Swimming Pools as Heat Sinks for Air Conditioners

Final Report

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Abstract

This paper describes the results from demonstrations and modeling of a retrofit technology for allowing air conditioner waste heat to be rejected to a swimming pool. The field test results showed that the technology reduced air conditioning energy use by 13% while also providing pool heating that increased pool temperatures by an average of 2.3°F during the monitoring period. The retrofit technology provided the largest benefit during hot conditions with a 31% improvement in air conditioning efficiency when outdoor temperatures were above 95°F. Simulations showed the technology can achieve over 500 kWh of annual cooling energy savings for a home in warmer climate zones while cooler climate zones showed minimal savings. The cost and complexity of the retrofit installation represents a market barrier, but this could be overcome as contractors gain more experience with the system or increased development by the manufacturer that results in a more straightforward installation.

Executive Summary

Overview

This document describes the results of field evaluations of a system that facilitates the rejection of waste heat to a swimming pool at two locations in California. The purpose of the study is to determine the cooling energy savings that can be achieved by the retrofit and measure the pool heating provided by the technology. Two residential homes in West Sacramento, CA, were retrofitted with the technology by integrating the equipment into their existing air conditioning systems. The technology evaluated is designed to be installed in combination with standard air conditioning equipment with controls to avoid overheating the swimming pool. The efficiency improvement of the air conditioner when rejecting heat to the pool was evaluated to determine the energy savings of the technology. Furthermore, this project provides additional validation of a pool thermal model that was used in this project to predict performance of the system in future applications. The model was used to evaluate the potential impact of the technology in each of the 16 California Climate Zones. This tool is intended to provide the utilities with a method for estimating energy savings from installations of the technology in their service territory.

Key Findings

The demonstrations in this project measured the air conditioning energy savings from the technology retrofit and provided necessary data to validate a model that can be used to predict energy impacts in different applications. Field results showed the technology achieved a 13 percent higher air conditioning efficiency than the existing air-source condenser. Rejecting heat to the pool was 31 percent more efficient than rejecting heat to ambient air when outdoor temperatures were above 90°F. Both the cooling capacity was higher, and power draw was lower during hotter outdoor air conditions. The data suggests that the pool-source and air-source systems performed comparably when ambient temperatures dropped to about 77°F. These results depend on the temperature conditions of the pool which for this case averaged 79.2°F when used as a heat sink for air conditioning events during the study period.

More than 2,000 simulations were conducted, using the model developed to evaluate the potential impact of the technology in different applications in each of the 16 California climate zones. The results showed significant energy savings potential in climate zones with higher cooling demand. The savings in the hottest climate zones (CZ15) were more than 2,000 kWh per year for a single-family home. Energy savings is highly variable, depending on climate zone, pool size, shading conditions, and more. Due to the variability in energy savings, the model is needed to better estimate energy savings in particular applications and could be used as part of a utility program to determine the benefits of the technology.

The retrofit system also provides “free” pool heating by sending heat to the pool that would otherwise be lost to the environment. Over the nine-week monitoring period, there were 285 more hours above 80°F, compared with the pool without added heat from the air conditioner. This technology can therefore improve the efficiency of air conditioning, while also offsetting fuel used for heating a pool. Unlike a traditional pool heater, the pool heating achieved by the pool-coupled air conditioner depends on the cooling load in the home relative to the size of the pool. To put this into context with traditional solar thermal pool heating systems, a simple analysis was conducted showing the pool-coupled air conditioner at Site 1 provided heat similar to a solar pool heating system sized at 40% of the pool surface area.

Recommendations

The field demonstrations and model simulations show that the technology evaluated can reduce cooling energy use of existing air conditioners while also providing pool heating. The simulations performed based on loads from two single-family prototypes showed energy savings that exceeded 500 kWh per year in multiple climate zones, with a significant fraction of this energy savings coming during peak times (4 p.m. to –9 p.m.). The installation complexity and cost could impact adoption rates, but it is expected that costs would come down as contractors became familiar with the installation process. Unfortunately, these costs could prevent the system from being cost-effective based strictly on the energy savings alone but installing it in place of a traditional pool heater may be a better pathway toward achieving cost effectiveness.

Below are some observations from the field studies that could help with maximizing energy savings and guide measure development:

- The technology does not have a sophisticated way to interact with the existing pool pump controls. It is the manufacturer’s recommendation to always send water to the pool-refrigerant heat exchanger to avoid issues related to controls, but they do have a control strategy that allows the system to simulate a solar thermal pool heating system. For systems with long plumbing runs to the heat exchanger, a three-way valve can be used along with the built-in solar thermal controls for the pool pump, to avoid additional pumping power when the air conditioner is not running.

- The system is not designed to turn the pool pump on and off, so the pool pump must be running to use the technology for cooling the condenser. For the demonstrations, the pool pumps were scheduled to perform filtering operations during the afternoon to coincide with air conditioning energy use. A variable speed pool pump allows for optimal control since the pump can be set at low speeds over longer periods of time for filtering, allowing the system to be available for air conditioning heat rejection over more hours of the day.

- The pool temperature setpoint should be set as high as possible to maximize pool-source heat rejection and energy savings. This setpoint temperature will not necessarily be maintained by the system but instead be considered the maximum allowable pool temperature for the homeowner.
- The pool modeling tool developed by WCEC, which authored this report, should be used to estimate the energy savings from a particular installation. The more information provided to the model, the better the prediction for energy savings will be. It is expected that the percentage cooling energy savings will likely be the best predictor of actual performance, since the total energy savings is based on loads from an EnergyPlus prototype. If the utility can estimate cooling energy use for a home, then combining that estimate with the percentage savings result will likely provide a better estimate for total energy savings.

Stakeholder Feedback

The stakeholders in this project evaluation include the manufacturer, utility program managers, and HVAC installers. The following is a summary of feedback received from each of these stakeholders throughout the project.

Manufacturers

Discussions with the manufacturer of the technology provided insight on their view of the primary market for the technology. This product is marketed as a pool heating system and the recommendations reflect that when discussing specific applications. As part of the recommendation, they provide guidance to prospective customers on the number of hours of runtime the air conditioner would need to maintain the pool at low- to mid-80 ° F temperatures. They used a combination of air conditioner capacity and pool surface area to make this determination, and for the sites in this study they recommended the air conditioner run for 7.9 hours per day for Site 1 and 4.1 hours per day for Site 2. They note that adding a pool cover would reduce the required hours for adequate pool heating. Clearly meeting the estimated air conditioning runtime would depend on the cooling load rather than the pool heating needs and is likely to be met on hotter days than cooler ones.

The other topics discussed with the manufacturer were what types of equipment the technology works with. They recommend against using this technology on variable capacity equipment due to the presence of additional sensors that may cause a fault when the technology interrupts the refrigerant flow or condenser fan operation. The technology does work with heat pump units, but only in the cooling mode. The manufacturer does not currently support using the pool as a heat source for a heat pump in heating mode, due to the expectation that the pool does not have enough thermal capacity to avoid overcooling. Simulation using the pool thermal model in this project show that this approach could be beneficial in some climate zones and should be a topic for further research.

Lastly, the project team discussed the potential for the manufacturer to offer the components in a pre-built package to simplify the installation. This approach would increase the equipment costs but reduce the installation costs. The HVAC contractors expressed concern about the complexity of the installation. These complexities and unknowns result in higher bids from contractors to perform the work to allow for contingencies. It is expected that a contractor familiar with the technology would quickly become comfortable with the installation, but reducing the field-installed components would streamline the install and allow contractors that are not familiar with a more straightforward scope.

HVAC Installers

The installer of the technology was contacted to discuss the complexity of the installation and overall potential from their point of view. The installation process required the same skillset as many other HVAC installations, but the fact that the technology was new to the installer meant that the installation team had to take more time to review installation guidelines and steps. The first installation took about twice as long as the second due to this lack of familiarity. With a familiar installation crew, the process would be similar to other HVAC installations. There is also a need to install plumbing on the pool equipment that HVAC installers may or may not be comfortable with. This project worked with a separate pool contractor for the pool equipment installation that is similar to the process for a solar thermal or mechanical pool heating system.

Utility Program Managers

One of the key products of this research was the development and validation of an evaluation tool that can be used to estimate energy savings potential from the system in different applications. This tool can be used by utility program managers to provide appropriate incentives for customer installations.

Abbreviations and Acronyms

Acronym	Meaning
AC	Air Conditioner
COP	Coefficient of Performance
CZ	Climate Zone
DB	Dry-bulb
EER	Energy Efficiency Ratio
HVAC	Heating, Ventilation, and Air Conditioning
HX	Heat Exchanger
IECC	International Energy Conservation Code
IOU	Investor-Owned Utility
kWh	Kilowatt-hour

Acronym	Meaning
RMS	Root Mean Squared
SEER	Seasonal Energy Efficiency Ratio
TMY	Typical Meteorological Year
UC	University of California
WB	Wet-bulb
WCEC	Western Cooling Efficiency Center

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Introduction

Heat rejected from air conditioners is generally directed to the outdoor air which is hottest when air conditioning is most required. By rejecting air conditioner heat to a swimming pool, the efficiency of air conditioner improves for the following reasons: 1) swimming pools are cooler than outdoor air during the hottest part of the day, and 2) rejecting heat to water is more efficient than rejecting heat to air. A secondary benefit of this approach is that the heat rejected from the air conditioner provides pool heating that improves comfort.

Previous research has indicated that rejecting heat to a swimming pool can save 25 to 30 percent on annual air conditioning electricity consumption in California (Harrington and Modera 2013). In addition, running a three-ton air conditioner for 2.5 hours would provide pool heating equivalent to one therm of natural gas used in a 90 percent efficient gas pool heater. This system could be used to offset natural gas used for pool heating.

This document describes the results of field evaluations of a system that facilitates the rejection of waste heat to a swimming pool at two locations in California. Two residential homes in West Sacramento were retrofitted with the technology by integrating the equipment into their existing air conditioning systems. The technology evaluated is designed to be installed in combination with standard air conditioning equipment with controls to avoid overheating the swimming pool. The efficiency improvement of the air conditioner when rejecting heat to the pool was evaluated to determine the energy savings of the technology. Furthermore, this project provides further validation of a pool thermal model that was used to predict performance of the system in future applications. This model was used to evaluate the potential impact of the technology in each of the 16 California Climate Zones.

Background

The California Residential Appliance Saturation Study (Palmgren, et al. 2021) states that air conditioner energy use is the main driver of residential peak load. The average annual unit energy consumption for air conditioning equipment is 1,136 kWh per household with several California regions using more than 2,000 kWh per year. Thus, reducing air conditioning energy use is a critical focus in order to achieve California’s goal of reducing greenhouse gas emissions by 40 percent, relative to 1990 levels, by 2030.

Air conditioning equipment often lasts twenty years or longer, so while air conditioning equipment performance has improved over the years, many older less efficient systems are still in operation. Identifying strategies for reducing air conditioning energy consumption on existing equipment will provide a path for addressing air conditioner energy use before replacement is required. The technology demonstrated in this project facilitates the rejection of waste heat from the condenser of an air conditioner to a swimming pool instead of ambient air. This technology has the added benefit of providing free heat to the swimming pool which can offset fuel used for heating swimming pools. This project will focus on the improved air conditioner performance as a result of the technology and provide necessary data to develop tools for predicting the performance for specific applications which can help utilities estimate energy savings.

Objectives

The objectives of this project include the following:

- Measure performance of air conditioner with the emerging technology relative to the existing baseline equipment
- Validate pool thermal model used for predicting performance of the technology
- Develop a tool for estimating energy savings that can be used in utility programs

The retrofit technology was installed on two residential swimming pools in California. The field tests measured the impact on air conditioner performance when rejecting heat to the swimming pool, compared with the performance of the existing baseline air conditioning equipment. The project team documented the installation process and reported on the cost and complexity of the installation. A pool thermal model was validated using the results from this field test. This model was ultimately used to predict performance of other prototype installations in each California Climate Zone. The simulations consider the energy implication of the system and provide general guidance as to where the system is most beneficial. The simulation model was packaged into a simple tool for determining deemed energy savings, based on information provided about a potential project site.

Methodology & Approach

Instrumentation was installed to measure the performance parameters of the air conditioning system, weather conditions, heat delivered to the pool, and power draw of the pool pump. The ratio of cooling capacity to power draw of the air conditioner is defined as the coefficient of performance (COP) and describes the efficiency of the system. There are several parameters that impact the COP of an air conditioner, including the temperature conditions of both the outdoor air or pool water and indoor air.

Data was collected to characterize the efficiency of the air conditioning system when rejecting heat to pool water and to outdoor air. A comparison was made between the efficiency of the cooling operation when rejecting heat to the pool versus the cooling operation when rejecting to outdoor air. This allowed an appropriate determination of the performance improvement of the technology.

The measurement period occurred over one cooling season in summer 2023. Baseline data was collected on the existing air conditioning system from May to August before the retrofit, which provided the baseline for energy savings calculations. After collecting the data on the existing air conditioner performance across a range of outdoor air conditions, the emerging technology was installed, and post-retrofit monitoring occurred from August to October. Performance data for the system across a range of conditions allowed for future simulations of the technology in different climate zones to determine the benefits to air conditioning energy use and pool comfort.

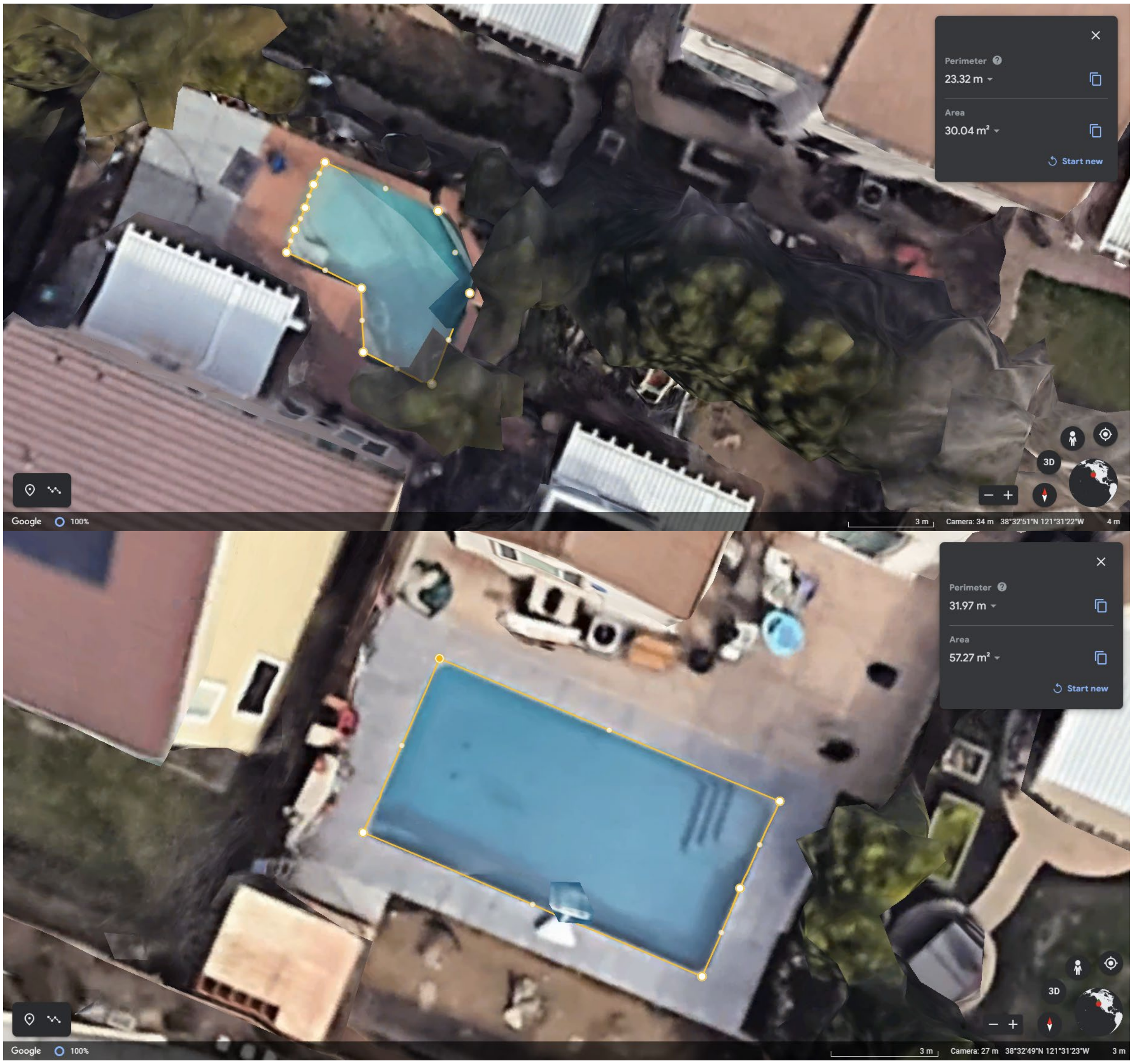
Cooling capacity was determined by monitoring the temperature and humidity of air at the supply and return of the air handler. The airflow of the single-speed air conditioner was measured in each zoning configuration, using a tracer gas airflow measurement device. The power consumed by both the outdoor and indoor units was monitored and used along with the cooling capacity to determine the overall system performance. Pool pumping power was also considered when evaluating air conditioner performance. In some cases, the pool pump will be operating to filter the pool at the same time as the cooling operation while at other times the pool pump will need to be running in order to perform the cooling operation with the pool. Ideally, the pool filtering schedule would be determined by subtracting the filtering performed during cooling cycles, but this control logic is not built into existing pool pump control systems.

Technology Description

The technology demonstrated in this project is a secondary condenser that sits beside the existing condenser unit. A controller can direct refrigerant to the existing air-source condenser or pool-source condenser, depending on the pool temperature conditions. The controls allow for management of pool temperature by switching to the existing air-source condenser when pool temperatures meet or exceed the setpoint temperature. The resident will be able to adjust this temperature to their desired comfort. The controls will allow the use of the existing air conditioning condenser when pool temperatures exceed the setpoint. When a call for cooling occurs, the air conditioner will start in its traditional mode and a signal will be sent to turn on the pool pump. After a preset delay to allow fresh pool water into the plumbing, the pool water temperature is measured, and it is determined whether the pool is below the setpoint temperature. If the pool temperature is below the setpoint, the system will switch the refrigerant valve to the pool-source condenser and shut down the condenser fan. The controller will continue to monitor pool temperature and switch back to the air-source condenser if the setpoint is met.

Test Sites

The sites for the project were single-family residences in West Sacramento, CA (Figure 1). One pool was heavily shaded, located in a north-facing yard, while the other had minimal shading in a south-facing yard. The existing air conditioning systems were monitored for a period of about three months. This allowed WCEC to characterize the baseline performance across a range of outdoor air temperatures. The retrofit occurred on August 16th, 2024, at which point the post-retrofit monitoring period began and continued for about nine weeks, at which point the air conditioner use was limited by cooler weather conditions. The installation required the following steps: 1) remove the refrigerant from the air conditioner, 2) add refrigerant components, including a three-way valve, refrigerant solenoid valves, check valves, liquid line receiver, water-to-refrigerant heat exchanger, and an install condenser fan relay, 3) recharge the unit, and 4) install the controller. No additional refrigerant is required when installing the technology, however, in one case, a low charge was discovered at one of the sites when performing the retrofit that required additional refrigerant charge to be added.



Perimeter 23.32 m
Area 30.04 m²
3 m
Camera: 34 m 38°32'51"N 121°31'22"W
4 m

Perimeter 31.97 m
Area 57.27 m²
3 m
Camera: 27 m 38°32'49"N 121°31'23"W
3 m

Figure 1: Residences used for testing emerging technology. The pool in the top image is heavily shaded in a north-facing yard, and the pool in the bottom of image is minimally shaded in a south-facing yard.

Test Plan

A general schematic of the system components and measurement points is shown in Figure 2. This outlines the plumbing connections that connect the technology water-to-refrigerant heat exchanger to the pool system, as well as the relative location of various sensors. Note that some of the instruments are only required for the retrofit period and will be added during the installation. These include the pool water flow, and temperatures entering and exiting the water-to-refrigerant heat exchanger. The specific sensors installed are outlined in Table 1 below.

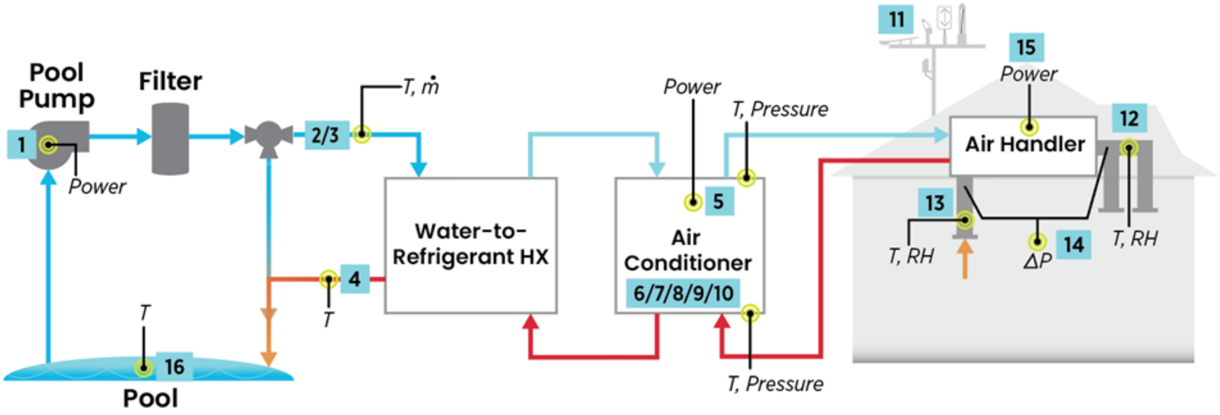


Figure 2: Instrumentation schematic showing points of measurement (T – temperature, $\dot{m}$ – flowrate, RH-relative humidity, ΔP – differential pressure).

Pool Heating

The heat absorbed by the pool from the air conditioner was measured by collecting data on the temperature entering and exiting the water-to-refrigerant heat exchanger of the retrofit technology combined with the water flow rate. This should agree with the air conditioner (AC) performance data collected (pool heating = AC cooling capacity + AC power – thermal losses).

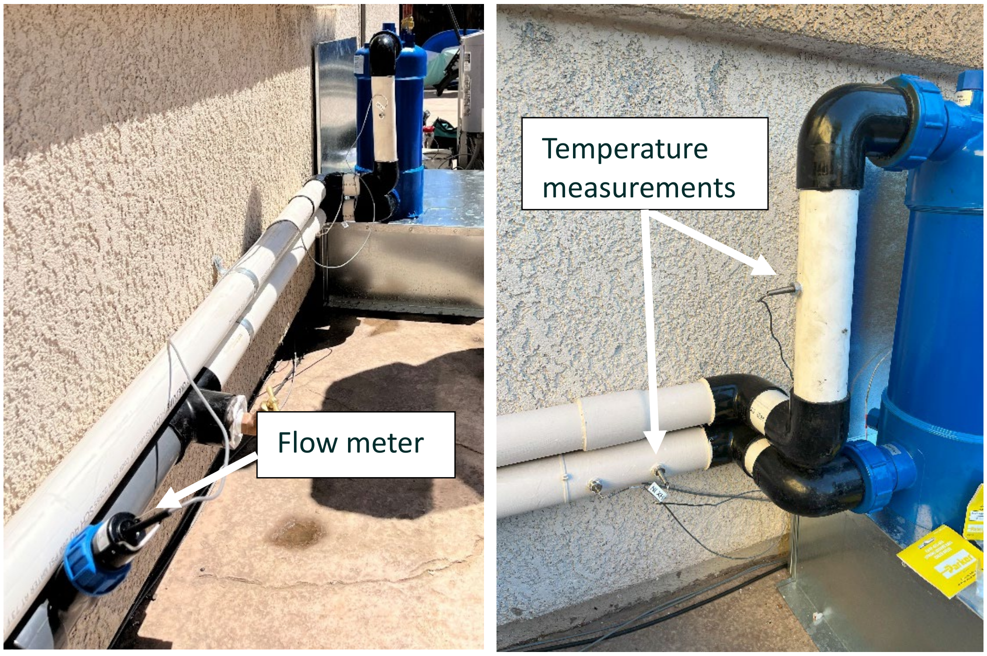


Figure 3. Instrumentation installed to measure heat transferred to pool from air conditioner.

Air Conditioner Performance

Cooling capacity was determined by monitoring the temperature and humidity of air at the supply and return of the air handler. The airflow of the air conditioner was mapped to a differential pressure across the air handler fan and calibrated with a tracer gas airflow measurement device. The tracer gas system injects a known mass of carbon dioxide (CO_2) in the air stream and measures the change in CO_2 concentration between upstream and downstream from the injection, allowing the volume flow of air to be determined. The power consumed by both the outdoor and indoor units was monitored and used along with the cooling capacity to determine the overall system performance. Pool pumping power was also considered when evaluating air conditioner performance.

Pool Pumping

Pool pump power was monitored to determine what impact the new system had on overall pumping power use. The heat exchanger in the technology does cause additional pressure to drop to the existing filtering loop but this effect had to be modeled, due to the limitations of the field data collected. It could be argued that pool pumping power could be attributed to the standard pool filtering process, but due to the control method employed by the retrofit system, the pumping schedule needed to be adjusted to maximize the time the system rejected heat to the pool, which included running the pump during peak electricity hours. This is discussed in more detail in the results.

Weather Data

Weather data was collected near the installations to monitor ambient weather conditions, including air temperature and humidity, wind speed and direction, barometric pressure, and precipitation. Outdoor temperature data was used to map the performance of the air conditioner, while the other parameters were used to validate the pool thermal model used for simulating performance.

Data Collection and Remote Monitoring

A central data acquisition system was used to record the measurements (Figure 4). All data was remotely transferred to a UC Davis FTP server once each day to monitor the system.

Figure 4. Data acquisition enclosure in attic of Site 2.

This allowed data to be evaluated for quality to assure everything was working appropriately. Table 1 shows the instrumentation used for each measurement outlined in Figure 2.

Table 1. Table of Instruments

Measurement #	Measurement Type	Manufacturer and Model #	Accuracy	Signal Type
1	Pool Pump Power	Dent Powerscout 3	±1%	RS-485
2	Pool Water Flowrate	Omega FP5600	±1% of reading	Pulse
3	Water Temperature Entering Water-to-refrigerant Heat Exchanger	Omega TH-44006	±0.2°C	Ohms
4	Water Temperature Exiting Water-to-refrigerant Heat Exchanger	Omega TH-44006	±0.2°C	Ohms
5	Condenser Power	Dent Powerscout 3	±1%	RS-485

Measurement #	Measurement Type	Manufacturer and Model #	Accuracy	Signal Type
6	Compressor Discharge Pressure	Climacheck S22	±1%	1-5 VDC
7	Compressor Discharge Temperature	Omega TH-44006	±0.2°C	Ohms
8	Compressor Suction Pressure	Climacheck S22	±1%	1-5 VDC
9	Compressor Suction Temperature	Omega TH-44006	±0.2°C	Ohms
10	Condenser Outlet Temperature	Omega TH-44006	±0.2°C	Ohms
11	Outdoor Air Temperature	Vaisala WXT520	±0.3°C	RS-485
11	Outdoor Air Humidity	Vaisala WXT520	±3%	RS-485
11	Wind Speed	Vaisala WXT520	±3% at 10 m/s	RS-485
11	Wind Direction	Vaisala WXT520	±3°	RS-485
11	Precipitation	Vaisala WXT520	<5%	RS-485
11	Barometric Pressure	Vaisala WXT520	±0.5 hPa	RS-485
12	Supply Air Temperature	Vaisala HUMICAP HMP110	±0.2°C	0-10 VDC
12	Supply Air Humidity	Vaisala HUMICAP HMP110	±1.7%	0-10 VDC
13	Return Air Temperature	Vaisala HUMICAP HMP110	±0.2°C	0-10 VDC
13	Return Air Humidity	Vaisala HUMICAP HMP110	±1.7%	0-10 VDC
14	Air Handler External Static Pressure	Dwyer 668	±2.5 Pa	4-20mA
15	Air Handler Power	Dent Powerscout 3	±1%	RS-485

Measurement #	Measurement Type	Manufacturer and Model #	Accuracy	Signal Type
16	Pool Temperature	HOBO TidbiT mX	±0.2°C	Internal Logging

Data Analysis

The data collected served two primary purposes. The first purpose was to evaluate the energy performance of the retrofit system compared to the baseline equipment, and the second was to validate the pool thermal model used to predict performance of the technology in other applications. For the energy savings analysis, the key parameters are air conditioning capacity and power use. For the pool thermal model, the key parameters are physical characteristics of the pool, weather conditions, and heat added to the pool through the heat exchange with the air conditioning equipment.

Air Conditioner Capacity

Air conditioner capacity is a measurement of the cooling provided to the home. A one-time measurement of air volume flow was conducted at each test site with a tracer-gas airflow measurement tool in each of the different operating modes for the system (i.e. upstairs only, downstairs only, and both upstairs and downstairs modes). Pressure sensors were installed at different locations in the duct system to identify which mode was active and allowing the appropriate airflow to be selected. The mass flow rate was determined from the volumetric flow rate and air density according to Equation 1, and the volume flow measurements are displayed in Table 2.

$$\dot{m} = \rho * \dot{V}$$

Equation 1

Table 2. Volumetric Flow Rates Measured at Both Test Sites in Each Mode of Operation

	Upstairs (CFM)	Downstairs (CFM)	Both (CFM)
Site 1	1,908	1,747	2,029
Site 2	1,727	1,790	1,924

Temperature and humidity measurements were collected in the return and supply duct to and combined with Equation 1 to evaluate the capacity delivered. The capacity was calculated according to Equation 2, where the enthalpy was determined from psychrometric functions using measured temperature and relative humidity.

$$q_{EvapCoil} = \dot{m}_{air} * \left[\, h(T, RH)_{return} - h(T, RH)_{supply} \right]$$

Equation 2

Energy Efficiency Ratio

The energy efficiency ratio (EER) was calculated according to Equation 3. The equipment power included both the indoor air handler and outdoor air conditioning unit. In some cases, the pool pumping power was included in the EER calculation, depending on the analysis performed.

$$EER = q_{EvapCoil}[Btu]/P_{equipment}[Wh]$$

Equation 3

Heat Delivered to Pool

To calculate the heating provided to the pool by the air conditioner, the water temperature entering and exiting the water-to-refrigerant heat exchanger was used along with the water flow rate. A primary assumption in Equation 4 is that there is negligible heat loss or gain in the pipes between the water-source condenser and the pool.

$$q_{CondCoil/Pool} = \dot{m}_{pool} * c_{p_{pool}} * (T_{HX,out} - T_{HX,in})$$

Equation 4

Modeling Methods

This project is largely focused on developing and validating a simulation tool that can allow accurate estimates of the energy savings that can be expected from the pool-coupled air conditioning or a heat pump system. The pool thermal model is a key component for making accurate energy savings estimates. As noted previously, the temperature of the heat sink/source for the air conditioning system has a significant influence on the performance of the system, including both cooling or heating capacity delivered and power draw. For air-source systems, this requires knowledge of the ambient temperature and humidity conditions for the climate of interest, which is widely available and commonly updated. For the pool-source system, this requires simulating accurate pool temperatures for the simulation period. Pool temperatures are influenced by the local climate, physical characteristics that include surface area and volume, shading of the pool and wind obstruction from nearby objects, and heat exchange with the heat pump.

Another component of the model is the building cooling and heating loads that will be used to calculate the energy use of the conditioning equipment, and that will have influenced the pool temperature condition. Building loads are highly variable, which makes accurate predictions challenging. The model presented here considers multiple prototypical building types to simulate the expected load in a particular instance but could be expanded to other building types in the future.

Lastly, the heat pump model must also account for differences in performance between one heat pump and another. Heat pump performance has improved as the technology changes and as a result of efficiency mandates from regulatory agencies, including the U.S. Department of Energy. Again, obtaining detailed performance data for each potential installation is not feasible, so the model presented here considers multiple heat pump performance parameters, depending on the standardized efficiency rating of the equipment utilized.

Pool thermal model

The pool thermal model was based on Woolley et al. (Woolley, Harrington and Modera 2010) and simulates several heat transfer mechanisms, including solar insolation, evaporation, convection, conduction, and longwave radiation. These heat transfer mechanisms are driven primarily by weather conditions and pool temperature. Other heat flows accounted for but not described below includes the impact of makeup water to replace water lost through evaporation, rain, and heat exchange with the heat pump, which is described in more detail in the Heat Pump Performance Modeling section. The heat transfer into and out of the pool was calculated for each mechanism on an hourly basis to determine the net heating or cooling effect on the pool. Previous testing has shown that it is appropriate to treat the pool as well-mixed with a single effective pool temperature, especially since pool filtering occurs daily.

SOLAR INSOLATION

Global horizontal solar insolation from weather data was broken into direct and diffuse components. For field validation of the thermal model, solar radiation data was collected from a weather station proximate to the field test site (CIMIS 2024) and the direct and diffuse components were estimated using the DISC model developed by the National Renewable Energy Laboratory (NREL) that uses the specific longitude and latitude of the location (Maxwell 1987). For the model simulations the direct and diffuse components of radiation are included in the Typical Meteorological Year weather (TMY) data (Vignola, McMahan and Grover 2013). The direct component was adjusted, based on shading parameters of the site while the diffuse component was not. Multiple shading parameters are considered from highly shaded to low shade, which provides an hourly fractional shading of the pool. Table 3 shows the shading factors that were used for the simulations, which considered three shading levels for the pools. The fraction of the pool surface that is shaded reduces the direct radiation incident on the pool proportionally.

Table 3. Hourly Shading Factors Considered for Simulations

Hour	Low Shading	Some Shading	High Shading
0	0	0	0
1	0	0	0
2	0	0	0
3	0	0	0
4	0	0	0
5	0	0	0
6	0	0	0
7	0.25	0.25	0.25

Hour	Low Shading	Some Shading	High Shading
8	0.5	0.5	0.25
9	0.75	0.5	0.5
10	1	0.75	0.5
11	1	1	0.75
12	1	1	1
13	1	1	1
14	1	0.75	0.75
15	1	0.75	0.5
16	0.75	0.5	0.5
17	0.5	0.5	0.25
18	0.25	0.25	0.25
19	0	0	0
20	0	0	0
21	0	0	0
22	0	0	0
23	0	0	0

One adjustment made to the Woolley et al. model is the fraction of diffuse radiation that is absorbed by the pool. Hahne and Kubler (Hahne and Kubler 1994) describe the relationship between solar incident angle on the pool and its impact on absorptance of the pool. Hahne and Kubler make the assumption that diffuse radiation has an isotropic distribution resulting in an effective incident angle of 71° and a calculated absorptance of 0.836. Woolley et al. perform a similar analysis for the direct portion of radiation. This portion accounts for the incident angle, which resulted in an average absorptance of 0.91.

EVAPORATION

Evaporation is driven by differences in partial pressure of water in ambient air and the partial pressure of water in air saturated at the pool temperature. This driving force is multiplied by a mass transfer coefficient that determines the amount of water evaporated in each hour. This value, combined with the heat of vaporization of water, gives the thermal energy required to evaporate the water from the pool. Evaporation is one of the primary cooling mechanisms for the pool, accounting for nearly half of heat loss during the summer.

CONVECTION

Convection was calculated based on the Bowen relationship that associates the convection energy from a pool surface with the evaporation from that surface. When no wind speed is present, convection was calculated based on free convection from a surface. Convection has a relatively small effect on the overall heat balance of the pool, accounting for only two percent of the pool cooling during the summer.

CONDUCTION

Conduction was calculated based on a shape factor analysis for a body in an infinite medium. The pool surface is assumed adiabatic for this analysis, since the conduction heat flow was calculated only for the interaction between the pool and the ground. Conduction to the ground had the lowest heat transfer impact of all modes, accounting for only one percent of the average heat flows.

LONGWAVE RADIATION

Longwave radiation was calculated, based on black body radiation between two objects. The pool radiates to an effective sky temperature and emissivity that was calculated based on ambient temperature, dewpoint, and cloud cover. On cloudy days the effective sky temperature is much warmer, reducing longwave radiation to the sky. In hot dry climates like California, longwave radiation with the sky is the largest single mechanism for cooling the pool during the summer. The pool was assumed to have an emissivity of 0.96 for this calculation.

Building Load Simulation

EnergyPlus modeling software was used to generate building heating and cooling loads for use as inputs to the pool thermal model. EnergyPlus is an established whole building energy modeling software developed and maintained by NREL and funded by the DOE. Two residential building types were considered for estimating the performance of the pool-coupled heat pump system. The first building type is an older one-story home based on information from the Mayfair Central Valley Research Home Figure 5, which is a single-family home built in 1953. The second model is a two-story, single-family home meeting the 2006 International Energy Conservation Code (IECC) recommendations for Climate Zone 3. For each model, cooling and heating loads are generated for simulation with the pool heat pump system in each of the 16 California Climate zones. Descriptions of each model are included in the sections below.

ONE-STORY MODEL

A model representing a smaller single-family home (872 ft^2) with building envelope properties representing an older vintage home was created in EnergyPlus 23.2. The construction of the building shell was modeled to represent the as-built construction of the Mayfair house (Figure 5). This house is meant to be representative of an older vintage home on a raised foundation with moderate levels of insulation in the wall and attic.

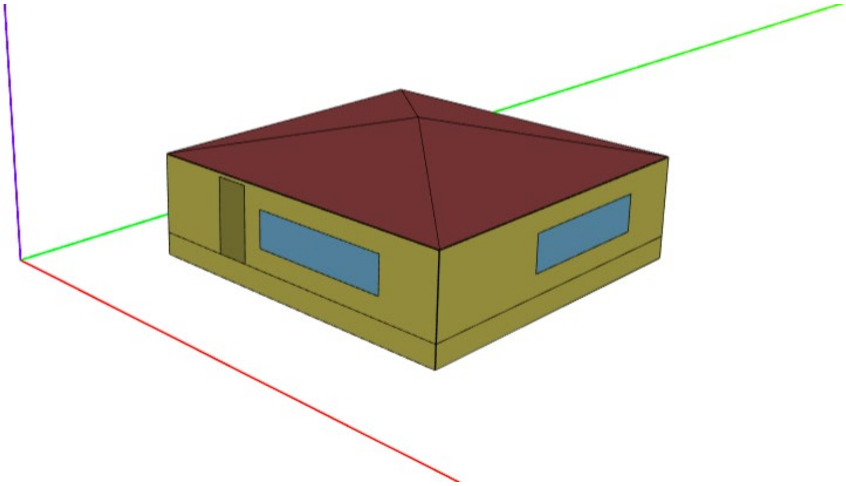


Figure 5. Three-dimensional rendering of the Mayfair model.

The key thermal properties of the opaque surfaces of the building envelope were based on a survey conducted on insulation levels in existing homes by the California Energy Commission (Miller and Griffin 1986). It is common for older single-pane windows to get replaced as part of the general maintenance of a home, so it was assumed that the windows meet the 2006 IECC requirements. Table 4 summarizes these key model input variables, including the thermal properties of the windows. It also includes the Solar Heat Gain Coefficient (SHGC), which provides the fraction of solar radiation that is transmitted, and the U-Factor, which is a measurement of the conductivity of the window unit including the frame, and wall and ceiling insulation levels. EnergyPlus uses a 1-dimensional heat transfer model to approximate heat flows through the building envelope, so the actual input values for the opaque surfaces differ slightly from the values reported in Table 4, to account for thermal bridging of the studs in a wall assembly.

Table 4. Mayfair Model Building Envelope Thermal Properties

Fenestration U-Factor	Glazed Fenestration SHGC	Ceiling R-value	Wall R-value
(Btu/h-ft^2-F)		(Btu/h-ft^2-F)	(Btu/h-ft^2-F)
3.69	0.40	19	9
Fenestration U-Factor	Glazed Fenestration SHGC	Ceiling R-value	Wall R-value

TWO-STORY MODEL

A model representing two-story single-family home that meets the 2006 IECC was also simulated. This model was based on a DOE prototype single-family residential home with a conditioned floor area of 2,400 ft^2. The home is representative of a newer vintage home, with higher levels of insulation relative to the one-story model. Table 5 provides a summary of some of the key performance characteristics of the home.

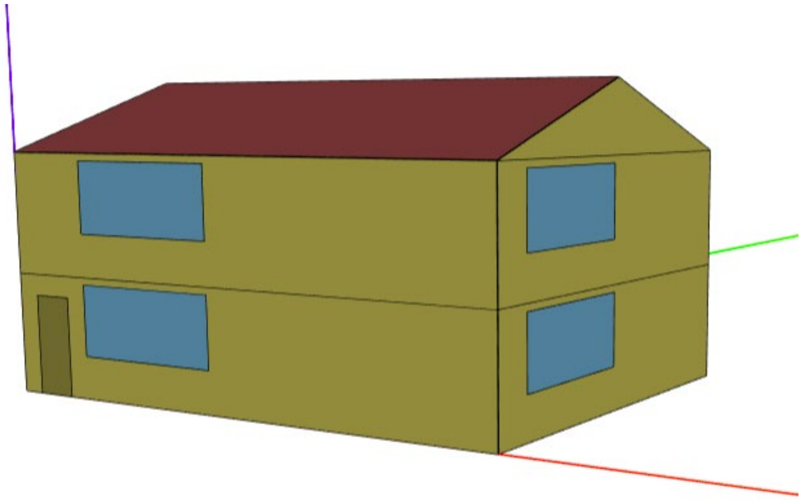


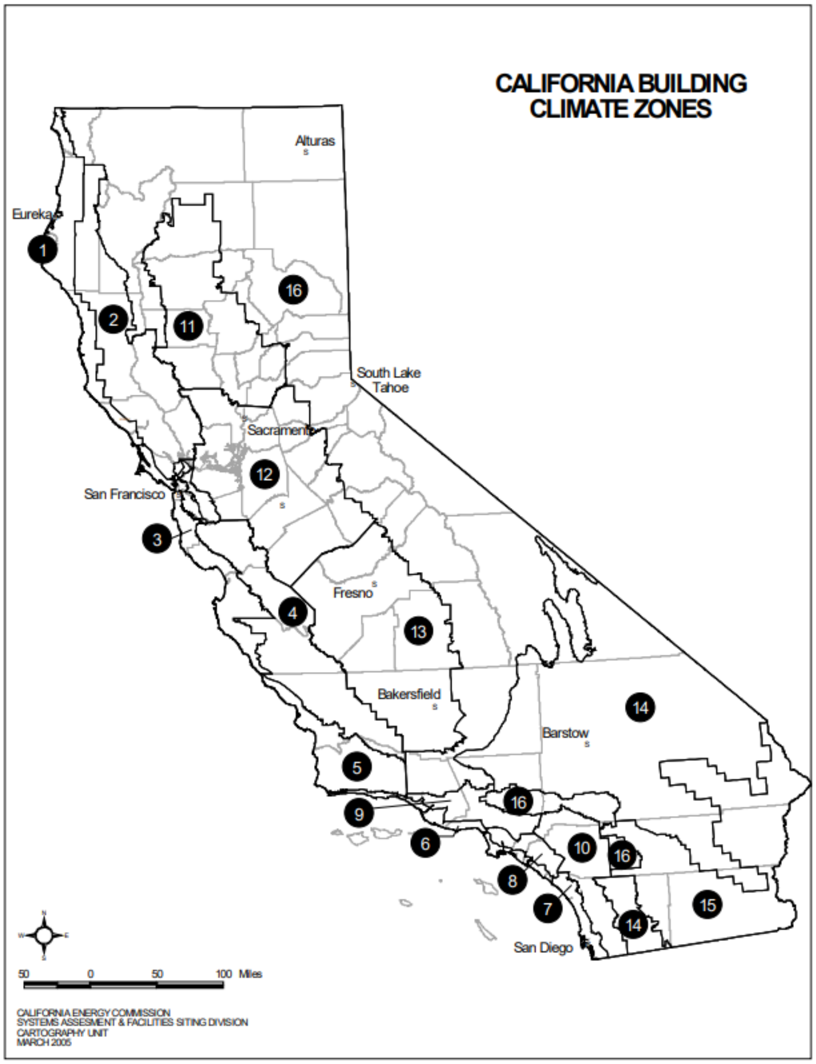
Figure 6. Three-dimensional rendering of Title 24 new construction model.

Table 5. Key Performance Characteristics for Prototype Single-family Home Model

Fenestration U-Factor	Glazed Fenestration SHGC	Ceiling R-value	Wall R-value
(Btu/h-ft²-F)		(Btu/h-ft²-F)	(Btu/h-ft²-F)
3.69	0.40	30	13
Fenestration U-Factor	Glazed Fenestration SHGC	Ceiling R-value	Wall R-value

Meteorological Conditions

The CEC has divided California into 16 distinct climate regions for the purposes of developing appropriate building codes based on a particular climate (Figure 7). The simulation tool allows the pool-source heat pump to be simulated in any of the 16 California climate zones, depending on the location of the installation using TMY data. The weather conditions for a particular simulation are used for both the pool thermal model and the building load model.



CALIFORNIA ENERGY COMMISSION
SYSTEMS ASSESMENT & FACILITIES SITING DIVISION
CARTOGRAPHY UNIT
MARCH 2005

Figure 7. California Climate Zone map (source: CEC Title 24 Residential Compliance Manual).

Heat Pump Performance Modeling

The pool-source heat pump system impacts the refrigeration cycle performance in two key ways, relative to the air-source operation. One is that the temperature conditions of the pool can be very different from the temperature conditions of ambient air. The other is that the heat exchanger fluid is changing from air to water. A typical condenser design strategy is to target a particular temperature difference between the fluid exiting the heat exchanger and the refrigerant condensing temperature, which for air-source condensers is typically 20°F and water-cooled condensers is 10°F (Smith and Parmenter 2016). This approach suggests that using water as the heat transfer fluid for a condenser can result in lower condensing temperatures, reducing the energy required from the compressor. Data collected on an air conditioner in this project showed a 1.5 percent reduction in COP for every one-degree Fahrenheit increase in outdoor air conditions.

The field data collected in this project did show that the pool-source mode operated at similar COPs as the air-source at slightly elevated temperatures. The impact was lower than the general rule suggested by Smith and Parmenter. Figure 8 shows a plot of the performance difference between pool-source and air-source modes, compared with the temperature difference between the pool and air. This trend shows the COPs in the two modes being the same when pool the temperature exceeded the air temperature by about 3°F.

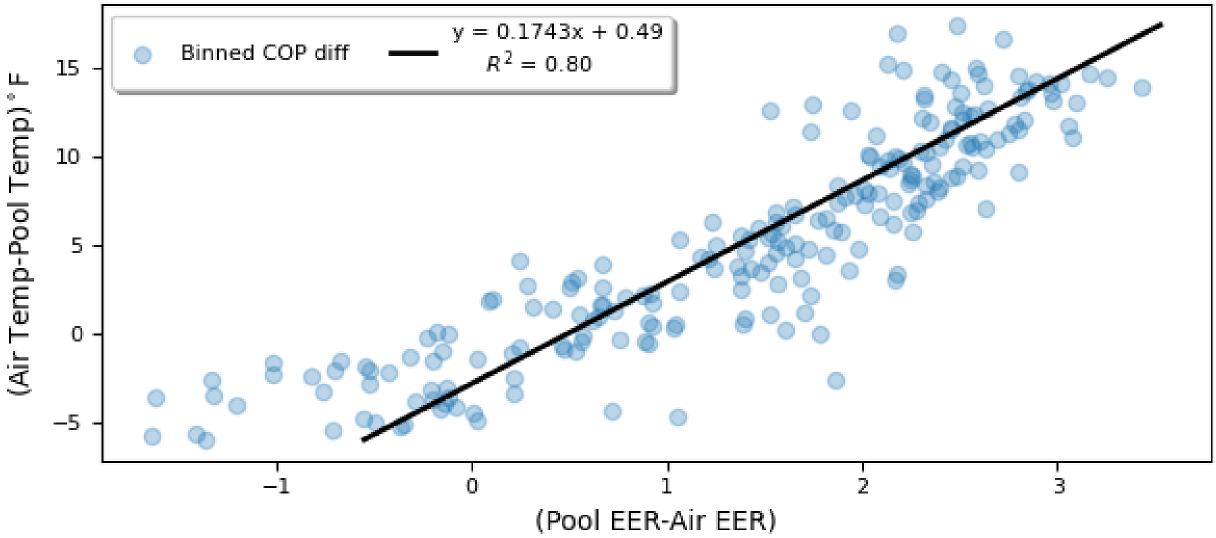


Figure 8. Performance comparison between pool-source and air-source modes, relative to the temperature difference between the pool and the air.

For the model tool, a heat pump curve describing the efficiency (COP) of the system relative to the heat sink/source temperature was used to predict the energy use to meet a modeled building load using Equation 3.

$$E = \frac{Q}{COP(T)}$$

Equation 5

In the above equation, E is the electricity energy use, Q is the building thermal load, and COP(T) is the COP as a function of sink/source temperature. The efficiency curves will change depending on many factors including the specific equipment, installation, and maintenance of a heat pump. The current model allows for a selection of different heat pump curves, based on their rated performance. The rated performance is based on required testing outlined by the Air-Conditioning, Heating, and Refrigeration Institute (AHRI 2023) Standard 210/240. Generic curves are included for heat pumps with the rated performance outlined in Table 6. These performance selections were based on minimum efficiency requirements over the past 15 years (EIA 2019) to cover a range of system types installed. Each equipment type in Table 6 gives the year in which that minimum efficiency was mandated by DOE in parenthesis. The performance data does not exactly match the minimum requirement but is intended to be representative of the equipment installed during those periods. The efficiency ratings are provided in seasonal energy efficiency ratio (SEER) and heating seasonal performance factor (HSPF) for heat pumps.

Table 6. Performance Ratings Used for Heat Pump Selection in Model

Equipment	SEER	HSPF
Low Efficiency (2006)	10	7.0
Medium Efficiency (2015)	13	7.7
High Efficiency (2023)	15	8.5

Performance curves were generated using the data provided by the manufacturers for heat pumps and air conditioners meeting the performance ratings outlined in Table 6. The performance curves provide the COP(T) function used in Equation 5 to evaluate the energy use of the heat pump. An assumed indoor condition of 75°F dry-bulb (DB) and a 63°F wet-bulb (WB) temperature for cooling was used for generating the curves, which matched the setpoints used in the building energy models. In addition, the cooling performance was based on an airflow rate of 400 cfm per ton of capacity. The performance curves used for the modeling are provided in Figure 9. The performance data for heat pump cooling was taken from a Carrier 38TKB series air conditioner for the 10 SEER and a Goodman GSX series air conditioner for the 13 SEER and 15 SEER.

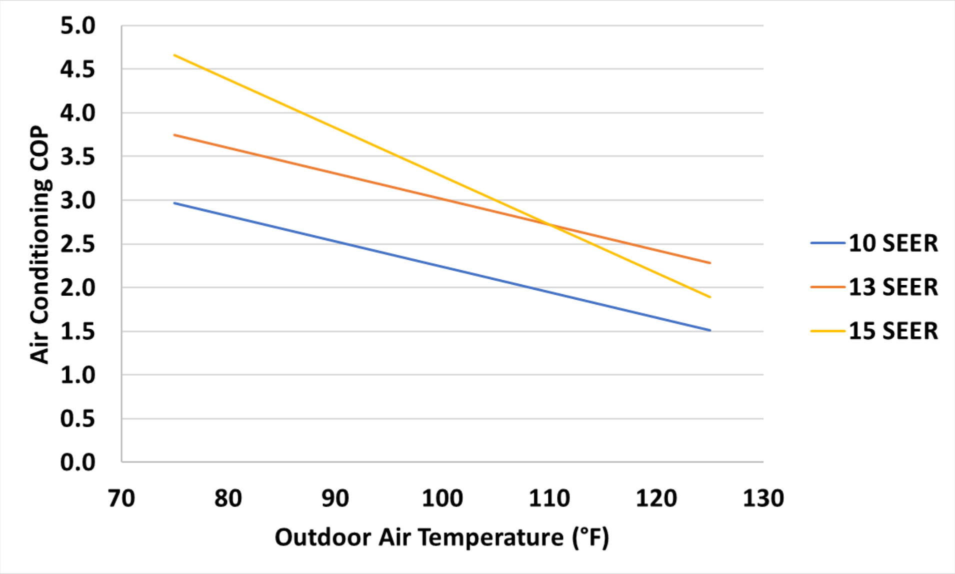


Figure 9. Performance curves used to calculate air conditioner energy use of heat pump simulations.

A similar process was used for generating COP(T) curves for heat pump heating. For heating, the indoor condition was 70°F DB. The outdoor coil WB temperatures were not published other than for the AHRI standard conditions of 47°F/43°F (DB/WB) and 17°F/15°F (DB/WB). In addition, the effect of supplemental electric heat is not included in the curves. Supplemental heaters are used during defrost cycles and during peak conditions where the heat pump cannot meet the house load. The use of supplemental heat in an actual install would result in lower heat loads being extracted from the pool. Since the load served by the supplemental heater represents a small fraction of the overall load, this impact was neglected for the purposes of this analysis. The performance data for the curves presented in Figure 10 are taken from three different Carrier heat pump units (38YCC-8PD for the 7.0 HSPF, 38YRA for the 7.7 HSPF, and 25HCA4 for the 8.5 HSPF).

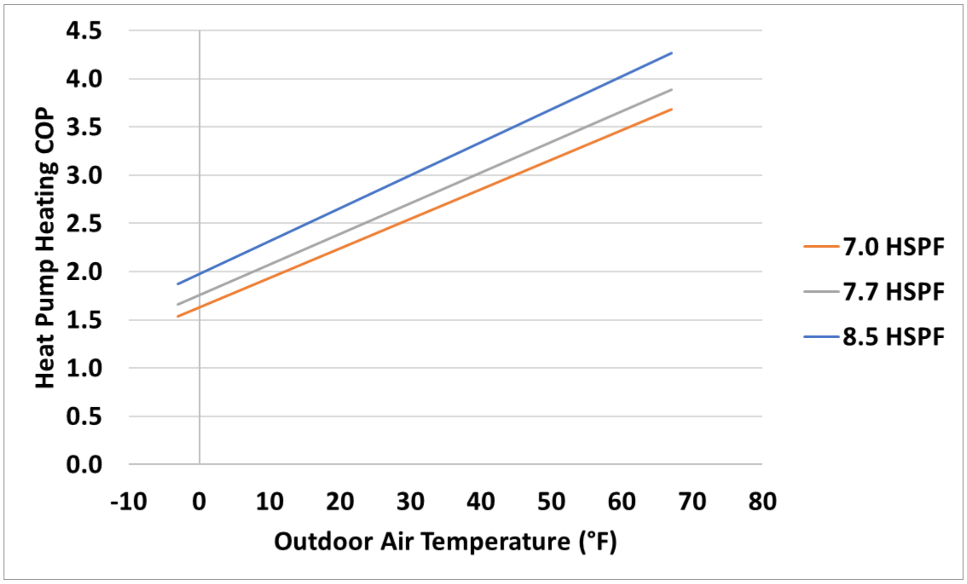


Figure 10. The performance curves used to calculate heating energy use of heat pump simulations.

The temperature, T, used for determining the operating COP of the heat pump at any timestep depends on the mode the system is operating in. In air-source mode, T is the ambient temperature condition during that timestep. For the pool-source mode, the pool temperature is used in place of the air temperature. An offset for the appropriate temperature to use was considered, based on the data provided in Figure 8, to account for the improved performance of the water-to-refrigerant coil. The data in Figure 8 suggested an offset of about 3 °F between the water temperature and the effective air temperature (air temperature at which the performance is similar between air-source and pool-source operation) when operating in pool-source mode. It was decided to use a 0 °F offset to provide conservative estimates of performance and account for the fact that the data provided in Figure 8 was only for a single field test unit.

The heat load added or removed from the pool is based on the outdoor coil load of the heat pump. The heat exchange with the pool was based on the process below. Equation 6 describes the heat added to the pool during cooling operation, while Equation 7 describes the heat removed (negative) during the heating operation.

$$Q_P = Q_H = W + Q_C = Q_C(1 + \frac{1}{COP})$$

Equation 6

$$Q_P = -Q_C = -(Q_H - W) = -Q_H(1 - \frac{1}{COP})$$

Equation 7

In Equation 6 and Equation 7, Q_P represents the heat exchange between the heat pump and the pool, Q_H is the heat pump condenser heat load during cooling operations, and Q_C is the heat pump evaporator load during heating operations.

Findings

Overview

The results for this project are divided into three main sections: 1) the first section provides results from the field testing of the technology, 2) the second provides the results from the model validation based on field test results, and 3) the third section provides results from simulations of the pool-coupled heat pump using the validated model.

Field Test Results

Installation of Technology

The installation of the technology did not require any permits but was challenging due to the number of field-installed components and lack of prior experience by the contractor installing this technology. The components included: a three-way valve, two check valves, a solenoid valve, a restrictor, and refrigerant receiver. Figure 11 shows photos of the installed components.

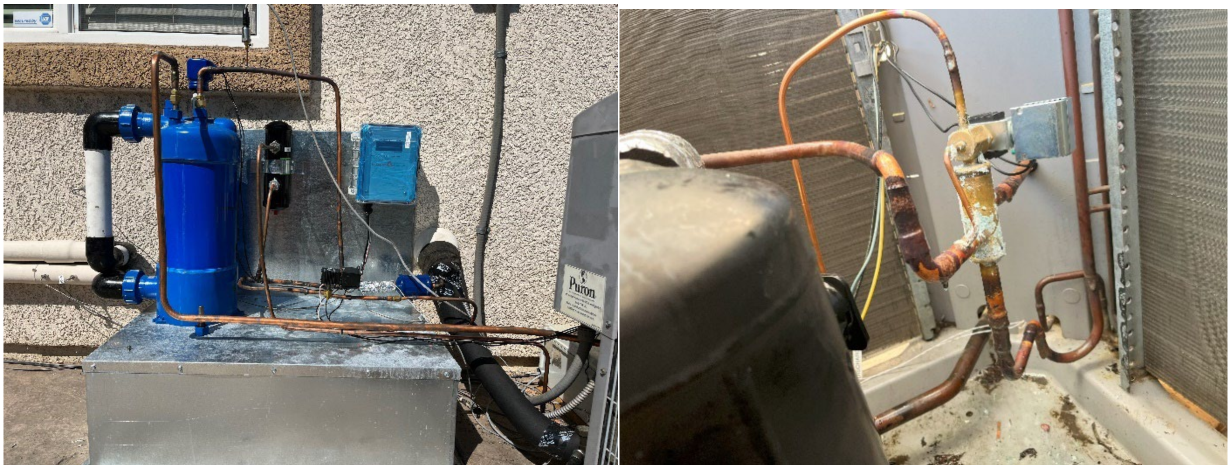


Figure 11. Photos of refrigerant components installed for the retrofit technology.

After installing the refrigerant components, the controller was installed. The controller is powered by a 24 VAC power transformer mounted inside the electrical cabinet of the air conditioner and pulling power from the 240 VAC power supply to the unit. The thermistor is installed on the water line entering the water-to-refrigerant heat exchanger to sense pool temperature during operation. The controller has 24 VAC output signals to the refrigerant solenoid valve, the relay to cut power to the condenser fan motor, and the three-way refrigerant valve to change the mode of the system from air-source to pool-source.

After installing the refrigerant components, the controller was installed. The controller is powered by a 24 VAC power transformer mounted inside the electrical cabinet of the air conditioner and pulling

power from the 240 VAC power supply to the unit. The thermistor is installed on the water line entering the water-to-refrigerant heat exchanger to sense pool temperature during operation. The controller has 24 VAC output signals to the refrigerant solenoid valve, the relay to cut power to the condenser fan motor, and the three-way refrigerant valve to change the mode of the system from air-source to pool-source.

The integration with the pool pumping system depends on the pool pump controls. In the two applications for this project, it required simulating a solar thermal heating operation by connecting a resistor signal to the thermistor input for the solar thermal system on the pool controller. The pool controller interprets the resistance value as a temperature in a solar thermal system, and if the temperature exceeds the pool temperature by a set amount, it will trigger the pool pump to send water to the refrigerant-to-water heat exchanger. A relay was installed to switch between two resistor values, depending on the status of the air conditioner. When there is no air conditioning operation, a 15k Ohm resistor is used to simulate the solar thermistor measuring a colder water temperature of 60°F. When the air conditioning starts, a 5k Ohm resistor is used to simulate a warmer water temperature of 105°F.

COSTS

Due to the general lack of familiarity with the technology, the installation costs were higher than anticipated. Table 7 shows the installation costs for the demonstrations in this project including the technology hardware and installation. The HVAC contractor became much more comfortable with the installation after the experience gained on this project, and it is expected that the HVAC installation costs could be about half of what is reflected in Table 7. The work to integrate the water-to-refrigerant heat exchanger with the pool system was performed by a local pool contractor and closely aligns with standard work performed to install other pool water heating systems. The cost for the pool-side integration is dependent on the complexity of the integration including distance from the pool pump to the air conditioner.

Table 7. Installation costs for retrofit technology

Site	Hardware Costs	HVAC Install	Pool Equipment Install	Total
Site 1	$2,230	$4,938	$3,313	$11,580
Site 2	$2,180	$4,938	$4,412	$10,431

Baseline Equipment Performance

Baseline data was collected to establish the existing air conditioners' performance before the retrofit. The baseline systems both had dual-zone setups with damper control for upstairs and downstairs zones. Air conditioning equipment performance is primarily dependent on outdoor air temperature, given that indoor conditions are relatively constant. Performance data was evaluated at different outdoor air dry-bulb conditions for each site to develop a baseline performance map. The performance was evaluated as close to steady-state as reasonable, by only considering data after the system had been running for several minutes. This avoids variations in performance due to transients experienced during the initial startup. The steady state performance maps allow the energy savings when rejecting heat to the pool to be determined relative to the system rejecting heat to ambient air.

SITE 1

Data collected at Site 1 provided a significant amount of run-time in each mode of operation. Figure 12 shows three distinct performance trends which describe the performance at each of the individual modes of operation including Zone 1 (downstairs), Zone 2 (upstairs), and Zones 1&2 (downstairs and upstairs). The highest performance was measured in the Zone 1 mode with an EER ranging from 10 to 15 depending on outdoor conditions.

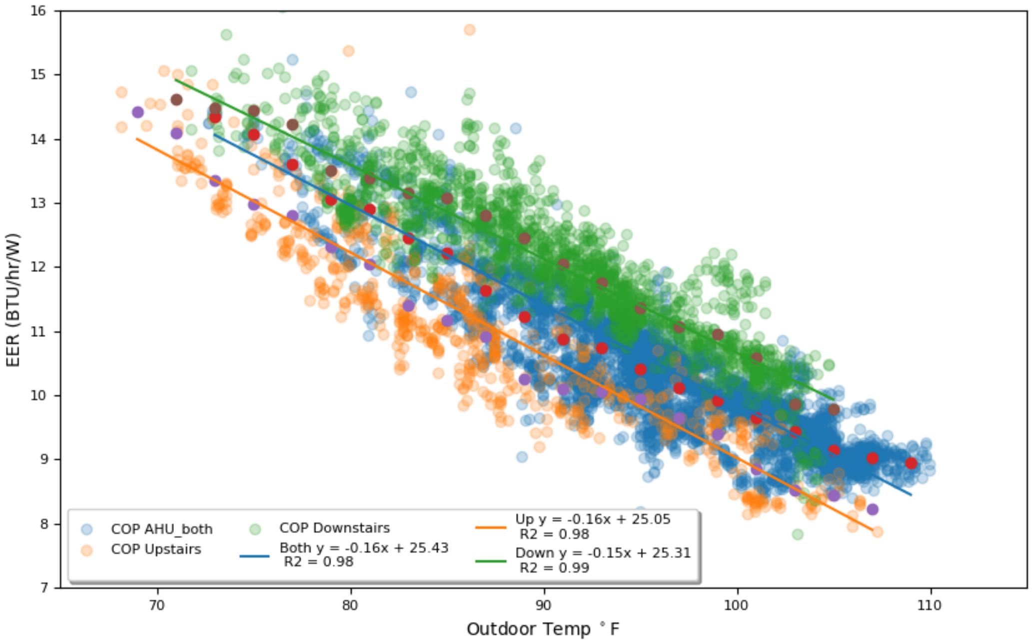


Figure 12: EER vs. ambient air temperature for baseline equipment at Site 1.

The EER for site 1 shows clear performance differences, based on the zoning arrangement due to changes in the measured airflow between modes. For each zoning arrangement, there is a clear trend that shows the efficiency going down as the outdoor air temperatures increase. This is consistent with typical air-source air conditioners, due to the higher temperature difference between outside air and inside.

SITE 2

At Site 2 the observed run-time was much lower than Site 1, with ten times fewer runtime hours. Figure 13 shows a plot of the EER versus the ambient air temperature for each zoning arrangement. Very few observations were made with both zones operating, so that mode was not included. The results show that performance trends were much less stable, compared with Site 1, as indicated by the lower r-squared values. This was likely due to the reduced run-time hours.

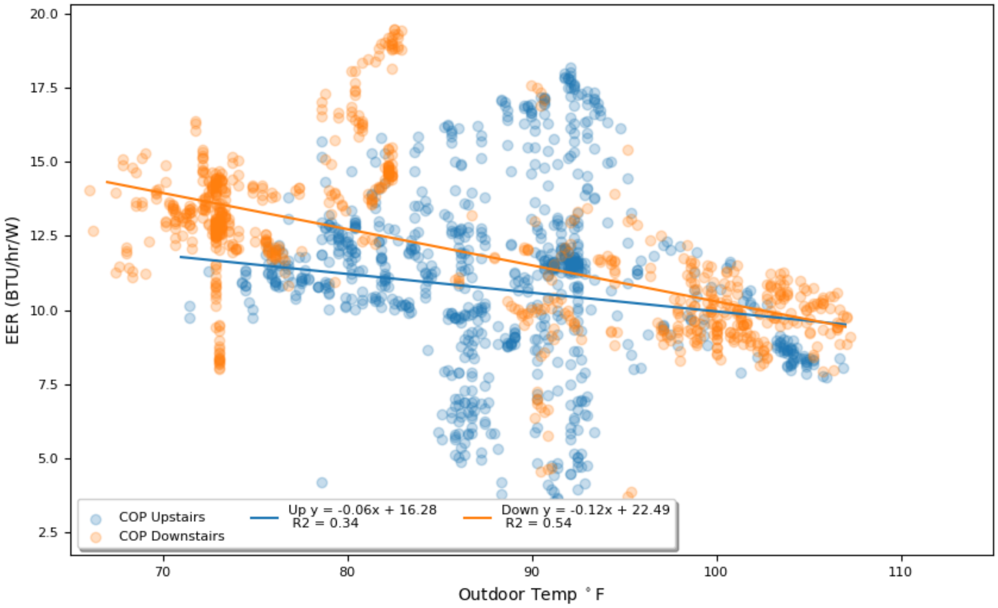


Figure 13: EER vs. ambient air temperature for baseline equipment at Site 2.

The baseline performance at Site 2 was generally lower than Site 1. Refrigerant monitoring indicates that the system appears to be low on refrigerant charge. The performance ranged from 10 EER during very hot conditions to more than 14 EER during cooler conditions.

Pool-source performance

After collecting baseline data on the air conditioner performance, the retrofit technology was installed, allowing condenser heat to be transferred to the pool. About one month of data was collected with the retrofit technology installed. Minimal operation was observed for Site 2, so the field test analysis focuses on Site 1 performance. Figure 14 shows the air conditioner performance at Site 1 when rejecting waste heat to the swimming pool, plotted against the outdoor air temperature. While the outdoor air temperature does not directly impact the performance when rejecting heat to the pool, it does allow a comparison to be made between air-source (baseline) and pool-source performance. The EER when rejecting heat to the pool had a much narrower range, with most of the results for the Downstairs zone ranging between 14 EER to 15 EER and is also on the higher end of the performance relative to the baseline.

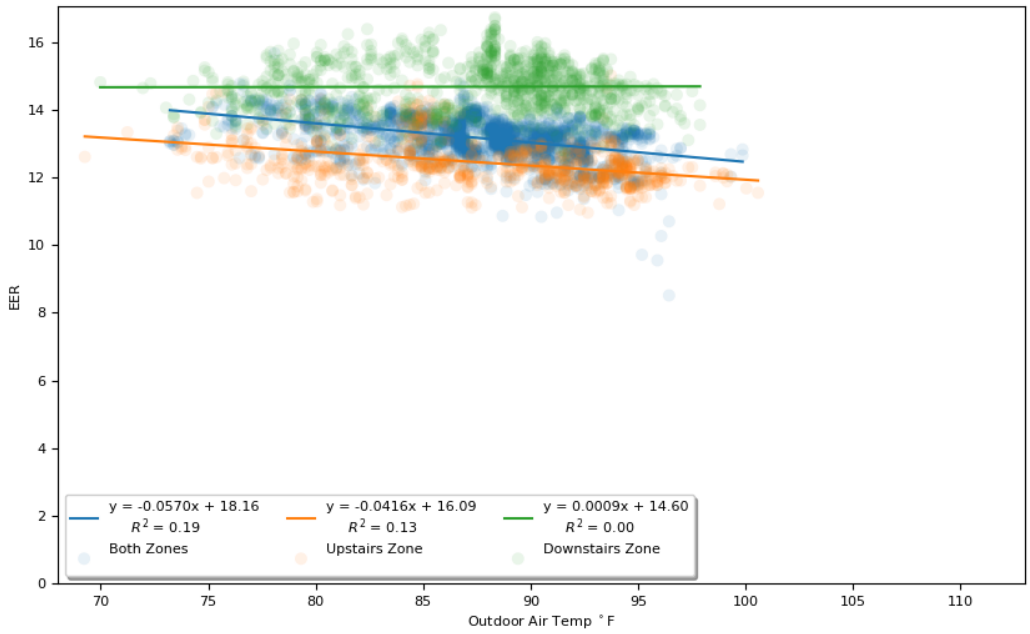


Figure 14. Pool-source COP vs. ambient air temperature for retrofit equipment.

The flatter COP profile can be explained by the relatively small changes in the pool temperature during the monitoring period, compared with the outdoor air temperature. The pool temperature only ranged between 75 to 86°F, compared with the ambient air which ranged from 68 to 108°F. Figure 14 shows the pool-source system COP variation with pool temperature.

Energy Savings

The impact of the retrofit on air conditioning energy use was significant, particularly at higher ambient conditions. Overall, the pool-source condenser operated at 13 percent higher efficiency than the air-source condenser when not considering the pool pumping power, and six percent higher efficiency when contributing all the pool pumping power during air conditioner operation. Pool pumps often run as much as eight hours per day during the swimming season and it was found that the modest additional resistance associated with the retrofit had minimal impact on pool pumping energy. Ideally, all pool pumping related to air conditioning would also count toward pool cleaning, but the authors are not aware of a pool controller that includes that feature.

Rejecting heat to the pool was 31 percent more efficient than rejecting heat to ambient air when outdoor temperatures were 90°F and above. Both the cooling capacity was higher, and power draw was lower during hotter outdoor air conditions. The data suggests that the pool-source and air-source systems performed comparably when ambient temperatures dropped to about 77°F. These results depend on the temperature conditions of the pool, which for this case averaged 79.2°F when used as a heat sink during air conditioning events.

Figure 15 and Figure 16 show the air conditioner power and cooling capacity for the air-source and pool-source modes plotted against the outdoor air temperature. The results illustrate the lower variation in these performance metrics when rejecting heat to the pool. Both power and capacity are consistent when rejecting to the pool at levels similar to the air source system operating at an outdoor air temperature of 77 °F. The overall energy savings measured was 57.5 kWh (13 percent) over the course of the nine-week monitoring period. If all of the pumping power during air conditioning operation is contributed, this savings drops to 30.8 kWh (seven percent).

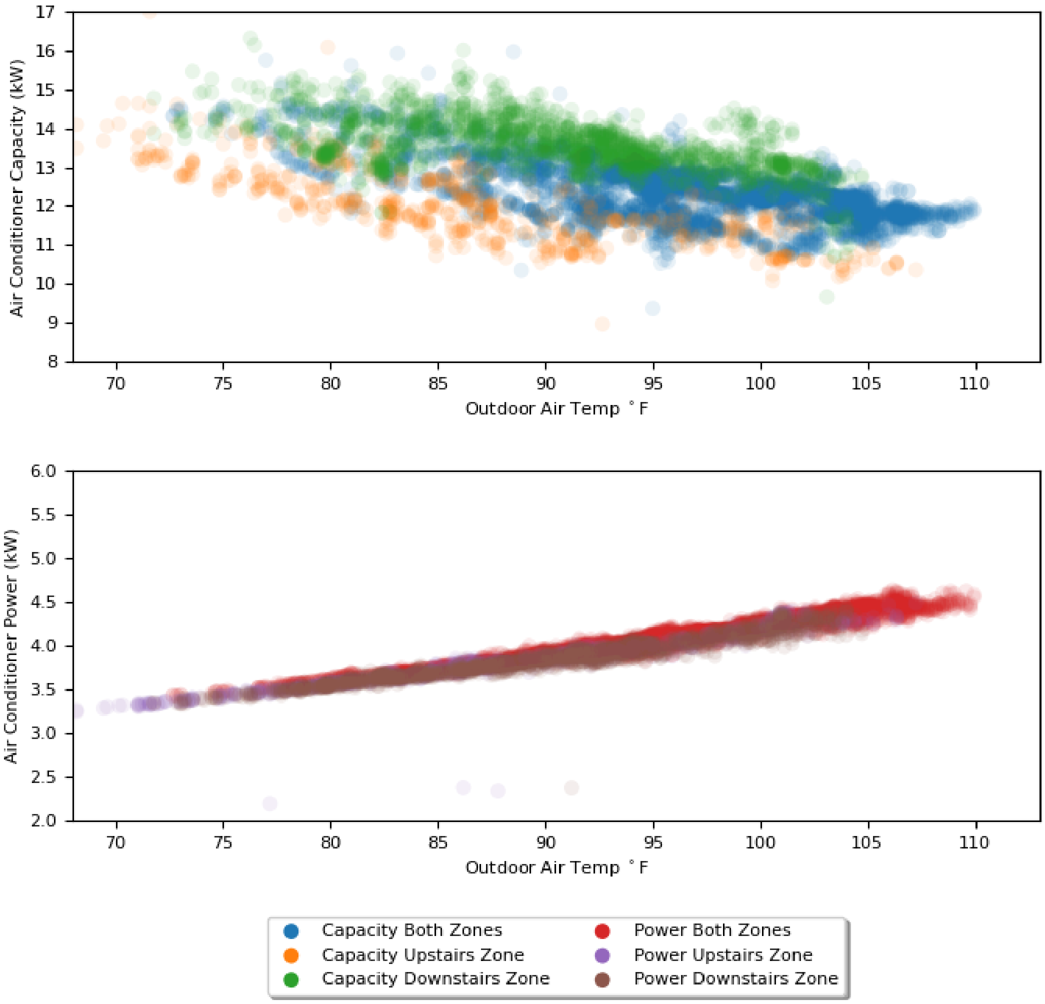


Figure 15. Air conditioner capacity and power for air-source (baseline)

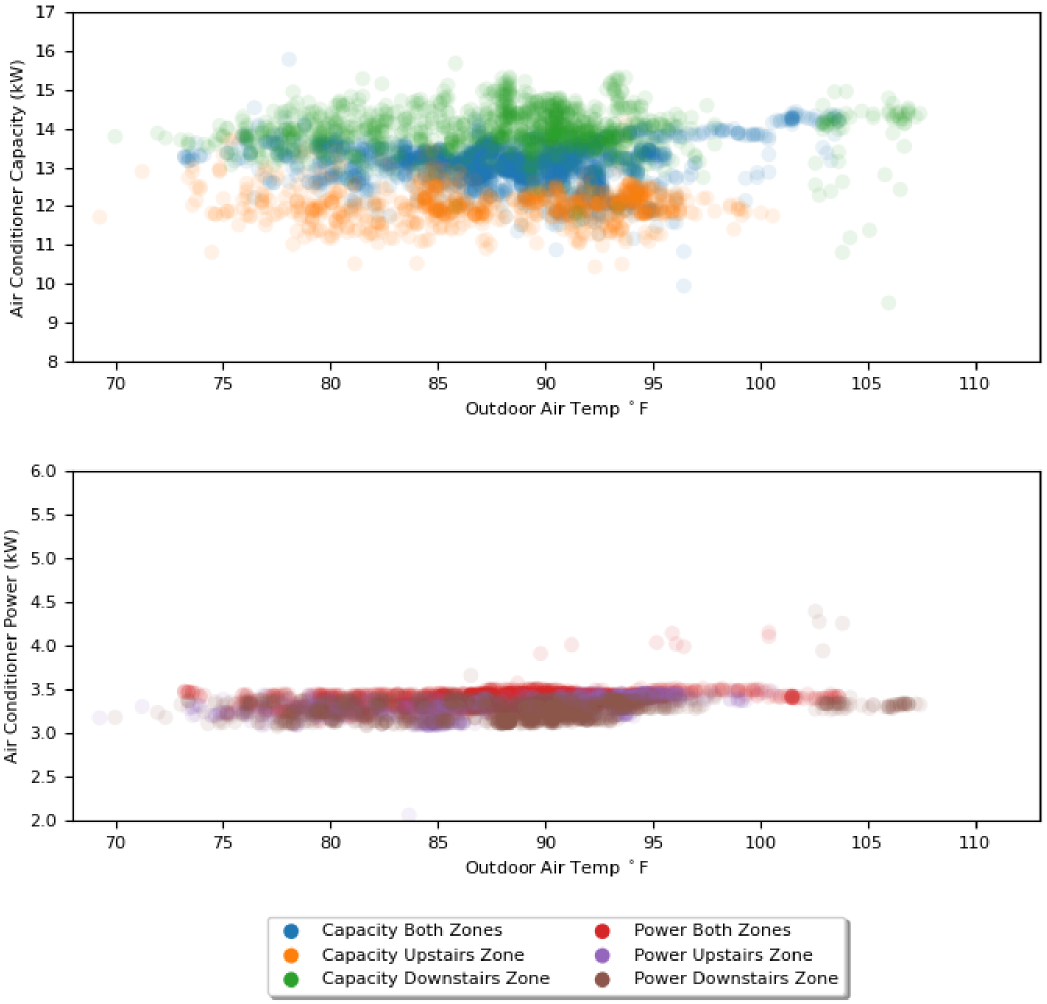


Figure 16. Air conditioner capacity and power for pool-source (retrofit).

In addition to the air conditioning energy savings, the heat rejected to the pool from the condenser added 6,977 KBTU of heat to the pool. If this heat was instead provided by a 90% efficient pool heater it would require 78 therms of natural gas over the 9-week monitoring period showing that the system can reduce air conditioning energy use while offsetting fuel used for pool heating purposes.

Pool Temperature Impacts

The retrofit system also provides “free” pool heating by sending heat to the pool that would otherwise be lost to the environment. Using a validated pool thermal model (Woolley, Harrington and Modera 2010), the additional heat from the air conditioner increased the average pool temperature by 2.3°F. Figure 17 shows the number of hours the pool was within each one-degree temperature bin. It shows that the pool with heat from the air conditioner has significantly more hours of warmer pool temperatures. Over the nine-week monitoring period, there were 285 more hours above 80°F, compared with the pool without added heat from the air conditioner. This technology can therefore improve the efficiency of air conditioning, while also offsetting fuel used for heating a pool.

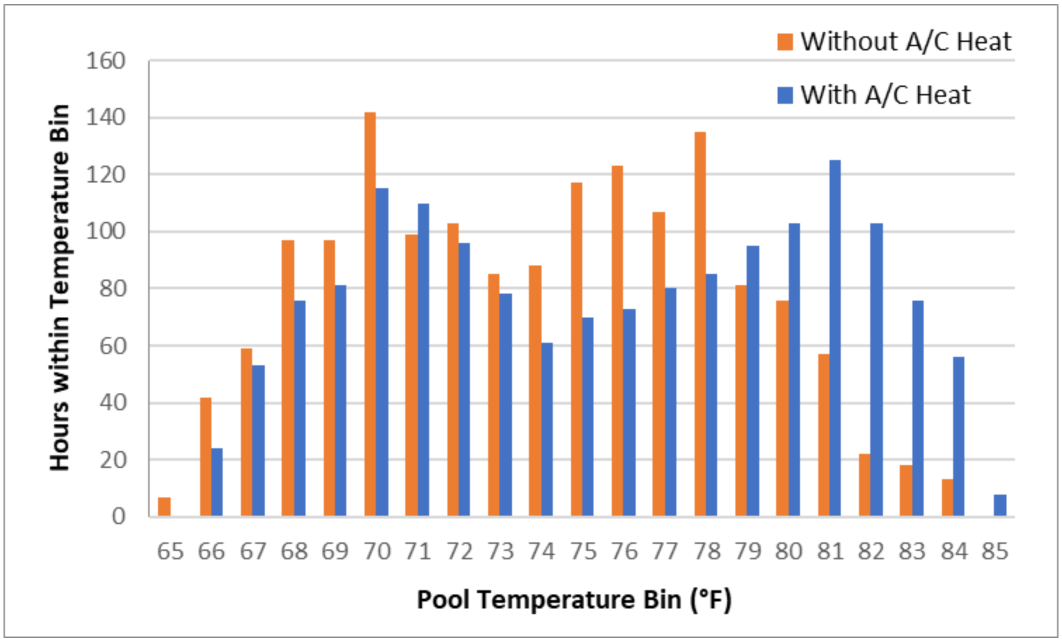


Figure 17. Modeled pool temperature conditions during nine-week monitoring period.

Lastly, the energy savings from this approach is highly dependent on the relative size of the pool and air conditioning load. A smaller pool would result in lower energy savings and warmer pool temperatures. To predict the potential energy savings in different applications, a pool thermal model would be needed to simulate pool temperature conditions as a function of pool characteristics, climate, and air conditioning loads.

Pool Model Validation

The focus of the validation effort was to assess the accuracy of model predictions of pool temperature, given the appropriate input data. An accurate pool thermal model is necessary for estimating energy savings of the pool-coupled heat pump system, as it is the key variable for estimating heat pump COP and the capacity for the pool to absorb additional heating or cooling loads. The system model was validated using the field data collected on the two pools in the study. Figure 18 shows the hourly pool temperature predicted by the model, compared with the measured pool temperature for Site 1. During this test there was 6,977 KBTU of heat rejected to the pool by the air conditioning system from August 16 to October 20. Some gaps appear in the measured data, indicating where data loss had occurred.

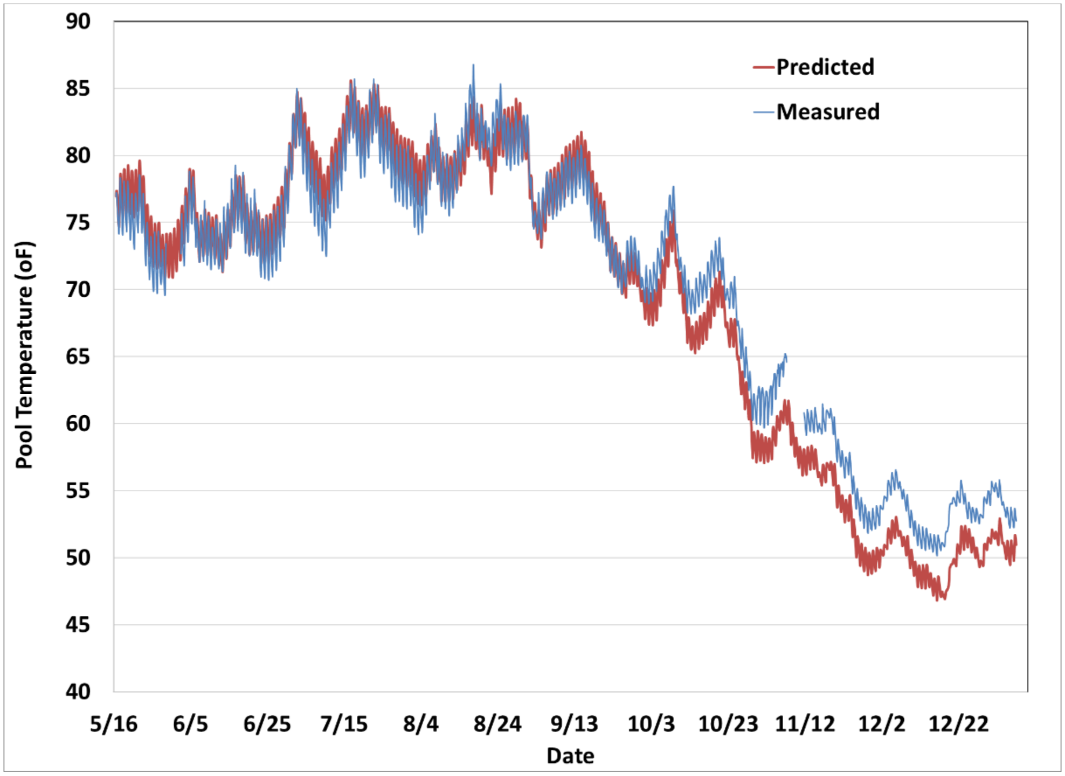


Figure 18. Predicted pool temperature versus measured pool temperature for Site 1.

Figure 18 shows a good agreement between the predicted and measured pool temperatures. The predictions in the warmer months were generally closer to the measured value than predictions in the cooler months. The maximum error in the warmer months was 1.6°C, whereas the maximum error in the cooler months was 2.8°C. The average root mean squared (RMS) error was 1.5°C across all measurements. Figure 19 shows the temperature predicted plotted against the measured temperature. A perfect model would result in a one-to-one relationship, which is illustrated by the red line in the plot. This plot illustrates the tendency of the model to predict cooler water temperatures when pool conditions are colder.

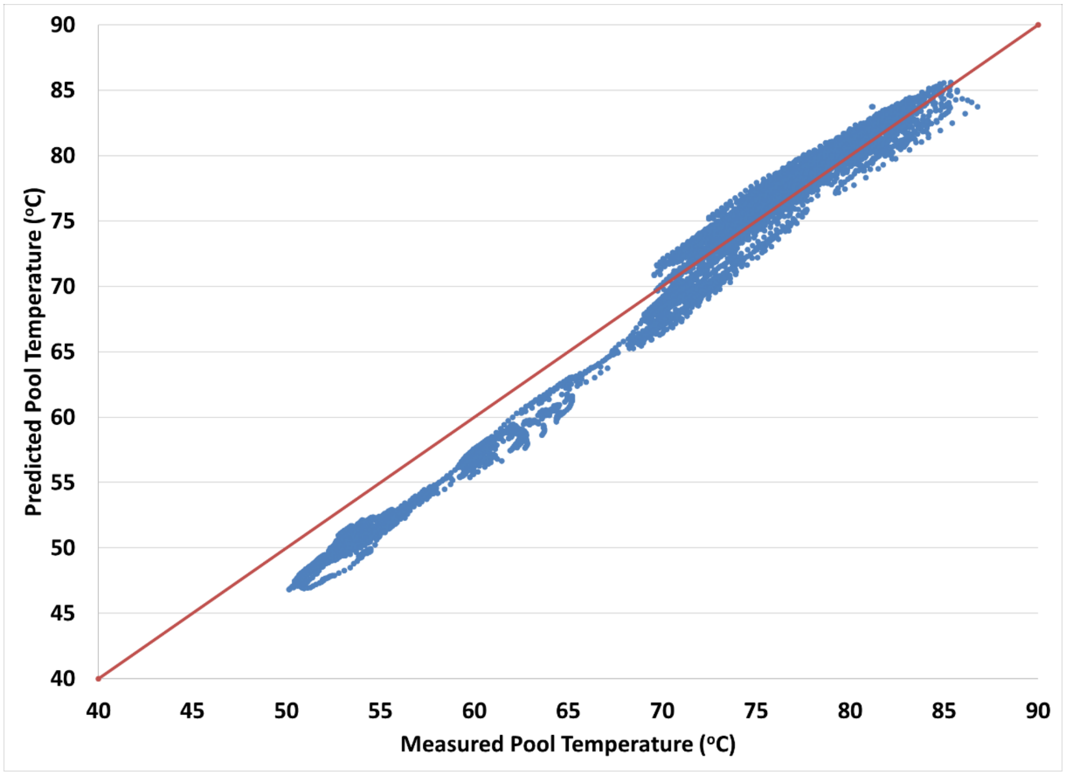


Figure 19. Measure pool temperature plotted against predicted pool temperature with line representing a one-to-one relationship for Site 1.

Figure 20 shows the hourly pool temperature predicted by the model, compared with the measured pool temperature for Site 2. During this test there was 6,977 KBTU of heat rejected to the pool by the air conditioning system from August 16 to October 20. Some gaps appear in the measured data where the data loss had occurred.

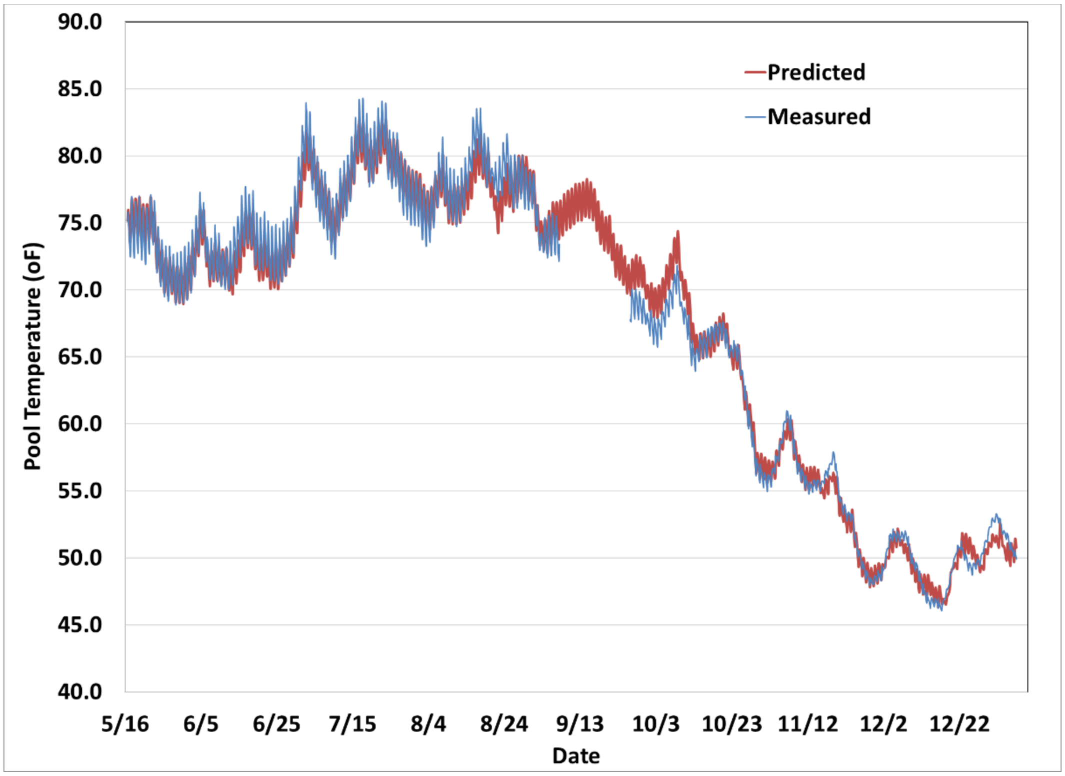


Figure 20. Predicted pool temperature versus measured pool temperature for Site 2.

The temperature predictions for Site 2 in Figure 20 show better tracking of the actual pool temperatures during colder conditions. The average RMS error in the hotter months was 0.5 °C, while the RMS error in the cooler months was 0.4 °C. The maximum error of the model for all hours was 1.7 °C. Figure 21 shows the predicted pool temperatures, plotted against the measured pool temperature, illustrating good temperature predictions across all observed hours. The average RMS error for all hours was 0.5 °C.

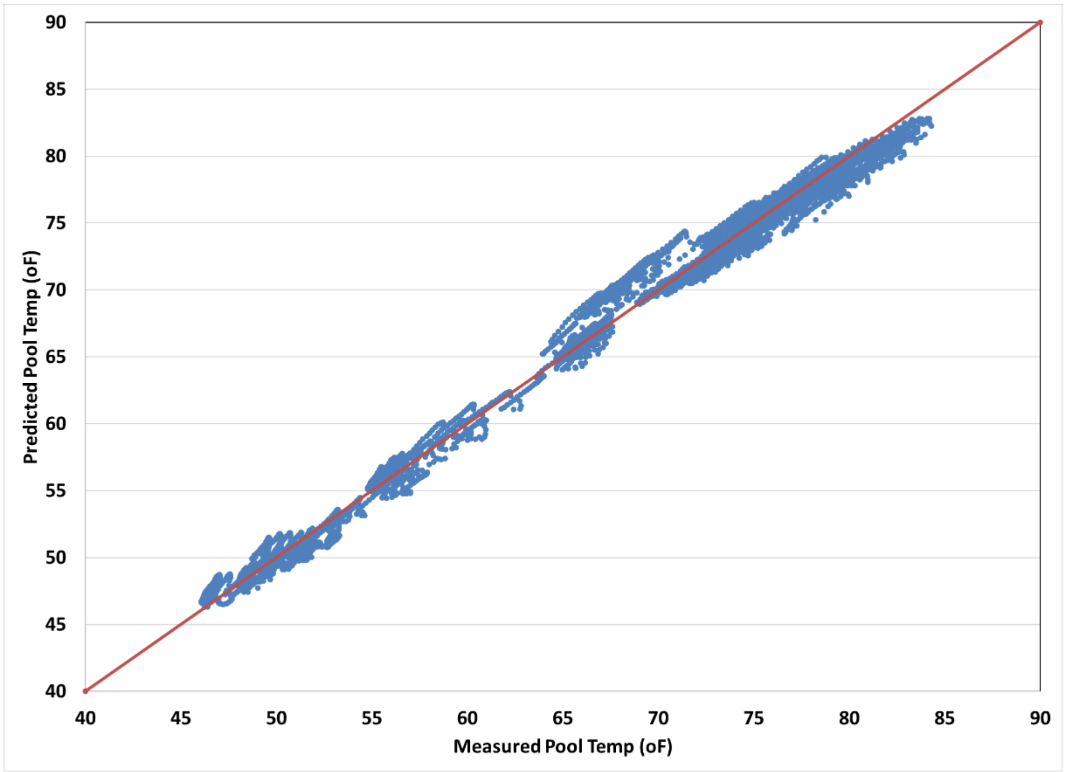


Figure 21. Measure pool temperature plotted against predicted pool temperature with line representing a one-to-one relationship for Site 2.

The model predicted the pool temperatures, show good agreement with measured values, suggesting that the pool model can be used to create reasonably accurate energy use estimates for the pool-coupled heat pump system. For Site 1, the pool temperature predictions in the summer were generally better than those in the winter. The model tended to predict lower pool temperature conditions for Site 1 in the winter, which would lead to lower estimates for heating efficiency for the heat pump system used for absorbing heat from the pool.

Data Analysis

Simulations were conducted using the validated pool thermal model, along with loads from building energy simulations, to estimate the energy savings potential of the pool-couple heat pump technology, as well as the impact on pool temperature conditions. The technology tested is currently only supported commercially for air conditioning operations of the heat pump, but this study also explored the potential to use the pool as a heat source in the winter.

The energy savings of the technology were evaluated for a wide range of scenarios to describe the broad potential of the technology to reduce HVAC energy use in California. The key parameters that were considered in the analysis were climate zone, house type, pool size, heat pump efficiency, shading level, and pool temperature setpoint. Table 8 shows the various parameters that were considered for evaluating the technology performance in California.

Table 8. Simulation Parameters Considered for Parametric Analysis of Pool-couple Heat Pump

Pool Volume	Shading Level*	HVAC Efficiency**	House Type	Pool setpoint	Climate Zone
10,000 gal.	Low Shading	High Efficiency	One-Story Model	90°F	California climate zones 1-16
15,000 gal.	Some Shading	Medium Efficiency	Two-Story Model	86°F	
20,000 gal.	High Shading	Low Efficiency			
25,000 gal.					

* Specific shading factors considered are outlined in Table 3
** Specific efficiency ratings outlined in Table 6

The simulation parameters investigated were meant to cover a range of potential installations. Overall, there were 2,304 unique model runs to evaluate each combination of parameters shown in Table 8. For a particular installation, the model inputs can be refined to reflect more specific project details, resulting in a more accurate estimate of energy savings and pool temperature impacts.

Energy Savings

The cooling performance was evaluated for each of the simulations to determine the impact of the retrofit technology on cooling energy use, including during peak times, defined as between 4pm and 9pm, and pool temperature.

The energy savings are presented in a series of boxplots below. Each boxplot represents a group of simulations that include all shading parameters, and the pool sizes considered. The results are generated for different equipment efficiencies, house model types, and pool setpoint temperatures. Figure 22Figure 24 show the cooling energy savings in each climate zone for the two-story model with a 90°F pool temperature setpoint.

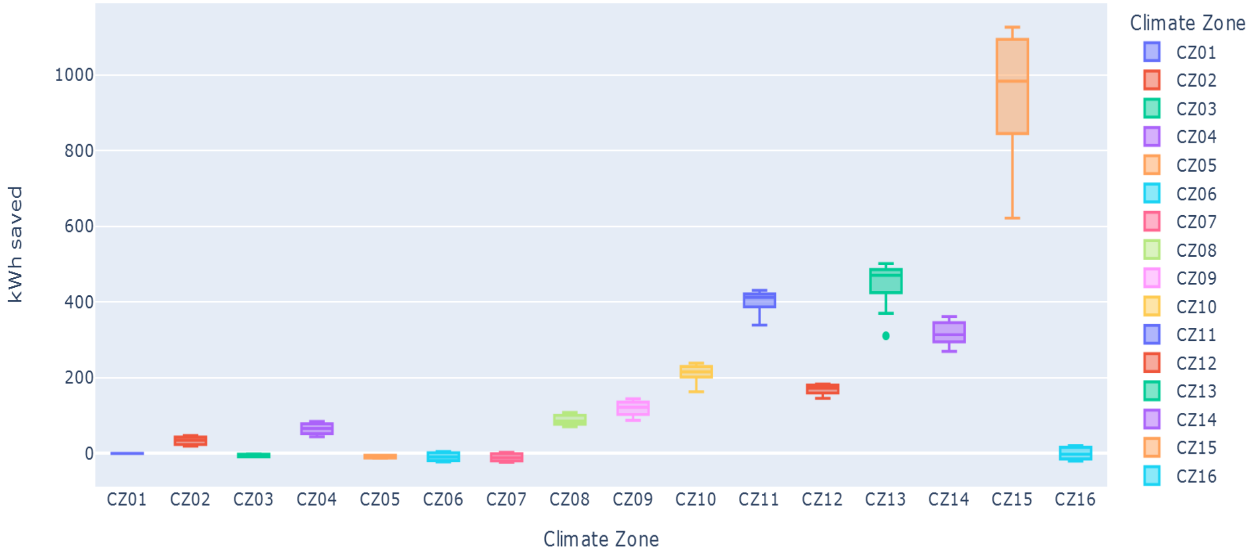


Figure 22. Cooling energy savings (Two-story model, High-COP, 90°F setpoint).

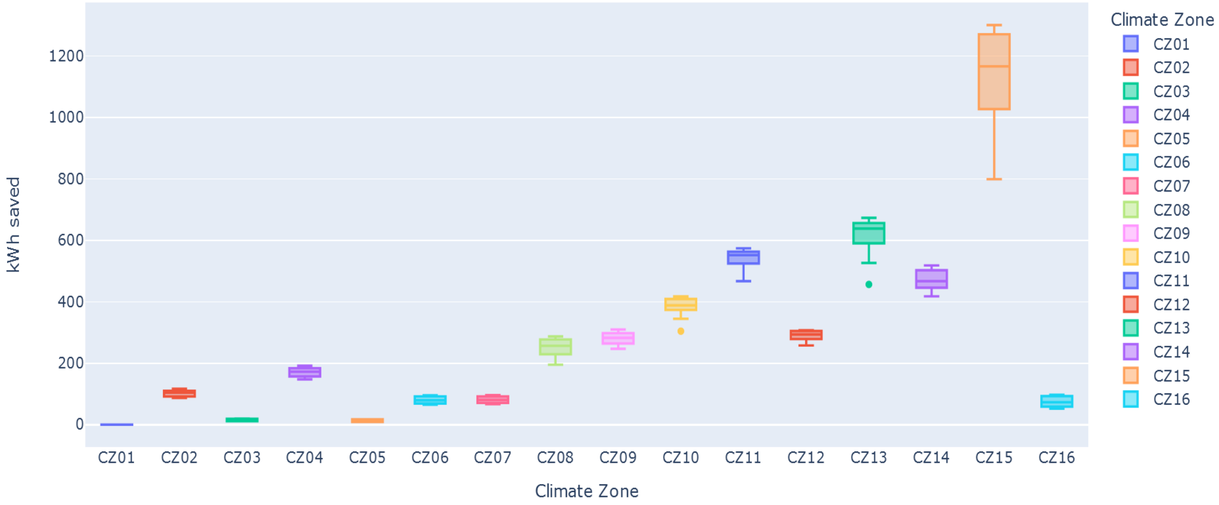


Figure 23. Cooling energy savings (two-story model, mid-COP, 90°F setpoint).

Figure 24. Cooling energy savings (two-story model, low-COP, 90°F setpoint).

The results show that installing the retrofit technology on an existing air conditioner that has a lower efficiency rating results in higher energy savings. The low-COP air conditioner showed about two-times as much energy savings as the high-COP air conditioner. The climate zone also had a big influence on the potential for energy savings. Some climate zones show low energy savings (heating dominated climates) and even negative savings in some circumstances, while others showed relatively high savings. Climate zone 15 showed the highest savings, with the potential to reduce air conditioning energy use by 2,000 kWh annually.

Figure 25 Figure 27 show the results for the two-story prototype model with a much lower 86°F pool temperature setpoint. This resulted in lower overall energy savings, due to the reduced number of hours that the system rejected heat to the pool.

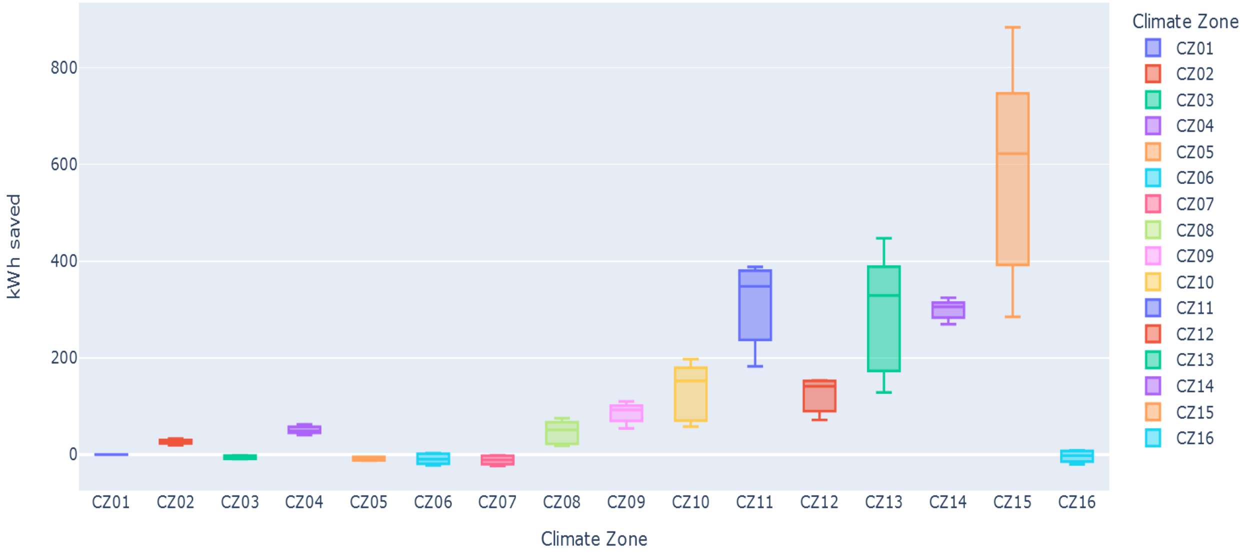


Figure 25. Cooling energy savings (two-story model, high-COP, 86 ° F setpoint).

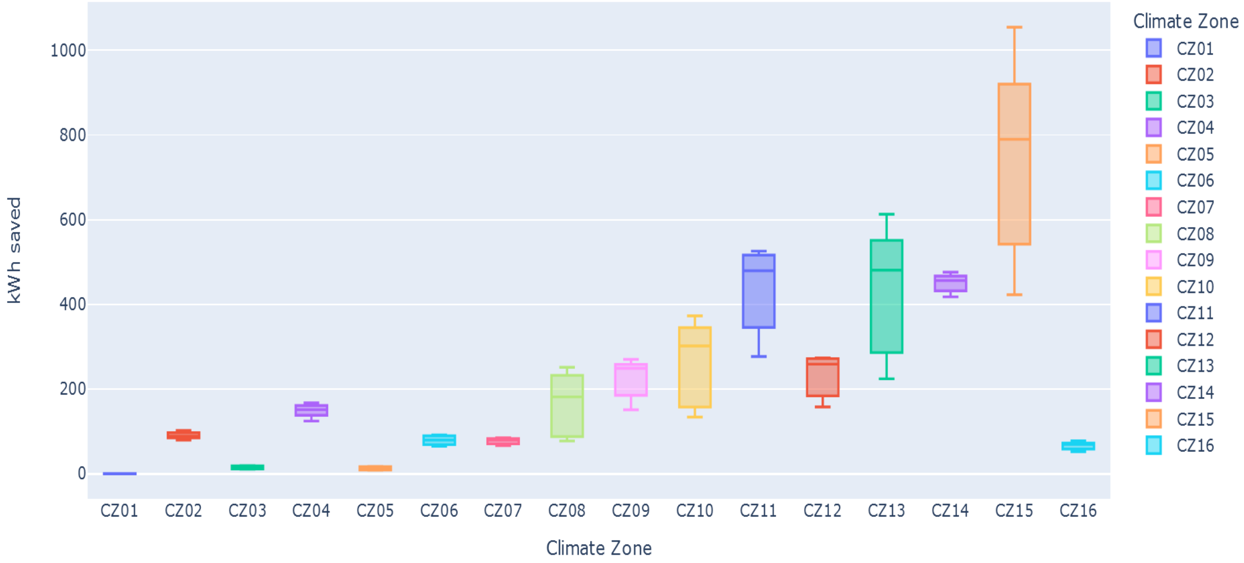


Figure 26. Cooling energy savings (Two-story model, Mid-COP, 86 ° F setpoint)

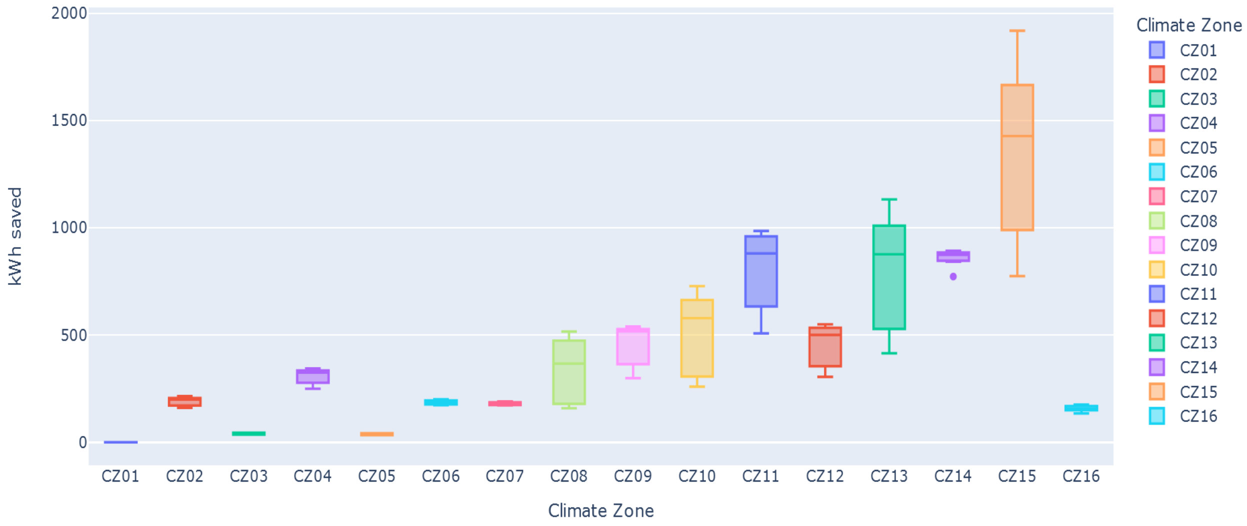


Figure 27. Cooling energy savings (two-story model, low-COP, 86°F setpoint).

Reducing the pool setpoint temperature resulted in lower energy savings. When operating with a lower setpoint, there is less thermal capacity in the pool to absorb air conditioner waste heat. The lower setpoint resulted in more air-source operation and lower energy savings potential. It is observed that the boxplots become larger in the scenarios with a lower pool setpoint temperature, especially in the climate zones with more cooling energy use. This is a result of the system switching to air-source mode when the pool surpasses its setpoint reducing energy savings. This is most apparent in climate zone 15, which has the largest cooling requirements of the California climate zones, since the sun exposure and pool size conditions cause some of the simulations to reach the setpoint more often than others. For example, the highest savings for climate zone 15 was for the largest pool with the highest shading, which switched to air-source model (surpassed the setpoint) for 32 percent of all cooling hours, compared with the scenario with lowest savings for the smallest pool with the most sun exposure that relied on air-source cooling for 45 percent of all cooling hours, due to overheating.

Figure 28Figure 30 show the same results as above but for the single-story prototype model. Given the lower cooling requirements for the home, the energy savings from the pool-source technology is lower than for the two-story model. Otherwise, the trends seen in the energy saving potential are similar.

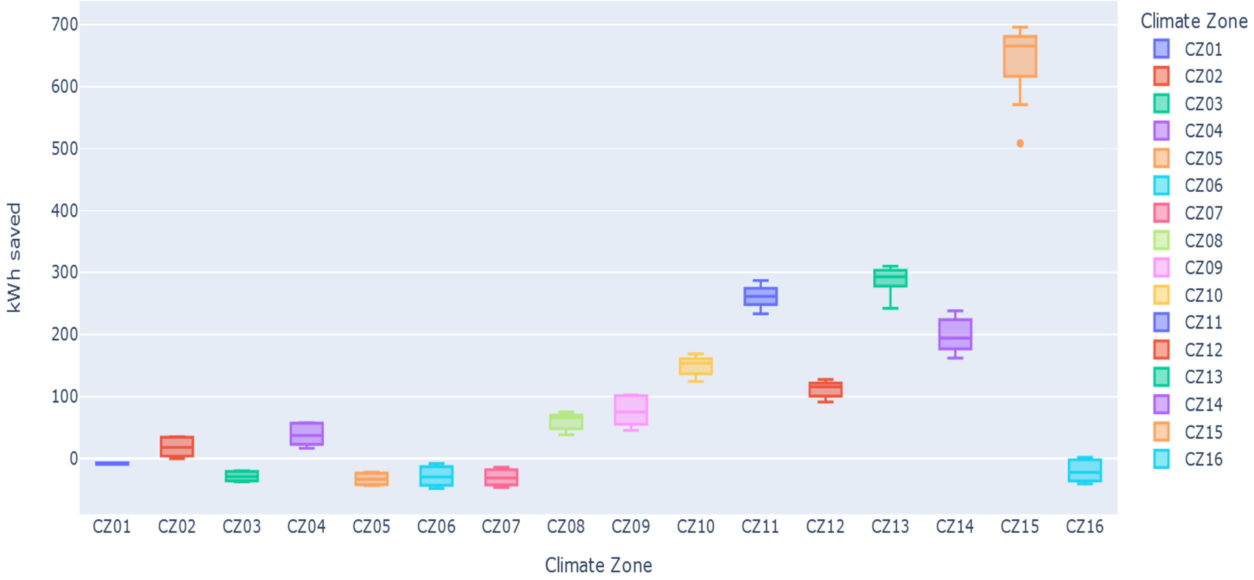


Figure 28. Cooling energy savings (one-story model, high-COP, 90 °F setpoint).

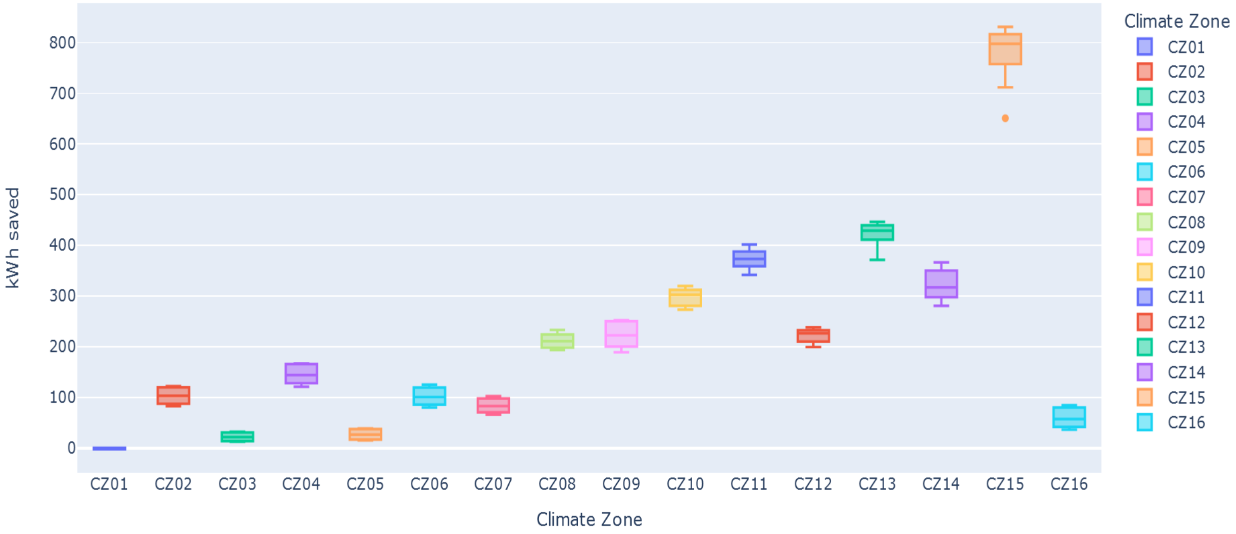


Figure 29. Cooling energy savings (one-story model, mid-COP, 90 °F setpoint).

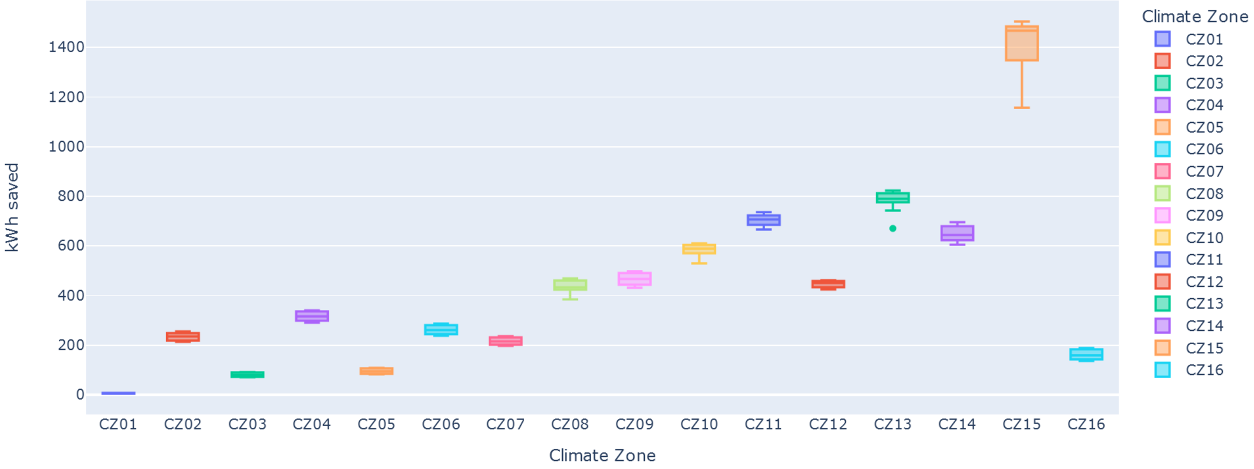


Figure 30. Cooling energy savings (one-story model, low-COP, 90°F setpoint).

Figure 31. Cooling energy savings (one-story model, high-COP, 86°F setpoint).

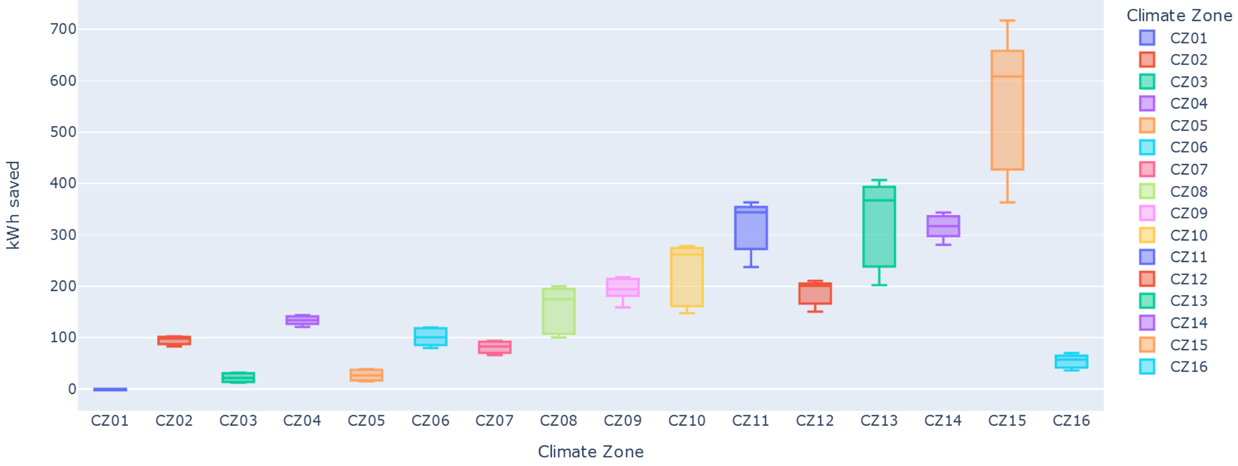


Figure 32. Cooling energy savings (one-story model, mid-COP, 86°F setpoint).

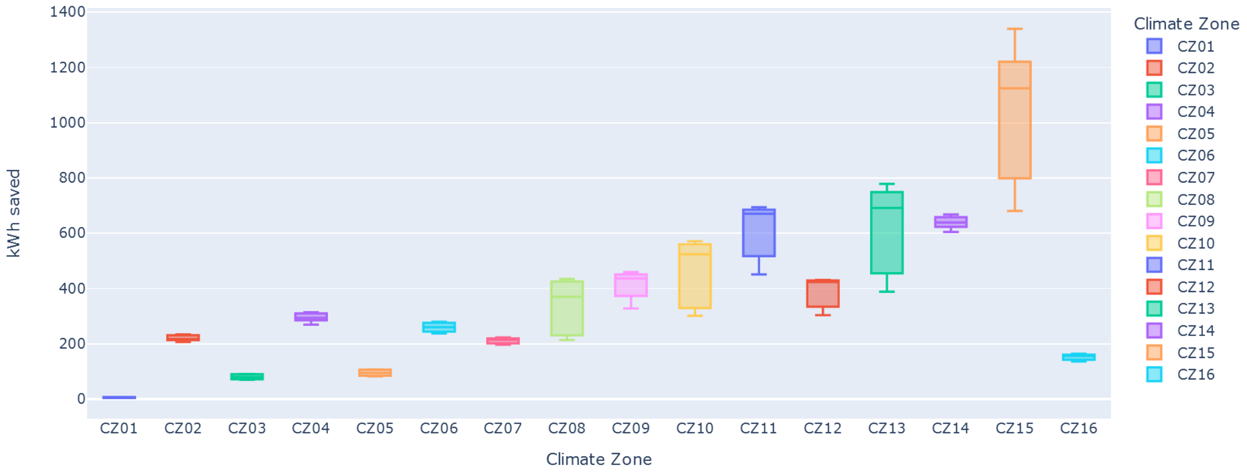


Figure 33. Cooling energy savings (one-story model, low-COP, 86°F setpoint).

Each boxplot in the figures above show the range of results for a series of simulations. In general, the pool with larger thermal mass and lower sun exposure resulted in higher energy savings. Larger pools can absorb more heat without changing temperature as much as smaller pools. This results in lower pool temperatures and better performance when used as a heat sink. Similarly, pools with higher amounts of shading have lower solar gains, which allow pool temperatures to remain lower than pools with more sun exposure.

The energy savings results show that some climate zones achieved very little or even negative cooling energy savings, depending on the specific simulation. Climate zones with very low cooling loads, such as CZ01, would not be a good candidate for this technology, due to the limited savings potential.

PEAK ENERGY SAVINGS

The results presented in Figure 22 to Figure 33 were repeated for the peak electricity hours only which are defined as the hours between 4 to 9pm. These hours represent the most challenging demand on the California electric grid and are often associated with higher electricity costs as part of a time of use rate structure. The energy savings during peak is provided in Figure 34Figure 45 below.

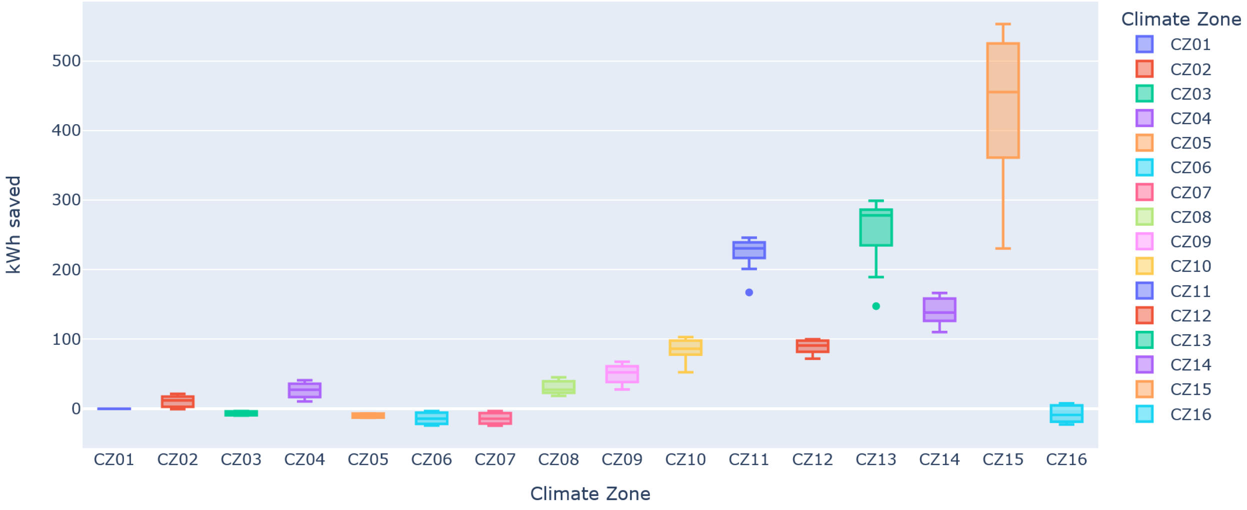


Figure 34. Peak cooling energy savings (two-story model, high-COP, 90 ° F setpoint).

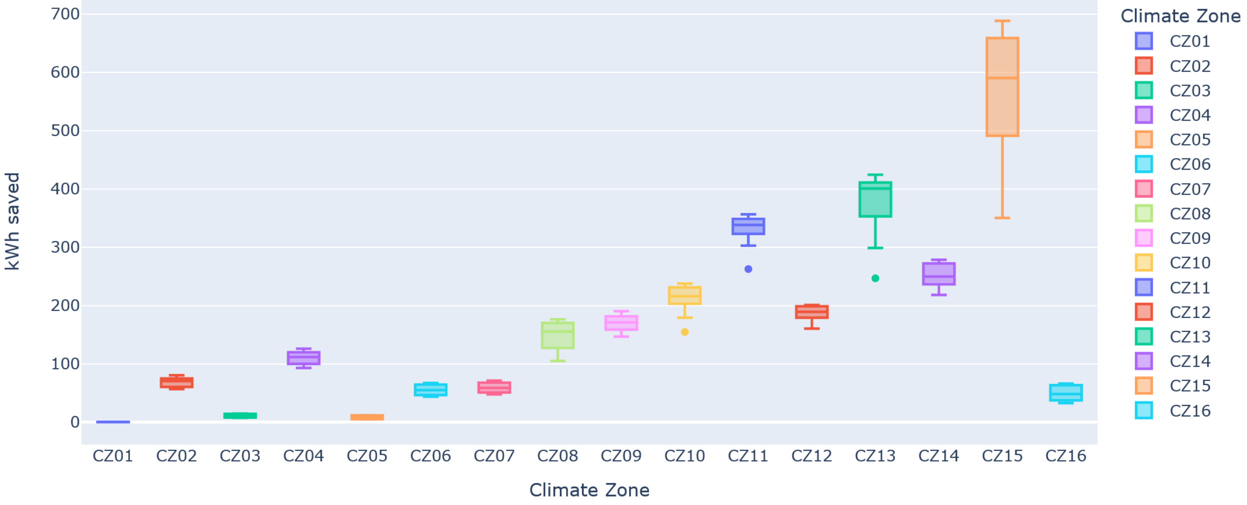


Figure 35. Peak cooling energy savings (two-story model, mid-COP, 90 ° F setpoint).

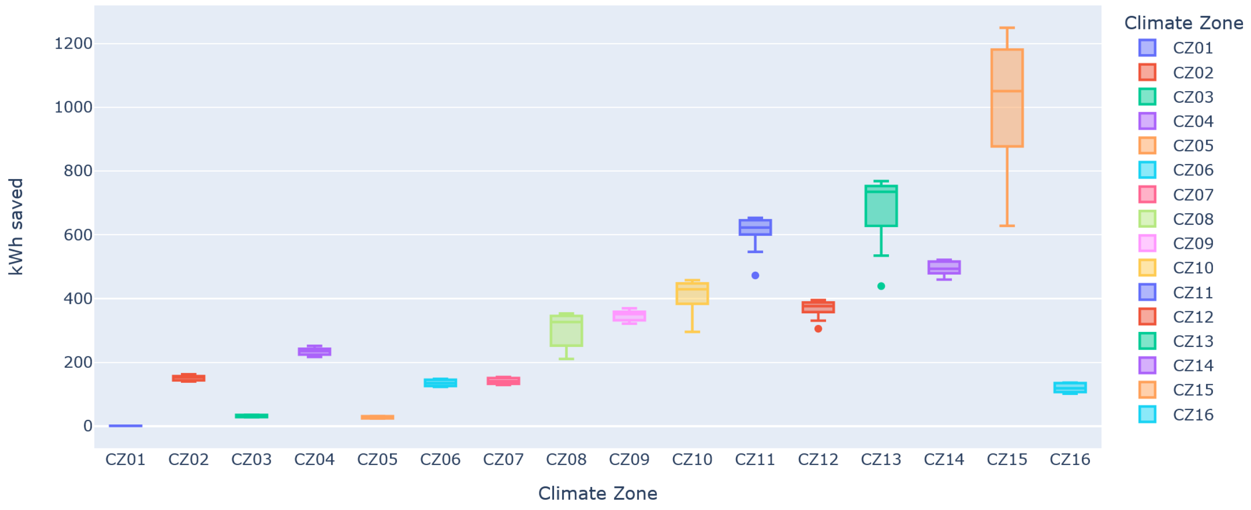


Figure 36. Peak cooling energy savings (two-story model, low-COP, 90 °F setpoint).

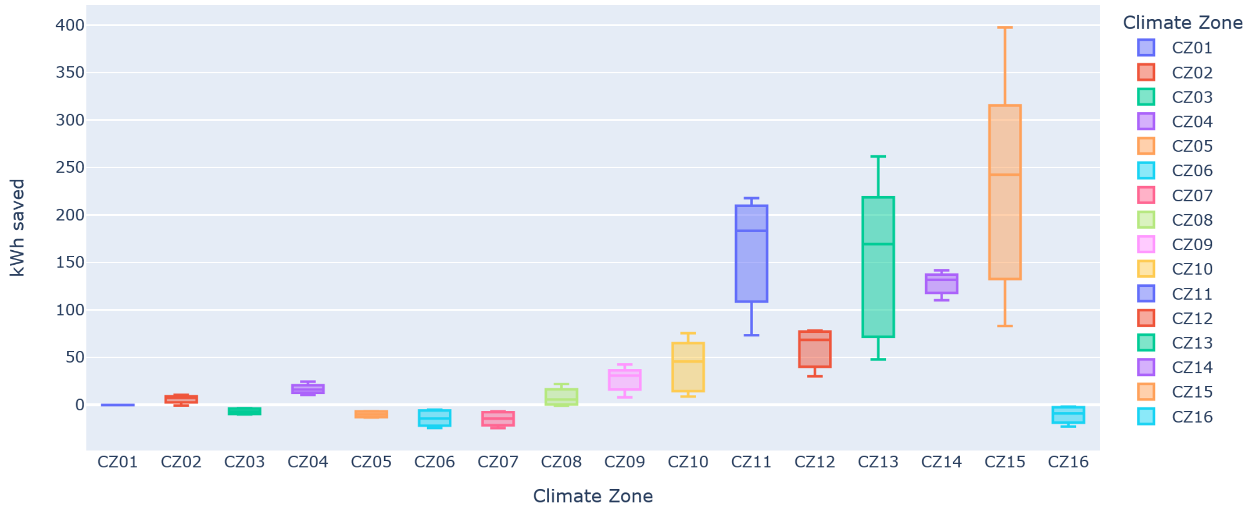


Figure 37. Peak cooling energy savings (two-story model, high-COP, 86 °F setpoint).

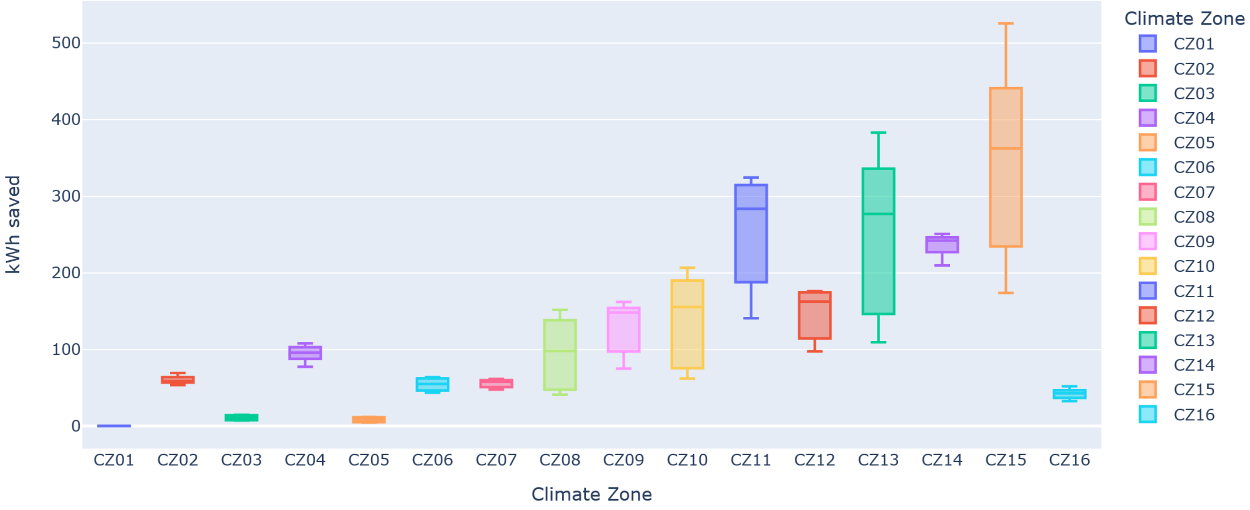


Figure 38. Peak cooling energy savings (two-story model, mid-COP, 86°F setpoint).

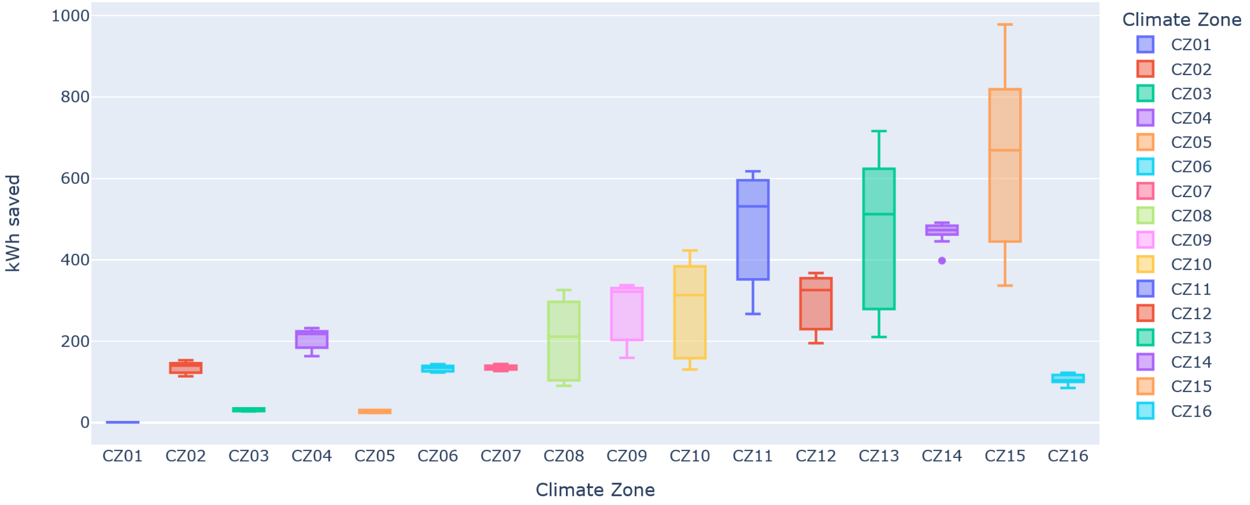


Figure 39. Peak cooling energy savings (two-story model, low-COP, 86°F setpoint).

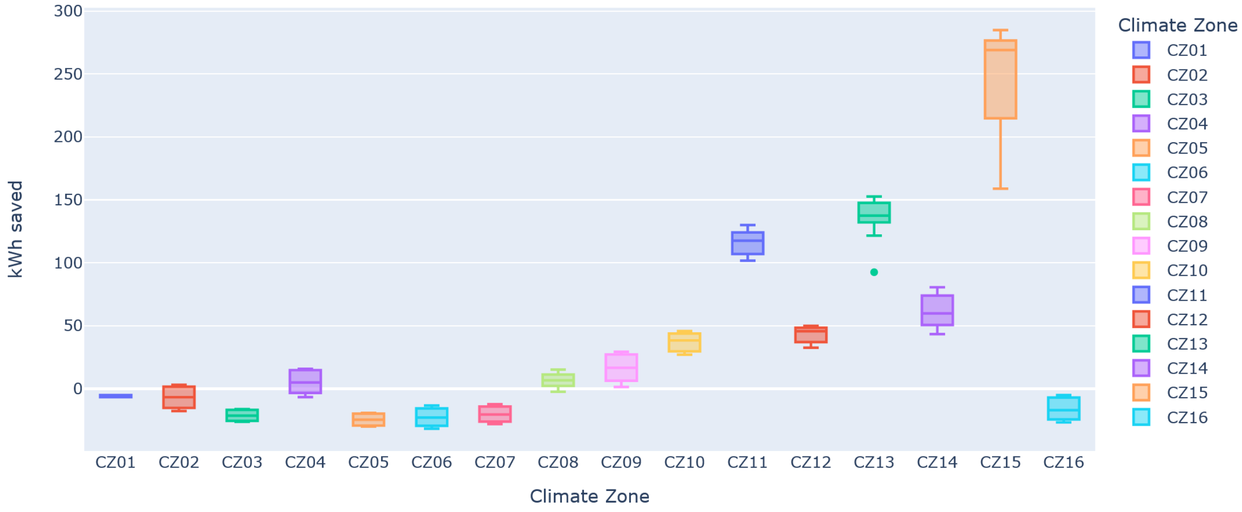


Figure 40. Peak cooling energy savings (one-story model, high-COP, 90 °F setpoint).

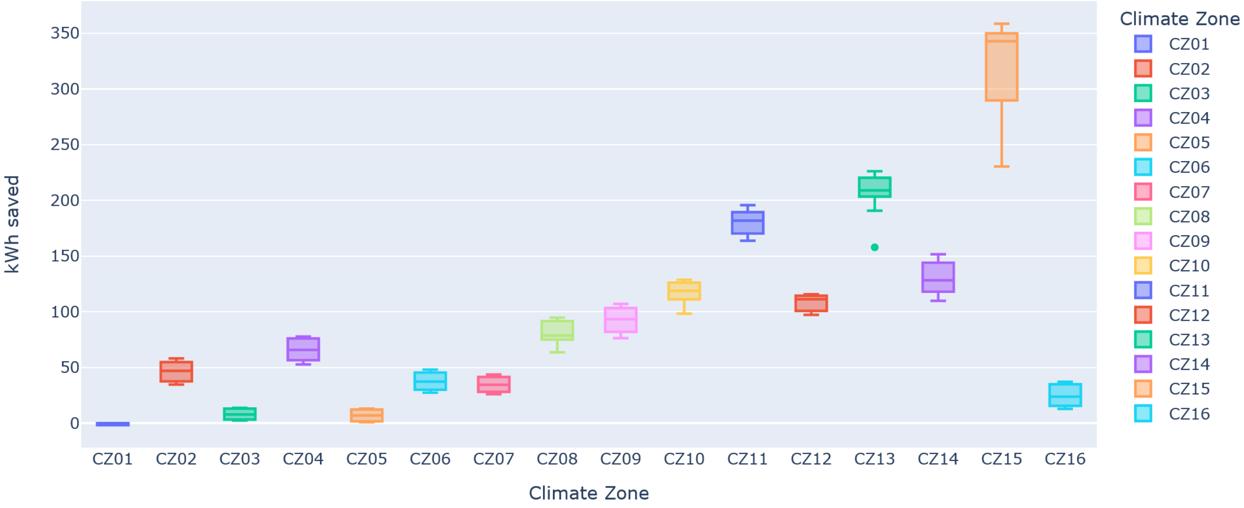


Figure 41. Peak cooling energy savings (one-story model, mid-COP, 90 °F setpoint).

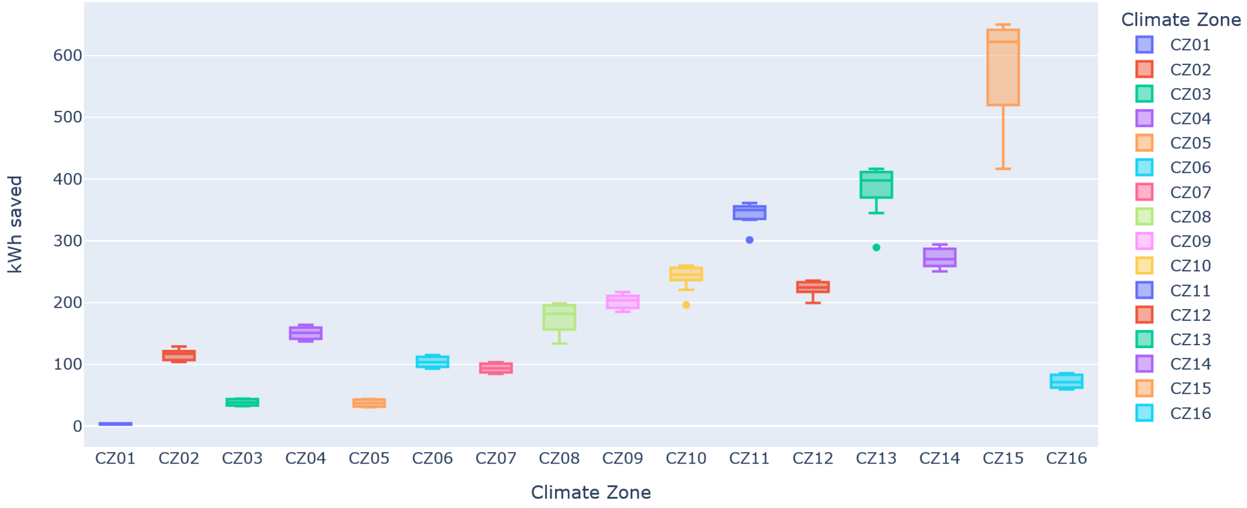


Figure 42. Peak cooling energy savings (one-story model, low-COP, 90 ° F setpoint).

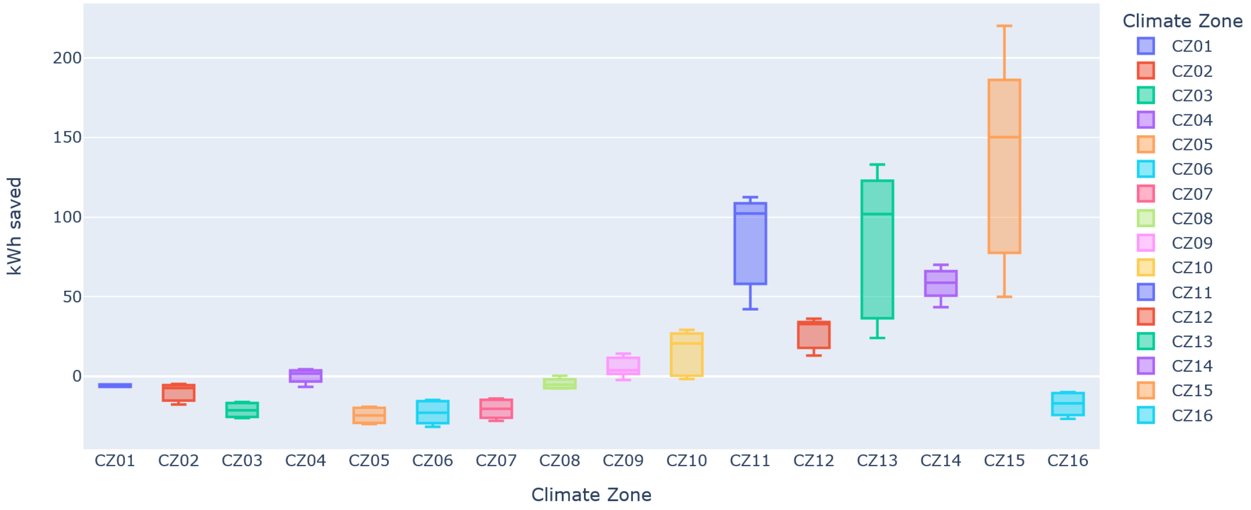


Figure 43. Peak cooling energy savings (one-story model, high-COP, 86 ° F setpoint).

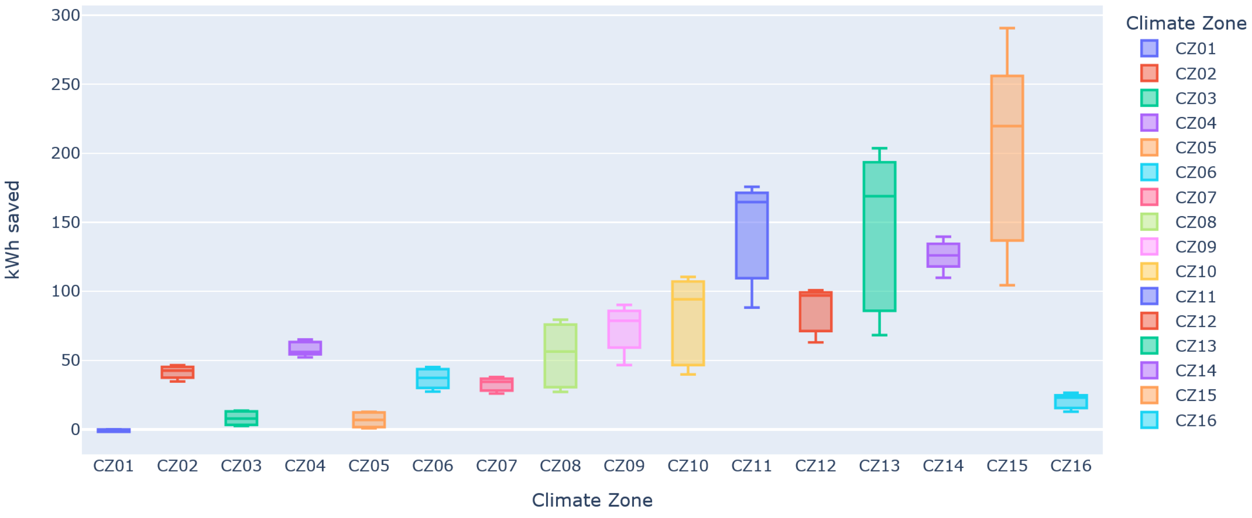


Figure 44. Peak cooling energy savings (one-story model, mid-COP, 86°F setpoint).

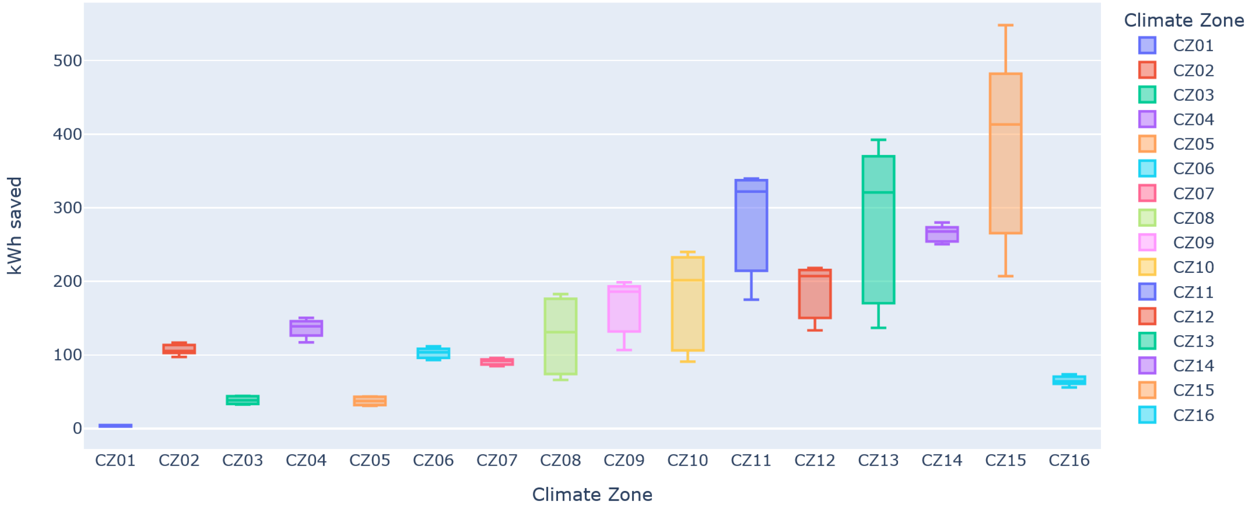


Figure 45. Peak cooling energy savings (one-story model, low-COP, 86°F setpoint).

Figure 34 to Figure 45 show that a substantial fraction of the overall energy savings occurs during the peak hours from 4 to 9pm. For climate zones with more than 100 kWh of cooling energy savings, the simulations showed 30-60 percent of the energy savings occurred during the peak. A higher fraction of peak savings was observed for simulations with the more efficient air conditioner than with the less efficient air conditioner. However, similar to the results for total cooling energy savings, more peak energy savings were found when retrofitting the technology with a lower efficiency air conditioner.

Pool Temperature Impacts

The impact of the technology on pool temperatures was also evaluated in the simulations. The heating provided by the air conditioning heat rejection is dependent on the cooling load in the house, pool size, and weather conditions. A small pool absorbing heat from a house with high cooling loads will experience more pool heating than a large pool absorbing heat from a house with lower cooling loads. The former scenario will lead to warmer pool temperatures and reduced energy saving potential. Figure 46 shows the impact on pool temperatures for the simulations, showing the average temperature difference between the natural pool temperature and the pool temperature with air conditioner heat rejection from May 1 to September 30. The results are broken out by pool size and climate zones, with each bar representing the average impact for all shading conditions and air conditioner efficiency.

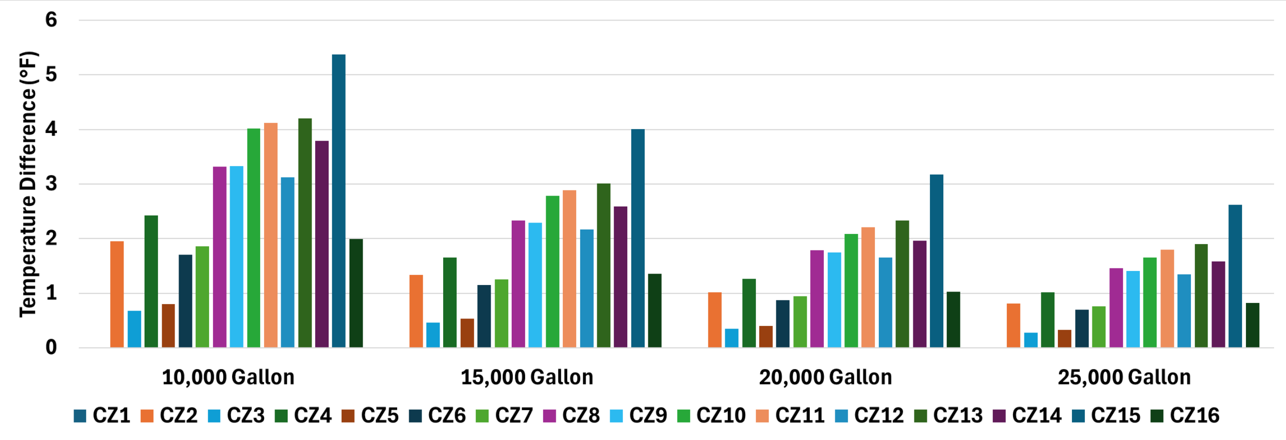


Figure 46. Average pool temperature difference from May 1 to September 30 between natural pool and pool with A/C heat rejection for all simulations.

The results in Figure 46 show that the technology increases the average pool temperature during the cooling season by several degrees in many climate zones. The smaller pool sizes and hotter climate zones resulted in more pool heating.

Site 1 House Comparison

To evaluate the simulation tool further, the energy savings results using the simplified inputs were compared to the Site 1 data collected in the field. Table 9 shows the simulation parameters used to test the model against the field test results measured for Site 1.

Table 9. Simulation Parameters Used to Evaluate Model Accuracy, Compared to Field Test Results for Site 1.

Pool Volume	Shading Level	HVAC Efficiency	House Type	Pool setpoint	Climate Zone
25,000 gal.	Low Shading	Medium Efficiency	Two-Story Model	90°F	California climate zone 12

The simplified inputs differed from the actual conditions used to validate the pool thermal model in the earlier section. The pool volume was consistent with the actual test, but the surface area for the simulation was based on simplified assumptions about average pool depth, rather than the measured surface area. The shading conditions also differed slightly from the shading observed at

Site 1. The air conditioner performance was based on the Goodman GSX series 13 SEER (Medium Efficiency) unit, rather than the performance map created for the unit measured at Site 1. The house for Site 1 was a two-story building with about 20 percent more conditioned floor area than the model for generating loads for the simulation. The pool setpoint was accurate for the conditions at Site 1, in that the pool-coupled heat pump never shut off on high temperature and was never observed to go over 90°F during the retrofit monitoring period. Lastly, the weather data for the simulation was based on TMY weather data for climate zone 12, rather than the actual weather experienced during the retrofit period.

The results showed good agreement between the fraction of cooling energy savings estimated using the simplified model and the measured result in the field test data. The model predicted 11 percent cooling energy savings for the scenario that was most similar to the field test versus 13 percent cooling energy savings for the nine-week retrofit period. This demonstrates the accuracy for the model to predict fractional savings even without detailed input parameters.

To evaluate the accuracy of the model to predict the actual amount of energy saved relative to the field test, the hourly model predictions during the specific nine-week period of the retrofit period were compared to the field test results. This process found that the model underpredicted the actual energy savings observed in the field, estimating only 31.1 kWh of energy savings, compared with the measured 57.5 kWh. This discrepancy can be explained by several factors. The field test house was larger and used a different thermostat setpoint schedule, relative to the model, which led to 36 percent higher cooling loads over the period of interest. Another source of error comes from the fact that the environmental conditions differed between the model and field test. The average outdoor air temperature during cooling hours was 86°F for the field test versus only 79°F for the model. This leads to differences in air-source system performance, resulting in lower energy savings estimates for the model. Similarly, the pool temperature conditions in the model during cooling hours were lower than the field test but only differed by 1.6°F.

These results suggest that the accuracy of the pool-coupled air conditioner model, like other building energy modeling software, is sensitive to differences assumed typical and real meteorological conditions. Furthermore, having more specific input assumptions that represent the conditions of the field test will result in better predictions. In the test case evaluated here, the actual building cooling loads were significantly higher than the prototype building which resulted in lower energy savings estimates.

Stakeholder Feedback

The stakeholders in this project evaluation include the manufacturer, utility program managers, and HVAC installers. The following is a summary of feedback received from each of these stakeholders throughout the project.

Manufacturers

Discussions with the manufacturer of the technology provided insight on their view of the primary market for the technology. This product is marketed as a pool heating system and the recommendations reflect that when discussing specific applications. As part of the recommendation, they provide guidance to prospective customers on the number of hours of runtime the air conditioner would need to maintain the pool at low- to mid-80°F temperatures. They used a combination of air conditioner capacity and pool surface area to make this determination, and for the sites in this study they recommended the air conditioner run for 7.9 hours per day for Site 1 and 4.1 hours per day for Site 2. They note that adding a pool cover would reduce the required hours for adequate pool heating. Clearly meeting the estimated air conditioning runtime would depend on the cooling load rather than the pool heating needs and is likely to be met on hotter days than cooler ones.

The other topics discussed with the manufacturer were what types of equipment the technology works with. They recommend against using this technology on variable capacity equipment due to the presence of additional sensors that may cause a fault when the technology interrupts the refrigerant flow or condenser fan operation. The technology does work with heat pump units, but only in the cooling mode. The manufacturer does not currently support using the pool as a heat source for a heat pump in heating mode, due to the expectation that the pool does not have enough thermal capacity to avoid overcooling. Simulations using the pool thermal model in this project show that this approach could be beneficial in some climate zones and should be a topic for further research.

Lastly, the project team discussed the potential for the manufacturer to offer the components in a pre-built package to simplify the installation. This approach would increase the equipment costs but reduce the installation costs. The HVAC contractors expressed concern about the complexity of the installation. These complexities and unknowns result in higher bids from contractors to perform the work to allow for contingencies. It is expected that a contractor familiar with the technology would quickly become comfortable with the installation, but reducing the field-installed components would streamline the install and allow contractors that are not familiar with a more straightforward scope.

HVAC Installers

The installer of the technology was contacted to discuss the complexity of the installation and overall potential from their point of view. The installation process required the same skillset as many other HVAC installations, but the fact that the technology was new to the installer meant that the installation team had to take more time to review installation guidelines and steps. The first installation took about twice as long as the second due to this lack of familiarity. With a familiar installation crew, the process would be similar to other HVAC installations. There is also a need to install plumbing on the pool equipment that HVAC installers may or may not be comfortable with. This project worked with a separate pool contractor for the pool equipment installation which is similar to the process for a solar thermal or mechanical pool heating system.

Utility Program Managers

One of the key products of this research was the development and validation of an evaluation tool that can be used to estimate energy savings potential from the system in different applications. This tool can be used by utility program managers to provide appropriate incentives for customer installations.

Recommendations

The field demonstrations and model simulations show that the technology evaluated can reduce the cooling energy use of existing air conditioners while also providing pool heating. The simulations performed, based on loads from two single-family prototypes, shows energy savings over 1,000 kWh per year in multiple climate zones with a significant fraction of this energy savings coming during peak times (4pm-9pm). The technology provided the most savings in the hotter climate zones including CZ 9-15. The installation complexity and cost could impact adoption rates, but it is expected that costs would come down as contractors became familiar with the installation process. Unfortunately, these costs could prevent the system from being cost-effective based strictly on the energy savings alone, but if installed in place of a traditional pool heater that may be a better pathway toward achieving cost effectiveness.

Below are some observations from the field studies that could help with maximizing energy savings and guide measure development:

- The technology does not have a sophisticated way to interact with the existing pool pump controls. It is the manufacturer's recommendation to always send water to the pool-refrigerant heat exchanger to avoid issues related to controls, but they do have a control strategy that allows the system to simulate a solar thermal pool heating system. For systems with long plumbing runs to the heat exchanger, a three-way valve can be used along with the built-in solar thermal controls for the pool pump, to avoid additional pumping power when the air conditioner is not running.

- The system is not designed to turn the pool pump on and off so the pool pump must be running to reject heat to the pool. For the demonstrations, the pool pumps were scheduled to perform filtering operations during the afternoon, to coincide with air conditioning energy use. A variable speed pool pump allows for optimal control, since the pump can be set at low speeds over longer periods of time for filtering, allowing the system to be available for air conditioning heat rejection over more hours of the day.

- The pool temperature setpoint should be set as high as possible to maximize pool-source heat rejection and energy savings. This setpoint temperature will not necessarily be maintained by the system, but instead be considered the maximum allowable pool temperature for the homeowner.

- The pool modeling tool developed by WCEC should be used to estimate the energy savings from a particular installation. The more information provided to the model, the better the prediction for energy savings will be. It is expected that the percentage cooling energy savings will likely be the best predictor of actual performance, since the total energy savings is based on loads from an EnergyPlus prototype. If the utility can estimate cooling energy use for a home, then combining that estimate with the percentage savings result will likely provide a better estimate for total energy savings.

References

AHRI. 2023. "Performance Rating of Unitary Air-conditioning & Air-source Heat Pump Equipment." Air Conditioning, Heating, & Refrigeration Institute.

CIMIS. 2024. "California Irrigation Management Information System." *Hourly Report for Davis, CA.* Prod. Department of Water Resources. https://cimis.water.ca.gov/.

EIA. 2019. "Efficiency requirements for residential central AC and heat pumps to rise in 2023." Energy Information Agency. https://www.eia.gov/todayinenergy/detail.php?id=40232.

Hahne, E., and R. Kubler. 1994. "Monitoring and Simulation of the Thermal Performance of Solar Heated Outdoor Swimming Pools." *Solar Energy* 53: 9-19.

Harrington, Curtis, and Mark Modera. 2013. "Swimming Pools as heat sinks for air conditioners: California feasibility analysis." *Energy and Buildings* 59: 252-264.

Maxwell, Eugene. 1987. "A Quasi-Physical Model for Converting Hourly Global Insolation to Direct Normal Insolation." Solar Energy Research Institute, National Renewable Energy Laboratory.

Miller, Peggy, and Karen Griffin. 1986. *How Insulated are California's Homes? Field Inspection and Survey Data on Residential Insulation.* California Energy Commission.

Palmgren, Claire, Miriam Goldberg, Ramirez Bob, and Williamson Craig. 2021. *2019 California Residential Appliance Saturation Study (RASS).* DNV GL Energy Insights USA, Inc., California Energy Commission.

Smith, Craig B., and Kelly E. Parmenter. 2016. "Chapter 8 - Management of Heating and Cooling." In *Energy Management Principles (second Edition)*.

Vignola, Frank E., Andrew C. McMahan, and Catherine N. Grover. 2013. "Typical Meteorologoical Year (TMY) Data Files." Chap. 5.3 in *Solar Energy Forecasting and Resource Assessment*, by Jan Kleissl.

Woolley, Jonathan, Curtis Harrington, and Mark Modera. 2010. "Swimming pools as heat sinks for air conditioenrs: model design and experimental validation for natural thermal behavior of the pool." *Building and Environment* 1-9.