USE OF AIR CONDITIONING HEAT REJECTION FOR SWIMMING POOL HEATING

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ABSTRACT

A significant fraction of the heating needs of a residential swimming pool and the cooling needs of a residence can be met by an air conditioning system that rejects heat to the pool instead of the environment. This study shows that significant pool heating energy and air conditioning electrical energy can be saved throughout the U.S.

1. BACKGROUND

More than six million American families own a swimming pool. Consequently, reducing the energy demand for pool heating and air conditioning helps save money and natural resources.

Residential swimming pools are common in suburban America and pool heaters are often needed to maintain comfortable pool temperatures during the summer and to extend the period of use from early spring to late fall. Swimming pool heaters commonly use natural gas or propane as fuel. The heating needs of an outdoor pool can result in significant operating expense and unnecessary use of natural resources.

Central air conditioning systems are common especially in those houses with residential swimming pools. Air conditioners are electrically driven, and the energy removed from the cooled space plus the electrical energy to the compressor are rejected to the ambient through air-cooled condensers. The average American household uses a significant amount of electricity for air conditioning (12 percent of total consumption according to the Energy Information Administration (1997)). The objective of this study is to explore and evaluate different methods of combining air conditioning and pool heating to reduce the energy requirements and electrical demand of both.

To investigate the performance of a combined swimming pool and air conditioner shown in Figure 1, a computer simulation has been implemented. TRNSYS (Klein (1996)) was employed to simulate the required components, where each component (building, air conditioner, swimming pool) is based on a physical model that describes its behavior. The benefits of such a system will be discussed. It will be shown that the swimming pool air conditioner (SPAC) lowers the operation cost and reduces the energy consumption for most locations in the United States.

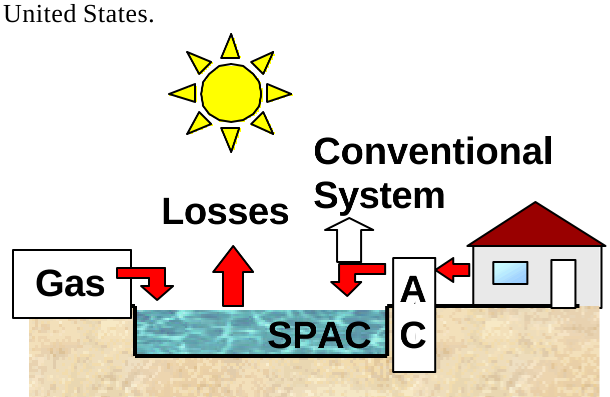

Fig 1: The swimming pool air conditioner (SPAC).

2. SYSTEM COMPONENTS

2.1 The Swimming pool

To develop a reliable model for swimming pool heat losses, four different computer programs were compared

(Wei, Sigworth et al. (1979), Beckman, Klein et al. (1977), Gunn, Jones et al.(1992) and Auer (1996)). The emphasis of the comparison is on evaporation models since evaporation accounts for a large percentage of the heat loss. All of these programs are based on measurements made on pools, lakes or ponds. In each case the measured results were used to find model parameters so that the model and measurements agree. In spite of this experimental verification, the programs predict somewhat different evaporative losses.

It was found that since the overall losses are relatively equal and the correlations behave similarly there is no advantage of choosing one correlation over the other. The TYPE 144 developed by the TRANSSOLAR Company has been used to model the swimming pool because it was already available as a TRNSYS subroutine.

2.2 The Residence

The TRNSYS package includes a subroutine that simulates a multizone building. For the purpose of this study a simple one-zone building with attic has been created. The living zone of the building has a total area of 250 m^2, a volume of 900 m^3 and a capacitance of 1080 kJ/K. The attic is a tilted roof with a volume of 450 m^3 and a capacitance of 540 kJ/K. The building has only one main zone. Solar gain is possible through the walls, the roof and windows that are integrated in the walls. Internal gains due to people inside the building were not included.

2.3 The Air Conditioner

In order to obtain detailed information on the air conditioning system performance as a function of environmental impacts, a model of a vapor compression air conditioner was implemented using EES (Engineering Equation Solver). The standard thermodynamic approach of a vapor compression cycle was used where the pressure drop in the evaporator and the condenser were neglected and the isentropic compressor efficiency was assumed to be constant. The evaporator and the condenser heat exchangers were modeled using the effectiveness-NTU method (Incropera and DeWitt (1985)). To achieve results that reflect the real behavior of a conventional residential air conditioner the EES simulation was calibrated using manufacturer performance data.

A major problem was how to make a fair comparison between a conventional air-cooled air conditioner and a water-cooled air conditioner. Manufacturers data are available for residential air conditioners, but such information is not available for a swimming pool air conditioner. The terminal temperature difference (TTD) was used as a parameter for the different systems. The TTD is the temperature difference between the condenser cooling fluid outlet temperature and the condensation temperature of the refrigerant. Values were based on experience with air conditioner design and were taken to be 10 °C for air and 5.5 °C for water.

The differences in the terminal temperature differences for water and air is based on their properties and different mass flow rates through the heat exchanger. Naturally, water performs better than air in a heat exchanger. Thus, by changing the working fluid of the condenser the terminal temperature difference changes. It is also necessary to include the effect of the mass flow rate. The TTD for water of 5.5 °C is consistent with a water flow rate of 0.035 kg/s per kW of refrigeration effect. Accordingly, a 10 kW air conditioner would have a water flow rate of 0.35 kg/s and a TTD of 5.5 °C. In order to investigate the sensitivity of a change in the TTD the TRNSYS model was run for a range of terminal temperature differences. It was found that the savings for the proposed approach of 5.5 °C for water and 10 °C for air would be about $36 of air conditioner operation cost. Assuming an uncertainty of ±10 % in the TTD, the amount of saved money differs by about ± $5, which is about 14 % of the original savings. The temperature approach was used to run calculations for a range of condenser cooling fluid inlet temperatures for both, water and air.

2.4 The Swimming Pool Cover

A swimming pool cover is the best mechanism to prevent heat losses from an outdoor swimming pool. A cover that is placed on the water surface minimizes the evaporation heat loss and can also reduce convection, and thermal radiation heat loss. In some climates the swimming pool cover alone can provide a comfortable swimming pool temperature. In warm regions a swimming pool with a cover can exceed the comfort temperature. In order to maintain a comfortable swimming pool temperature, an automatic swimming pool cover is used that is controlled by the pool temperature. The cover automatically opens whenever the swimming pool gets too hot and allows heat dissipation from the pool to the environment. The pool owner can achieve the same effect by manually uncovering the pool if the water is above a personal comfort temperature.

For the purpose of this study a bubble pool cover was chosen. A transparent plastic bubble cover, 1 cm thick, is composed of a layer of plastic “floating” on a number of small bubbles formed by a second layer of plastic. The cover allows direct absorption of sunlight by pool water. The air spaces between the top layer of plastic and the water provide insulation value (R=0.2 m^2/W-K). The plastic allows for a relatively high radiation heat loss (emittance = 0.6).

2.5 Controls

A comfortable swimming pool temperature of 27°C (80°F) has been assumed. Correspondence with swimming pool manufacturers verified a temperature between 25 °C and 29°C as desirable. The ASHRAE Applications Handbook also recommends a swimming pool temperature of 27°C (ASHRAE (1999))

The swimming pool behavior for different cover control strategies has been investigated for four cities in the U.S. Seattle, WA, Madison WI, New York, NY and Austin, TX have been chosen to represent various climates. The three different pool cover control strategies investigated are:

1. The pool remains uncovered the entire season
2. The pool remains uncovered between 11 am and 2 pm.
3. The pool remains uncovered whenever the swimming pool temperature is above 26°C and follows a daily schedule if the temperature is below the set temperature.

3. RESULTS

Figure 2 shows the pool temperatures for an unheated and uncovered pool in four different locations. The water surface is completely exposed to the ambient conditions and therefore is very sensitive to changes during the day. It can be seen that without any protection against environmental influences, a comfortable temperature cannot be reached in New York, Madison and Seattle. Only in Austin and for a short season between June and September is the swimming pool water above the desired temperature.

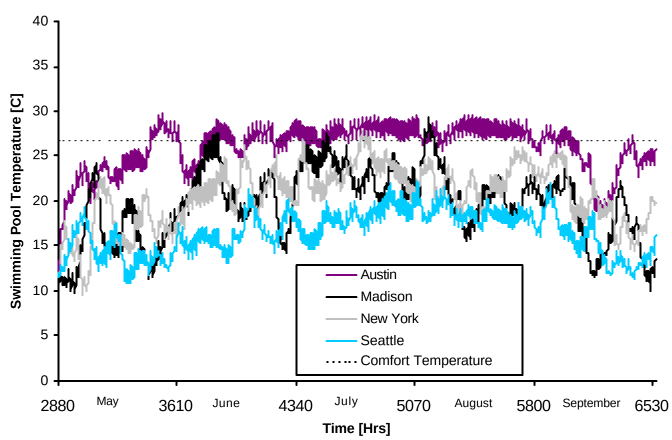

Fig 2: Swimming pool temperatures for an uncovered and unheated pool for different locations

Adding a swimming pool cover changes the situation significantly. If a swimming pool cover remains on the pool for the entire season except during a daily swimming time between 11 am and 2 pm, the changes in the pool temperature over a day are significantly smaller than without a pool cover since the heat losses are reduced. The temperature of the covered pool is on average about 4°C higher than the uncovered pool. In Austin, Texas the swimming pool temperature exceeds the desired temperature for much of the summer while in Madison and New York it is heated to an acceptable temperature. The installation of a pool cover in Seattle raises the temperature, but the pool temperature remains below 25°C.

In the next scenario the pool cover strategy remained the same but the residential air conditioner rejected heat into the pool. In Austin, where the cooling demand is high, the swimming pool temperature almost reaches 40°C, which is a temperature that is definitely too high for recreational swimming. New York and Madison provide an agreeable temperature for part of season, but approach 33°C more than once. Due to the small air conditioning demand in Seattle the pool heating effect is small and the pool is below 27°C for almost the entire season.

The advanced pool cover control strategy in which the pool remains uncovered if the temperature exceeds 26°C was evaluated. The extreme pool temperatures for Austin are reduced to a maximum of 30°C with this strategy. The pool temperatures for Madison and New York are maintained near the desired temperature. Since the control strategy only affects high pool temperatures the results for Seattle are not affected. In this case a swimming pool gas heater is needed.

A summary of average and maximum covered swimming pool temperatures is provided in Table 1. Without a cover the average swimming pool temperature is about 4°C lower. Combining a pool cover with the swimming pool air conditioner increases the temperature about 4°C. To avoid overheating, the automatic pool cover controller adjusts the pool temperature to a lower temperature level.

3. ECONOMIC ANALYSIS AND SYSTEM CONTROL STRATEGIES

To compare the operation costs for the conventional air conditioning and gas pool heating system with the combined house cooling and pool heating system on a fair basis the following economic scenarios are used. The separate air conditioning and gas pool heating is referred to as conventional system, while the combined swimming pool heater and air conditioner will be called the swimming pool air conditioner (SPAC). For swimming pool temperatures less than 25°C a gas pool heater adds heat to the pool. The gas heater maintains this temperature for both system configurations

If the swimming pool temperature exceeds 26°C the automatic swimming pool cover controller opens the pool and regulates the temperature by evaporation. The building temperature is controlled during the entire season so that heat is removed by the air conditioner whenever the building temperature exceeds 25°C. One possible arrangement of the system components modeled in the SPAC simulation program is shown in Figure 1 where the air conditioner is in water-cooling mode and the gas furnace joins to maintain the desired swimming pool temperature.

Based on these control mechanisms, simulations of the SPAC and conventional systems were run in ten locations in the United States. The ten locations were examined for pool behavior and heating requirements to observe the impact on the economic analysis and to narrow down the regions where the SPAC system performs best.

For each location the monthly energy requirement was calculated for a conventional air conditioner with a gas pool heater and for a swimming pool air conditioner with a gas pool heater. The simulation was started in the beginning of May and continued until the beginning of October. For this period the swimming pool temperature was maintained to be at least 25°C using the gas pool heater when necessary. For some locations the pool exceeds the desired temperature resulting from solar gains and heat removed from the building that cannot be controlled by the cover controller. Table 1 shows that the maximum pool temperature stays below 32°C, even for warm climates like Miami or Austin.

The table also shows the component operation cost for cooling and heating for both, the conventional and the SPAC system. Figure 3 shows this result for each system and location in the form of a bar graph. The cities are ordered by decreasing cooling demand. The left bar represents the conventional system, where the air conditioning operation cost is added to the seasonal pool heating cost. The right bar shows the operating cost for the SPAC system and, if additional pool heating is necessary, the cost for natural gas.

In Phoenix, for example, gas heating is not needed for either the conventional or SPAC system to maintain a comfortable swimming pool temperature. But, due to the better performance of a water-cooled air conditioner the operation cost is lower. By comparing the swimming pool temperatures for both systems, Table 1 shows that there is no major change in swimming comfort due to the heat rejection to the pool. The maximum temperature increases only about 1.5°C, while the average only changes about 1°C.

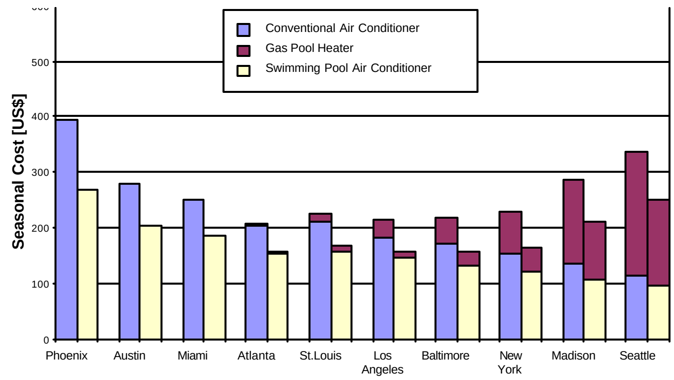

Fig 3: Economic analysis for locations in different climates in the United States. For each City the left bar shows the conventional house cooling and heating, while the right bar includes the swimming pool air conditioner plus additional pool heating cost.

With decreasing ambient temperatures, the cooling demand for a building decreases. Accordingly, the rejected heat to the swimming pool is less and pool heating becomes more important. Also, due to the lower ambient temperatures in cooler climates the general need for gas pool heating increases. Thus, the electricity cost decreases while the cost for natural gas increases.

Based on the natural gas consumption two city groups can be identified. The first group includes cities where gas pool heating is not necessary at all. Phoenix, Austin, Miami and Atlanta can be counted to this group. The second group consists of cities that need gas pool heating for both system configurations to maintain the desired swimming pool temperature as seen in New York, Seattle, Madison, St. Louis and Baltimore. A few locations cannot be assigned easily to one of the groups. Los Angeles, for example, has almost no heating demand for the swimming pool air conditioner and could be counted to the second group.

Compared to the conventional system, using the swimming pool air conditioner can reduce seasonal costs. Because of the better air conditioner performance, the SPAC system saves electricity. The higher the expenses for the conventional air conditioner, the higher the seasonal savings. Because the SPAC rejects the heat to the pool that is usually released to the ambient, the cost for heating is reduced.

In addition to the swimming pool investigated above, the impact of varying pool sizes was examined. Starting with the base case pool size of 55 m^2 a smaller swimming pool (27.5 m^2) and a larger pool (110 m^2) were investigated. Since the building and the air conditioning system remained the same, the amount of rejected heat was constant for the three cases. Independent of the pool sizes the pool conditions can be adjusted without supplemental heat from a gas pool heater in Phoenix, Austin, Miami and Atlanta. For locations that require pool heating to maintain the swimming pool at the comfortable swimming pool temperature of 27 °C the natural gas consumption increases for increasing pool area. There is basically no effect of swimming pool size on the results.

4. SPAC EQUIPMENT COST

Further investigations have been carried out to estimate the amount of money that is available to install a swimming pool air conditioner. The fact that SPAC is more efficient than a conventional air conditioner provides the possibility for the manufacturer to add options. A reasonable estimate of the additional product cost is reached when the life-cycle cost of the SPAC is the same as the conventional system. Duffie and Beckman (1991) provide a method to calculate the life cycle cost for a system. The life cycle cost (LCC) is the sum of all the costs associated with an energy delivery system over its lifetime or over a selected period of analysis, in today's dollars, and takes into account the time value of money. Life cycle savings is defined as the difference between the life cycle costs of a conventional air conditioner and pool heating system and the life cycle cost for the swimming pool air conditioner system. Duffie and Beckman (1991) have shown how all economic parameters can be cast in only two parameters, P_1 and P_2. Thus, the life cycle cost for the conventional system and the SPAC can be written as:

$$LCC_{Conv} = P_1\left(C_{e,conv} + C_{g,comv}\right) + P_2 \cdot C_{eq,conv} \qquad 1$$

$$LCC_{SPAC} = P_1\left(C_{e,SPAC} + C_{g,SPAC}\right) + P_2 \cdot C_{eq,SPAC} \qquad 2$$

where C_e is the electricity cost for the first year of analysis, C_g the natural gas cost for the first year of the analysis and C_{eq} the equipment cost of the system.

The difference between Eqn. 1 and 2 is the life cycle savings of the SPAC system. For a break-even calculation the life cycle savings are zero.

$$LCS = P_1\left(\Delta C_e + \Delta C_g\right) - P_2 \cdot \Delta C_{eq} = 0 \qquad 3$$

Since the savings ΔC_e and ΔC_g are known, Eqn. 3 can be solved for the difference in equipment cost ΔC_{eq}.

$$\Delta C_{eq} = \frac{P_1}{P_2}\left(\Delta C_e + \Delta C_g\right) \qquad 4$$

This difference in the equipment cost is the maximum amount of money that can be charged for a swimming pool air conditioner that has the same life cycle cost as a conventional air conditioner and pool heating system.

Because the detailed system component cost and various economic parameters, especially for the swimming pool air conditioner, are not available, an approximate value for the ratio of P_1/P_2 can be obtained by the following assumptions: If the inflation rate of fuel (electricity and gas) is of the order of the general inflation rate, then P_1 is of the order of the period of the economic analysis. P_2 is unity if the system is paid for in cash. Therefore, the ratio of P_1/P_2 equals the period of the economic analysis. For the present work, a period of ten years has been chosen. Figure 4 shows the result of this approach. The allowable costs are between about $600 and $1000 for most locations, with higher values in the very hot climates of Austin and Phoenix. A minimum is found for Atlanta.

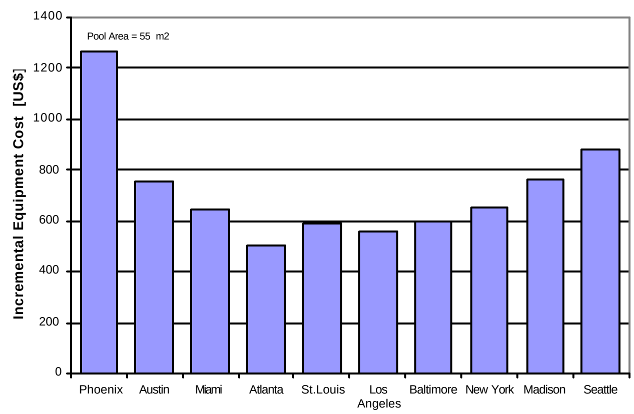

Fig 4: Incremental equipment cost for a SPAC system compared to a conventional system because of better performance. Time period: May 1st to October 1st.

An important aspect for power plant companies is the power demand for air conditioners. Since air conditioning consumes power mostly during the daytime where the energy demand is high, a reduction would be beneficial to the power company. The air-cooled air-conditioner power demand is the same at all locations at about 6 kW. The SPAC system energy demand is about 5 kW, which results in a demand saving of 1 kW compared to conventional air conditioning systems. With the swimming pool air conditioner the electricity demand can be reduce by about 20%.

5. CONCLUSIONS

Water-cooled air conditioners that reject heat to a swimming pool are more efficient than conventional air-cooled air conditioners. In warm climates where swimming pool heating is not necessary at all, the improved performance of a water-cooled air conditioner reduces the operation cost. Even though in most locations in the United States additional pool heating is necessary, the SPAC system still performs better than conventional methods by rejecting heat to the pool.

Compared to a conventional system, using the swimming pool air conditioner can save on seasonal expenses. Because of the better performance, the SPAC saves electricity. The seasonal electricity savings vary for different climates but are between $40 and $80 for most locations. Because the SPAC rejects the heat to the pool that is usually released to the ambient, the cost for swimming pool heating is reduced. The customer can save about $40 on natural gas by using the SPAC system.

The allowable incremental equipment costs for a swimming pool heater system compared to a conventional system configuration are between about $600 and $1000 for most locations, with higher values in the very hot climates of Austin and Phoenix. The SPAC system energy demand is about 5 kW, which results in a demand saving of 1 kW compared to conventional air conditioning systems.

6. REFERENCES

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Table 1 Temperatures and Operation Cost for the examined systems. GPH is a Gas Pool Heater, AC is a Conventional Air Conditioner and SPAC is a Swimming Pool Air Conditioner.

City		**Conventional System**				**SPAC System**				**Seasonal Savings [$]**
		Average Pool Temp [C]	Max Pool Temp [C]	Cost [$]		Average Pool Temp [C]	Max Pool Temp [C]	Cost [$]		(May 1st - October 1st)
				AC	GPH			SPAC	GPH	
Atlanta	GA	26.2	29.9	202	3	26.6	31.3	154	1	50
Austin	TX	27.2	32.0	279	0	27.8	33.6	203	0	76
Baltimore	MD	25.8	29.2	171	46	26.2	30.2	133	24	60
Los Angeles	CA	25.7	27.6	182	31	26.0	28.4	147	11	56
Madison	WI	25.4	28.1	136	150	25.7	29.0	105	105	77
Miami	FL	27.3	31.3	251	0	28.0	32.7	186	0	65
New York	NY	25.6	28.6	154	75	25.9	29.6	120	44	65
Phoenix	AZ	26.7	30.5	394	0	27.4	32.2	268	0	126
Seattle	WA	25.1	26.8	113	224	25.4	27.4	95	154	88
St.Louis	MO	26.1	29.8	209	16	26.5	31.2	158	8	59

Control Strategies	**Economic Analysis**
Gas Pool Heater(GPH): Cover opens if Tpool > 26 C , Else the pool is open between 11am - 2 pm Heater activates if Tpool < 25 C *Swimming Pool Air Conditioner(SPAC):* Cover opens if Tpool > 26 C , Else the pool is open between 11am - 2 pm	*Gas*: 0.02 $/kWh *Electricity:* 0.075 $/kWh