Solar Powered Commercial DC Pool Pump

ET13SCE1090

Prepared by:

Emerging Products
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Executive Summary

This field assessment evaluates the effectiveness of an emerging energy efficient technology that uses solar energy. It directly supports the penetration of similar technologies in the residential and small commercial marketplace. The assessment demonstrates how a multifamily pool pump system was retrofitted with a variable speed drive (VSD) pump and two solar-powered pumps to reduce grid energy consumption, especially during peak hours. The project seeks to verify that this proposed emerging technology system is able to maintain the minimum health code required filtration flow rate and to quantify the total energy savings. The energy savings result from the installation of an efficient VSD pump and two solar photovoltaic powered pumps.

The evaluation measures all parameters involved in the community pool's pump system. Two weeks of baseline data were compared to three months of emerging technology system data. The baseline system consisted of two constant speed pumps with 1.5 HP motors operating in parallel and running 24/7. The new installation required the removal of the two existing pumps and the installation of two 2.3 HP direct current (DC) solar-powered pumps and one 3.0 HP alternate current (AC) grid powered pump with VSD. The solar pumps operate whenever sufficient sunlight is available. The grid powered pump speed is modulated by a controller that is connected to a flow meter installed in the pool return line. This maintains the health code required flow rate of 139 gallons per minute (gpm) for this size pool at all times. In other words, the grid pump provides whatever is needed in addition to the solar pumps.

The evaluation found that the system is able to meet the minimum health code required flow rate; the solar pumps produces energy savings; and the VSD pump contributes to further savings. Some savings can be attributed to a change in system piping, but it is difficult to determine to what extent. In order to extrapolate the monitoring data to annual savings, regression analysis with solar insolation was used to accurately predict solar production and how it affects the speed of the grid powered pump throughout the year. The total system cost was $35,298.56. By factoring in an annual 2% utility rate increase, a 30% investment tax credit, and a blended utility rate of 0.15 dollars per kilowatt hour ($/kWh), the estimated payback period is 8.0 years. The results are shown in Table 1.

Table 1. Summary of Energy Savings and Demand Reduction

	Annual Energy Usage (kWh/yr)	Annual Energy Savings (kWh/yr)	Avg On-Peak Demand (kW)	Avg On-Peak Demand Reduction (kW)	Cost Savings [$]	Estimated Payback [Yrs]
Baseline	32,560	-	3.7	-	-	-
Emerging Technology System	13,710	18,840	1.3	2.4	$2,826	8.0

It should be noted that the flow rate of the baseline system was on average 20% less than the new system. If we correct for this by increasing the baseline flow rate 20% and adjust the baseline energy consumption appropriately, the estimated payback period drops to approximately 4.5 years.

The technology is sound and is a combination of existing technologies that are already understood, widely deployed, and incentivized by the utilities (and through government tax credits). The recommended next step is to create an incentive for the entire system to support market penetration.

ABBREVIATIONS AND ACRONYMS

AC	Alternating current
ACC	Average cost of capital
DC	Direct current
EE	Energy efficiency
EUL	Estimated useful life
MFR	Multi-family residence
PV	Photovoltaic
SCE	Southern California Edison
SFR	Single-family residence
VSD	Variable speed drive
gpm	Gallons per minute

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INTRODUCTION

Pool pumps are a substantial energy end-use in the residential and commercial marketplaces. Water is a relatively heavy substance and the power required to pump pool water through filtration, treatment, and heaters is significant. This is exacerbated by commercial pool health code requirements; while private single-family residence (SFR) pools are not governed by health code requirements. Common area residential and commercial pools require constant, uninterrupted flow according to California code. California code requires that commercial and common area residential pools have sufficient capacity to provide a complete turnover of pool water in six hours or less [California Code of Regulations]. Based on this requirement, the flow rate for a 50,000 gallon pool must be maintained at 139 gallons per minute (gpm) or greater whenever the pool is open, regardless of occupancy patterns.

Standard practices typically include weekly maintenance of pool systems and daily skimming. Skimming and increased pumping often occur during peak hours of the day based on pool professional operating procedures. This impacts the on-peak demand by further increasing pool pump energy consumption.

Typical equipment includes one- or three-phase pump motors powered by the utility grid. These pumps can be constant speed or multi-speed, with multi-speed models often programmed with daily schedules. Multiple constant speed pumps can be controlled by time clocks in order to provide added pump power during peak hours, as is typical of many pools. Pumps and motors typically have lifespans of 10-15 years and so existing equipment is often outdated with low efficiency ratings.

In order to quantify the impact of commercial pool pumps in California, it is necessary to estimate the number of commercial pools in the state. The table below provides the total estimated number of common area residential pools as calculated for this study [California Energy Commission, US Census]. The estimates were developed according to US Census data and the 2009 California Residential Appliance Saturation Study (RASS).

TABLE 2. ESTIMATED MARKET SIZE FOR COMMON SFR AND MULTI-FAMILY RESIDENCE (MFR) POOLS

TERRITORY	SFR QUANTITY	MFR QUANTITY (10+ UNITS PER PROPERTY)	% SFR WITH COMMON POOL	% MFR WITH COMMON POOL	TOTAL COMMON POOLS
SCE	4,460,100	1,155,900	1.6	35.9	11,800[1]
California	8,950,390	2,319,600	1.6	29.4	19,900[1]

Since each of these pools has at least one pump that operates on the order of several kilowatts, the opportunity for demand reduction and energy savings in the commercial pool market is substantial. However, the health code requirement of a constant flow rate presents a challenge that requires unique emerging technology solutions. Utilities and technology companies have been working to address this energy efficiency need through various approaches.

[1] Assumes 50 SFR and 40 MFR homes per common area pool.

BACKGROUND

The commercial pool pump market and associated health code requirements necessitate an advanced pool pump technology for energy and demand reduction. Since these pools must have a constant minimum flow rate, and pump efficiency is a difficult parameter to improve, targets for improvement are the energy source and pump controls. By combining an alternative energy source with existing pump and control technologies, grid demand and consumption can be reduced while maintaining a healthy, sufficient flow rate system.

The emerging technology in this study is a system that integrates photovoltaic (PV) generation, Direct Current (DC) pumps, grid-powered Alternating Current (AC) pumps, and variable speed drive (VSD) pumps to create an advanced pool pump system.

EMERGING TECHNOLOGY

By using existing technologies (VSD, PV, DC and AC pumps) in a new configuration, energy efficiency and health code requirements can be satisfied. The new pool pump system is a hybrid AC/DC platform designed as an open architecture that focuses on reducing inefficient, grid-powered AC pool pump usage. The goal is to improve reliability and energy efficiency across commercial pool pump applications while reducing on-peak demand.

The new pool pump system uses a PV array to power two DC pumps whenever sufficient sunlight is available. In a DC pool pump system, the DC motors are directly fed by PV panels via an automatic digital motor controller. This system changes the torque and speed of the DC motors based on the power supplied by the PV panels. The system also incorporates closed-loop feedback from a flow meter with automatic controls that engage a secondary AC pool pump with a VSD to supplement any flow loss due to decreased PV power. This makes the DC pumps the primary drivers, while the grid-powered pump acts as a supplementary driver to meet minimum flow rate requirements when solar power is insufficient or unavailable.

If installed at an existing pool location, this combined solar DC and grid AC pump system must replace the existing pump system. The typical one- or two-grid AC pump system would be removed and replaced with a re-routed system and PV panels. The existing filtration and heating systems, along with most of the piping, can remain relatively unchanged. In some cases, the existing pump assemblies may be used as the VSD grid pump if the motor type can accommodate a VSD. Figure 1 and Figure 2 show the baseline and emerging technology system configurations, respectively.

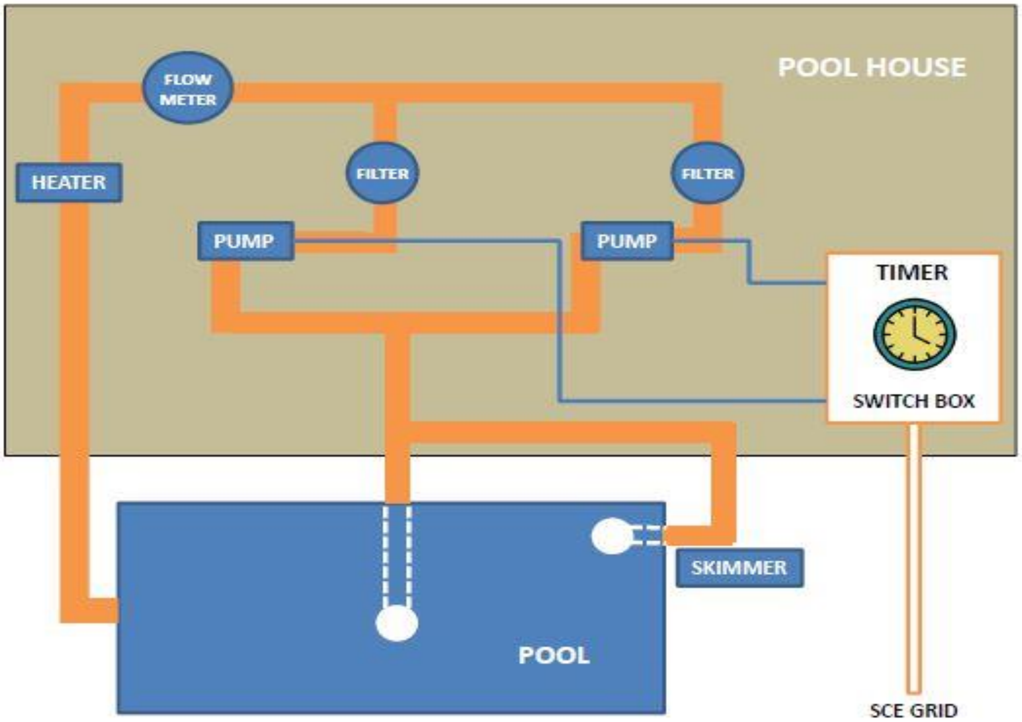


FIGURE 1. BASELINE POOL PUMP SYSTEM SCHEMATIC

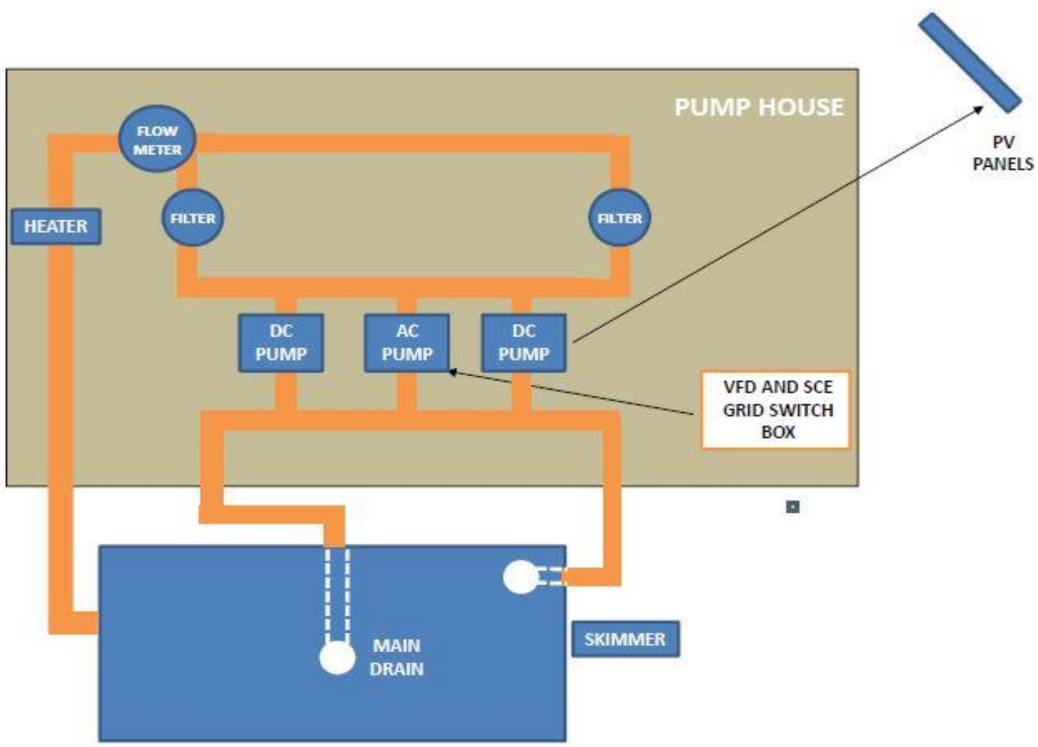


FIGURE 2. EMERGING TECHNOLOGY POOL PUMP SYSTEM SCHEMATIC

The system will have an estimated useful life (EUL) that is dictated by its individual components. According to the following values, the system as a whole will have an EUL of at least 10 years, with the most expensive component (PV array) lasting at least 20 years. The components with the shortest EUL are the pool pumps and the VSD. Since the pool pumps are already necessary for the baseline system, the emerging technology system has no reduced EUL. Table 3 lists the EUL of the major system components.

TABLE 3. SYSTEM COMPONENT ESTIMATED USEFUL LIFE

COMPONENT	EUL [YEARS]	SOURCE
Pool Pump	10	DEER2014 – OutD-PoolPump (High Efficiency Pool Pump)
PV Panels	20	Go Solar California
VSD	10	DEER2014 – Agr-VSDWellPmp (Well Pump Variable Speed Drive)

Other than peak demand reduction, energy savings, and cost savings, there are reliability advantages to this system over a typical system. The solar pumps are able to operate during a grid outage. Operations and maintenance will be similar except for added solar panel cleaning, caring for one or two additional pumps, and VSD operation management. Additionally, the VSD pump requires ongoing monitoring and additional training since the existing systems will likely use a constant speed pump or multi-speed pump on a time clock.

Market barriers to this new type of system include high upfront costs, and resistance by pool installation and maintenance professionals to operational changes. The new system demands additional training and maintenance procedures. Pool contractors may be wary of reliability health code issues, and hesitant to alter the customary time-proven pool pump designs. Finally, the performance of the emerging technology system will depend on solar availability, performing best and providing the best return-on-investment (ROI) in sunnier locations.

Retrofit applications will have more barriers than new construction. New construction installations will incur fewer additional costs and have fewer complications in construction compared to a retrofit. Retrofit applications will be complicated by existing building systems and the costs associated with early retirement and replacement of existing equipment.

ASSESSMENT OBJECTIVES

The goal of this technology assessment is to identify the demand, energy, and operational benefits of the emerging technology pool pump system. To this end, several objectives were established:

- Install the proposed emerging technology system.
- Take measurements of the flow and power consumption of the existing baseline and emerging technology systems.
- Use the measured data to calculate energy, demand, and cost savings for the baseline and emerging technology systems.
- Determine if the minimum flow requirement is achieved by the emerging technology system.
- Estimate economic metrics, such as payback.
- Discuss system effectiveness and provide recommendations for further efforts.

For this field technology assessment, the proposed emerging technology system was installed at a mixed multi-family residence (MFR) and single-family residence (SFR) community pool.

TECHNOLOGY EVALUATION

The system was installed at a 50,000 gallon MFR and SFR community pool in Ontario, California. Ontario's climate is semi-arid with average daily high temperatures ranging from 68 to 92° Fahrenheit throughout the year, and annual precipitation of 16.8 inches. It is located in California climate zone 10. Figure 3 is a satellite image of a section of the community.

FIGURE 3. SFR AND MFR COMMUNITY AND COMMUNITY POOL (ENTIRE COMMUNITY NOT SHOWN)

A field study is most appropriate for this assessment as it requires a full-size commercial pool and the benefits of installing the emerging technology system should be realized by an actual customer. The host site was selected as a representative site based on the maintenance procedures, pool size, and pool use. While pool purposes, sizes, and locations will vary across California and SCE's service territory, pool health code turnover requirements can serve as the normalizing factor for comparison across various sites. For example, although the occupancy patterns of this pool were unknown, the flow rate must be kept at or above a constant value regardless of usage patterns. This code-mandated turnover rate may vary for other counties and jurisdictions across California, but must be at minimum one pool volume turnover every six hours.

The installation and commissioning of the emerging technology system was performed by Alan Smith Pool Plastering, Inc., a certified pool contractor with extensive experience in commercial and solar applications. The data collection, analysis, and report writing was performed primarily by Alternative Energy Systems Consulting (AESC), an energy engineering practice at the intersection of public and private efficiency interests.

BASELINE AND EMERGING TECHNOLOGY POOL PUMP SYSTEMS

The baseline pool pump system is comprised of two constant speed grid-powered pumps of the same make and model. The two pumps were powered by 1.5 HP motors and were housed in the site's pool mechanical room along with heating and filtration equipment. Both pumps operated in parallel 24/7 and were powered by grid-sourced electricity. It should be noted that in the original configuration, each of the two pumps discharged water to one of the two filters, after which the two flows connected in a combined flow before feeding back into the pool. Figure 3 shows the baseline pump system configuration.

FIGURE 4. BASELINE, TWO GRID PUMP SYSTEM

The installed emerging technology system uses twelve 190 Watt PV panels to power two 2.3 HP DC pumps. A 3.0 HP AC, grid-powered pump with VSD was used to supplement the flow rate as needed in order to satisfy health code turnover requirements. All equipment was installed at the existing location as in a typical retrofit application. The piping configuration was altered as necessary to operate the three pumps in parallel. All three pumps had a common suction pipe and a common discharge pipe from which the water flowed to both filters. All new equipment was located in the existing pool mechanical room except for the PV panels which were mounted on the roof. Figure 5 shows the new pump system configuration at the host site.

FIGURE 5. POST-INSTALLATION, TWO SOLAR DC PUMP AND ONE GRID PUMP SYSTEM

The system configuration at the test site had a total installation cost of $35,298.56 with itemized costs listed in Table 4.

TABLE 4. SYSTEM COSTS

ITEM	COST
(2) DC 3 phase pool pump assemblies	$5,729.56
(2) DC 3 phase pool pump controller	$2,347.66
(2) PV disconnect	$1,093.68
(12) 190 Watt PV panels	$7,7725.60
(2) 5 Year Warranty	$719.10
Roof Mount	$1,082.29
(24) Quick Mounts	$1,018.08
(2) DC cables	$72.80
(2) Solar panel extension cables	$175.24
VSD	$917.87
Wi-Fi interface card	$733.34
Flow meter	$964.31
AC pool pump motor	$304.67
Labor	$12,414.36
Total	**$35,298.56**

TECHNICAL APPROACH & TEST METHODOLOGY

A measurement and verification test plan was developed for the field assessment of this emerging technology pool pump system. The test was developed using IPMVP standards [Department of Energy] and followed the path of Option B Retrofit Isolation by measuring all parameters used for developing energy and demand savings calculations.

The evaluation was performed over five months, encompassing baseline monitoring, emerging technology system installation, and emerging technology monitoring. Baseline data was collected over 15 days and was very consistent without the need for further extended monitoring. The emerging technology data was collected over 140 days in order to capture usable data across various weather and solar availability conditions. The test timeline is detailed in Table 5.

TABLE 5. MEASUREMENT PERIODS

PHASE	TIMESPAN [DAYS]	DATES
Baseline	15	January 22 – February 5, 2014
PV DC Pump System	140	March 13 – July 31, 2014

Due to various complications, as discussed in later sections, the measurement period was curtailed to the sections of usable data listed in Table 6. These three periods were at the beginning, middle, and end of the overall emerging technology monitoring period. This captured performance during the full span of weather and solar availability conditions, despite the smaller dataset. These three periods were combined into one dataset for the calculation of energy and demand savings results.

TABLE 6. ISOLATED DATA PERIODS

PHASE	TIMESPAN [DAYS]	DATES
Baseline	15	January 22 – February 5, 2014
Post Period 1	14	March 13 – March 27, 2014
Post Period 2	14	May 29 – June 12, 2014
Post Period 3	15	July 16 – July 31, 2014

Throughout the baseline and post-installation periods, no standard operating procedures or maintenance practices were altered except for those necessitated by the emerging technology pool pump system. All other schedules and practices were kept constant. By keeping maintenance procedures consistent, no operational and maintenance bias was introduced into the study.

FIELD TESTING OF TECHNOLOGY

The hybrid system of technologies was installed at a single location in an MFR and SFR community common area pool selected for its representation of the target market. Commercial and common area pools are larger than the average private pool (which is typically about 20,000 gallons). The most common type of commercial-use pool is shared residential. The community was located in a dusty windy location with a semi-arid climate conducive to pool use. The pool was 50,000 gallons and the baseline pool pump system consisted of two 1.5 HP constant speed pumps running constantly, except for short periods during the bi-weekly filter cleanings.

TEST AND INSTRUMENTATION PLAN

The baseline and emerging technology pool pump systems were installed at the same location. Maintenance procedures were kept constant to avoid affecting results from added filter cleaning and other procedural changes. Few other factors needed to be controlled to ensure a fair comparison since pump operation is constant and occupancy patterns have no effect.

There were, however, environmental and instrumentation issues that necessitated the exclusion of periods of data from the emerging technology monitoring period. In this manner, any complicating environmental and measurement issues that could have created uncontrolled results were removed.

The test followed IPMVP standards and a timeline as described at the beginning of this section. In order to provide valuable results that are applicable to a range of host sites and locations, the solar availability was considered a driving factor in the test design. The energy and power production of the emerging technology pump system is highly dependent upon solar availability. By conducting the test across a range of solar availability conditions over several months, the results can be used to develop annualized correlations to solar insolation data. These correlations can then be used to predict annual performance of similar systems at other locations using their respective solar data. This is explored further in the results sections.

BASELINE INSTRUMENTATION

A GF Signet 2536 Low flow Rotor-X paddlewheel flow sensor was installed in the four-inch pool supply line. The sensor has a repeatability of ±0.5% and a linearity of 1%, and was coupled with a GF Signet 9900 Field Mount Transmitter with an output accuracy of ±32 μA maximum error at 25ºC at 24 Volts DC with resolution of 6 μA or better. The meter, manufactured under ISO 9001 for Quality, and ISO 14001 for Environmental Management, was installed per the manufacturer's installation instructions, more than twenty hydraulic diameters from an upstream 90 degree elbow and five diameters from any downstream flow restricting device to ensure fully developed flow. The flow meter was not moved for the emerging technology system monitoring. Flow readings were recorded in one-minute intervals. Figure 6 shows a picture of the flow meter installed at the test site.

FIGURE 6. FLOW METER

A Keller Valueline pressure transmitter was installed (1/4" NPT male) in the top of each of the two sand filters served by each pump, replacing the pre-existing dial gauges. The sensors have an accuracy of ±0.2%. Pressure readings were taken in one-minute intervals across the duration of the test and the locations were not moved for the emerging technology monitoring period.

FIGURE 7. PRESSURE TRANSDUCERS

Amperage, voltage, and power factor were monitored for each single phase 1.5 HP motor. Both pumps were monitored with HA 1000 AC current transducers and volt probes connected to a PS250 and PS2500 Powersight power meters. The Power Sight meter and the current transducers both have an accuracy of ±0.5%, yielding a combined accuracy of ±1.0%.

Figure 8 is a picture of the connection in the main circuit breaker. The breaker was covered to allow the pool operator to shut off the power for maintenance while ensuring safety.

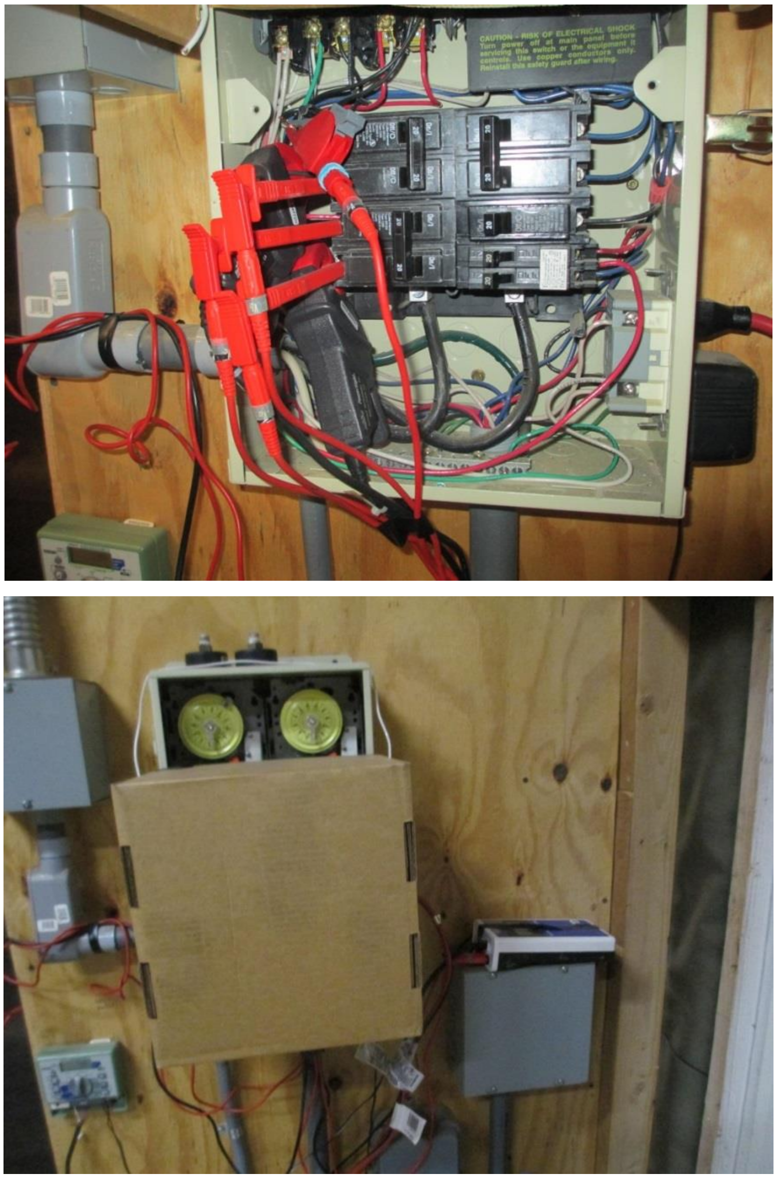


FIGURE 8. GRID PUMP MEASUREMENT POINT AT THE MAIN CIRCUIT BREAKER

EMERGING TECHNOLOGY INSTRUMENTATION

The flow and pressure were measured at one-minute intervals using the GF Signet 2536 low flow Rotor-X paddlewheel flow sensor and the Keller Valueline pressure transmitters. They were mounted for the baseline monitoring and were never removed or relocated.

The power to the DC motors was separately monitored using the Powersight PS250 and PS2500 meters from the pre-installation. Two single phase Powersight DC600 current transducers were used, with accuracy to ±3%. The AC motor was monitored with a Powersight 3000. All measurements were taken in one-minute intervals.

Figure 9 shows the instrumentation of the two switchboxes where the DC pumps were powered from the solar panels.


FIGURE 9. SOLAR PUMP POWER MONITORING AND FLOW METER SHOWING 141 GPM (INDEPENDENT BUBBLE FLOW METER)

The monitored data points that were measured and logged at one-minute intervals are listed in Table 7.

TABLE 7. MEASUREMENT POINTS

PHASE	MONITORED POINT	UNIT	MEASUREMENT DEVICE	ACCURACY
Baseline	Filter 1 Pressure	psi	Keller Valueline	0.2%
	Filter 2 Pressure	psi	Keller Valueline	0.2%
	AC Pump 1 V, I, pf	Volts, Amps	Powersight PS250	1%
	AC Pump 2 V, I, pf	Volts, Amps	Powersight PS250	1%
	System Flow Rate	gpm	GF Signet 2536	0.5%
Post	Filter 1 Pressure	psi	Keller Valueline	0.2%
	Filter 2 Pressure	psi	Keller Valueline	0.2%
	Solar Pump 1 V, I,	Volts, Amps	Powersight PS250	3%
	Solar Pump 2 V, I,	Volts, Amps	Powersight PS250	3%
	Grid Pump V, I, pf	Volts, Amps	Powersight PS3000	1%
	Flow Rate	gpm	GF Signet 2536	0.5%

RESULTS

The data collected through implementation of the test plan was used in a detailed analysis of the emerging technology. The results of this analysis are detailed throughout the following sections. In general, the goals were to calculate energy and demand savings on an annual basis using the collected data and historical solar insolation data. From this, the payback period could be calculated for this particular site.

Table 8 lists the energy, demand, and cost savings for the host site over the test timeline and an annual extrapolation. An electricity rate of $0.15/kWh was used in the economic calculations.

TABLE 8. ENERGY, DEMAND, AND COST SAVINGS

TIMESPAN	ENERGY SAVINGS [KWH]	AVERAGE DEMAND SAVINGS [KW]	AVERAGE ON-PEAK DEMAND SAVINGS [KW]	COST SAVINGS [$]
Test Period	2,420	2.42	2.90	$363
Annual	18,841	2.15	2.29	$2,826

The emerging technology, when considered as a whole system, does not currently apply to any existing SCE incentive or rebate program. However, the individual components that comprise the system do fall under various incentive programs including a Federal tax credit, the California Solar Initiative, and the Energy Efficiency Customized Solutions program.

DATA ANALYSIS

BASELINE DATA

The baseline system was monitored for 15 continuous days between January and February of 2014. The daily pump power usage and flow rate profiles were consistent throughout the 15 days, demonstrating that extended baseline monitoring was not needed. The baseline system operation had no correlations to pool usage patterns, seasons, or weather due to the pumps constant speed control strategy. This enabled averaging of the 15 days of data into a representative baseline day profile as shown in Table 9 and Figure 10. This average baseline day was used as a basis for all savings calculations.

Data from the consultant installed flow meter indicates that the minimum average flow rate of 139 gpm needed to comply with the health code requirements, was not achieved during the baseline monitoring period. An average flow rate of 103 gpm was recorded. As mentioned in the baseline equipment configuration description, the two pumps feed their respective filters first before the flow is combined in a common return line. As a result, if one filter loads up more than the other, it throttles the pump flow and creates a difference between the consumption of the two pumps. From the data it appears that the pump closer to the skimmer return pipe (pump 1) had the most filter loading.

TABLE 9. AVERAGE BASELINE DAY FLOW RATE AND PUMP POWER

AVERAGE FLOW RATE [GPM]	PUMP 1 POWER [W]	PUMP 2 POWER [W]	TOTAL PUMP POWER [W]	TOTAL PUMP ENERGY [KWH]
103	2,135	1,582	3,717	32,560

Equation 1 can be used to estimate the baseline system total pump power using information from the baseline pump nameplate. The two baseline pumps have a nameplate horse power of 1.5 hp. An efficiency of 60% can be assumed, as it is typical for pool pumps [Pacific Gas and Electric Company], and a nominal service factor of 1 should be used. With these values Equation 1 yields a baseline system total pump power of 3.7 kW, the same as what was measured at the site. Therefore the power measured at site is within the operating parameters of the values listed on the pump nameplate.

EQUATION 1. PUMP SYSTEM POWER

$$\boldsymbol{Pump\ System\ Power\ Measured\ at\ Meter\ (kW)} = (hp\ of\ pump\ \times\ \#\ of\ pumps\ \times\ 0.746\ \times\ Service\ Factor) \Big/ (Pump\ Efficiency\ \%)$$

Since the two baseline grid-powered pumps would be replaced with a single grid-powered pump in the emerging technology installation, the powers were combined into a single value as shown in Figure 10.

Figure 10 shows the average grid pump power for the baseline system across the hours of the day, as determined by the entire baseline monitoring period. In other words, the power at 2 PM on the plot is the average of all power measurements at 2 PM for each day of the baseline period. This average baseline day is used as the basis for all savings calculations resulting from the emerging technology system. This is justified since the baseline system had consistent data profiles across the baseline monitoring period and should be the same every day of the year.

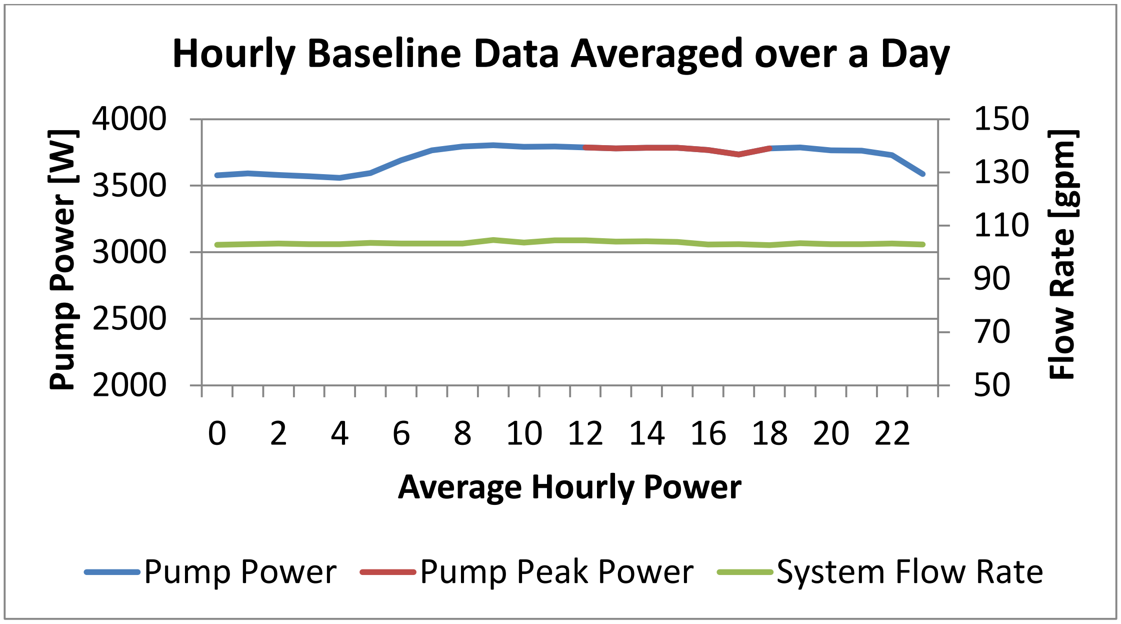


FIGURE 10. AVERAGE BASELINE DAY

Note that the on-peak pump power is higher than the overall daily average. The daytime pump power is higher due to the periodic power pattern shown in Figure 11. For this reason, the daily profile is used as a baseline for energy savings calculations rather than a single average pump power value. On-peak hours for this study are assumed to be 12 PM to 6 PM in all instances.

Figure 11 shows a plot of the total baseline period. Note that the consistent daily pattern allows for the consolidation into the average daily profile found in Figure 10. This enabled averaging of the 15 days of data into a representative baseline day profile as shown in Table 9 and Figure 10. It can be noted that at the 7th day of the monitoring, some obstruction in the filter system slightly reduced the flow and the power consumption, primarily for Pump 1. After 6 days, the filters were cleaned, resulting in increased flow and power.

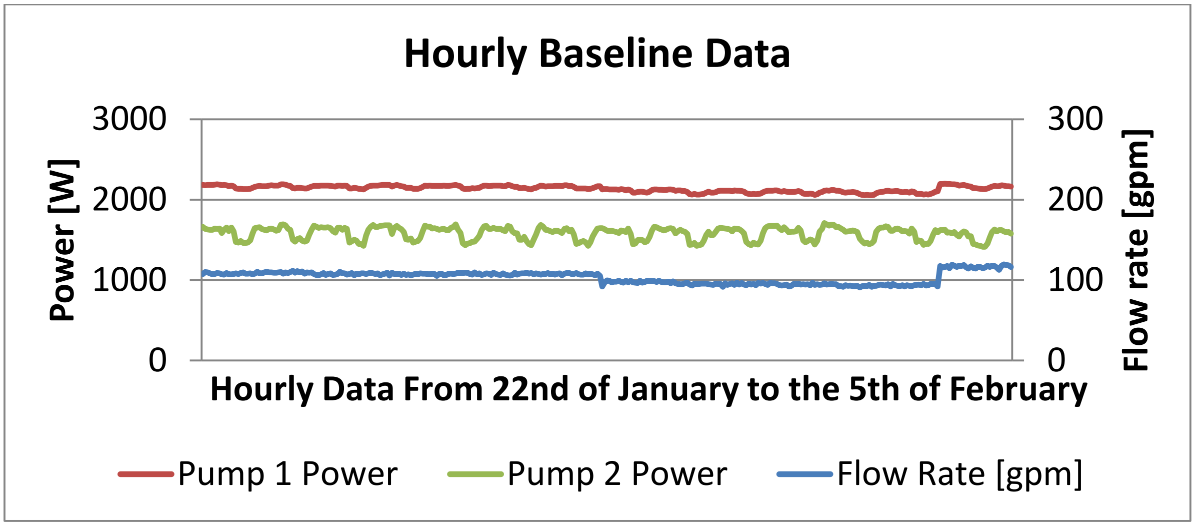


FIGURE 11. BASELINE PERIOD PUMP POWER AND FLOW RATE

EMERGING TECHNOLOGY DATA AND CORRECTION

As mentioned in the Technical Approach & Test Methodology section, portions of the emerging technology system data required treatment or had to be excluded due to various measurement and environmental issues. These included PV system failure, measurement system failures, inadvertent manual shutdowns, filtration blockages due to a storm, and others.

The details are as follows:

- The solar pump 2 data logger was accidentally disconnected from power during a routine filter cleaning. Maintenance discovered that the logger stopped recording when an engineer went to retrieve the data 2 weeks later.
- Similarly, the solar pump 1 logger was disconnected from the power during a maintenance event about 1 week after the first occurrence.
- On April 30 a big storm sent leaves and other debris into the pool. As a result, the flow meter stopped working. It took two weeks to discover this and another two weeks for the pool contractor to thoroughly clean the pool and the pump system.

After a month of stable operation, it was determined that an additional two weeks of data collection would be beneficial at the end of July. Figure 12 shows the total emerging technology monitoring period and the three sections of usable data at the beginning, middle, and end. Gaps in various data elements are apparent outside these three sections.

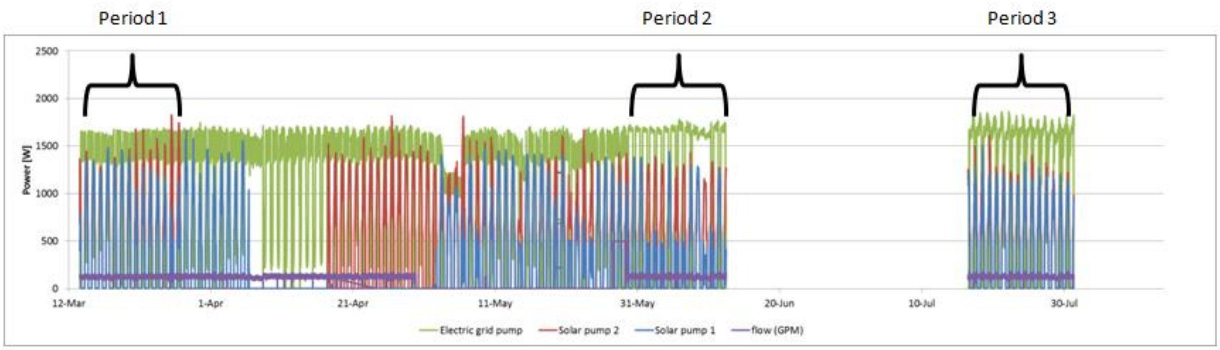
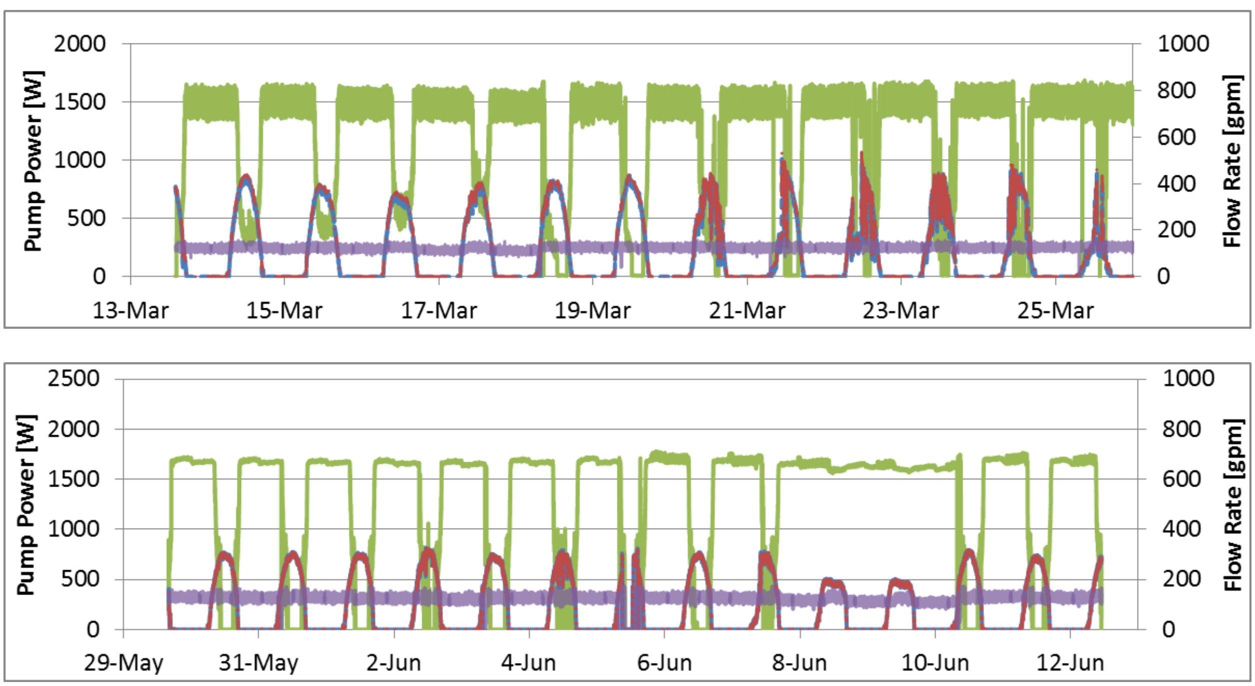


FIGURE 12. EMERGING TECHNOLOGY RAW DATA (AFTER CONVERSION TO POWER IN WATTS)

The daily flow rate profile was consistent throughout the 45 days of emerging technology system monitoring. The grid pump power usage was consistent at night but during the day varied inversely to the power consumption of the solar pumps. This was affected daily by cloud coverage and solar contribution, which increased from March to June and slightly decreased in July as should be expected (based on the sunrise and sunset times).

Figure 13 shows the grid pump power, solar pumps power, and flow rate across the three post-installation measurement periods. Both solar pumps power are plotted but overlay each other. Smoother solar power curves indicate cloudless days and have an obvious inverse relationship to the grid pump power. Days with intermittent cloud cover show more chaotic solar and grid pump power usage.



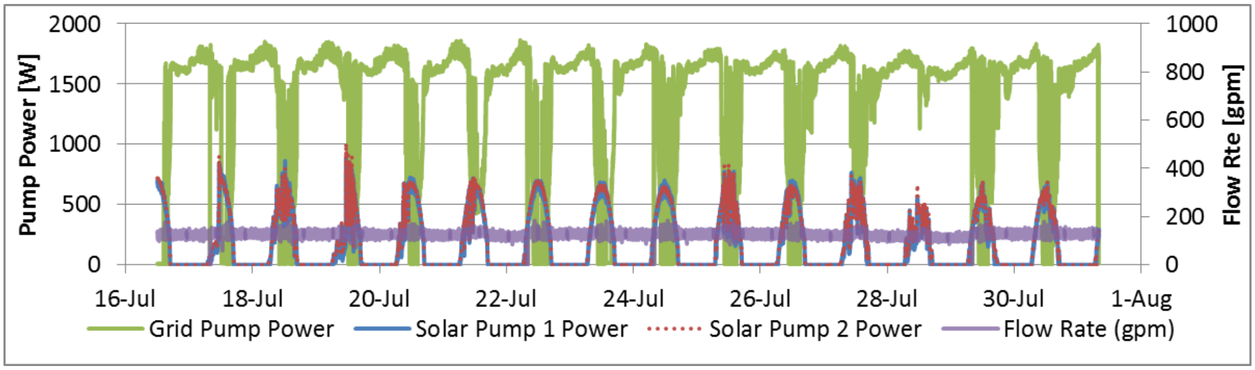


FIGURE 13. POWER AND FLOW RATE FOR 3 POST-INSTALLATION PERIODS

FLOW RATE AND POOL TURNOVER

The California health code for commercial pools requires a flow rate that produces one pool volume of water pumped every 6 hours. The data shows that during the baseline monitoring periods, the flow was not reaching the minimum 139 gpm required by the code; an average of 103 gpm was recorded. With the installation of the new system, the flow was increase to 124.4 gpm on average. This is about a 20% increase, but still not enough to meet the health code requirement. The pump controller installed by the vendor had its own flow meter that read on average 15 gpm more than the one installed by our consultant. When the Health Department visited the installation to ensure the new system met code, the inspector used the vendor-installed meter and approved the installation. The average flow measured by the vendor flow meter was enough to satisfy the code as shown in Figure 14. The consultant and the vendor had several discussions about the difference in readings due to the different type of flow meter, location, and pipe diameters where they were installed. Since both appeared to be installed according to the manufacturer instructions and appropriately calibrated, the discussion was not taken any further.

FIGURE 14. FLOW METER SHOWING INSTANTANEOUS CODE FLOW RATE VALUE (POST-INSTALLATION)

Had a higher flow rate been required by the Health Department, it could easily be achieved by increasing the flow rate set point on the emerging technology system's grid pump controller. Because the flow rate of the new system is dynamic and dependent on the vendor's flow meter, if the vendor-installed flow meter is accurate, and the grid pump is sized appropriately, the minimum required flow rate will be met. Compared to a traditional constant flow rate system, this is preferable to meet health code flow rate requirements.

Flow rates were also fairly constant, without large fluctuations - even with control system response times. Figure 15 shows the pump power and flow rates for March 16 and July 19, with the two solar pump powers combined.

The first plot in shows a typical day where the solar power increases then decreases smoothly with solar production and the grid power reacts inversely. The second plot shows a specific day where clouds passing by intermittently disrupted the solar production and the grid pump compensated fairly quickly to keep the flow rate constant.

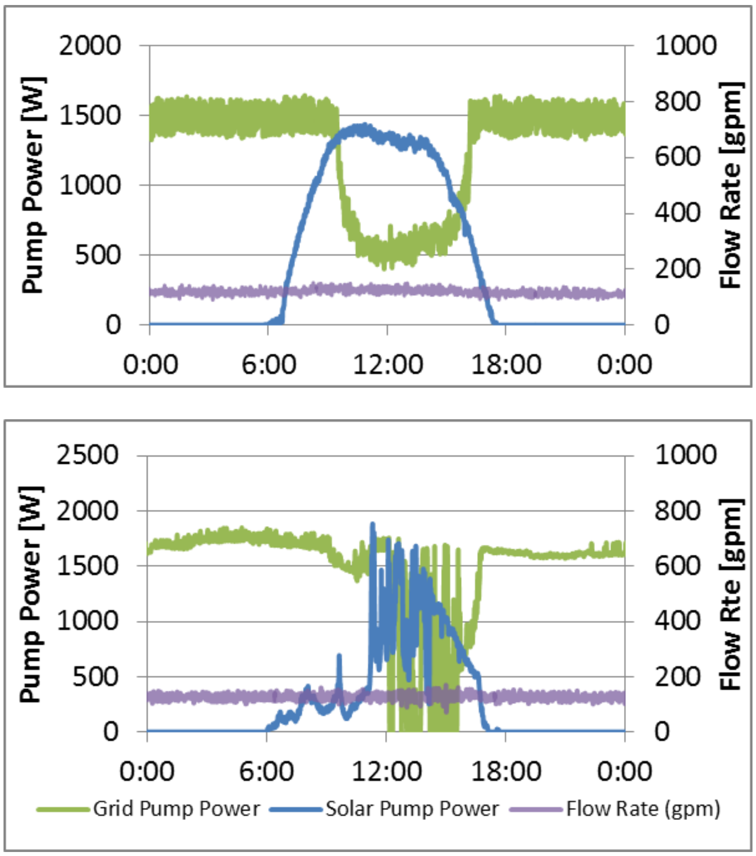


FIGURE 15. EXAMPLE OF TWO POST-INSTALLATION DAYS SHOWING CONSTANT FLOW RATE OVER PV POWER FLUCTUATIONS

SAVINGS OVER MEASUREMENT PERIOD

Power and energy savings were calculated for the data periods. Baseline conditions were steady with fairly constant pump power usage at 3.7 kW. Figure 10 shows the hourly demand profile used to calculate savings. For the emerging technology system, the solar and grid pump power usage profiles varied over the monitoring period. Notably, as the spring progressed, the amount of solar radiation increased in intensity and in length of time per day. As a result, the grid pump used less energy towards the end of the monitoring period than in early March. The average consumption over the three emerging technology monitoring periods averaged 1.3 kW for the grid pump, yielding an average demand savings of 2.4 kW.

The average daily power profile over the emerging technology monitoring periods is shown in Figure 16. The grid pump power curve represents the average daily profile across the three measurement periods. The grid pump power at 12 PM is the average of all grid pump power measurements at 12 PM in Figure 13.

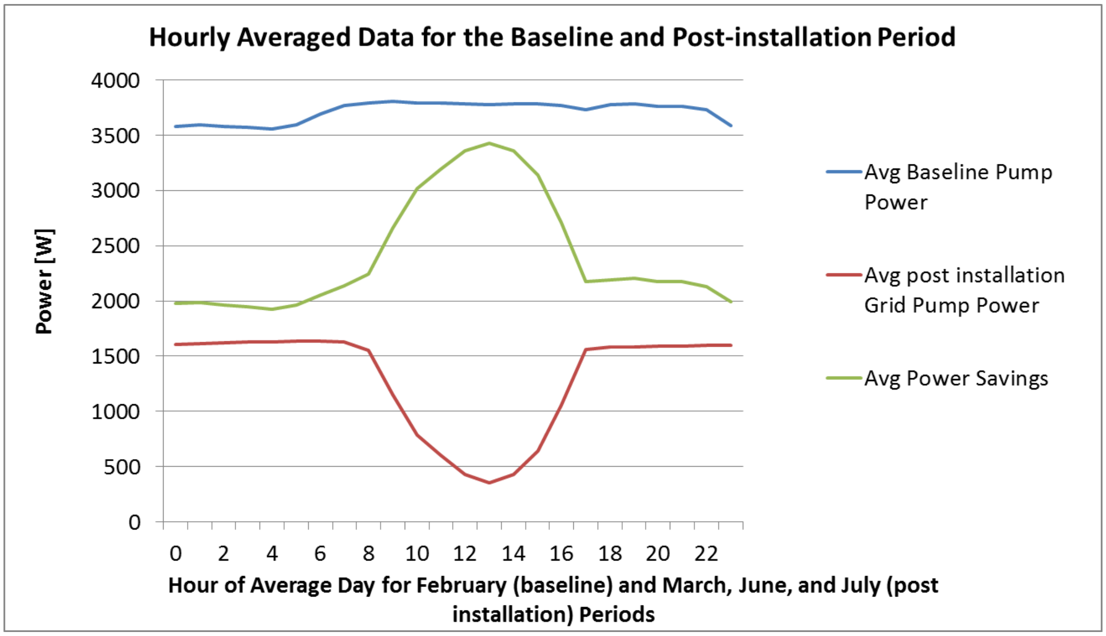


FIGURE 16. AVERAGE DAILY POWER PROFILE OVER EMERGING TECHNOLOGY MONITORING PERIOD

Figure 16 also shows that grid power usage is inversely related to the solar pump power usage. The power savings are calculated by subtracting the average day, hourly power usage of the emerging technology system from that of the baseline system. The savings are a result of both pump efficiency improvements and contributions from the solar pumps. Note that the solar pumps benefits occur during on-peak periods, providing added demand reduction value.

It should be noted that the addition of the more efficient grid pump with VSD, as well as the reconfiguration of the system piping, are responsible for approximately 75% of the overall savings. The solar energy accounts for the remaining 25%. As discussed previously, the common header after the pumps, but before the filters, helps redistribute flow among the two filters. As a result, if one filter loads up more than the other, the other filter helps to reduce potential throttling of pump flow. This helps to reduce an increase in pump energy consumptions. However, it is uncertain to what degree this contributed to the overall energy savings.

Table 10 shows the average hourly flow rate, pump power, demand reduction, and energy savings for the average monitoring period day. The average on-peak demand reduction was 2.9 kW and the total energy savings over the monitoring periods was 2,488 kWh.

See Table 10 for the hourly averaged results.

TABLE 10. AVERAGE POST-INSTALLATION HOURLY POWER AND ENERGY SAVINGS

Hour	Avg Baseline Pump Demand [W]	Avg Baseline Flow Rate [GPM]	Avg Post Flow Rate [GPM]	Avg Solar Pump Power [W]	Avg Grid Pump Power [W]	Avg Demand Savings [W]	Avg Peak Demand Savings [W]	Total Energy Savings [kWh]
0	3578	102.8	123.0	0	1602	1976	-	85
1	3593	103.0	122.9	0	1610	1983	-	85
2	3582	103.3	123.1	0	1618	1964	-	84
3	3570	103.1	123.0	0	1626	1944	-	84
4	3559	103.1	122.7	0	1632	1926	-	83
5	3595	103.5	123.2	3	1634	1961	-	84
6	3691	103.3	123.3	98	1639	2053	-	88
7	3766	103.2	121.1	471	1625	2141	-	90
8	3796	103.2	123.8	781	1552	2244	-	92
9	3805	104.6	128.8	983	1150	2660	-	110
10	3791	103.7	125.3	1146	784	3020	-	127
11	3796	104.5	124.9	1279	600	3196	-	131
12	3787	104.5	125.0	1324	428	3360	3360	141
13	3781	104.0	124.8	1289	351	3430	3430	144
14	3786	104.2	127.7	1124	425	3360	3360	144
15	3785	103.4	128.1	830	644	3141	3141	135
16	3768	102.9	127.8	366	1060	2708	2708	119
17	3734	103.1	125.0	20	1559	2175	2175	96
18	3780	102.6	123.9	0	1587	2193	2193	96
19	3788	103.4	123.8	0	1586	2203	-	97
20	3766	103.0	123.6	0	1588	2177	-	96
21	3765	103.0	123.4	0	1592	2173	-	96
22	3730	103.2	123.3	0	1597	2133	-	94
23	3589	102.9	123.3	0	1597	1992	-	88
Avg	**3715**	102.8	**124.4**	**396**	**1300**	**2416**	**2901**	**2488**

While analyzing the average emerging technology monitoring period day is valuable, it does not capture the effects of solar and weather patterns across the monitored months. To capture this, the data was separated into three periods encompassing all usable data in March, June, and July. Figure 15 shows the average daily power profiles for each monitored month. As over time the solar panels become dusty and solar transmittance goes down, the peak solar power decreases. Along with this reduction, time per day of solar availability increases from March to June as indicated by the wider solar pump power peaks. This then decreases from June to July.

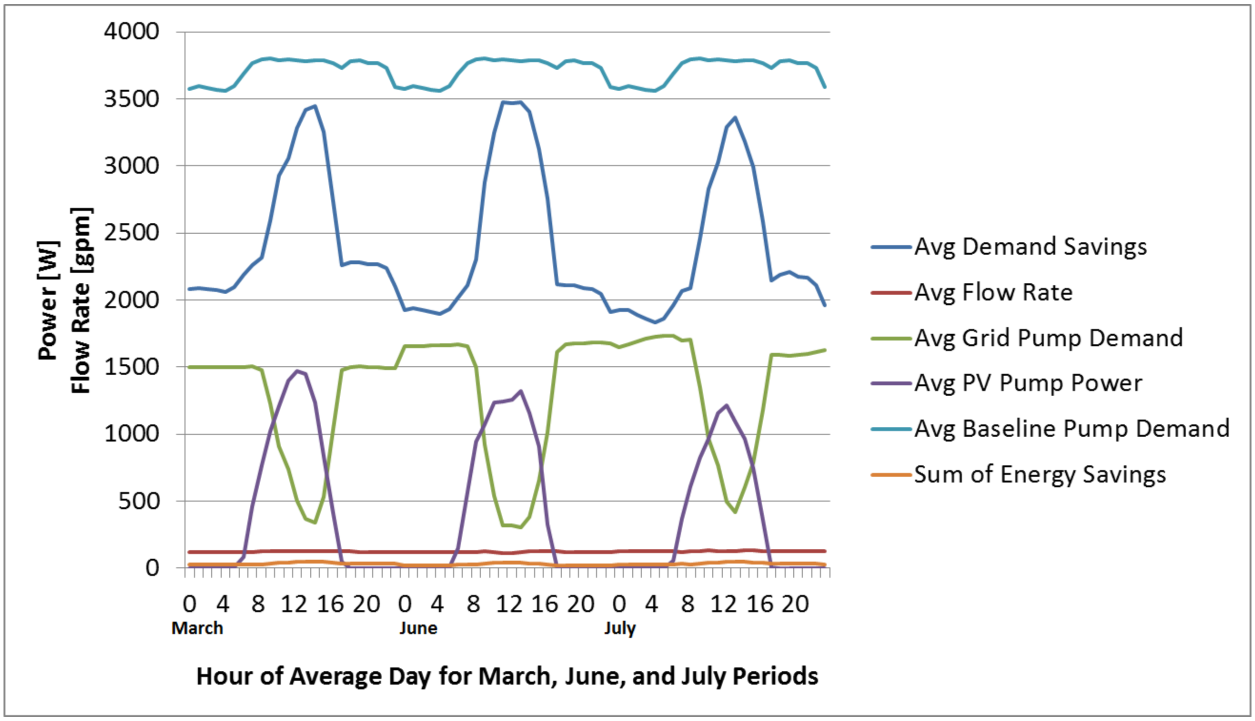


FIGURE 17. AVERAGE DAILY PROFILE OVER POST-INSTALLATION MEASUREMENT PERIOD BY MONTH

Table 11 lists the average flow rate, solar pump power, grid pump power, and demand savings for each of the monitored months.

TABLE 11 - AVERAGE POST-INSTALLATION DEMAND AND ENERGY SAVINGS BY MONTH

MONTH	AVERAGE FLOW RATE [GPM]	AVERAGE SOLAR PUMP POWER [W]	AVERAGE GRID PUMP POWER [W]	AVERAGE DEMAND SAVINGS [W]
March	**124.0**	**425**	**1231**	**2488**
May	**128.7**	**426**	**1235**	**2484**
June	**122.3**	**423**	**1296**	**2418**
July	**125.6**	**343**	**1381**	**2334**
Total	**124.4**	**396**	**1300**	**2416**

ANNUALIZED DATA REGRESSION METHOD FOR EMERGING TECHNOLOGY SYSTEM

In order to determine the annual emerging technology system performance and savings, an annual regression technique is necessary. It should be noted that for the baseline system, multiplying average power usage by 8,760 hours leads to a relatively accurate representation of the total annual energy consumption. This is because baseline power usage should be constant throughout the year.

On the other hand, the emerging technology system requires regression analysis with solar insolation to accurately predict annual solar production and how it will affect grid pump power usage throughout the year. This is because solar pump power is directly impacted by the variation in solar availability. The grid pump power is also impacted since the grid pump must pick up the extra pump work that the solar pumps cannot supply.

By correlating the solar and grid pump powers to historical solar insolation data in W/m^2, regressions were developed for calculating annual performance. The hourly horizontal, terrestrial solar insolation data was averaged over 10 years of NREL data for Ontario, California [National Renewable Energy Laboratory]. Figure 18 and Figure 19 plot the hourly and two-day example of this solar availability data, respectively.

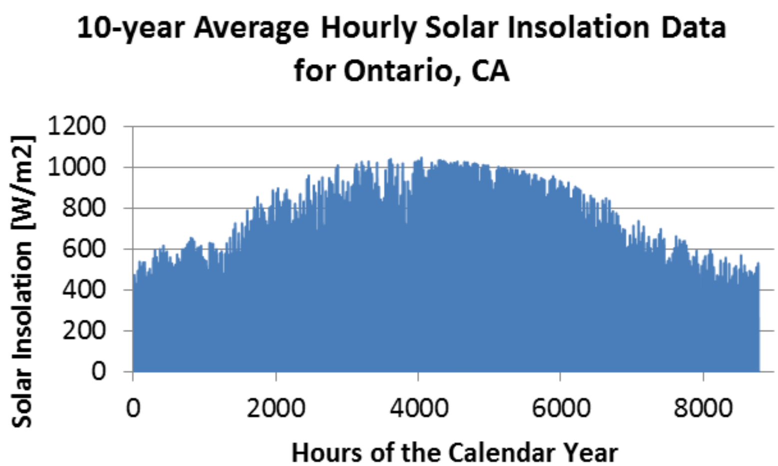


FIGURE 18. HOURLY SOLAR INSOLATION DATA FOR ONTARIO, CA (AVERAGE OF 10 YEARS FROM 2000-2009)

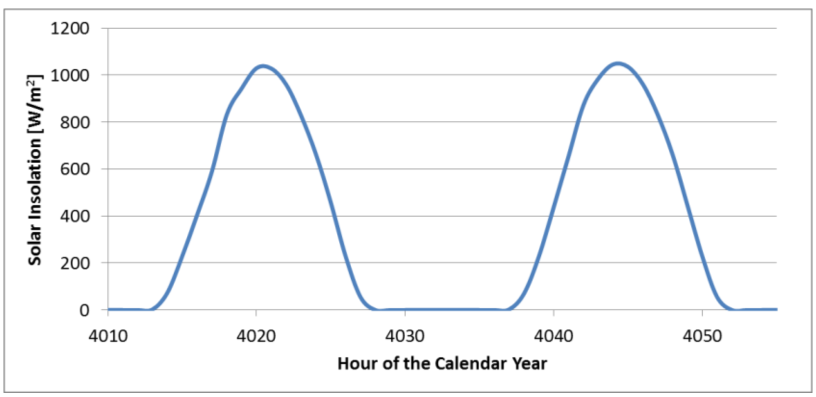


FIGURE 19. EXAMPLE OF TWO SUMMER DAYS' SOLAR INSOLATION

Linear regressions were developed for the solar pump power and a second-order polynomial regression was applied to the grid pump power using an Excel analysis. The solar pump power and grid pump power were aligned with the historical hourly insolation data by timestamp for the 43 days of usable data. A linear equation for solar pump power (as determined by solar insolation) was formulated. This equation was used to calculate the solar pump power throughout the year.

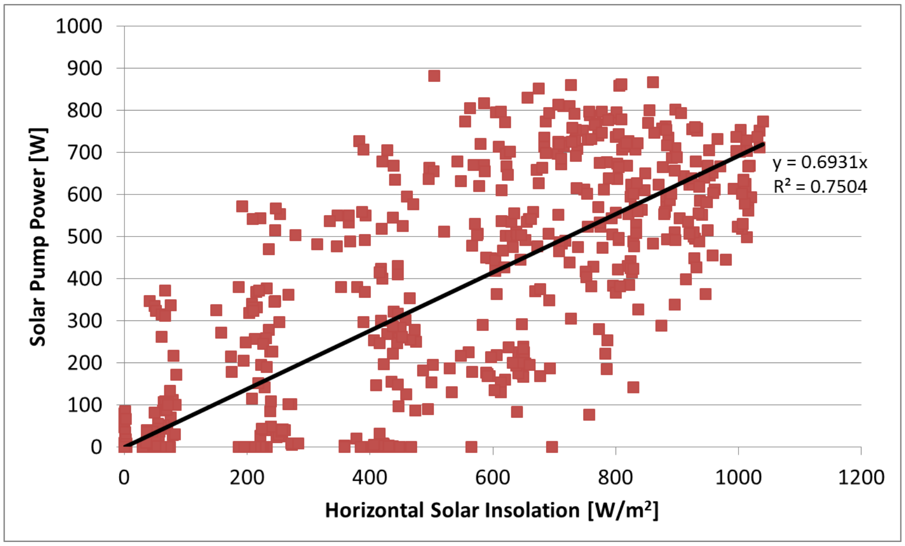


FIGURE 20. LINEAR REGRESSION FOR ONE SOLAR PUMP POWER

Similarly the grid pump power consumption was analyzed against solar radiation levels. In this case, as expected, the grid pump consumption is inversely related to solar radiation. More solar radiation means more solar pump work and less work required by the grid pump to meet the minimum required flow rate. The grid pump regression equation was used to forecast the grid pump power consumption over an entire year based on the location's average solar insolation data.

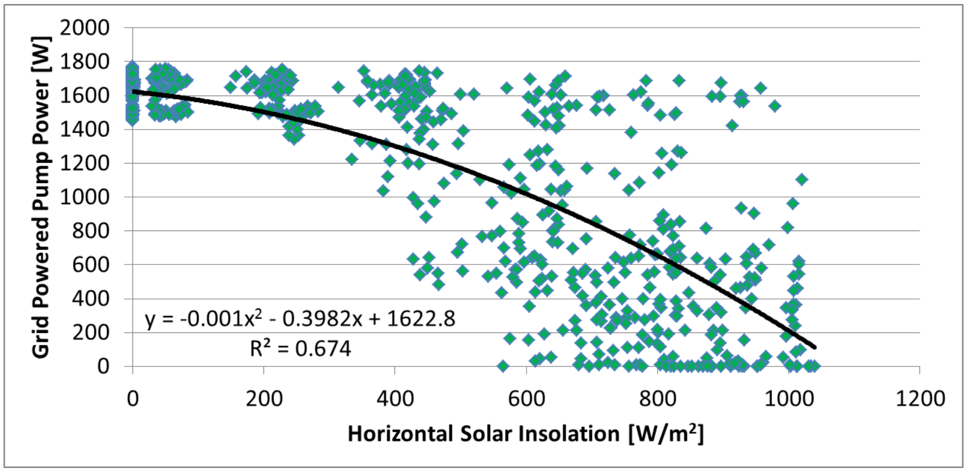
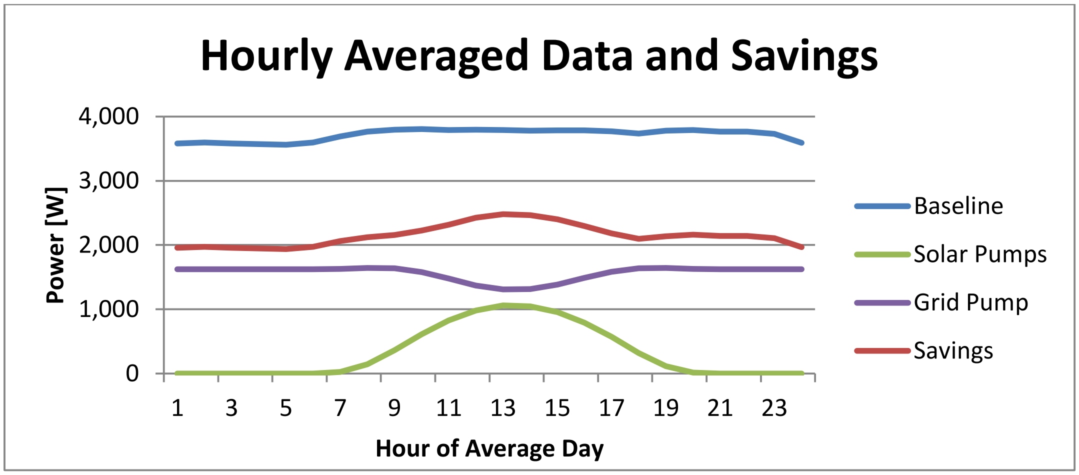


FIGURE 21. SECOND ORDER POLYNOMIAL REGRESSION FOR VSD GRID-POWERED PUMP

ANNUALIZED PUMP POWER AND DEMAND SAVINGS

Using the regression equations above, hourly solar and grid pump power was calculated for the average calendar year in Ontario, CA. The grid and solar pump powers were calculated for each hour of average solar insolation. The results are annualized assuming regular cleaning of solar panels in order to maintain the effectiveness observed over the test period.

The average daily pump power usage and demand savings are plotted in the following figure as averaged for the entire year. Since the flow rate increased with the installation of the emerging technology system, the savings are presented using both the actual flow rate results and an adjusted method. The baseline energy consumption and demand were calculated for the baseline system with a flow rate equal to that of the emerging technology system. The savings are calculated with reference to the average baseline day presented in Figure 22. The second of the two figures shows the savings if the baseline system had produced the same flow rate as that of the emerging technology system. Again, the savings are a combination of improved pump and piping efficiency along with solar pump performance.



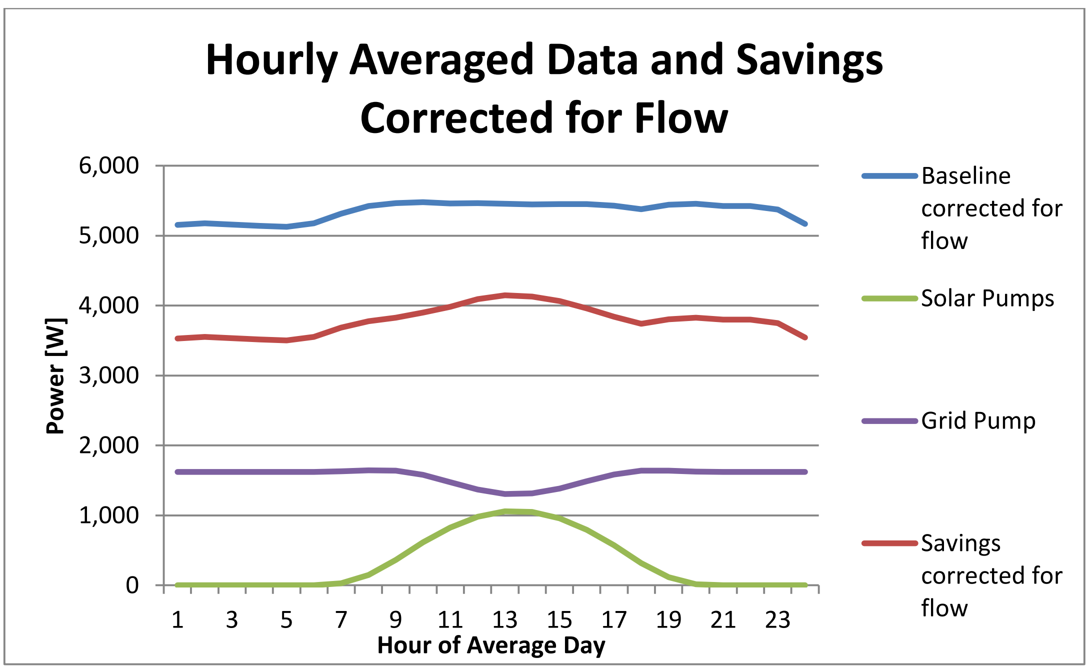


FIGURE 22. AVERAGED DAILY PROFILE FROM ANNUALIZED RESULTS

As a result of the regression analysis, the annual energy savings normalized for the solar radiation throughout the year were calculated to be 18,840 kWh or 57%

including both solar and VSD related savings. The average annual on-peak demand savings is 2.3 kW.

Since performance will vary significantly across seasons, the average daily power and savings for each month are shown in Figure 23 and Table 12.

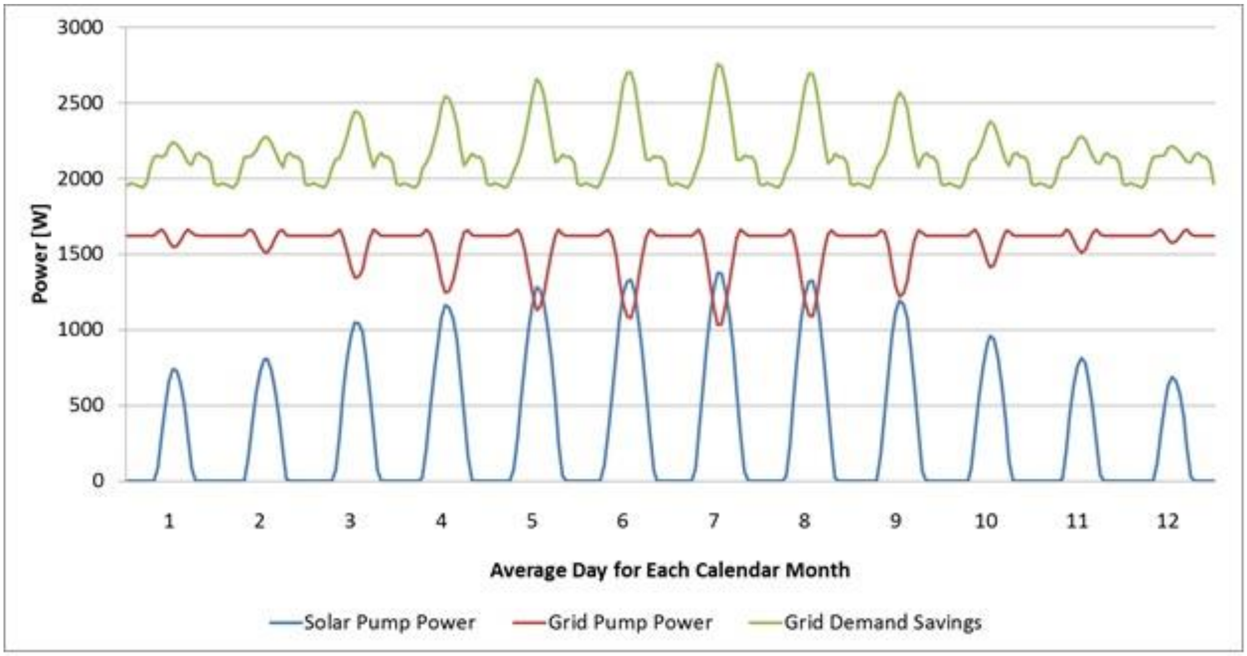


FIGURE 23. AVERAGE DAILY PROFILES FOR EACH MONTH OF THE ANNUALIZED RESULTS

TABLE 12. AVERAGE MONTHLY DEMAND AND ENERGY SAVINGS

MONTH	AVERAGE OF SOLAR PUMP POWER (BOTH PUMPS) [W]	AVERAGE OF GRID PUMP POWER [W]	AVERAGE OF DEMAND SAVINGS [W]	AVERAGE OF ON-PEAK DEMAND SAVINGS [W]	SUM OF ENERGY SAVINGS [KWH]
Jan	190	1620	2096	2167	1560
Feb	226	1612	2104	2186	1414
Mar	317	1576	2140	2275	1592
Apr	378	1551	2165	2328	1559
May	426	1526	2190	2391	1629
Jun	456	1509	2207	2429	1589
Jul	469	1498	2218	2448	1650
Aug	433	1514	2202	2412	1638
Sep	365	1550	2166	2326	1560
Oct	270	1594	2122	2223	1579
Nov	213	1613	2103	2179	1514
Dec	174	1624	2092	2156	1557
	327	**1565**	**2151**	**2294**	**18,840**

It should be noted that the flow increased approximately 20% because the contractor needed to meet the health code pool turnover requirements. The energy savings normalized to this 20% increase in flow rate would have been much higher. If the baseline system had the same higher flow rate as the emerging technology system, the savings would have been approximately 33,160 kWh/yr. These estimated savings are calculated by using the regression analysis of the solar pump power and the increased amount of flow that the baseline AC grid pumps would have to provide. Due to the exponential behavior of kinetic losses, the savings increased significantly because of the power of the pumps affinity laws.

Alternatively, if the emerging technology system had the same lower flow rate as the baseline system, the annual savings would have been approximately 23,000 kWh/year, as calculated using pump affinity laws. This is calculated by using the regression analysis of the solar pump power and reducing the emerging technology grid pump's energy consumption to a level equivalent to that of the decreased flow rate.

ECONOMIC RESULTS

Using the annualized savings and total installation cost, the economics of the system can be discussed. Table 13 presents some simple economic metrics without accounting for cost of capital, but includes a 2% utility rate annual increase and the 30% investment tax credit that the federal government allows if the system is installed by 12/31/2016. The system would also be eligible for the CSI program, but the funds for that program are nearly depleted and unless the state legislation acts, they will not be available in the future. The calculations assume a utility rate of 0.15 $/kWh. The second line in Table 13 shows the exact dollar savings when the customer's time of use rate (TOU-GS-1-A) is applied on an hourly basis. Payback time drops due to the cost benefit of the solar pumps reducing grid power consumption during on-peak and mid-peak periods.

TABLE 13. FIRST YEAR SAVINGS AND ASSOCIATED FINANCIALS

SYSTEM COST	ANNUAL ENERGY SAVINGS [KWH]	MAX ON-PEAK DEMAND REDUCTION [KW]	ESTIMATED TAX CREDIT [$]	ANNUAL COST SAVINGS [$]	SIMPLE PAYBACK [YEARS]	NPV (WITH 3% ACC)	ANNUAL CO_2 SAVINGS [TONS]
$35,300	18,840	2.84	$10,590	$2,826	8.0	$26,109	13
$35,300	18,840	2.84	$10,590	$3,291	6.9	$34,349	13

The annual savings are plotted in the following figure for the utility rate of $0.15/kWh and assumes a 2% annual rate increase. The calculations assume a 0.5% degradation in PV effectiveness per year [Dirk Jordan] and equivalent operations and maintenance costs between an emerging technology system and a typical pump system.

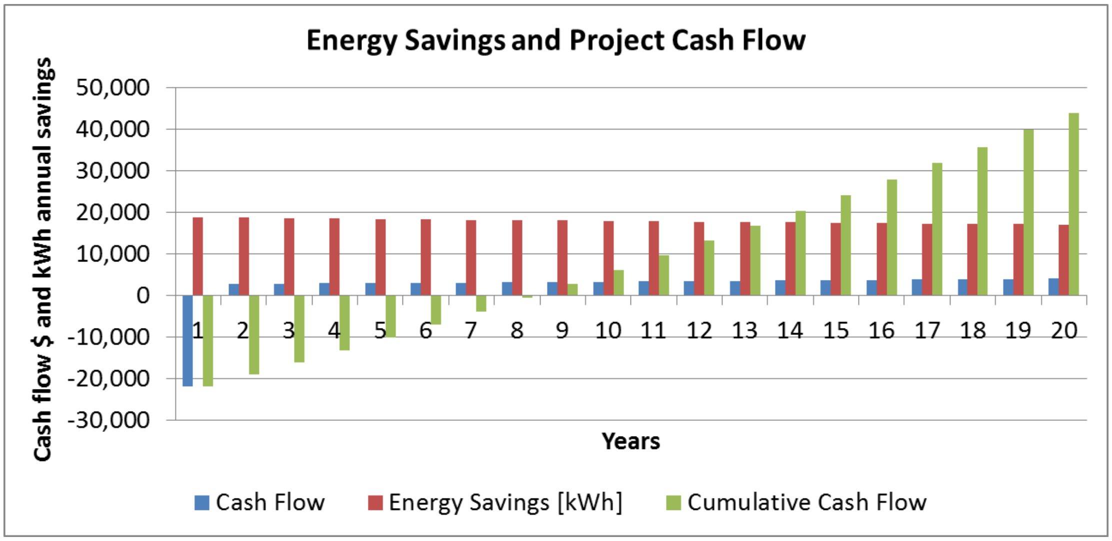


FIGURE 24. RETURN ON PV PUMP SYSTEM AND ANNUAL ENERGY SAVINGS DEGRADATION

DISCUSSION

The emerging technology pool pump system was successful in achieving a lower demand profile and energy consumption while being able to maintain the necessary pool turnover rate required by health code. These savings are apparent during all times of the day as the emerging technology is a prime opportunity to not only install solar-powered DC pumps but also to improve grid-powered pump efficiency and piping design. Chief among the achievements of the technology is the integration of solar PV production without incurring net metering or any other form of power sent back to the grid. From a grid perspective, this installation has the advantage of lowered demand during sunnier, on-peak and mid-peak hours without overproducing or creating any other issues for the grid.

From an energy efficiency and reduced emissions perspective, the new pool pump system has benefits over the typical design. Energy and demand savings are significant, and because of this, payback times are less than the system EUL. Using a utility rate of $0.15/kWh, we see a payback of about 8 years. With the baseline flow rate corrected to meet health code requirements (increasing the baseline flow rate by 20%), there is a payback of 4.5 years. Other than energy and demand savings, there are few operational benefits other than reduced emissions. The technology is most appropriate for new construction, but retrofit applications are worth consideration. There are some market barriers to widespread adoption including possible pool professional resistance and high upfront costs.

There were difficulties during the post-installation measurement period including environmental and instrumentation issues that reduced the overall measurement period from the planned 3 months to 43 days. Despite this, the field test clearly showed energy and on-peak demand savings of about 2,500 kWh and 2.9 kW over the 43 days of post-installation monitoring. When annualized using 10-year average solar insolation data for Ontario, California, annual energy and average on-peak demand savings of 18,840 kWh and 2.3 kW can be estimated. Once the data includes a correction for the changes in flow rate from baseline to emerging technology, the savings increase to about 23,000 or 33,160 kWh, depending on the normalization method.

CONCLUSIONS

Based on the discussion, this is a promising hybrid system of existing technologies that may be attractive to many commercial pool owners and pool professionals. Not only will it save the owner money over the life of the technology, it can also serve as a public relations and marketing boon. Many companies often list their energy efficiency and conservation efforts as accomplishments and accolades to attract customers. It will also better maintain the pool turnover rate required by health code over traditional constant speed systems.

RECOMMENDATIONS

Since this system, as a whole, is a combination of energy efficiency and distributed generation technologies that are already eligible for utility incentives, the system is not likely suited to an entirely new program offering. However, since the market size is large and consumes a lot of energy, and the system has apparent energy efficiency benefits, supporting the implementation of this type of system may be worthwhile. In order to avoid unnecessary time spent on incentive applications for the various technologies, perhaps a streamlining of incentives for this type of system is reasonable.

To support the implementation of this pool pump technology, several things can be done as follows:

- System design refinement: The field trial of the system required a lot of fine-tuning, commissioning, and ongoing adjustments over the measurement period. This was, in part, due to the novel nature of the system and the uncertainties in control procedures in early application situations. Refining the design and control of such a system can aid in reducing the complexity and design deficiencies during installation.
- Best practices: Best practices and standard operating procedures for this type of pool pump system can take the guesswork out of owning and maintaining it.
- Follow-up study: Follow-up studies can recalculate the energy and demand savings using the refined system design mentioned above. In addition, extrapolation of these findings to other locations with differing solar insolation patterns and different pool sizes may prove valuable in assessing the overall benefit to SCE, California, and customers of various size and location.
- Technology advocacy and showcasing: Becoming an expert and championing this technology would allow SCE to encourage its adoption by the market. One way to do this is to develop a showcase system or model for public viewing.
- Professional training: Seminars and training courses for pool professionals and owners are another way for SCE to increase public awareness of this new pool pump system.

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