Field Studies of Two-Speed and PV-Powered Pumps and Advanced Controls for Swimming Pools

David Springer, Davis Energy Group, Inc.
Fred Rohe, Southern California Edison

Swimming pool pumps constitute a significant fraction of residential energy use, consuming over 2000 kWh per pool per year. At 1990 saturation levels, over 1 million pools are available for retrofitting in the Southern California Edison and Pacific Gas & Electric service areas.

This paper describes research conducted to cost-effectively decrease swimming pool pump energy use and electrical demand, and evaluates three different energy efficiency measures: (1) replacement of single speed motors with two speed motors, (2) installation of photovoltaic-powered pumps, and (3) application of an intelligent pump control to replace existing pool timers.

Measure 1

Retrofitted two-speed pump motors were tested at five residential sites located in Edison service area. Timers were set to double filtration times so that the volume of water filtered per day was not decreased. Energy savings ranged from 38% to 65% and no decline in pool water clarity was noted. An owner simple payback of 1.8 years, and a utility benefit-cost ratio (BCR) of 12.4 was calculated for a typical retrofit application.

Measure 2

Two additional sites, different from those used to test two speed pumps, were outfitted with PV-powered DC pool pumps. Filtration (turnover rate) was found to be adequate and pool water clarity was maintained. A utility BCR of 0.34 was calculated using actual installation costs, but ‘‘mature market’’ cost assumptions raise the BCR to 0.84.

Measure 3

A controller was developed for controlling pump and filter operation based on pool water turbidity. Field tests verified that a low cost control with sufficient accuracy for maintaining acceptable turbidity levels can be produced. Further testing is needed to determine pool pump savings, but cost-effectiveness appears promising.

INTRODUCTION

Residential swimming pool pumps present a significant untapped opportunity for energy efficiency improvements. The potential for reducing pool pump loads is large: there are more than 1 million pools in the combined Pacific Gas & Electric (PG&E) and Southern California Edison (Edison) service areas, where the saturation is about 7.2% and 25% respectively (Xenergy 1990; Blodgett & Powers 1992). Each pool is typically equipped with a 1–2 kW pump operated 4–8 hours per day.

Compared to other residential energy efficiency measures, pool pump efficiency improvements have several advantages. For example, replacing single speed pump motors with two speed motors is rarely complicated by interactions with other building features or by access difficulties. Modifications are inconspicuous, non-intrusive, have no comfort consequences, and have low ‘‘take-back’’ potential. Energy cost savings likely could support pool pump replacement programs without need for direct incentives in most locations. Energy savings are predictable and relatively unaffected by weather variables. Finally, the infrastructure required for carrying out replacement programs (the pool service community) is already in place.

This paper draws from three projects to present empirical results of pool pumping and filtration energy efficiency strategies. A field test of two speed pump motors conducted by Edison (Pierce & Hobson 1994) yielded direct measurement of energy savings resulting from reduced pump speed and extended filtration time. Another Edison project (Bourne & Hoeschele 1995) measured performance of two photovoltaic pool pump systems. An extension of the second project administered by the California Institute for Energy Efficiency (Springer 1995) yielded field test results for a pump control device which measured pool water clarity.

Pool pumps are operated for several purposes, including filtration to remove suspended particles, mixing of pool chemicals to reduce algae growth, bottom vacuuming, and to operate automatic pool cleaning devices. In spas they are needed to operate massage jets. For systems with diatomaceous earth (DE) or sand filters, they also are used for filter backwashing. Each of these functions have unique pump flow, head, and operational requirements.

Pump affinity laws, which state that pump brake horsepower varies with the cube of rotational speed and flow rate, provide a theoretical basis for two speed motor replacement savings. If pump speed is reduced by 50% (from 3450 to 1725 RPM) and operating time is doubled so as to filter the same volume of water, low speed energy use should be one fourth of high speed use. Actual energy savings resulting from low speed operation and prolonged filtration time are lower than this predicted 75% due to pump and motor inefficiency at reduced speeds. Two-speed motors are readily available in standard pool pump frame sizes.

Photovoltaic powered pool pumps completely eliminate pumping energy costs, but have high initial costs. PV powered pumps suffer reduced flow rates during cloudy periods and at low sun angles, but provide maximum filtration during warm sunny weather when the most pool cleaning is needed.

The National Pool and Spa Institute recommends pool filtration equipment should be operated to achieve one ‘‘turnover’’ per day (F. Hare 1995). For example, an 18,000 gallon pool would need to be filtered for 6 hours at 50 gallons per minute. While this amount of filtration may be appropriate on a national average, actual filtration necessary to maintain pool water quality may be much different, and depends on use, surrounding debris, water temperature, solar exposure, water quality, pool cover use, and many other factors. In the pool industry, ‘‘clarity’’ is a subjective term used to describe the visibility of an object, such as a coin, on the bottom of a pool. Since clarity is strongly influenced by suspended particles (which can be removed by filtration), controls for operating filtration systems to achieve a desired level of water clarity may have potential for reducing pumping costs.

METHODOLOGY

Site descriptions, test equipment, and test and evaluation methods for two-speed pool pumps, photovoltaic-powered pool pumps, and pump turbidity controls are provided below.

Two-speed Pool Pump Test

An Edison project was initiated with the objective of verifying energy savings resulting from replacement of single speed pump motors with two-speed motors (Pierce & Hobson 1994). Five pools, constructed between 1960 and 1980 and located in Edison service territory, were selected by Edison staff as test sites. Site C is a community pool shared by fourteen residences; all other pools are associated with single family residences. Table 1 describes general characteristics of the pools, and Table 2 lists service factor and horsepower of original and replacement pumps. Diatomaceous earth (D.E.) filters typically have higher pressure loss than cartridge filters, and require backwashing at high flow rates. Service Factor is the ratio of horsepower at which the pump can safely be operated to the rated horsepower. High service factor pumps draw more power than low service factor pumps.

Original pump motors were replaced with motors of equivalent horsepower. Pumps with service factors greater than unity can be operated above their nominal horsepower; because of its 1.25 SF, the Site W replacement pump is equivalent to the original 2.5 HP pump. Seals, gaskets, and impellers (if damaged) were replaced at the same time as the motors. Since most pool pump motors are the same frame size, motors and heads were compatible.

Replacement pump motors were provided with switches for manually operating the pumps at high speed for filter backwashing and pool vacuuming. Existing time clocks were reprogrammed to approximately double the filtration times from the original 6–8 hours. Owners were permitted to select timer settings which scheduled pump operation to suit their pool use and noise criteria.

Pumps with replacement motors were monitored for approximately two months at both high and low speed. Power was recorded using a power monitor connected to a two channel datalogger. One-time flow measurements were made at some of the sites. Original pumps were instrumented prior to replacement, but a conflict between the logger sampling rate and the power monitor pulse rate, not discovered until after the pumps were replaced, resulted in loss of these data and eliminated the opportunity to gather baseline data. High speed operating data for the replacement pumps was used as a proxy for the pre-retrofit data. Sites S and D were both disqualified from testing due to irregularities in owner operation and maintenance which occurred during the test period.

Data were downloaded at the conclusion of the test period, and converted to ASCII format. A text processing language (AWK) program was used to reduce the data to obtain average power use and run time for each operating session during the monitoring period.

Table 1. *Pool Descriptions*

Site	Pool Size	Filter Type	Accessories	Maintained by
W	24,000 gal.	48 s.f. D.E.	none	owner
D	20,000 gal.	30 s.f. D.E.	heater	service co.
C	25,000 gal.	47 s.f. D.E.	heater	service co.
S	22,500 gal.	cartridge	heater, spa	service co.
H	15,000 gal.	cartridge	pool sweep	owner

Table 2. *Pump Replacement*

	Existing (1 speed)		Replacement (2 speed)	
Site	Service Factor	Horsepower	Service Factor	Horsepower
W	1.0	2.5	1.25	2.0
D	1.4	1.0	1.4	1.0
C	1.4	1.0	1.4	1.0
S	1.5	1.5	1.5	1.5
H	1.4	1.0	1.4	1.0

PV Pumping Tests

Photovoltaic (PV) arrays and direct current (DC) motor powered pool pumps were installed at two single family residential sites, one new house in Palm Desert, and one existing house in Rancho Mirage, both in the Coachella Valley. Both sites were the subject of an intensive energy efficiency project, the Coachella Valley Project (CVP), which was modeled after Pacific Gas & Electric Co.'s Advanced Customer Technology Test. PV pool pumping, one of numerous selected measures, was chosen using a detailed design process which evaluated energy efficiency measures based on their ''mature market'' costs. In the design analysis, DC pumps were assumed to cost the same as conventional AC powered pumps in a mature market, and PV panel costs were assumed to be $1.50 per Watt.

At the retrofit site, the new 1/4 HP DC pump was connected in parallel to the existing 1 HP (1.4 SF) pump so that the older pump could be used for vacuuming the pool, and as a backup. Power of the existing AC pump was measured at 1.4 kW. Six 53 Watt PV panels were installed on an existing south-facing trellis at a 45° tilt angle.

At the new site, a 1/2 HP DC pump was installed and connected to ten ground-mounted 53 Watt PV panels. These panels were also oriented due south at a 45 degree angle. The original pool design included an attached in-ground spa which overflowed to the pool. As a part of the overall pool/spa energy efficiency strategy, the spa was separated from the pool to eliminate loss of warm water to the pool, and equipped with a separate AC powered two-speed pump and filter.

Energy savings estimates for the retrofit site were based on pre-conditions monitoring data. Savings for the new site were based on Edison pool pump energy use data (RAEUS 1991).

To determine monthly average turnover rate, short term tests were conducted to relate insolation levels to pump flow rate.

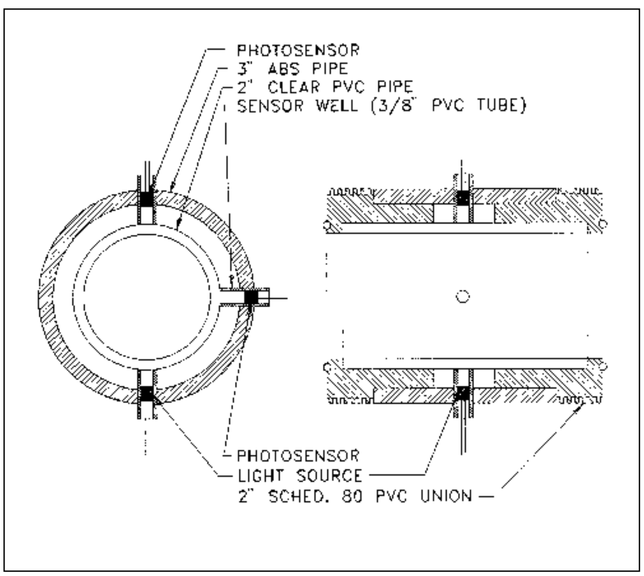
Insolation data were obtained from Cathedral City weather files, and average incident radiation profiles were developed for each month of the year. Regression equations from short term tests were applied to incident radiation data to calculate hourly flow rate profiles. As a further measure of pool water quality, water samples were taken at each site over a six week period to determine the impact of PV pump filtration on turbidity levels over time. Samples were submitted for laboratory testing.

Turbidity Control Tests

For the CIEE-funded project, one task was to develop a control which would limit pump operation to maintain water clarity, or turbidity, at acceptable levels, while decreasing pump operating time. A survey of available turbidity meters located none that were suitable for swimming pool use, either because of inappropriate design or excessive cost. References describing turbidity measurement techniques (Hach, Vanous & Heer; Jethra 1993) were used to develop a specialized ''photoelectric nephalometer'' for measuring turbidity in pool water flowing through a pipe. A sensing device was constructed from plastic pipe which measures light scatter from suspended particles using one light source and two photosensors, as shown in Fig. 1. A variety of light sources and photosensors was tested using standard solutions with known turbidity levels (measured in nephelometric turbidity units, or NTU), and a preferred conbination was selected.

An infrared emitting diode was selected as the optimal light source for the turbidity sensing device based on low cost, reliability, and strong, stable light output. A light-to-frequency converter was selected for the photosensor. Advantages of this device include elimination of the need for analog-to-digital conversion, programmable sensitivity, and immunity to electrical noise which was found to compromise accuracy of analog sensors tested.

Figure 1. *Turbidity Sensor Design*



The assembled turbidity sensor was bench tested by capping the ends and filling it with formazin standard test solutions and pool water samples of known turbidity (verified by laboratory tests). Bench tests showed excellent response down to 1 NTU, but poor repeatability below 1 NTU, probably due to settling of suspended particles during the static tests. However, readings were of sufficient accuracy to develop a linear regression equation ($R^2 = 0.71$) for converting sensor counts to turbidity units (NTU).

A prototype controller, based on the Motorolla 68HC11 microcontroller, was developed to process sensor signals and control both pump speed (for two-speed motor) and operating schedule. Control logic was developed to control both pump speed and operating time to achieve ''target'' turbidity levels, minimize operation during on-peak periods, and maximize low speed operation for overall energy savings. For initial field test purposes, the controller was programmed to record turbidity data rather than to operate the pump.

The sensing device and controller were installed at Site W, and operated for about one week. Water samples were removed from the pool for laboratory analysis of turbidity. The owner maintained an eight hour filtration schedule (low speed) during the test period.

RESULTS

Results from each of the three test projects are reported below.

Two-speed Pool Pump Test Results

Performance Data. Because pre-retrofit data were not available due to datalogger configuration problems, energy savings were based on high speed power for the replacement motors. Thus measured improvements are not attributable to any impeller repairs made during motor installation, or to improved high speed performance of the new motors relative to those replaced.

Table 3 summarizes power, run time, and measured flow rate for the three sites from which reliable data were available. Piping configuration prevented installation of a flowmeter at Site H. The pump at Site H was located near the master bedroom, prompting the owner to reset the timer to its original settings to eliminate nighttime noise.

Table 3. *Two-speed Pool Pump Power and Flow Rate*

Site	Speed	Power (W)	Run-Time (hrs.)	Flow Rate (gpm)
W	high	1157	6.2	n.a.
	low	334	11.9	22
C	high	1301	8.4	38
	low	359	16.2	23
H	high	1486	7.2	n.a.
	low	404	7.2	n.a.

Table 3 data show that low speed pump power averaged about 28% of high speed power, therefore low speed operation at twice the run time should yield energy savings of about 44%. The water filtration rate for Site C increased from 0.77 turnovers per day to 0.89 turnovers per day as a result of doubling the run time and lowering the speed. Adjusting run time to achieve equivalent turnover rate (based on Site C flow rates) would increase the energy savings to about 51%.

No decline in pool cleanliness or water clarity was noted after one month of low speed operation, even for Site H, which had a significantly reduced filtration volume. However, the pool sweep at Site H, which attaches to the skimmer, would not function at low speed.

Table 4 compares high and low speed average daily energy use over the monitoring period, and energy savings. ‘‘Low speed’’ values include some high speed operation for vacuuming and filter backwash.

For Sites W and H, average energy use was about equal to the product of pump power and operating time. Site C was vacuumed twice per week, and pool service personnel occasionally left the pump set to high speed after vacuuming was completed. High savings for Site H are attributable to no increase in low speed run time.

Table 4. *Two-Speed Pump Average Energy Use and Savings*

Site	High (kWh/day)	Low (kWh/day)	Average Savings
W	7.3	4.0	45%
C	10.9	6.7	38%
H	8.2	2.9	65%

Economic Analysis. Costs to install the two-speed motors averaged $350 for the five sites. Two-speed motors are about $50–75 more costly than one speed motors (G.E. 1½ HP). Using an economic model developed for Edison (Bourne & Hoeshchele 1995) which assumed 1500 kWh annual savings, $75 incremental materials cost, and a 15 year lifetime, a benefit cost ratio of 12.4, and cost of conserved energy of 5 mils were calculated. At $.013 per kWh, the direct payback to the owner would be 1.8 years at the $350 full replacement cost, and 0.4 years if the old motor is at the end of its useful life (for $75 incremental cost).

PV Pool Pump Test Results

Performance Data. Conventional pool pump energy use (and energy savings) estimates for the Palm Desert (new) and Rancho Mirage (retrofit) sites were 2,105 kWh/year and 3,796 per year, respectively. The estimate for the new site was based on SCE RAEUS data averages. Retrofit site energy use was extrapolated from monitoring data.

Despite the larger pump and PV array used at Palm Desert (La Paloma), average flow rates were higher at the Rancho Mirage site. Annual average turnover rates were 0.85 pool volumes per day for Palm Desert and 1.15 pool volumes per day for Rancho Mirage. Fig. 2 compares monthly pool turnovers for the two sites. Insolation and flow rate data suggest that the La Paloma pump was oversized, since it delivered a higher flow rate between 11 AM and 1 PM, but a lower flow rate than the Rancho Mirage system at all other times.

Table 5 shows results of laboratory testing of turbidity levels over the six week sampling period. All samples were collected by homeowners using laboratory grade sample bottles. For comparison, a distilled water sample submitted for labo-

Figure 2. PV Pool Pump Performance Based on Cathedral City Weather Data

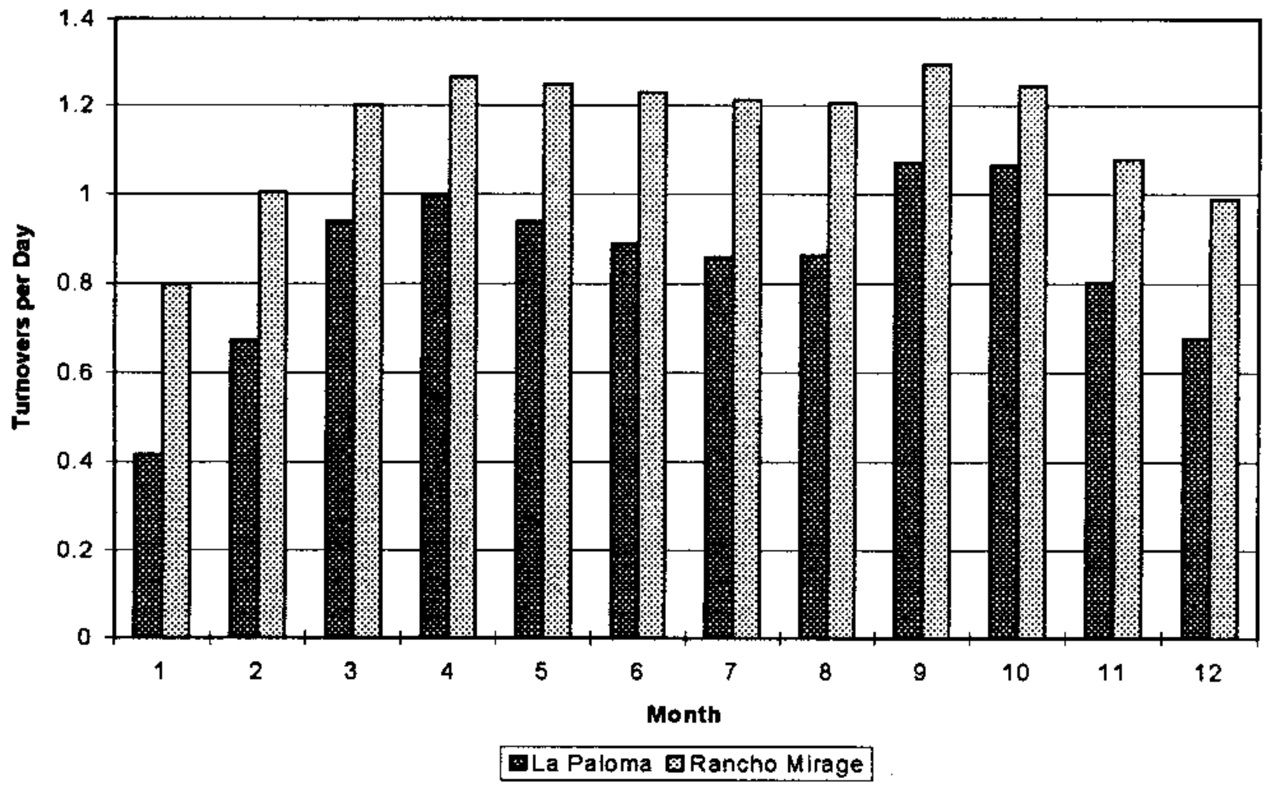


Table 5: Water Sample Test Results

Week No.	Palm Desert NTU	Rancho Mirage NTU
1	0.01	0.10
2	0.58	0.32
3	0.26	0.21
4	0.28	0.34
5	0.68	0.39
6	1.26	0.06

ratory testing yielded 0.02 NTU. No visible differences in pool clarity were detected at any time during the period. The high value obtained for Palm Desert week 6 may have resulted from sample contamination.

Economic Analysis. Current costs of PV arrays and DC pumps are prohibitive. Complete systems for the new and retrofit sites cost $6209 and $6444, respectively. Retrofit site costs included installation of a new cartridge filter to reduce system pressure drop. With annual savings of $274 for the new site and $493 for the retrofit site (at $0.13/kWh) and a benefit-cost ratio of 0.34, ''current cost'' economics are not favorable. However, application of ''mature market'' assumptions lowers the initial cost to about $2200 and raises the benefit-cost ratio to 0.84.

Turbidity Control

Field Test Results. Though static bench tests of the turbidity sensor suggested poor accuracy below 1 NTU, field tests were conducted to determine whether the sensor was capable of detecting changes in pool turbidity while measuring flowing water. The turbidity sensor assembly was installed in a 2″ PVC line between the pump and filter at Site W, and the attached microcontroller was used to gather continuous data. The first three days of testing showed that daylight was being transmitted through the PVC pipe to the photosensors, so the sensor assembly and surrounding pipe were covered with an opaque plastic sheet. Tests conducted over an additional five days showed very low turbidity measurements. On each day of testing the turbidity measured at the beginning of filter cycles was slightly higher than at the end of the cycles, suggesting that control of pump operation based on turbidity is technically feasible, even if pool water clarity is maintained to a very high standard.

Economic Analysis. Materials and installation cost for volume production of the turbidity control was estimated to be $150. If the turbidity control reduced operating time for a 2 HP pump by 2 hours per day, the control cost could be recovered in 0.6 years at a utility benefit-cost ratio of 6.4.

CONCLUSIONS

Both two-speed pool pumps and turbidity controls offer near-term solutions to reducing pool pump energy use. Two-speed motors are readily available with manual switches for selecting speed. Field test experience showed that addition of a timing mechanism would prevent forgetful service personnel from compromising energy savings by leaving pumps set at high speed. Utility programs to alert pool service companies to market opportunities, inform customers of potential savings, and to provide financing could be highly cost-effective. Application guidelines must be developed to insure low speed pump compatability with the variety of pool equipment in use.

Turbidity control development efforts demonstrated that reliable, accurate controls for maintaining water clarity can be assembled using inexpensive components, and that manufactured controls are likely to be cost-effective, particularly for large pools. Each swimming pool is subject to different filtering requirements to maintain water clarity. All pool filtration system functions should be considered in developing control strategy, including filtering out particulates, mixing chemicals into the water, and operating pool cleaning devices. Prior to commercialization, turbidity controls will require extensive field studies to develop optimal control logic, verify adequacy of pool water clarity, obtain user feedback, and determine energy savings

Cost constraints currently discourage implementation of PV-powered pool pumps, though anticipated reductions in PV array and pump costs could boost the benefit-cost ratio above unity. Project testing demonstrated the ability of PV pumps to provide adequate filtration (more than one turn-over per day) in the Coachella Valley climate. Retrofit sites are potentially more cost-effective than new sites, because existing pumps can be used for supplementing PV pump flow for pool vacuuming. Solar access is, of course, necessary to maintain pump operation, and could become a limiting factor in widespread implementation.

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