems are increasingly being utilized not only in clubs and gyms, but also in houses and residential apartment condominiums. The energy demand for heating swimming pool water should be better understood, regardless of what source the energy may come from. It is an item that can be considered a competitive edge or even a decisive factor in choosing a property to live in. On the other hand, Sao Paulo City has relatively low temperatures, with a monthly average minimum temperature around 16º C (61ºF) from July to August and monthly maximum average temperature of 22.5ºC (73ºF) in February (OLIVEIRA ET AL. 2002). This restricts the periods when a swimming pool can be used. Pollution and the huge quantity of buildings, which block a great portion of solar radiation, are also factors indicating the need for a swimming pool water heating system, in view of the fact that, according to ASHRAE (1999a) apud Lund (2000), the ideal temperature for pool water for recreational use or swimming competitions should be between 24 to 29ºC (75 to 84ºF).

Some works about heat transfer mechanisms in swimming pools, energy conservation mechanisms and heating systems performance have been published worldwide. Dang (1986) carried out a parametric study of a swimming pool solar heating system. Although the final purpose of the study had been to determine and describe the swimming pool heating system through solar energy, the means used for this was the calculation of the energy balance of the swimming pool. The evaporation mechanism as a means of heat transfer was pointed out in that work. Heat loss in swimming pool water was simulated under two different conditions: during 8 hours in the swimming pool without any device for blocking water evaporation and during a period of 16 hours in which the pool remained covered with a thermal cover. The values found for the drop in temperature in both situations were respectively: 3.8ºC and 1.9ºC (39ºF and 35ºF).

Smith, Luf and Jones (1994) did some field research for measuring and analyzing heat transfer rates, especially those due to evaporation and radiation in an unused open-air swimming pool that was kept at a temperature of 29ºC (84ºF) by means of a natural gas heating system. The tests, ranging from 1.1 hour to 16.2 hours, took into account measures of water temperature, ambient air temperature, relative air humidity, air speed, solar radiation incidence and water evaporation rate. All tests were run at night and results showed that, as for form, the equations of evaporation rate in function of the difference of water vapor pressure and especially of wind velocity correspond to the equations of ASHRAE (1991), and vary only as for their coefficients. Such variations resulted in evaporation rates 28% lower for a wind velocity near zero and 16% higher for wind velocities in the order of 2.2 m/s.

Szeicz and McMonagle (1983) carried out computer simulations to evaluate the effect of some heat preserving mechanisms in a swimming pool. They carried out simulations for sixteen different combinations of the following mechanisms: shelters, sun-shading, use of windbreaks (barriers to wind on the surface of a swimming pool), thermal covers and thermal solar collectors. The combinations were compared with one another and with a control model. Excluded from the comparisons were thermal solar collectors, that showed the best performances, the thermal cover showed to be very efficient in reducing heat loss. Windbreaks showed to be efficient, but the further (in multiples of their heights) they are from the swimming pool, the worse is their performance.

Votsis et al (1989) investigated the effect of freezing and defrosting on the coil of an “air-water” type heat pump evaporator. Under certain climate conditions, the coil of the evaporator freezes, which reduces the performance coefficient (COP) of the equipment. The heat pump studied had a defrosting system. When the ambient temperature is too low, air condenses on the surface of the evaporator, and freezing occurs. The defrosting system, when necessary, takes hot water that comes from the outlet of the equipment and returns it to the inlet of the evaporator to defrost it. The conditions of freezing and defrosting can impact the system COP in a negative way.

Lam and Chan (2001) evaluated the theoretic thermal performance and life cycle of electric heat pumps for swimming pools in hotels located in subtropical climate areas.
An energy balance for a swimming pool in a Hong Kong hotel was performed and the use of a heat pump was evaluated vis-à-vis the utilization of electric boilers or gas boilers (conventional and condensing type). The application of performance coefficients from 2.5 to 4.5 range for the heat pump was studied. The life cycle was ten years. For an average COP of 3.5, the savings achieved during the life cycle would be 75%, when compared to that of an electric boiler heating system. In a second study, involving instruments in the field for a heat pump installed in a hotel in Hong Kong, Lam and Chan (2003) found that the average value for the COP was between 1.5 and 2.4, the average being near 2. Although the average COP found in the experiments had been lower than the hypothetical values in the theoretical study, the use of the heat pump proved to be a good investment in terms of operational efficiency, by showing a return on investment in a little more than two years.

In line with the issue of environmental sustainability and by seeking energy efficiency, this work aims at providing users, owners and operators of swimming pools with information for operating heating systems in a sensible way. The research encompasses, in addition to scientific literature revision, placing instruments at two pools in the same swimming school facility that uses two of the most utilized types of heating systems: indirect type natural gas heating system and electric heat pump. The data collected in those swimming facilities were analyzed and results referring to energy and operational performance and are presented and compared.

The research aims at understanding the influence of climate and microclimate on the pool and especially on the operation of the heating system involved in terms of energy and operational performance. The relationship between energy and climate variables is presented for the two types of heating systems that were chosen in the beginning. This data will allow the owners/ operators of swimming pools all over Brazil to decide on which is the best way to operate the system throughout the year, so as to reduce energy consumption without impairing the wellbeing of users and the continuous operation of the pool.

2. Objectives

The specific objectives of this work are:

- ✓ To design, prepare and install systems for collecting data at swimming schools in order to allow the continuous storage of climate and microclimate variables required for understanding the heat transfer mechanisms in heated pools, and also to determine the energy performance parameters for each one of the systems;
- ✓ To design, prepare and install all the instruments to measure and store the relevant variables of interest according to the type of pool heating system used.
- ✓ For one of the swimming schools, to determine the energy parameters for the two pools it has (electric heat pump system and indirect type gas heating system), such as the efficiency (gas system) and the performance coefficient (heat pump) by seeking:

- To correlate the energy performance of these heating systems with the climate variables;
- To relate energy consumption required for heating the pools with microclimate variables of their rooms;
- To determine the average temperature for maintenance of pool water and its variation during the analysis period;
- To determine the requirement of energy needed for maintaining the water average temperature of these two pools;
- To determine the operation time of the heating systems in relation to the analysis total time.

3. Research Methodology

The instruments installed in the room of the pools aimed at obtaining data that would allow the correlations between climate and microclimate and energy performance of the pool heating systems studied. Data on energy consumption, both raw and specific, and the suitability of the systems for their respective applications also accounted for the instruments selected. During the research the following variables were monitored:

1. Variables influencing the energy balance of the pool:

a. Roof temperature

Essential for determining thermal exchanges between the pool surface and roof by radiation, the measurement at the roof were carried out with the use of T-type thermocouples (copper constantan junction).

b. Swimming pool water reference temperature

The most stable spot for measuring pool water is at its bottom, and it can be measured by inserting the temperature sensor into the suction pipeline of its heating system ; T-type thermocouples were used.

c. Air temperature in the pool room

As it is important to determine heat transfer by convection as well as correlations between energy consumption and microclimate, this variable was monitored by means of a temperature sensor of the PT-100 type . One instrument with two built-in sensors can transmit both the air temperature and relative ambient air humidity.

d. Air speed in the pool room

This variable, since it is the third influence factor on heat transfer by convection, was monitored with “unidirectional” air speed transmitters, as illustrated in Figure 1.

Figure 1 - Omnidirectional wind speed transmitter by "heated mass"

e. Relative air humidity in the pool room

The relative air humidity in the pool room is related to the heat loss mechanism due to water evaporation on the surface of the pool. In this research, the relative humidity of internal air is monitored by means of the double function transmitters.

2. Variables that influence the determination of the quantity of heat added to the pool water by time unit:

a. Water flow through the heating system

In this research, volumetric type flow meters installed in the pool return water ("pool return jet") in order to measure the water quantity drained away through the pool heating system are being used.

b. Temperature of water upstream through the heating system inlet and water downstream through its outlet.

The temperature measurements at these two points allow calculation of temperature gain provided by heating system possible. This difference, multiplied by water outflow, is the quantity of heat transmitted to the pool water.

3. Variables for determining energy consumption, collected energy and efficiency and performance coefficients of heating systems:

a. Measurement of natural gas flow

The gas diaphragm meters are equipped with a magnetic pulse emitter whose operational principle is identical to those emitters for hydrometers.

b. Measurement of LPG (Liquefied Petroleum Gas) flow.

Due to a higher pressure (2 kgf/cm^2), a gas turbine meter was used. This meter has a built-in electronic plate that converts turbine rotations into a signal.

c. Measurement of electrical energy consumption

Electrical energy consumption of heat pumps was monitored by electrical energy meters, as shown in Figure 2.

Figure 2 - Electrical energy meters used

By monitoring the isolated electrical energy consumption of the heat pump in addition to monitoring the water input and output into the system and the water flow circulating through the system per time unit, it was possible to determine the coefficient of performance (COP).

4. Variables for correlating climate and energy performance of heating systems
a. External ambient temperature

A double signal transmitter (temperature and relative humidity), which was identical to the one described above including the measurement range (0 to 60ºC – 32 to 140ºF) was used.

b. Relative external air humidity

The monitoring of the relative humidity of the external environment is carried out with the same sensor mentioned in the previous item.

c. External air speed

The monitoring of the air speed in the external environment, at a place near the heat pumps, was carried out by means of a shell type air speed transmitter.

The data collecting system:

The solution adopted for collecting data was the utilization of Programmable Logic Computers (PLC), as shown in Figure 3. This type of system is based in modules that fit into the matrix system (CPU). These modules can be added in any quantity, as the user may need them.

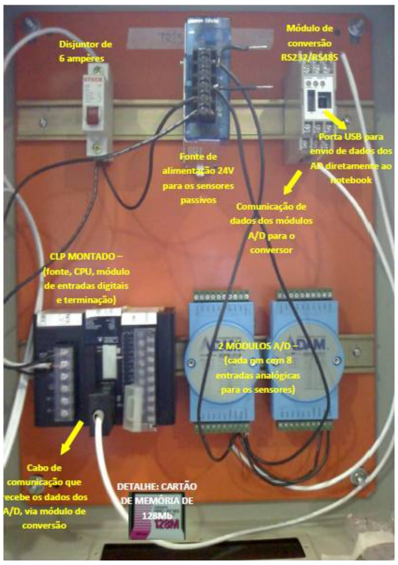

Figure 3 - Data acquisition system assembled and its respective components

The storage of data collect by PLCs is done on a memory card, which can at any time be downloaded to a notebook by means of a PCMCIA card, for instance. A drawback for this kind of system is that most PLCs have very few analogue inputs. This problem was solved with the utilization of converters. These converters receive analogue signals from the sensors (all with the exception of the instruments for measuring water flow, electrical energy and natural gas, since these emit a signal in the form of a pulse) and convert them into digital signals, which can be read and recorded by the PLCs. The communication between converters modules and CLPs is made through an RS232-RS485 protocol converter.

4. Results

Spot “A” was chosen for the research because, in addition to having two swimming pools in a same room under the same microclimate conditions, it has different heating systems for each of the pools. In one of the pools, the water is heated by means of an indirect type natural gas heating system, while in the other the water is heated by means of electric heat pumps. These are the two types of swimming pool heating systems most used in Sao Paulo.

The period of measurement of 85 consecutive days analyzed in this work began on 5 July 2009 and ended on 28 September 2009. During this time interval, the data were collected at each minute, but some analysis required data grouping and extracting average values from each data group. This procedure, besides minimizing likely discrepancies, allows to obtain neater results.

For grouping data and extracting averages from the respective intervals, the MatLab software was utilized. Table 1 shows the conditions of monitored variables (averages and limits) during the data collecting period.

Variable	Indoor Air Temperature	Indoor Air Relative	Indoor Air Velocity	Outdoor Air Temperature	Outdoor Air Relative	Rooftop Temperature
Minimum	14.2°C	19.0%	0.00m/s	7.5°C	14.1%	10.4°C
Average	21.5°C	77.8%	0.07m/s	17.4°C	78.7%	23.8°C
Maximum	35.2°C	100%	1.25m/s	34.1°C	100%	67.6°C

Table 1 - Climate conditions in the room during the research

The “wind speed” variable, which was monitored all the time both internally and externally to the room, was not correlated to any performance parameters because, besides showing average values that were extremely low (and for that reason not relevant in heat transfer processes), did not show great variations in its values. Without variations in the values of that variable, it is impossible to extract correlations by using such parameter.

1. Temperature ranges for maintenance of swimming pool water

a. Semi olympic sized pool heated by natural gas

During the total period analyzed, the pool water temperature presents the behavior showed in Table 2.

Miminum Water Temperature	**24.5°C**
Average Water Temperature	**31.5°C**
Maximum Water Temperature	**37.3°C**
Variation Above Average Value	**5.9°C**
Highest Water Temperature Variation	**12.8°C**

Table 2 - Temperature ranges of swimming pool heated by means of natural gas

b. Hydrogymnastics/water aerobics pool heated by means of electric heat pumps

During the total period analyzed, the pool water temperature is showed in Table 3.

Miminum Water Temperature	**18.6°C**
Average Water Temperature	**32.2°C**
Maximum Water Temperature	**36.2°C**
Variation Above Average Value	**4.0°C**
Highest Water Temperature Variation	**17.6°C**

Table 3 - Temperature ranges of swimming pool heated by means of electric heat pumps

Both swimming pools at spot “A” showed a particularity as to the control of the heating systems. There is neither automation nor temperature control with exception of the totally manual control carried out by the maintenance personnel. The swimming pool operators can rely only on a thermometer to measure the pool temperature and make decisions on whether they should turn on or off the heating systems. It is obvious by interpreting the data showed above that, even if there were an ideal temperature set for the pool water, the variation around this value would be huge for both pools.

The semi olympic sized swimming pool, which is heated through a natural gas heating system, should be kept between 27.0ºC and 28.0ºC (81ºF and 82ºF) according to the maintenance personnel, and nevertheless, the average temperature is kept between 3.5ºC and 4.5º C (38ºF and 40ºF) hotter than the ideal temperature. For the hydrogymnastics pool, heated by electric heat pumps, the ideal temperature informed is 30.0ºC (86ºF) but the water temperature is kept 2.2ºC (36º F) above that value.

2. Energy stored in pool water

A heated swimming pool can be considered as an open thermal reservoir. The heat stored in the water, artificially produced by means of heating systems, is rapidly transferred to ambient air and therefore, to raise the water temperature to a level which exceeds the required level to provide comfort and wellbeing to users is to waste energy.

Table 4 shows the quantity of heat wasted due to not caring enough to keep water within a correct temperature range. Besides the energy required achieving a hotter temperature, it is necessary to keep it at this level. The greater the difference between water surface temperature and the temperature of the air immediately above such surface, the higher the water evaporation rate and consequently, the heat transfer rate from the water to the room rises substantially, adding more energy consumption for recovering (or keeping) the water temperature.

The installation of a simple automated system for controlling the water temperature and triggering the heating systems, made up by a temperature sensor, a temperature control and a relay command for the pumps of the filtration and heating systems would be much more rational and efficient, in addition to saving manpower needed for maintenance personnel, and probably reducing system maintenance costs in a substantial way, since both heat pumps and natural gas heating systems were not designed for operating lengthy periods without breaks.

Pool	Water Volume (m^3)	Average Water Temperature (°C)	Exceeding Useful Energy (kcal)	Energy Source	Heating Value or Energetic Conversion Factor	System Average Efficiency or System Average Coefficient of Performance	Exceeding Energy or Exceeding Gas Volume Consumption
Semi-Olympic	490.0	31.5	2,209,900	Natural Gas	8,600 kcal/m^3	0.82	313.4m^3 (NG)
Hidrogymnastic	117.6	32.2	256,368	Electric Energy	860 kcal/kWh	4.01	74.3kWh (Electric Energy)

Table 4 - Excess energy used to raise water temperature above ideal average temperature

3. Pool heating systems operating time

A well sized pool heating system should meet the desired temperature requirement even during the worse possible climate conditions in the place where it is installed. At the same time, the heating system should have enough thermal power to dispense with the need for operating for lengthy periods.

a. Swimming pool heated by means of natural gas

Through analyzing data for natural gas consumption recorded by the pulse emitter connected to the gas meter, it was possible to determine the quantity of hours, during the analysis phase, in which the heating system was required, and also to determine the percentage of operation hours in relation to total time, as showed in Figure 4. Thus, it is possible to verify whether the heating system evaluated is well sized or not.

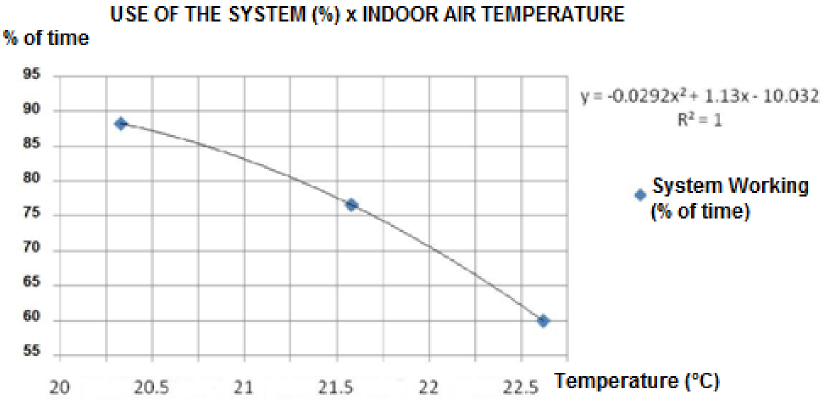

Figure 4 - Relationship between internal temperature and percentage of operation time of heating system – natural gas heating system.

b. Hydrogymnastics/water aerobics pool heated by means of electric heat pumps

In a similar way for electrical energy, as showed in Table 5, it was possible to determine the quantity of hours which the heating system was required, and also to determine the percentage of operation hours in relation to total time. Thus, it is possible to verify whether the heating system evaluated is well sized or not.

HEAT PUMP SYSTEM - HYDROGIMNASTIC SWIMMING POOL

	HEAT PUMP 1		HEAT PUMP 2		HEAT PUMP 1 AND 2	
	Duration (h)	% of total time	Duration (h)	% of total time	Duration (h)	% of total time
System On	81,773	67.6	66,855	55.3	35,201	29.0
System Off	39,104	32.4	54,022	44.7	85,676	71.0
Total	120,877		120,877		120,877	

Table 5 - Operation time of heat pumps

By analyzing the table above, it can be observed that, even if it is not as overcharged as the heating system for the semi olympic sized pool, the heat pumps that made up the heating system for the hydrogymnastics pool also operate during most of the time. The operation times of the equipment items in relation to the idle time intervals showed to be far higher the ideal one. There is a mitigating factor in this case: The operation of the heat pumps is very often in alternation, that is, the two pumps operate separately most of the time, and alternate operation times. Only in 29% of the time both of them operate simultaneously.

4. Useful energy, used energy and efficiency of the pool heating systems

a. Swimming pool heated by means of natural gas

Useful energy in the form of heat can be seen as the transfer rate of the heat effectively available to replace pool heat losses to other media. The replacement of heat losses consistently generates consumption of energy. Depending on the type of heating system, this energy spent can be higher or lower than the available useful energy. The required factor for determining whether energy consumption will be higher or lower than the available useful energy is the efficiency of the heating system. For heating systems by means of fossil fuel combustion, as it is the case with natural gas, it is difficult to be in the situation of consumption lower than the required demand. The next table shows the results for total and average useful energy available for keeping the temperature of the semi olympic sized pool, as well as the results for energy consumption.

Energy Used for Heat Losses Recovery	Energy Consumption for Heat Losses Recovery	Global Efficiency (% over HHV of NG)	NG Consumption
Average	Average	Average	Average
63.8kWh	83.8kWh	76.1	7.6m^3/h
Total	Total		Total
128,495kWh	168,951kWh		15,457m^3

Table 6 - Total and average useful energy, global efficiency and energy consumption - semi olympic sized swimming pool heated by means of natural gas

The efficiency calculated is not only the efficiency of the combustion of the natural gas, but also the global efficiency in which the heat losses from the heaters to the hydraulic connections with the pool return fitting for hot water. By considering a typical combustion efficiency for tankless water heaters, like those that make up the heating system in question as being equal to 0.82 (82%), one will have:

$$\eta_{\text{global}} = \eta_{\text{heating system}} \text{ x } \eta_{\text{piping}}$$

$$0.761 = 0.820 \text{ x } \eta_{\text{piping}}$$

$$\text{then, } \eta_{\text{piping}} = 0.928.$$

Therefore it is concluded that thermal losses along the distance covered from the hot water outlet of the heaters to the point where the thermocouples are inserted (junction with the pool return fitting pipeline of the pool filter system) are 7.2% in average.

The next table shows the distribution of useful energy available for the months under analysis (July, August and September). The data were adjusted or indicating months with exactly thirty days. This adjustment is necessary for preventing distortions in the interpretation, since the days of effective reading varied during the period.

	July	August	September
Indoor Air Temperature (°C)	20.3	21.6	22.6
Total Useful Energy (kWh)	51,980	44,927	40,822
Total Energy Consumption After Correction (kWh)	67,852	60,869	52,147

Table 7 - Variation of useful energy and energy consumption in function of monthly average internal temperature – semi olympic sized pool heated by natural gas

The correlations confirm that, the lower the air temperature in the pool room, the higher the heat transfer and, consequently, the higher the energy consumption for keeping the water temperature.

b. Hydrogymnastics/water aerobics pool heated by means of electric heat pumps

For the heat pumps, differently from what happens to the gas heaters, in terms of average values, energy consumption is lower than the useful energy made available in the form of heat for heating water. This occurs because, due to the equipment, the heat pump uses the thermal energy available in the air of the room where it is installed, in the form of latent and sensitive heat. As the energy used in this transport (energy necessary for making the heat pump compressor and fan operate) is usually lower than the thermal energy transported and there is a positive balance, the efficiency of the system is higher than the unit and consumption is lower than the useful energy made available. The results for consumption, demand and Coefficient of Performance – COP of the heating system by means of heat pumps for the hydrogymnastics pool are presented in Table 8.

Consumed Energy	COP	Useful Energy
Average	Average	Average
6.3kWh	4.0	25.3kWh
Total		Total
12,654kWh		51,029kWh

Table 8 - Energy available and used up (total and average) and average performance coefficient - COP obtained for the electric heat pumps for the hydrogymnastics pool.

The table above shows the average Coefficient of Performance - COP, of the two heat pumps during the period under analysis. It is important to point out that the COP is a variable value and extremely sensitive to changes in temperature and relative air humidity in the place where the pump is installed. By analyzing the collected data, it is possible to verify the significant COP variations during the day, and therefore, the average value showed here is valid for the period in question. To consider it an average value valid for the entire year or valid for different climate conditions can be a mistaken approach.

Figure 5 shows the evolution of COP in function of the variation of average temperature in the room where the heat pumps are installed and also in function of the relative air humidity in that same room. Observe that the trend line showed in the chart indicates that the COP rises as the local average temperature rises.

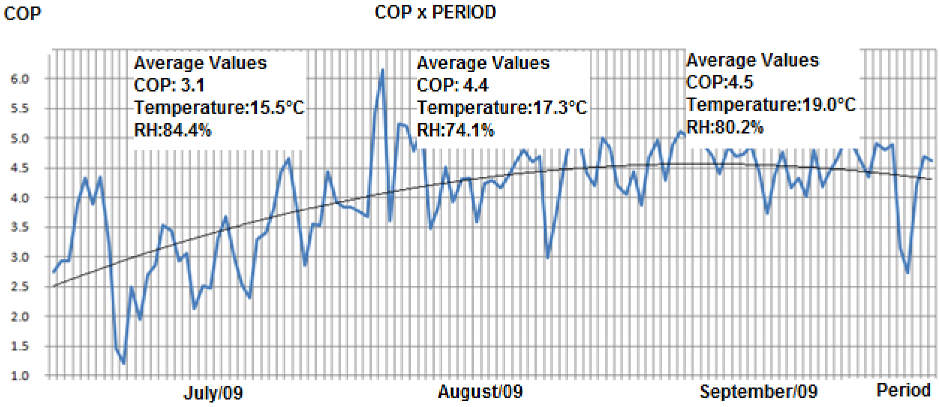

Figure 5 - COP variation during the period under analysis in function of the variation of temperature and relative air humidity.

The charts below are correlations between COP and ambient air temperature where the heat pumps are installed. Such correlations were extracted in short periods of one and two days in the month of September. During those periods, the ambient air temperature varied between 12ºC and 15.5ºC (59ºF and 60ºF) in one day time. For the period of two days, the temperature varied between 12ºC and 17.5ºC (54ºF and 64ºF). In both cases, a strong linear correlation was observed. For periods with little temperature variation, the correlation between the temperature and COP was weaker, as showed in Figure 6 and 7.

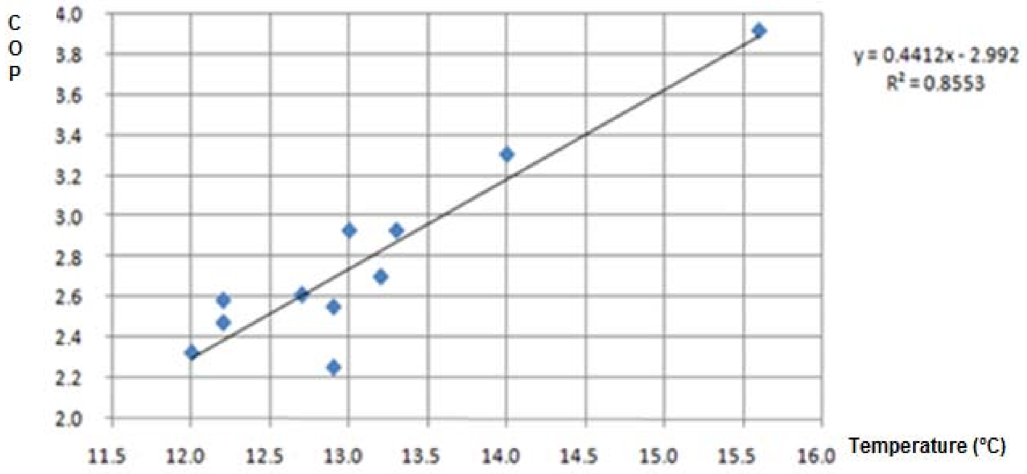

Figure 6 - Correlation between COP and air temperature for the period of one day.

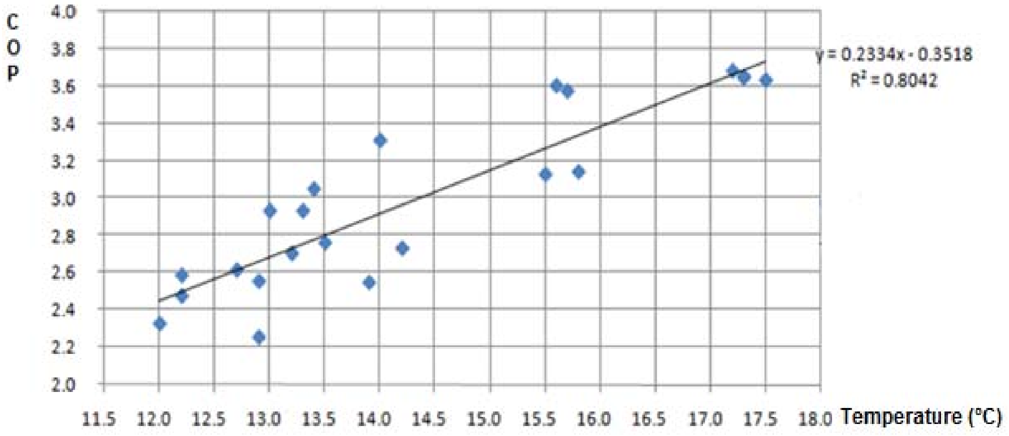

Figure 7 - Correlation between COP and air temperature for the period of two consecutive days.

Indicators of useful energy and energy used on comparable bases

With the aim of comparing the average energy consumption and demand for keeping the average temperature of the swimming pools, it was necessary to use indicators of the same basis. Table 9 shows the indicators of demand and consumption of each pool in terms of water volume (m^3 or cu. mt.) and in terms of surface area of the pools (m^2 or sq. mt.).

	Useful Energy Indicators		**Consumption Indicators**	
	per unity of water surface	per unity of water volume	per unity of water surface	per unity of water volume
	Wh/m²	Wh/m³	Wh/m²	Wh/m³
Pool				
Semi-Olympic	182	130	239	171
Hydrogimnastic	258	215	64	53

Table 9 - Indicators of useful energy and consumption energy per area and volume units – Comparative chart for the two pools.

By comparing the indicators of useful energy per area unit and volume unit it can be seen that the semi olympic sized pool shows a better performance than the hydrogymnastics pool. The hydrogymnastics pool demands 42% more heat by area unit. However, the indicators above mentioned did not take into account the average temperature of the water.

Table 10 shows a correlation of these indicators according to the average temperature of the water for each pool. Thus, the consumption and demand values are shown in Wh per area (or volume) unit per Celsius degree.

Indicators Corrected by Average Water Temperature

			Useful Energy Indicators		Consumption Indicators	
	Average Water Temperature	Surface/Volume Rate	per unity of water surface	per unity of water volume	per unity of water surface	per unity of water volume
	(°C)	(1/m)	(Wh/m².°C)	(Wh/m³.°C)	(Wh/m².°C)	(Wh/m³.°C)
Pool						
Semi-Olympic	31.5	0.71	5.8	4.1	7.6	5.4
Hydrogimnastic	32.2	0.83	8.0	6.7	2.0	1.7

Table 10 - Indicators of useful energy and consumption energy per area and volume unit, per Celsius degree – Comparative chart for the two pools.

After this correlation by average temperature, the hydrogymnastics pool now demands 39% more heat per area unit than the semi olympic sized pool, which represents a drop of 7%. Considering that both pools are in the same room and under the same conditions of air temperature, relative air humidity and air speed and considering that both pools show similar degrees of use intensity, this remaining difference between energy demand from one and the other pool must be accounted for by a relationship between the surface area and water volume of the pool (values shown in the table above). It is well known that most portion of heat transfer that occurs in a heated pool occurs through its surface.

In this specific case, it can be seen a difference or 17% in the relationship between the area and volume, which is the difference seen when the relationships between the hydrogymnastics pool and the semi olympic sized pool are compared. There had been a demand rise per area unit, adjusted by temperature, in the order of 39%. The relationship of consumption increase is 2.32 or 232%. In short, for the same surface area, the deeper is the pool, the lower its specific heat demand, the other parameters being kept constant. As for the consumption indicators, the hydrogymnastics pool showed more favorable values. This is due to the adequate efficiency of the heat pump, which showed an average COP of 4.0 for the period under study.

5. Final considerations

The analysis of the results that were obtained brought to light several aspects that are intrinsic to the equipment features, to the design, installation, and operation of the systems. It has been shown that the energy used up for heating the two pools that were analyzed could be saved with the introduction of well-defined operating practices to be followed and with the installation of low complexity automated systems.

The water temperature of the two pools is poorly controlled in the two cases and varies hugely around their average value. For that reason, the consumption for maintaining the pool temperature stable rises to unnecessary levels.

Other neglected aspect thereof is the sizing of the heating systems that were studied. In both cases, the nominal power installed showed to be insufficient to meet the demand for replacing heat losses of the pools. This entails in a great increase in the operation time of the systems and consequently, an increase of the costs for maintaining the equipment components and also a greater vulnerability of the heating process, once the wear and tear of components occurs in an accelerated way, since such pieces are not usually designed for continuous operation.

It was seen in all cases under analysis a great concern on the part of the swimming schools to prevent air renewal in the room of the pools. This concern aims at reducing the heat transfer from the room of the pool to the outside, which would entail a consumption increase in order to heat the pool. This concern proved to be coherent, since, as showed in the results of this work, the decrease of the temperature in the room of the pool can cause a consumption increase.

The result of such action is an uncomfortable room for humans. The relative air humidity indexes for the place that was studied were around 80 %. In some cases they reached 100%. The room temperature exceeded 36ºC (97ºF) during some days. As an aggravating factor, the air speed in side the pool room is very low, its average being 0.07 m/s. These data show that the concern with comfort and especially with the health of the users comes second. If the improvement of the air quality were achieved, this would certainly lead to an increase in the rate of heat transfer from the pool room to the outside, but however, it would not lead to a consumption increase if actions to improve the efficiency of the heating systems were concurrently taken.

The monitoring of the semi olympic sized pool heated by means of natural gas showed some worrisome aspects. The first of them relates to the heat losses in the pipe from the heating system outlet to the interconnection of same with the water circulation system of the pool water, in the order of 7%. This loss could be minimized if, at the time of the design, the optimization of the positioning of components would have been considered, so as to shorten the distance to be traversed by hot water in the pipes. As a palliative solution, the pipes could be coated with a thermal insulating material. Another aspect is the material of the pipes that carry hot water from the heating system to the interconnection with the water circulation system. All pipes were in PVC, a polymeric material that is not fitted for carrying hot water. It was observed that in some moments the water in the interior of the pipes exceeded 60ºC (140ºF), a temperature far higher than the temperature recommended by manufacturers. Such situation could have been inferred even without the actual measurement or even without witnessing the operation of the heating system , since that pipeline was much curved.

As for the efficiency of the heating systems themselves, and excluding from the analysis the losses inherent to the water driving, this work confirms the performance of the natural gas heating system is in accordance with the manufacturers' information. The system efficiency, obtained by means of comparing the data of natural gas consumption measured to the thermal energy balance actually provided to the pool water, generated a result of 83%, very close to the nominal value of the apparatus, which was 82%.

In the case of the heating system by electric heat pumps that heats the hydrogymnastics pool, the COP found, obtained through the measurement of the thermal energy balance actually provided to the pool water, with the values of the electrical energy used showed an average result of 4.0, which represents a good performance of the system. Nevertheless the value of the COP that Brazilian consumers usually have access is taken from laboratory tests run under specific conditions of temperature, both of the water and the air, and also of the relative air humidity, which does not portrait the average value during an significant period.

It was possible to ascertain the correlation between the temperature of the external air and the COP of the heat pump. The higher the temperature, the better is the system efficiency. This result can serve as a basis for configuring hybrid heating systems, made up of heat pump and another type of supporting heating system. This would make possible to operate a heat pump when the COP is high. The supporting heating system would be set in motion when situations unfavorable to that type of heating occur, and the general efficiency of the pool heating system would improve.

In Europe and in the USA, it is a usual practice of heat pump manufacturers to perform long-duration tests to obtain average data on the equipment efficiency. Such tests generate a season average coefficient for the product performance. This coefficient is called HSPF (heating season performance factor) and it is simply a COP that takes into account average conditions during a season operation. This factor makes it much easier for the consumer to choose the best equipment available and should be adopted in Brazil.

Finally, this research made it possible to corroborate aspects related to energy consumption for heating water that are not connected to the heating system itself, but to the building features of swimming pools. As for the relationship between the pool surface area and its volume, the rates of heat transfer that occur on the surface are greater and therefore, higher is the energy consumption needed for keeping the pool heated at a certain temperature.

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7. Presentation of Author

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