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A Solar-Cooling Pool Assisted Heat Pump System

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A SOLAR-COOLING POOL ASSISTED HEAT PUMP SYSTEM

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Abstract

A swimming pool is used in parallel with a water-source heat pump for both cooling and heating. For cooling, the pool is used as a spray pond (cooling tower); and for heating, the pool is used as a solar collector, and thermal energy storage. Both theoretical studies and experimental work have been done on this system. A full scale system is almost complete and has been used during the summer for cooling. Economically, on both an operating basis and a capital basis, the system appears feasible.

1. INTRODUCTION

One of the national policies is to conserve energy. One of the main uses of energy is the cooling and heating of homes. One of the methods of heating and cooling homes is the heat pump. This study analizes a system to increase the performance of a heat pump system, especially in the heating mode.

The coefficient of performance for heating and cooling are a function of the temperature potential over which energy must be moved. In the ideal case for the Carnot Cycle[1] these are given as a function of absolute temperatures as:

$$COP_{Heating} = \beta' = \frac{T_H}{T_H - T_L} \quad \text{and}$$

$$COP_{Cooling} = \beta = \frac{T_L}{T_H - T_L}$$

where T_H and T_L represent the high and low temperatures between which the system operates. As may be noted, the most sensitive part of the equation is $T_H - T_L$. As in the ideal case, performance in the actual case can be maximized by minimizing this temperature difference.

In order to accomplish control over these temperature conditions, a water-source heat pump is used in parallel with a swimming pool. Figure 1 shows a schematic of the system. Water temperature is controlled in the summer by spraying the water into the pool. The water is returned underwater to a covered pool in the winter. The pool acts as a solar collector and the thermal energy storage unit during this period.

Numerous methods have been employed to provide water and thermal energy storage to water-source heat pump systems. General articles on the use of water wells have been appearing in Popular Science, for example Reference 2. This system has been very popular in Florida during the early fifties with a rebirth during the last few years. Louisville, Kentucky had been using water-source heat pumps for heating and cooling the downtown area for many years. A loss in water table level canceled most usage. Using soil as thermal energy storage was analized in the late forties and early fifties as in Reference 3. Some actual systems using water lines buried in the ground have taken place in Germany.[4,5] In Italy it has been suggested that warm water be stored in a large lake.[6]

Rather than use these exotic systems, this paper incorporates the backyard swimming pool into the system. Public acceptance of such an energy savings system might be influenced by the recreational effects and the possible government credit on taxes for the solar collector and thermal energy storage system (pool).

2. SWIMMING POOL SYSTEM

The swimming pool is the source of the controlled temperature water. In the summer, the return water

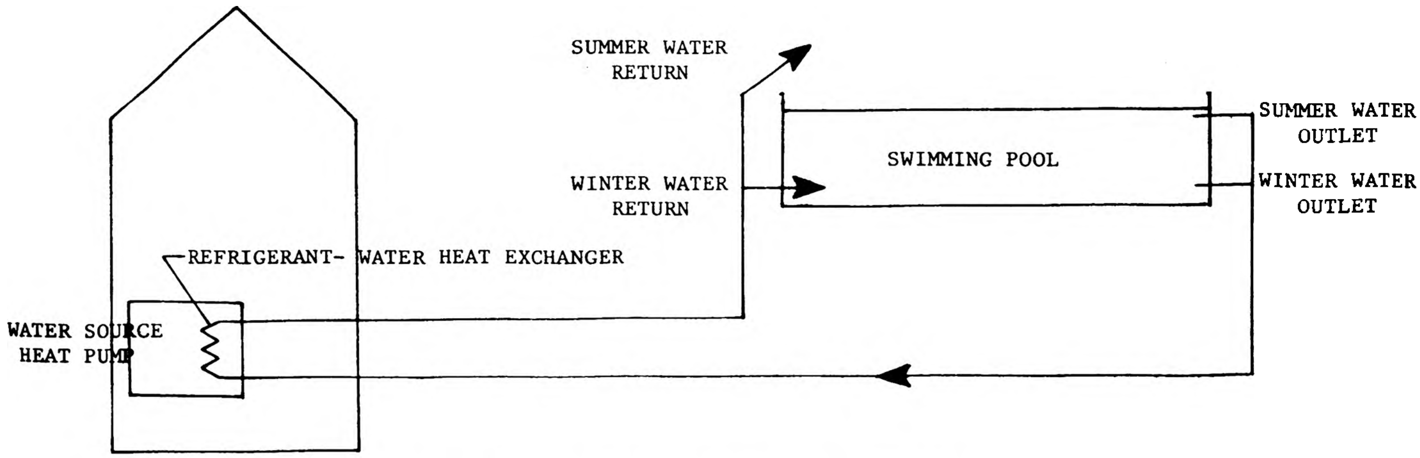

Figure 1. SOLAR-COOLING POOL ASSISTED HEAT PUMP SYSTEM

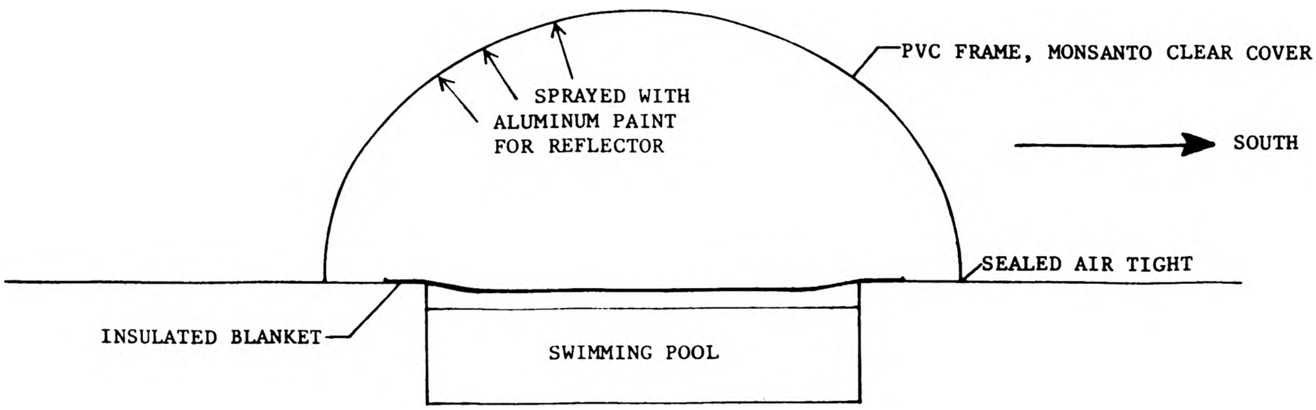

Figure 2. SWIMMING POOL ENCLOSURE (WINTER ONLY)

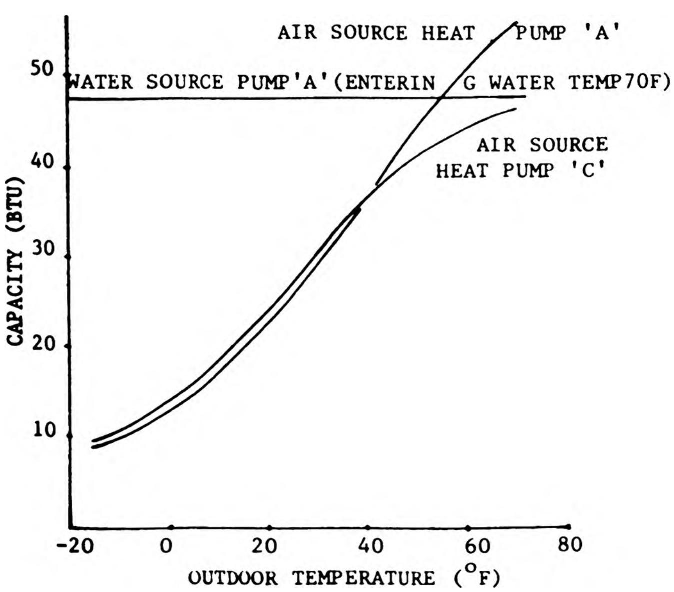

Figure 3. HEAT PUMP HEATING CAPACITY COMPARISON

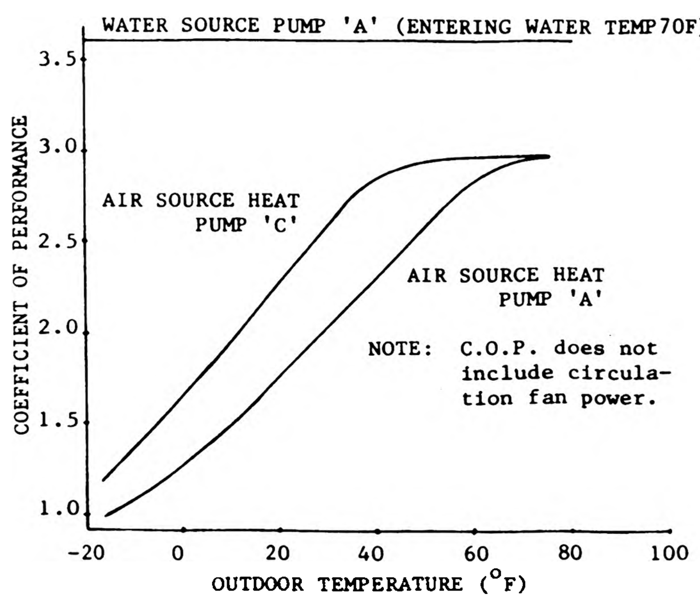

Figure 4. HEAT PUMP HEATING PERFORMANCE COMPARISON

is sprayed into the pool for the evaporative cooling effect. In the winter, the pool is covered and acts as a solar collector and thermal energy storage system.

Except for excessive humidity areas, one major return spray nozzle will keep pool water below 85°F. This system can be run 24 hours per day if required. The pool will normally be filtered continuously during this period due to the high use factor. A major public pool in Atlanta, Georgia expects pool temperature to drop 15°F with a nozzle spray system operating overnight.

To determine solar energy effects, a small pool was constructed at The University of Alabama for use during the school year 1973-74. It was 4 ft. deep and 4 ft. wide and 8 ft. long. A hole this size was dug, lined with black polyethylene and filled with water. A single layer of Kalite (Fiberglass-plastic material with higher light and ultraviolet light transmission value than glass) was placed over the pool. Instrumentation was with twenty thermocouples at various locations. Reading was haphazard with only thermocouples near the surface, 3 inches deep, read regularly. For the first three months, October, November, and December, the temperature varied form 69°F to 85°F, with zero energy withdrawal. Air leakage could be detected by condensation patterns on the cover. The system was sealed by piling dirt around the edges. No freezing occurred in the area directly adjacent to the cover. Within a few days, the temperature reached over 90°F and varied between 89 and 95°F. It must be noted the primary temperature reading, in many cases the only daily temperature reading, was acquired between 7:45 and 8:15 am each morning. With outside temperatures dropping to 10°F, pool temperature was never recorded below 89°F during January, February and March. Again, there was no energy withdrawal from the pool during this period. On this basis, it is assumed that 80°F water will be available for heating with a pool sufficiently large to provide the required thermal energy collection and thermal storage.

The full size pool is 16 ft. wide, 12.5 meters long and 4 to 8 ft. deep. An average depth is 5 ft. Volume is 3280 $ft.^3$ or 25,000 gallons. Water storage is 200,000 lbs. and thermal storage with a 20°F change in temperature is 4,000,000 Btus. With a heat pump COP of 3.5, this is sufficient to provide storage plus (heat pump energy input) 5,700,000 Btus of heating. Maximum load on the utilized house at 0°F is 50,000 Btus/hr or 114 hours at this condition. Maximum average load per hour over a 24 hour period is below 35,000 Btus/hr or the storage provides 165 hours or about 7 days of heating without energy input. It should be noted energy input occurs even on cloudy days.

With a 100% reflector as noted in Figure 2, maximum incidence of radiation is expected to be over 200 $Btus/hr\text{-}ft^2$ on a clear day at the worst time of year (December 21). Average input under these conditions is over 1000 $Btus/day\text{-}ft^2$ or over 600,000 Btus/day. This is marginal for the heating requirements on the worst days of the year, however in the past, not more than 2 days in a row have gone under 10°F in Tuscaloosa, Alabama. These occur during crystal clear days after a major cold front. When the weather is cloudy, temperatures in this area do not go below freezing. Actual usage will be the final test. Resistance heating fireplaces and well water are available as backup systems

Capital costs for no frill swimming pools have decreased appreciably in the last few years. On one Sunday, four separate advertisements in a Philadelphia newspaper[7] quoted a price of $3000 or less for a 16 ft. by 32 ft. inground swimming pool completely equiped with pump and filter system. This does not include landscaping, diving boards, etc. The pool constructed (650 ft^2) for this study costs approximately $2500, but included forms (over $700) and a footer for solar collector housing. If two polyethylene thermal blankets for double glazing had been added (at 35¢/ft^2), the pool and cover could be constructed commercially at $5/$ft^2$. Using a building similar to low cost greenhouses adds $2/$ft^2$ for a total of $7/$ft^2$. Most pools would be slightly higher by choice. A cost of $4000 for pool, covers, and pumping system is used in cost analysis. The pool schematic is shown in Figure 2. The pool housing is shown as a circle. In actual construction, the cover more closely approximates an A-frame with a slight curvature for good reflection 12 ft. high and 32 ft. wide. The aluminum coating on the north side cover provides the reflection.

Table 1. **HEATING AND COOLING PERFORMANCE COMPARISONS**

				High Performance Air-Source Heat Pump						Water-Source Heat Pump					
					Cooling		Heating				Cooling		Heating		
City, State	Cooling Design Temp	Heating Design Temp	Annual Heating Load KWH	Annual Cooling Load KWH	KWH	EER[1,2]	Heat KWH	RESIS	COP[1,3]	Annual Cooling Load	KWH	EER[1,2]	KWH	RESIS	COP[1,3]
Birmingham, Ala.	95	13	10635	25473	8504	10.22	3959	198	2.56	25408	8718	9.94	2911	0	3.65
Tucson, Arizona	98	38	12001	32250	11306	9.73	4237	334	2.63	32467	11140	9.94	3285	0	3.65
Los Angeles, Cal.	87	50	12816	14017	4347	11.00	4414	147	2.81	13902	4770	9.94	3508	0	3.65
Denver, Colorado	88	6	22158	15726	5145	10.43	8218	2050	2.16	15561	5340	9.94	6066	0	3.65
Miami, Florida	82	41	1411	77454	25059	10.55	493	2	2.85	74871	25690	9.94	386	0	3.65
Atlanta, Georgia	88	11	10494	29937	9780	10.44	3891	152	2.60	29638	10170	9.94	2873	0	3.65
Hilo, Hawaii	81	65	77	75545	23562	10.94	26	0	2.99	71549	24550	9.94	21	0	3.65
Chicago, Ill.	89	-9	17946	17953	5858	10.46	6922	1246	2.20	17782	6102	9.94	4913	0	3.65
New Orleans, La.	87	19	6459	46253	15121	10.44	2317	29	2.75	45481	15606	9.94	1768	0	3.65
Boston, Mass.	92	13	22252	11609	3746	10.57	8198	1550	2.20	11546	3962	9.94	6092	0	3.65
Detroit, Mich.	90	4	22070	14524	4689	10.57	8405	1533	2.22	14381	4935	9.94	6042	0	3.65
Saint Louis, Mo.	88	-4	14779	26339	8709	10.32	5689	656	2.33	26081	8949	9.94	4046	0	3.65
New York, New York	85	9	18077	19493	6165	10.79	6813	589	2.44	19023	6527	9.94	4949	0	3.65
Akron, Ohio	90	-8	19085	12611	4042	10.64	7471	1031	2.24	12488	4285	9.94	5225	0	3.65
Tulsa, Okl.	97	4	12603	24080	8235	9.98	4787	382	2.44	24074	8260	9.94	3450	0	3.65
Portland, Oregon	95	27	23600	5335	1720	10.59	8550	487	2.61	5328	1828	9.94	6460	0	3.65
Philadelphia, Pa.	90	6	16828	18757	6095	10.50	6397	491	2.44	18563	6369	9.94	4607	0	3.65
Providence, R.I.	90	8	21293	11727	3745	10.68	7982	1282	2.30	11625	3989	9.94	5829	0	3.65
Columbus, S.C.	95	19	11566	26225	8798	10.17	4259	281	2.55	26173	8981	9.94	3166	0	3.65
Nashville, Tenn.	89	5	12838	27619	9149	10.30	4857	382	2.45	27346	9383	9.94	3514	0	3.65
Houston, Texas	90	28	6583	42065	13924	10.31	2363	66	2.71	41602	14275	9.94	1802	0	3.65
Salt Lake City Utah	91	8	21981	16971	5694	10.17	8291	1327	2.29	16800	5765	9.94	6017	0	3.65
Seattle, Wash.	86	31	29620	4942	1551	10.87	10679	721	2.60	13234	4541	9.94	5874	0	3.65
Milwaukee, Wis.	86	-8	21456	13564	4322	10.71	8220	1948	2.11	4843	1662	9.94	8109	0	3.65

1. EER and COP does not include circulation fam power
2. 85°F water
3. 70°F water

3. HEAT PUMP ANALYSIS

For performance analysis, a water-source heat pump is compared to air-to air heat pumps. Figures 3 and 4 show the variation in heat pump performances between high performance air-source and water-source heat pumps. The performance and capacity variations of the air-source heat pumps vary appreciably with air temperatures. The least performance is under the worst conditions. The curves definitely show the advantage of the water-source heat pumps if the proper water temperatures are available. In addition, water-source heat pumps have a much greater potential for improvement. A coefficient of performance of over 5.5 has been achieved by Honeywell for a water-source chiller.

Cost estimates of the installed heat pump costs according to References 8 and 9 show water-source heat pumps at half the price of air-source heat pumps. This analysis is used for pricing of heat pumps in the economic section. Using 3½ ton units, the cost is $2500 installed for the air-source unit and $1297 installed for the water-source unit.

4. PERFORMANCE ANALYSIS

Using 3½ ton heat pumps a performance analysis has been made for twenty-four cities in the United States. Cooling loads and heating loads were kept constant across the country as only relative final results are desired. Loads were varied proportionally to outdoor temperature relative to indoor temperature. Annual hours for temperatures in five degree increments are available from NOAA averaged over a ten year period. These are used as actual outdoor temperatures. The results are given in Table 1. The performance does not include indoor fan energy input. In general, maximum savings occurred for heating, with savings up to 50% available. Comparing to gas or oil heating of 62% efficiency, the water-source heat pump saves over 50% of the energy required when a 33% efficient power plant and distribution efficiency is utilized. Large energy savings are available with this system, especially in cold climates.

5. ECONOMIC ANALYSIS

Using the economic numbers in Section 2 and Section 3, both capital costs and energy comparisons for Birmingham, Alabama are given in Table 2. Performance numbers are taken from Table 1. The energy savings are small, but show large increases in colder climates. The capital costs have some question, but appear favorable.

As less efficient collectors and larger pools are required in the north and in regions with a large percentage of cloud cover, the capital cost comparisons will be more questionable. However, energy comparisons show improvements in these areas. In general the economics look good.

6. SUMMARY

The system provides energy savings on a reasonable capital cost basis for a major solar heating system. It is a system the public might accept with the additional recreation benefits.

Table 2. ECONOMIC ANALYSIS FOR BIRMINGHAM, ALABAMA
Assumes 40,000B/hr Heating Load at 13°F
Assumes 36,000 B/hr Cooling Load at 95°F

Water-Source Heat Pump Installed Cost	$1,297
Swimming Pool with Cover and Pumping System Installed (600 ft^2)	4,000
Installed System Cost	5,297
Air-Source Heat Pump Installed	2,500
Additional Power Plant Capital Cost (4.4 Kw at $600/Kw)	2,640
Installed System Cost	5,140
Annual Energy Costs Based on Computer Analysis	
Air-Source Heat Pump Plus Resistance (12,463 Kw. hrs. at 4.5¢/Kw.hr.)	561
Water-Source Heat Pump Plus Resistance(11,629 Kw hrs. at 4.5¢/Kw.hr.)	523

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