Pool Heating Analysis

Project Number ET24SWG0001

GAS EMERGING TECHOLOGIES (GET) PROGRAM
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SoCalGas

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Acknowledgements

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Disclaimer

Executive Summary

This report presents an in-depth analysis of quantifying pool heating technologies. The study evaluates energy savings, cost impacts, and greenhouse gas (GHG) emissions reductions across various pool heating systems—including traditional gas heaters, gas absorption heat pumps (GAHPs), electric heat pumps, solar thermal systems, and hybrid gas-electric heaters—installed in residential, multifamily, and small commercial pools.

Key objectives include:

- Synthesizing insights from literature and subject matter expert (SME) interviews
- Updating an existing Excel-based tool to model hourly energy use, costs, and GHG emissions for alternative pool heating technologies
- Assessing the energy, cost, and GHG emissions saving potential of different pool heating technologies in California climate zones

Major findings from tool development and parametric analysis include:

- Pool covers have a significant impact on reducing evaporation heat loss and heating energy required. There is significant reduction in evaporation heat loss (up to 50%) when pool cover is in place during the unoccupied pool hours. For an outdoor residential pool, during the summer months, there is minimal, or no heating energy required to heat up a pool when pool cover is on.
- GAHPs paired with existing gas pool heaters, have the highest average percent cost savings in multifamily sectors, followed by hybrid electric-gas pool heaters when running in “minimum cost” mode.
- Heat pump pool heater and hybrid pool heater—when run in “efficiency” mode—have the highest GHG emissions saving potential for the multifamily sector.
- The parametric runs infer that effectiveness of an added external GAHP heat exchanger (required due to the pool water chemistry) is a critical design parameter. The effectiveness of the heat exchanger needs to be higher than or equal to 0.8 for positive energy savings. Average percent energy cost savings of GAHP technology in multifamily sector increases from 17% to 25%, if the effectiveness of heat exchanger is increased from 0.8 to 0.9. This highlights the fact that cost saving potential of GAHP technology would increase significantly if GAHPs were designed with integrated heat exchangers, like hybrid pool heaters.
- For indoor pools, GAHP paired with existing pool heaters demonstrate the highest percent cost savings followed by hybrid pool heaters when run in “minimum cost” mode.

Project recommendations

The study recommends conducting field studies of GAHPs and hybrid pool heating technologies to gather real-world equipment performance data, understand design, installation and commissioning challenges, monitor actual energy savings, and assess payback periods for both indoor and outdoor pools.

The study recommends updating the Excel-based tool for field tested data of this GAHP equipment as well as performance data provided by other GAHP manufacturers. The study also recommends conducting a comprehensive techno-economic analysis to determine energy saving potential of GAHP and hybrid heating technology for pool heating applications.

Introduction

This emerging technology (ET) study investigates the energy saving potential of different pool heating technologies. The scope of this project covers pool heating systems installed in residential, multifamily, and small commercial sectors in both indoor and outdoor environments. The comprehensive analysis of different types of pool heating equipment, pool-related parameters, and scenarios will further guide the pool heating technology to reduce GHG emissions and increase energy cost savings. These outcomes will provide valuable insights to customers and utilities on energy-saving potential of researched pool heating technologies and actionable recommendations. Additionally, the tool offers actionable recommendations to equipment manufacturers on energy efficient design and controls.

The objective of this study is to examine the energy savings, benefits, and drawbacks of various types of pool heating equipment, through a combination of literature review, subject matter expert (SME) interviews, and tool development. A macros-based Excel tool is updated to conduct an hourly energy, cost, and GHG emissions analysis. This study addresses a critical gap in current energy modeling capabilities by updating the tool to evaluate the energy-saving potential of various pool heating technologies. The technologies investigated include traditional gas heaters, GAHPs, solar thermal heating systems, electric pool heaters, and hybrid gas-electric pool heaters. The attributes of pool heating technologies are investigated, including applications, physics behind the technology, advantages and disadvantages, and high-level energy savings.

Background

Pool heating allows the swimming season to extend beyond summer. But heating a pool requires a significant amount of energy. With the California Public Utilities Commission (CPUC) goal to reduce natural gas usage, the energy consumption of pool heaters is important to consider across sectors. Natural gas fired pool heaters remain the most popular system for heating pools. The output of gas fired heaters for multifamiliy and small commerical applications typically vary from 75 kBTU to 450 kBTU.

According to the estimates by PoolResearch (2023), Florida and California have the most swimming pools out of all the states in the U.S. The estimated number of residential pools in California is 1.34 million and small commercial or public pools are around 40,000. In northern California, most people use outdoor pools 5-8 months per year [1]. The typical swimming season for outdoor pools is about 5-6 months, ranging from May through September. The warmer climate zones may have longer swim seasons. Pool heaters can extend this swimming season by several months, and up to the entire calendar year, ehancing the usability of the pool.

Solar pool heaters have also garnered some interest in wide scale implementation. However, there might be other cost-effective alternatives such as GAHPs, Electric heat pumps, and hybrid heat pumps depending on the pool activity/usage and climate zone. There is an opportunity to explore if these are technically and operationally feasible and cost effective. Additionally, time-of-day carbon emissions savings are of particular interest relative to reducing GHGs.

Literature Review

Water heating is energy intensive, as water has a high specific heat capacity. To raise 1 gallon of water by 1°F, 8.33 BTUs are required. For the average sized pool of about 30,000 gallons, nearly 250,000 BTUs are required to bring the pool to a standard operating temperature of 80°F from 79°F. This large energy draw has both high costs and has high emissions from the incumbent technology, traditional gas heaters. Finding alternatives to this technology can vastly reduce the costs associated with heating a pool. Beyond that, it can also help reduce greenhouse gas (GHG) emissions.

Various systems for pool heating have been produced and studied, but limited research or recommendations have been published to provide recommendations for energy and emissions savings while still maintaining consistent occupant comfort for pool use. Many of these studies discussed later in this document focus on the comparison of solar thermal technology used in combination with existing traditional gas heaters.

Pool Heat Losses

Heat losses from the pool that cause the temperature to drop to uncomfortable levels for occupants come from several avenues: evaporative losses to the atmosphere, convective losses from the temperature differences between the ambient air and the pool, radiation from the pool to the atmosphere, and temperature differences between the water and the surrounding materials. Many studies have indicated that the conductive heat loss to surrounding materials is small compared to total heat loss and can be neglected. Thus, only the other mechanisms are considered for this analysis.

Many variables affect heat loss, including whether the pool is indoors or outdoors, the amount and type of activity in the pool, and climate factors outlined below.

- Evaporative heat loss is one of the major contributors to overall pool heat loss. For outdoor pools, forced convection (air currents caused by wind) is usually the mechanism for air movement. The evaporation rate from an outdoor pool varies depending on pool temperature, air temperature and humidity, and wind speed at the pool surface. Higher water temperatures increase the rate of evaporation because the vapor pressure difference between the water surface and the air is greater. High humidity slows down the evaporation due to reduced vapor pressure gradient. Additionally, higher wind speeds increase the evaporation rates significantly.
- For indoor pools, natural convection mechanisms are the predominant form of air movement. In indoor pools, airflow is primarily due to building ventilation systems.
- Evaporation heat loss from occupied pools is higher than unoccupied pools. This increase is attributed to an increase in contact area between air-water due to waves, occupants, and wetting of the deck.
- Solar radiation adds heat to pool water and thus reduces the energy needed for heating the pool. However, the pool loses heat from radiation to the sky, which must be made up by additional heating.
- Pool covers or thermal insulation covers, placed on the surface of the pool when it is not being used, could reduce heat loss from the surface. This includes both evaporative and convective heat loss. Pool covers minimize evaporation from both outdoor/indoor pools and hot tubs. Indoor pools aren't subjected to the outdoor environment. Pool covers on indoor pools not only can reduce evaporation losses but also the need to ventilate indoor air and replace it with unconditioned outdoor air. Installing and using pool covers is the most effective means of saving energy costs—savings of 50%-70% are possible [2].
- Pool water temperatures typically range from 78°F to 82°F. A setpoint of 78°F is recommended for competitive swimming. However, young children and elderly people may require a set point of 80° F [3]. The selection of pool water temperature setpoint affects the sizing of pool heaters and the overall annual pool heating costs.

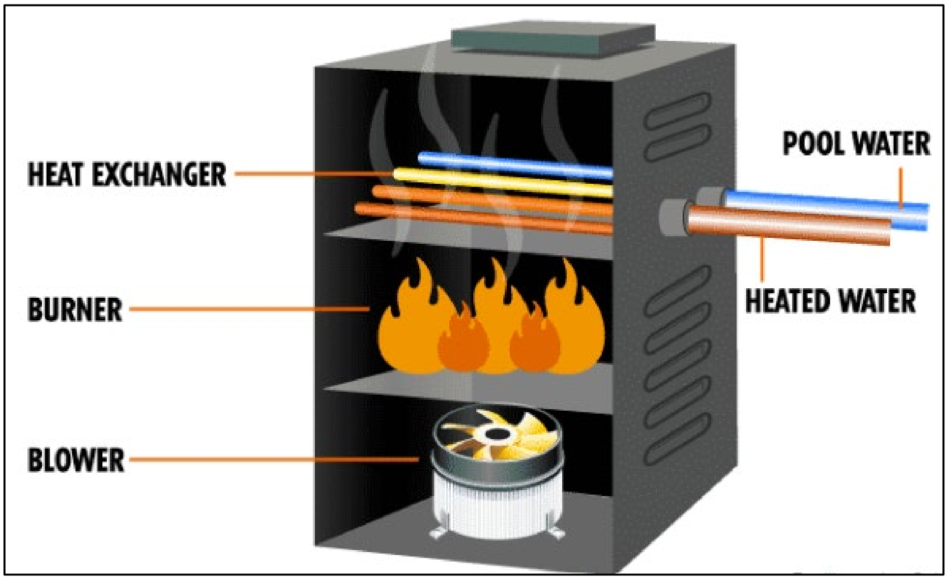
Technologies

All pool heaters function in series with the pool pump. The pool pump pulls the pool water through a filter and circulates it through a hydronic loop, either through the heater or through a heat exchanger, and back into the pool via vents. This section provides an overview of the different types of pool heating technologies.

Traditional Gas Heaters

Traditional gas heaters are the incumbent pool heating technology. As the pump circulates the pool water, the water drawn from the pool passes through a filter and then to a heater. The natural gas burns in the heater's combustion chamber, generating heat that transfers to the water that's returned to the pool. These heaters have efficiencies between 82%-90%. The typical useful life of these systems is about 10 years.

Figure 1: Schematic Diagram of Gas Pool Heater



Gas fired heaters remain the popular system for heating pools and are ideal for heating the pools quickly. Gas pool heaters are rated by BTU/hr (British thermal unit per hour) output. Typical gas pool heater outputs are in the range between 75,000 BTU/hr to 450,000 BTU/hr. The sizing of gas pool heater depends on the pool water temperature setpoint, average temperature of the coldest month, and pool surface area. The empirical formula used to calculate the outdoor pool heater size is given by [3]:

$$(1)\quad Temperature\ rise\ = (average\ temperature\ or\ the\ coldest\ month) - (pool\ water\ temperature\ setpoint)$$

$$(2)\quad \frac{BTU}{hr} output\ = 12.\ (Temperature\ rise) \cdot (pool\ surface\ area\ in\ ft^2)$$

Note that this formula is based on 1 to 1.25°F temperature rise per hour and 3.5 miles per hour average wind speed at the pool surface.

Table 1 demonstrates the annual pool heating costs for two locations in California, considering the season and pool water temperature setpoints. The higher cost to heat pools in Los Angeles is primarily attributed to the longer pool heating season in Los Angeles.

Table 1: Costs of Outdoor Pool Gas Heating by Location [3]

Location	Season	78°F	80°F	82°F
San Francisco	6/1-8/31	$2,126	$2,529	$2,954
Los Angeles	5/1-10/31	$2,540	$3,237	$3,957

Notes:

1. These are heating costs for a 1,000 sq. ft. swimming pool with an 80% efficient gas pool heater at $1.09 per therm.

Gas Absorption Heat Pump

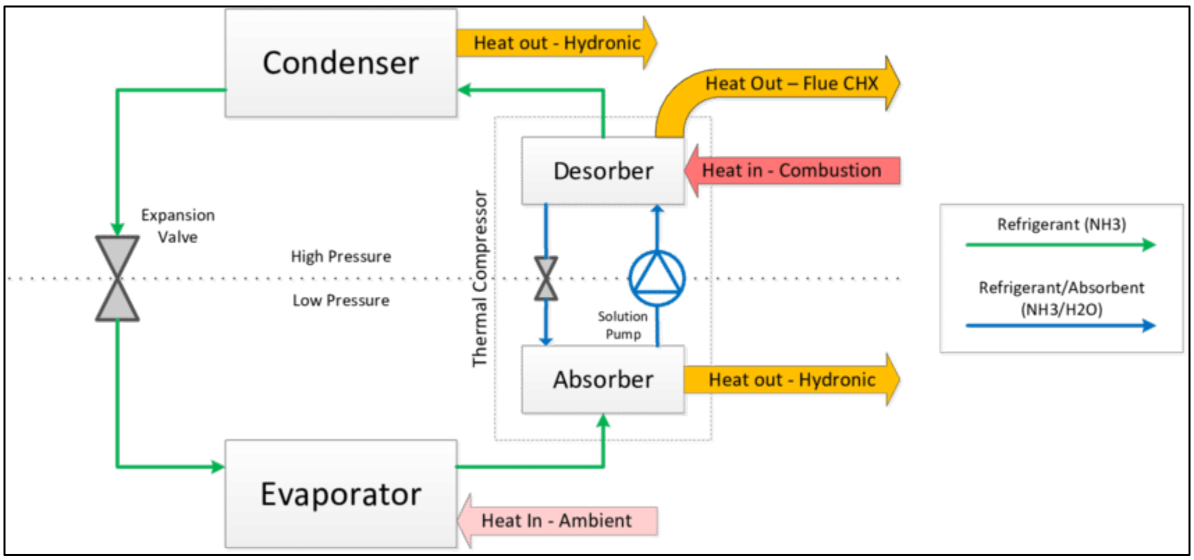


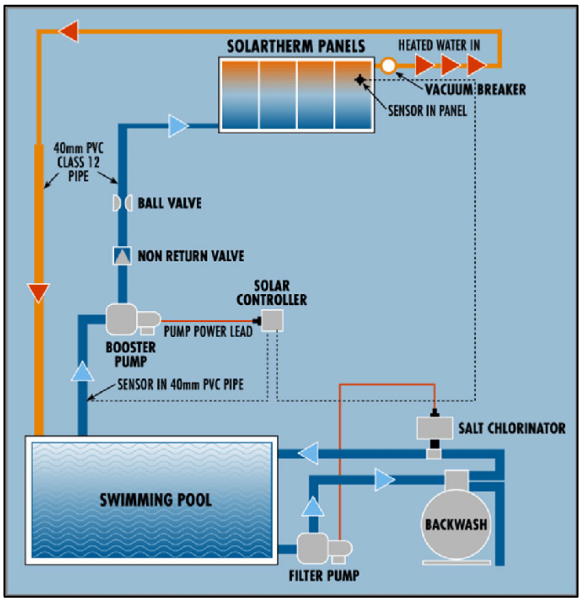
Figure 2: Schematic Diagram of Gas Absorption Heat Pump Cycle [4]

GAHPs are air-source heat pumps that utilize an absorption cycle instead of the typical compressor cycle to move heat. An ammonia-water refrigerant mixture absorbs heat from the ambient air, then delivers this heat to another loop via a heat exchanger. The ammonia-water mixture is then heated by a gas-burner within the unit, separating the ammonia and water through boiling of the ammonia out of solution. This allows the cycle to begin again.

Relative to electric heat pumps, this absorption /desorption process reduces the energy requirements of the system, as a typical electrical compressor has a large electrical draw to drive the refrigerant to a higher pressure. The moving parts within the GAHP unit are minimal, consisting of a fan motor and a hydronic pump. The electrical draw of the GAHP unit is less than 1 kW and, depending on the manufacturer and unit, produces between 80,000-123,000 BTU/hr. The GAHP units have a nominal COP of 1.4-1.5 for space heating under optimal conditions, but this may increase to 1.5-1.6 for pool heating applications as the pool water is usually heated up to 80-85 °F only. These maintain high efficiencies at low temperatures and produce water temperatures up to 140 °F. Several units can be bundled together to increase the heat production capacity of the system. For pool heating, GAHPs would require an external heat exchanger between the unit and the pool loop to avoid equipment corrosion and require installation outside to allow ventilation and air circulation requirements [4].

Solar Thermal Pool Heater

Figure 3: Schematic Diagram of Solar Thermal Pool Heater System [5]



Solar thermal pool water heating systems utilize solar radiation incident upon a solar collector to heat water pumped through the system. These systems typically consist of solar collectors, a flow control valve, and a controller. Solar collectors are either glazed or unglazed, although unglazed ones are common for pool heating applications. Glazed collectors feature a glass covering that enhances heat retention and efficiency, making them suitable for cooler climates and year-round use. Unglazed collectors are typically made of heavy-duty rubber or plastic and are more cost-effective but have reduced performance in colder temperatures (but are actually better performers at warm ambient temperatures and low wind conditions).

The pool pump circulates water through the filter and then through the solar collectors, mounted outside in an optimal location for the site and for solar collection. The solar collectors absorb solar radiation and transfer this heat to the pool water passing through them. The heated water is then returned to the pool.

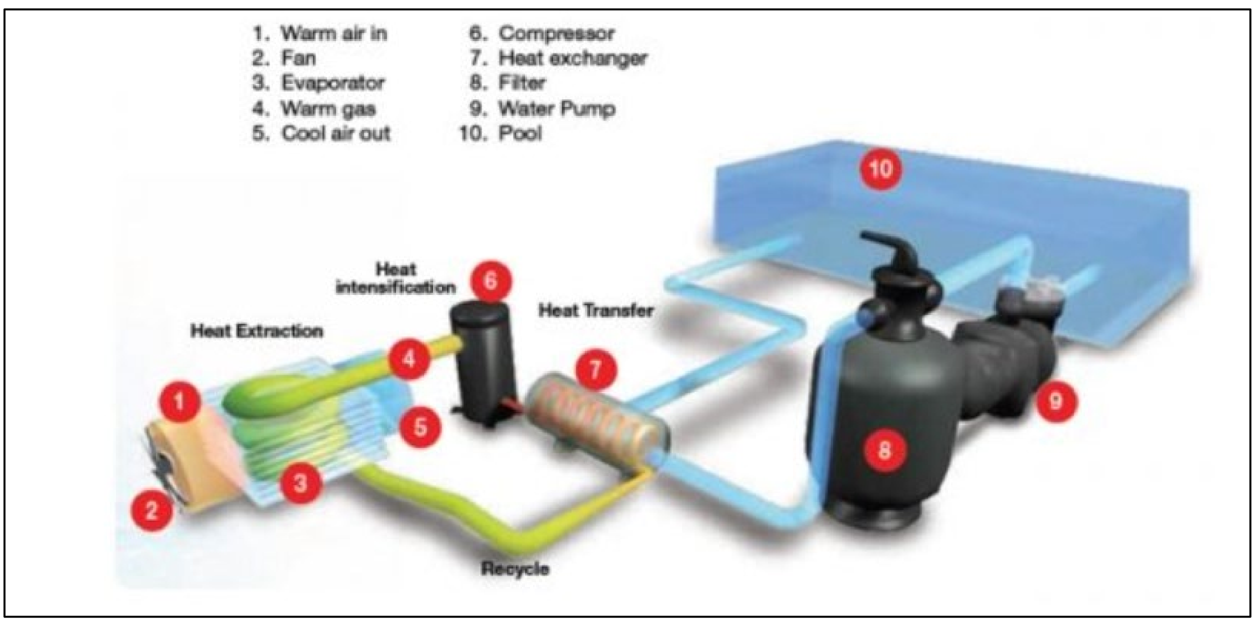
As the pump source for the water through the solar collectors is the pool pump, with little required head pressure, there is no significant added energy to utilize this heating system. The efficiency of solar thermal systems can vary based on the type of collector used, the climate, and the system design, but has nominal efficiency of 90% and delivers heat during the available 6-7 hours of sunlight per day. This efficiency refers to the amount of solar energy transferred to the water from the total amount of radiation available [6]. Unglazed collectors may utilize chlorine inhibitors while glazed systems utilize copper, which requires the use of an external heat exchanger with the pool water loop.

SRCC (Solar Rating and Certification Corporation) plays a crucial role in ensuring the quality, safety, and performance of solar thermal systems, including solar thermal pool heaters. SRCC 400 focuses on minimum safety and reliability requirements of solar pool and spa heating systems- which is required by International Swimming Pool and Spa Code (ISPSC) and California Energy Code [7].

Solar thermal pool heaters can work in tandem with traditional gas fired pool heaters as well as alternative heating technologies (such as GAHP, electric and hybrid heat pump) to ensure reliable performance. However, solar thermal pool heaters might not be able to meet the entire heating load on their own as they are entirely dependent on availability of sunlight. The heating output is not adjustable to ramp-ups or match sudden increases in demand, especially outside solar peak hours. Additionally, the system size and effectiveness of solar thermal pool heaters is constrained by roof or ground space limitations.

Heat Pump Swimming Pool Heater

Figure 4: Schematic Diagram of Heat Pump Pool Heater [8]



Electric heat pumps are air-source heat pumps that operate by extracting heat from the ambient air and transferring it to refrigerant within the unit. The pool pump circulates water through the heat pump, where a fan draws in outside air and passes it over an evaporator coil containing a refrigerant. The refrigerant absorbs the heat from the air and evaporates into a gas. This gas is then increased in pressure by a compressor, increasing its temperature further, and passed through a heat exchanger, where the heat is transferred to the pool water. The cooled refrigerant is then cycled back to the evaporator coil to repeat the process. See Figure 4.

Electric heat pumps are efficient, with COPs typically ranging from 3-7 under optimal conditions. They are most effective in warmer climates, as their efficiency decreases with lower ambient temperatures. Heat pump pool heaters are efficient for heating with outdoor air that's above 50 °F. Heat pump pool heaters are rated by BTU/hr. Typical sizes include 75,000 BTU/hr, 100,000 BTU/hr, and 125,000 BTU/hr.

These systems are relatively quiet and have a lower operational cost compared to traditional gas heaters due to their higher efficiency. However, the incremental cost of a heat pump pool heater is higher than that of a gas pool heater. Also, gas pool heaters heat the pool faster than when compared to heat pump pool heater [8].

Hybrid Gas-Electric Heaters

Hybrid gas-electric heaters combine the benefits of both gas and electric heating technologies to provide pool heating. These systems integrate a traditional gas heater with an electric heat pump, allowing the system to switch between the two heating methods based on efficiency and demand of the pool system and usage.

When the ambient temperature is too low for the heat pump to operate efficiently, the system automatically switches to the gas heater, which combusts natural gas or propane to generate heat.

Hybrid pool heater offers four distinct modes of operation: In heat pump mode, it extracts heat from the ambient air and transfers it to the pool water. In gas heat mode, it uses natural gas to quickly heat up the pool. In hybrid mode, the most efficient heating method between gas and electric is selected. In dual mode, it runs on both gas heater and heat pump simultaneously. This provides the fastest heating possible, which is useful for large pools or during urgent heating load requirements.

This dual approach aims to maintain the pool system at the desired temperature regardless of external conditions. Hybrid systems are optimal for locations with variable climates, as they can optimize energy use and reduce the operational costs required to maintain the pool at comfortable occupant temperatures. The gas heater provides rapid heating when needed, while the electric heat pump offers high efficiency during milder conditions, effectively supplying baseload and peak heating requirements. This combination results in a versatile and reliable pool heating solution that balances performance and energy efficiency, while lowering GHG emissions from those of a traditional gas heater [9].

System Combinations

Combining higher efficiency systems mentioned, including GAHPs, solar thermal, and electric heat pumps, with a traditional gas heater can optimize energy efficiency and ensure consistent pool temperatures. This hybrid approach leverages the strengths of both systems, using a controller to manage the operation and switch between them as needed. This pool heating strategy is similar to the last technology option discussed, hybrid pool heaters.

In this setup, the higher efficiency system serves as the primary heating source, reducing operational costs and environmental impact. The pool pump circulates water through the higher efficiency system heating system, which absorbs and transfers heat to the pool water. This system provides baseload heating, or pre-heats the incoming pool water for the gas heater.

The traditional gas heater is integrated into the system to provide both quick heating and peak load heating as necessary. When the high efficiency system cannot meet the heating demand—due to insufficient sunlight, low ambient temperatures, or high usage, the controller activates the gas heater. The gas heater rapidly raises the pool temperature, working unaffected by external conditions.

This combination allows for efficient use of energy while maintaining the reliability and performance of a gas heater. The controller optimizes the system by prioritizing the renewable source and only using the gas heater when necessary. This approach is explored in literature and case studies explored further in this document.

The following are the best practices for integrating GAHPs with existing boilers or gas fired heaters published by FortisBC for non-pool heating applications [10].

1. Right-sizing GAHP is critical to maintain a reasonable temperature difference and to prevent short cycling of units. GAHPs are ideal for steady load conditions, as compared to intermittent loads.
2. It is recommended that thermal insulation is installed on all piping and the distance between the GAHP, and the existing system is kept to a minimum to reduce the loss of hot water temperature in the loop connecting the GAHP to the pool water loop.
3. Drainage is required for all external condensing units. For condensing GAHPs, there is a requirement to provide a drain and acid neutralizer to the bottom of the condensation flue.
4. During the pilots, approximately 6%-12% of thermal losses were experienced across the double walled heat exchanger.

Lessons Learned From Previous Studies

Several organizations have undertaken research projects related to pool heating. This section summarizes the findings from previous studies.

a. **Swimming Pool Heating Technology: State-of-the-Art Review**

Yantong Li et. al. from City University of Hong Kong China, conducted a comprehensive review of heating technologies for swimming pools [11]. This includes both passive and active techniques to minimize heat losses and maximize heat gain for the optimal occupancy comfort. Passive techniques include various pool covers, including both opaque and transparent. Active techniques include conventional gas heaters, electric heaters, solar collectors and solar assisted heat pumps, air source heat pumps, geothermal heat pumps, absorption heat pumps, heat pump dehumidifiers, waste heat recovery, cogeneration, and biomass heating. The research presented mathematical models, which were developed to describe the heat transfer processes in swimming pools, including heat loss from evaporation, convection, conduction and radiation, and the heat gained from solar.

Following are the key findings from this study:

- A thermal insulation cover can reduce the heating load of swimming pool effectively. An opaque cover was found to be more effective for maintaining the temperature of pools during the night as the cover was able to cut down on long wave radiation emittance. However, the use of transparent covers during the day obtained more thermal energy from the sun than opaque ones.
- Relevant results indicated that the annual energy usage of an indoor pool is 3 times that of an outdoor pool of the same size. This is primarily due to high sensible, latent, and ventilation loads in indoor pools. Additionally, indoor pools operate all year round and outdoor pools typically operate during the swimming season (such as May-September). This is assuming that the indoor heating equipment is designed to provide heat for the water of the pool as well as to satisfy the indoor heating and ventilation loads.
- Solar collectors have been extensively used for pool heating applications. The storage water tank is used to store heat from solar collectors. The “on/off” of the associated pumps of the solar collector can be controlled according to the real time solar irradiance or the temperature difference between inlet and outlet water temperatures of the solar collector. The “on/off” of other pumps can be controlled by the water temperature of the pool.
- The energy consumption of swimming pool facilities is affected by many factors such as location, climate, and operating time.

b. **Solar Assisted Heat Pumps Energy Savings in Italian Climates**

Luca Tagliafico et. al., from the University of Genoa, conducted a study on modeling the performance of a water-solar assisted heat pump for usage in heating Olympic sized pools with nominal standard heating loads of 150 kW in Italian climates [12]. The systems' performance was analyzed as a function of the environment's heating degree days (HDD), ranging from 700 to 3,000 HDD within the tested Italian climate. The system design was comprised of a field of solar thermal panels acting as heat collectors and transferring the heat energy through a condenser to a direct expansion heat pump. Utilizing water in the solar thermal panels increases the COP of the heat exchanger and heat pump system. This heat energy is then transferred to a storage tank and used in a primary heat exchange to pre-heat a flow of pool water. A back-up system of a gas-fired boiler and a secondary heat exchanger is utilized to provide peak-load heating. The solar thermal panels also utilize a bypass valve to connect to the hot-water storage tank when the heat-load of the pool or heat-loss of the pool is negligible to store excess thermal energy.

The key findings of this study include:

- The primary energy savings of the system decrease as the degree days increase with a linear relationship, showing energy savings of 47% in the most favorable conditions with annual savings of 37%.
- The increase in degree days required increased solar collector surface area to increase thermal absorption and corresponded with a decrease in primary energy savings.
- The degree day parameter is suitable to make preliminary estimates on solar panel surface area and system sizing.

c. **Solar Thermal Pool Heater Performance with Low Flow Conditions**

Zhao et. Al., at the School of Photovoltaic and Renewable Energy Engineering, conducted an experimental study on a solar outdoor pool heating system used in combination with a pump running under low flow and low speed conditions in Sydney, Australia [13]. The goal of the study was to optimize the flow rate through the solar thermal collectors to minimize the electrical requirement of the pump while still delivering optimal thermal energy to the pool, ultimately reducing the energy requirement of the pool heating system. A model was first built in TRNSYS, then a measurement system was added to an existing solar thermal collector and residential pool. The model was then validated with the existing system and measurement data used to optimize the flow rate, with the efficiency of the heating being measured by COP. The optimal flow rate conditions use approximately 40% of the energy of the same system under high-speed conditions.

Following are the key findings from this study:

- The system achieved high efficiency to heat the residential pool by 1°F under low flow rate conditions.
- The optimal mass flow rate found for unit collector performance was 0.016$\frac{kg}{(s \cdot m^2)}$ using a 3-speed pump at the lowest speed. A range of 0.01-0.03 $\frac{kg}{(s \cdot m^2)}$ is recommended to reach the highest COP.
- The lower pump speed produced lower pump pressure, reduced friction and other energy losses in the system. Note that the approach did not compromise the thermal comfort of the pool. However, this approach added 1.5 hours to the daily pump running time when compared to the high-speed case.
- Running the pump at the recommended conditions reduced energy consumption by 3.6 kWh/day - about 20% of the daily household average in the region.

d. **Integrated Electric Heat Pump and Gas Boiler Performance on Cruise Ship Pool**

Yicong Xu et. Al. conducted a study through the Wuhan University of Technology in 2021 proposing air source heat pump water heaters and chillers combined with an exhaust gas boiler to heat a pool located on a cruise ship [14]. It was assumed that the heat pump supplied the baseload energy requirement of the pool, while the gas boiler contributed to peak heating loads and instantaneous heating. This system was then modeled on a simulation platform named TRNSYS to perform the transient analysis of pool heating loads and each system component. In this modeling, the heat pump module was selected with a rated COP of 5.9 in heating mode and the heat transfer effectiveness of the heat exchanger is set to 0.95. The system performance was defined using variables comparing the operating time to the pool occupancy comfort and energy usage of the hybrid system to the previous gas-fired system. The model stated that the average heat load of the pool varied from 30 to 75 kW, with the maximum heating load reaching 110 kW.

The key findings of this study include:

- The heat pump sizing was optimized for performance, and the simulation showed that the heat pump provided 40% of heat supply and utilized about 10% of the total energy consumption of the system, significantly reducing the GHG emissions from the system.
- The total energy and cost reduction calculated by the system was modeled to be 77.1% and 69.6% respectively from the base gas-fired system.

e. **Hybrid Solar Thermal and Gas Boiler Pool Heater Performance**

A study conducted by Cezar-Dumitru Popa and Constantin Ungurean through the University of Suceava, Romania, aimed to determine the energy efficiency of solar thermal water collectors in combination with a natural gas boiler with a storage tank for supplying domestic hot water and pool heating [15]. Special design considerations were planned with the optimal location of the solar thermal panels for occupant comfort, building design, and greatest solar energy collection. The recirculated pool water is pumped through a filter and heated via a plate heat exchanger. The hot water production and collection system also provided DHW needs to the facility.

The key findings of this study include:

- Well-designed solar thermal systems have up to 40% solar coverage for climates that are north of 45 degrees in latitude.
- The solar system produces no or very minimal emissions and 98% of the construction materials are recyclable.
- Solar water heating systems cost more than conventional gas and electric water heating systems. A combined system can reduce the thermal energy costs of solar and electric system by 46% and by 50% for solar plus natural gas heating system.

Pool Heating Codes

This section discusses the code requirements and regulations on pool heating systems nationally and focuses on California. These regulations are compiled from the California Appliance Efficiency Regulations (Title 20), California Building Energy Efficiency Standards (Title 24), and the Code of Federal Regulations, given in Appendix B. These regulate the minimum efficiency and installation requirements.

<u>California Appliance Efficiency Regulations–Title 20</u>

Section 1605.1(g)(1)

This section states the minimum thermal efficiency for gas-fired pool heaters and oil-fired pool heaters to be 82% and 78% respectively.

This section also covers necessary energy efficiency standards for pool pumps, including adhering to various limits for weighted energy factors and hydraulic horsepower. These limits are dependent on the type of pump used and can be found in the section. Some pool pump types also have default operation control limits to ensure efficiency in usage [16].

Section 1605.3(g)(3)

This section states that natural gas pool heaters must not utilize constant-burning pilot lights.

Heat pump pool heaters must have an easily accessible on-off switch mounted on the outside of the heater that allows the heater to be turned off without adjusting the thermostat settings. The energy efficiency standards for heat pump pool heaters must have an average COP at both standard and low temperature rating of at minimum 3.5.

This section also gives regulations on pool pump types and usage. To ensure motor efficiency, pool pump motors cannot be manufactured to be split phase or capacitor start type. Pumps with more than one speed or utilizing variable speed must utilize a controller capable of running the pump at more than one speed and have a default circulation speed of less than ½ of the motor's maximum rotation rate [16].

California Building Energy Efficiency Standards–Title 24

110.4

This section states that any pool or spa heating equipment may only be installed if it has the following listed requirements.

i. Efficiencies as stated by the federal code of regulations or appliance efficiency standards.
ii. The readily accessible on-off switch, as stated by the previous code.
iii. A permanent and easily accessible waterproof plate with instructions on the operation and care of the pool heater and system.
iv. Contains no electric resistance heating. This has exceptions with pools using solar thermal or solar energy systems, recovered energy, or units in fully insulated enclosures with tight-fitting covers that are insulated to R-6.
v. Installation requirements include:
   a. 36 inches of piping between the filter and heater, or built-in connections to allow for future addition of solar heating equipment.
   b. Pool covers for outdoor pools that use a heat pump or gas heater.
   c. Directional inlets to mix pool water.
   d. A time switch to allow the pump to run on off-peak electricity demand periods and the minimum time to maintain the pool water at applicable public health standards [17]

Section 110.4(c) in the 2025 Energy Code allows for five different options for pool and spa heating systems.

a. Solar pool heating system: non-residential and multifamily public pools with solar collector area of at least 65% of the pool area; single-family or multifamily residential pools with solar collector area of at least 60% of the pool area.

b. Heat pump pool heating system sized to manufacturer recommendations

c. Heating system derived from at least 60% on-site renewables on an annual basis

d. Combination of solar and heat pump with no supplemental heat source

e. Another heating system: This allows for technology not supported above to be considered as alternatives during the code cycle by the California Energy Commission (CEC).

Federal Standards–Code of Federal Regulations–430.32(k)

The code of federal regulations states the minimum efficiency for a gas-fired pool heater to be 82%, or a COP of 0.82. It also gives minimum thermal efficiency requirements based on the certified input capacity for a gas fired heater or certified active electrical power for an electric heater [18].

Code Impacts

These codes and regulations cover minimum efficiency requirements for gas-fired and electric heat pump systems, as well as installation requirements to allow for future modifications, ease of use, and optimal system design efficiency. If making repairs to an existing pool heating system, the code requirements for heated pools and spas will not apply.

Subject Matter Expert Interview Findings

This section summarizes the findings from subject matter expert (SME) interviews. The interviews were conducted as a part of this ET study to gain insights from various stakeholders on aspects of pool heating technologies: technology and usage understanding, market environment, and energy saving potential. The interviews were conducted from July to August 2024. The organizations interviewed consisted of product manufacturers, utility, and pool maintenance specialists. The response rate is summarized in Table 2. The interview length was 30-60 minutes on average. Amazon gift cards worth $100 were shared with them after the interview. As indicated in Table 2, a response rate of 60% and participation rate of 83.3% were recorded.

Table 2: Organization Response Rate

Number of organizations contacted	Number of organizations that responded	Target number of interviews	Actual participation	Response rate	Participation rate
10	6	5	5	60%	83.3%

The focus of these SME interviews was centered around the understanding of commercially available pool heating technologies, associated market barriers, usage pre-qualifications, control methodologies, range of cost impacts, energy efficiency, and market usage. Refer to Appendix A for the detailed interview questionnaire. The individual SME responses can be found in Appendix B.

Key Findings

This section summarizes the key findings of the interviews.

- **Market findings:**
  1. Most of the pool heaters used are traditional gas heaters. However, it is unclear how often each unit runs, so there is limited understanding of total emissions impacts.
  2. The largest limitation to the adoption of alternative pool heating technologies, such as GAHPs, is lack of knowledge, consumer awareness and installer training.
  3. No GAHP units have yet been installed for heating pools, and the equipment manufacturers expressed a strong interest in conducting field ET studies for pool heating applications.
- **Advantages and disadvantages of pool heating technology options:**

Table 3: Advantages and Disadvantages of Pool Heating Technology Options- High Level Comparison

Technology	Traditional gas heater	Gas absorption heat pump (GAHP)	Electric heat pump pool heater	Solar pool heater
Advantages	▪ Speed of heating ▪ Low first cost ▪ Heating capacity ranging	▪ Can achieve COP values up to 1.4 ▪ Lower GHG emissions ▪ Lower fuel operating costs	▪ Lower GHG emissions ▪ COP values range between 3 to 7 ▪ High fuel operating	▪ No emissions post-installation ▪ No usage cost ▪ High efficiency

Technology	Traditional gas heater	Gas absorption heat pump (GAHP)	Electric heat pump pool heater	Solar pool heater
	from 75 to 450 kBTU ▪ Can supply peak heating needs ▪ Modulation capacity	▪ Heating capacity up to 123 kBTU ▪ Modulation capacity in some models ▪ High performance at lower ambient temperatures	cost in California ▪ Heating capacity up to 125 kBTU	
Disadvantages	▪ Higher operating cost than GAHP ▪ High GHG emissions ▪ Low efficiency	▪ Lower speed of heating ▪ May not be able to supply peak heating needs ▪ Highest first cost	▪ Lower heating capacity per unit traditional gas heaters ▪ High first cost ▪ Low speed of heating ▪ May not be able to supply peak heating needs ▪ Reduced performance at low ambient temperatures	▪ High first cost ▪ Speed of heating is location and sun-dependent-large space requirements ▪ May not be able to supply peak heating needs ▪ Low energy output and heating capacity at off-peak solar times

Note: The comparison of pool heating technologies based on metrics such as fuel operating costs, GHG emissions, and speed of heating is done with respect to the baseline-traditional gas fired pool heaters.

- Installation and usage of best practices:
  1. Alternative systems can be installed with a traditional gas heater as a backup system to meet base heating requirements. Utilizing alternative systems combined with gas heaters can vastly decrease operational costs and emissions due to higher efficiency.

2. GAHPs, solar pool heaters, and heat pump pool heaters must be installed outside with location and space requirements. Traditional gas heaters may be installed indoors.
3. GAHPs, some solar pool heaters, and heat pump pool heaters require an external heat exchanger for the hydronic loop, as pool water cannot run through these systems.
4. Utilizing a pool cover decreases heat loss from the pool from evaporation during unoccupied periods, vastly decreasing the energy requirements from the system. Savings of 30%-50% are possible.

- Controls and optimization:
  1. Control and sizing optimization is imperative to reduce energy consumption and cost, but it is not always done.
  2. Using controls to run the heating system at night decreases temperature drop during the timeframe when the pool loses the most heat to the ambient air. This decreases the load on the system during the day.
  3. Utilizing a variable speed pump for the pool decreases the overall energy consumption of the pool system and heater when integrated into the control system.
- Energy and efficiency savings:
  1. Traditional gas heaters have a nominal efficiency of 82-87%.
  2. GAHP's have a nominal efficiency of 130-140% and save ~50% of emissions over a traditional gas pool heater.
  3. Electric heat pump pool heaters have a low heating output, so although the nominal efficiency of available units was not found from the interviews, several units would be necessary to meet the existing heat output capacity requirements.
  4. Solar pool heaters do not require direct energy input using electricity or gas, as the pumping comes from the pool pump. The collector efficiency is about 90%. However, pool heating is limited to solar energy availability and will only deliver heating during the day.
- Cost observations table:

5. These costs are range estimates, as GAHPs have not been installed for pool systems, and system requirements of each installation effect installer price. These estimates come from the manufacturer, with limited knowledge of final installed cost. Refer to Table 4.

Table 4: Cost Comparison Table

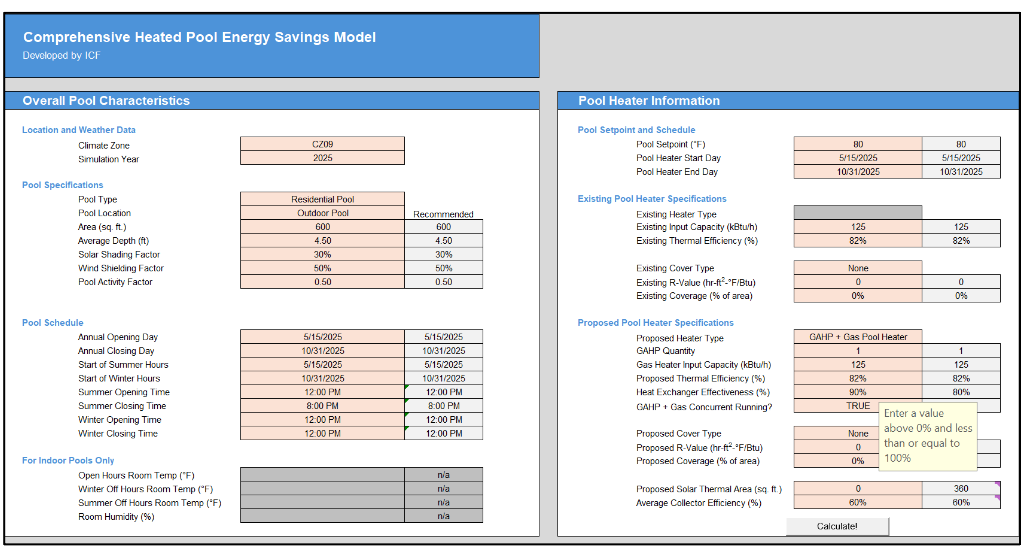
Technology	Traditional Gas Heater	GAHP	Hybrid pool heater	Electric pool heater	Solar pool heater
First Cost	$3,000	$10,000–$15,000	$8,000–$9,000	NA	$5,000–$8,000
Heat Production Capacity	75,000–450,000 BTU/hr	80,000–135,000 BTU/hr	Up to 220,000 BTU/hr in dual mode	75,000–125,000 BTU/hr	1,200 - 2,100 BTU/(hr*ft^2)[18]
Estimated Payback	NA – incumbent	1.5–3 years	NA	NA	NA

Tool Updating and Parametric Data Analysis

This summarizes the key remarks and assumptions made during the tool updating and parametric analysis. The existing ICF pool cover calculation tool was updated using the components relevant to the project scope.

This tool has the capability of calculating different heat losses for a pool and determining baseline and measure case energy consumption values. On the **'Input'** tab (refer Figure 5), the tool takes in user input for several parameters including climate zone, pool specifications, temperature setpoint, pool cover specifications and heater operation schedule. The tool also has a tab for **'Constants'** which is used in governing equations of heat transfer. Additionally, the tool uses the following components: weather data for 16 CEC climate zones in California, gas and electric rate tariffs, corresponding hourly GHG emissions factors, and hourly solar profiles.

Figure 5: Snapshot of Inputs Tab



The heating equipment/measure cases such as GAHP, hybrid pool heater (with two modes- minimum cost and minimum emissions), electric pool heater, and solar thermal pool heater. The tool is set up to pair a solar thermal pool heater with each of the other pool heating technologies.

The following is the summary of key remarks and assumptions made during the tool development and parametric analysis.

1. The length of swim season varies by climate zone. Table 5 summarizes the start and end date assumptions for each climate zone [20]. For outdoor pools in Residential and Multi-family building types, the following start and end dates are used. Indoor pools are assumed to be in use year-round across all building types.

Table 5: Swim Season Assumptions

Climate Zone	Swim Season Start	Swim Season End
CZ1 Arcata	Jun 15	Sep 15
CZ2 Santa Rosa	May 1	Oct 31
CZ3 Oakland	June 1	Sep 30
CZ 4 San Jose	May 15	Oct 31
CZ 5 Santa Maria	June 1	Oct 15
CZ 6 Torrance	May 15	Oct 31
CZ 7 San Diego	June 1	Oct 15
CZ 8 Fullerton	April 15	Oct 31
CZ 9 Burbank	May 15	Oct 31
CZ 10 Riverside	Apr 1	Oct 31
CZ 11 Red Bluff	May 1	Oct 31
CZ 12 Sacramento	May 1	Oct 31
CZ 13 Fresno	April 1	Oct 31
CZ 14 Palmdale	April 15	Oct 31
CZ 15 Palm Springs	April 1	Oct 31
CZ 16 Blue Canyon	Jun 15	Sep 15

1. The existing tool has built-in ASHRAE reference values of pool dimensions, pool activity factors, wind shielding factor, solar shading factor, opening and closing pool hours for each pool type. The same reference values are used for parametric analysis. See **'Input Dropdowns'** spreadsheet tab in the tool.
2. The recirculation system has the capacity to provide a complete turnover of pool water in 6 hours or less for public pools [21]. Note that the pumping assumes constant flow required for GAHP even if pool does not need it.
3. The minimum solar collector surface area of non-residential and multifamily public pools should be 65% of the pool surface area. Whereas the solar collector surface area of single family and multifamily residential pools (accessible to one dwelling unit) should be a minimum 60% of the pool surface area [21]. Unglazed solar

collectors are typically used for pool heating applications. The average efficiency of this type of solar collector is assumed to be around 60% [22].

4. Table 6 shows the assumptions regarding opening hours, room temperature, and relative humidity in the existing tool. Same reference values are used for parametric analysis.

Table 6: Assumptions for Indoor Pools

For Indoor Pools Only	
Open Hours Room Temp (°F)	82
Winter Off Hours Room Temp (°F)	70
Summer Off Hours Room Temp (°F)	70
Room Humidity (%)	60%

1. For GAHP as a measure case equipment, it is assumed that the gas absorption heat pump acts as a base heating equipment and the peak loads are handled by the existing gas fired pool heater. The existing gas fired pool heater turns ON, whenever the pool heat loss and corresponding demand requires more heat than the GAHP (s) can provide on its own. Currently, the modified tool is set up for calculating heating capacity using the outdoor ambient temperature and input water temperature from the manufacturer provided performance data (shared by Robur). The existing gas pool heater provides any load difference between the GAHP(s) at full load and the demand of the pool. During the first hour when GAHP turns ON, it is assumed that it takes about 20 minutes to achieve steady state COP for the given operating conditions. Hence, the heating output and the flow rate are assumed to be two-thirds in the first hour of the operation. Note that GAHP is paired up with external heat exchanger in the loop. It is assumed that the heat exchanger has minimal heat loss, and the effectiveness of heat exchanger is 0.97.
2. The hybrid pool heater has two modes of operation which combines heat pump and gas fired heating technology. One is 'minimum cost mode' which runs on the gas first and turns electric heat pump ON, when the pool heat loss is greater than what gas heater can provide. The other mode is a 'high efficiency mode' which runs on the electric heat pump first and turns the gas pool heater ON, when the pool heat loss is greater than what electric heat pump can provide. Thus, the equipment can run both gas and electric heating at the same time. Also, this hybrid pool heater has a built-in titanium heat exchanger, eliminating the need for a separate heat exchanger.
3. Sizing the electric heat pump and hybrid heat pump are kept same as the previous tool. To calculate an approximate heater size, the following parameters are desired: desired pool temperature setpoint, average temperature of the coldest month of pool use, pool surface area (sq. ft.). [23].

$$Heater\ size\ (BTU) = 15.(Pool\ Area).(Temperature\ Rise)$$

4. The tool automatically estimates the number of GAHP/heat pump/hybrid pool heater units needed to meet the capacity requirement given by the above reference equation.

Table 7 summarizes the specifications of a hybrid pool heater and an electric heat pump [24]. These values are also summarized in **'Constants'** spreadsheet tab in the tool. Note that both electric and hybrid heat pumps don't require external heat exchanger, like GAHP and in some cases solar thermal pool heating.

Table 7: Specifications of Hybrid Pool Heater and Electric Heat Pump

	Parameter	Value
1	Hybrid heater output- gas (kBTU/h) and efficiency	110 kBTU/h and efficiency of 93%
2	Hybrid heat pump output (kBTU/h) and COP	108 kBTU/h and COP of 5.8
3	Electric heat pump COP	[25]

1. The tool uses hourly weather data for each of the 16 climate zones in California. Climate zone weather data is based on CZ2022 weather data for the years 1998-2017 and maintained by CALMAC [26].
2. The tool uses hourly GHG emissions factors for electricity and a fixed GHG emissions factor for natural gas as per documentation of the 2022 Distributed Energy Resources Avoided Cost Calculator (ACC) [27]. Additionally, the tool uses average natural gas and electricity utility rates specific to each climate zone in California, compiled in Tables 11 and 12 (Appendix C: Datasets).

Notes:

1. Once **'Calculate'** macros button is hit after selecting all the input parameters, the tool calculates hourly values of energy consumption, costs, and associated GHG emissions produced. See columns **CN-DA** on the **'Calcs'** spreadsheet tab in the tool.
2. The updated tool also has the capability to create CET input file.

Parametric Analysis:

Parametric analysis is a systematic approach used to analyze how variations in input parameters influence the outputs of the model. The goal is to identify critical parameters that significantly affect energy and emissions saving potential of pool heating technologies and optimize the design choices. In this section, we explore this impact of key parameters using the data visualizations from Power BI to illustrate trends and dependencies.

The following parameters and their corresponding values were selected to analyze the impact on energy savings and emissions savings of different pool heating technologies. See Tables 8 and 9 for outdoor and indoor pools respectively.

Table 8: Parameter Selection–Outdoor Pools

	Parameter	Level
1	Climate Zone (16)	CZ01-CZ16 (16)
2	Pool or Building Type (5)	Residential Multi-family Residence Hotel Schools/Colleges- Recreation Pool Private Health Club- Large Pool
3	Existing and Proposed Cover Type (3) (assumed same for baseline and measure cases)	None Vinyl Bubble/Solar
4	Proposed Heater Type (4)	GAHP + Gas Pool Heater Heat Pump Hybrid Heat Pump- Cost Mode Hybrid Heat Pump- Efficiency Mode
5	Proposed Solar Thermal Area (2)	0 Recommended
6	Effectiveness of GAHP Heat Exchanger (6)	0.5, 0.6, 0.7, 0.8, 0.9, 1

$$Total\ number\ of\ Permutations\ = (16) * \ (5) * \ (3) * \ (4) * \ (2).* (2) = 3{,}840$$

For Indoor Pool Location:

Table 9: Parameter Selection–Indoor Pools

	Parameter	Level
1	Pool or Building Type (5)	Residential Multi-family Residence Hotel Schools/Colleges- Recreation Pool Private Health Club- Large Pool

	Parameter	Level
2	Existing and Proposed Cover Type (3) (assumed same for baseline and measure cases)	None Vinyl Bubble/Solar
3	Proposed Heater Type (4)	GAHP + Gas Pool Heater Heat Pump Hybrid Heat Pump- Cost Mode Hybrid Heat Pump- Efficiency Mode

$$Total\ number\ of\ Permutations\ = (5) * \ (3) * \ (4) = 60$$

The following hourly output variables from the tool are analyzed for comparing energy and emissions saving potential of different pool heating technologies.

Table 10: Parametric Outputs–Variables

	Output Variables
1	Baseline and Measure Therms Usage
2	Measure kWh Usage
3	Baseline and Utility Costs
4	Baseline and Measure GHGs
5	% of load from GAHP (for GAHP Measure Case Equipment only)

These hourly values are then used to compute Annual therms savings, Annual kWh consumption, Annual GHG Emissions Savings, Energy Costs Savings, % Therms Savings, and % GHG Emissions Savings. Therms savings and energy cost savings are normalized with respect to pool area to facilitate comparison of key metrics for pools of varying sizes.

Figure 6 shows the snapshot of '**Parametric Inputs'** tab in the tool. Once all the desired permutations of input parameters are added to this tab and this macros button **'Run Analysis'** is hit, the associated outputs for all the permutations are generated on the **'Parametric Outputs'** tab.

Figure 6: Snapshot of Parametric Inputs Tab

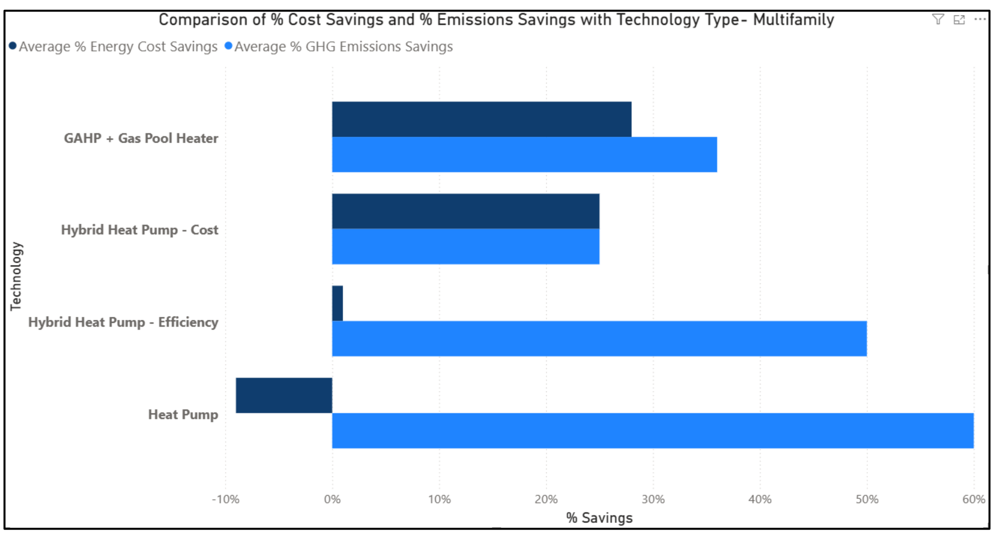
	A	B	C	D	T	U
1	Run Analysis	Input|E10	Input|E11	Input|E14	Input|E35	Input|E36
2	Iteration Index	Climate Zone	Simulation Year	Pool Type	Winter Off Hours Room Temp (°F)	Summer Off Hours Room Temp (°F)
3	1	CZ09	2025	Schools/Colleges - Recreation Pool	Recommended	Recommended
4	2	CZ09	2025	Schools/Colleges - Recreation Pool	Recommended	Recommended
5	3	CZ09	2025	Schools/Colleges - Recreation Pool	Recommended	Recommended
6	4	CZ09	2025	Schools/Colleges - Recreation Pool	Recommended	Recommended
7	5	CZ09	2025	Hotel	Recommended	Recommended
8	6	CZ09	2025	Hotel	Recommended	Recommended
9	7	CZ09	2025	Hotel	Recommended	Recommended
10	8	CZ09	2025	Hotel	Recommended	Recommended
11	9	CZ09	2025	Private / Health Club - Large	Recommended	Recommended
12	10	CZ09	2025	Private / Health Club - Large	Recommended	Recommended
13	11	CZ09	2025	Private / Health Club - Large	Recommended	Recommended
14	12	CZ09	2025	Private / Health Club - Large	Recommended	Recommended
15	13	CZ09	2025	Multi-Family Residence	Recommended	Recommended
16	14	CZ09	2025	Multi-Family Residence	Recommended	Recommended
17	15	CZ09	2025	Multi-Family Residence	Recommended	Recommended
18	16	CZ09	2025	Multi-Family Residence	Recommended	Recommended
19	17	CZ09	2025	Residential Pool	Recommended	Recommended

Final Plots and Data Analysis–Outdoor Pools

1. **Comparison of % Cost Savings and % Emissions Savings With Technology Types**

Figure 7 shows the comparison of different pool heating technologies for the multifamily sector based on two metrics- cost savings and % GHG emissions savings. Gas absorption heat pump (GAHP) paired with existing gas pool heater, has the highest % cost savings (28%), when all climate zones in California are considered. As anticipated, the heat pump pool heater and hybrid heat pump (when run on efficiency mode) have the highest GHG emissions saving potential for the multifamily sector (more than 50%). Note that the percentage changes in energy costs and GHG emissions are in comparison with the corresponding baseline values (gas pool heater with baseline efficiency of 82%).

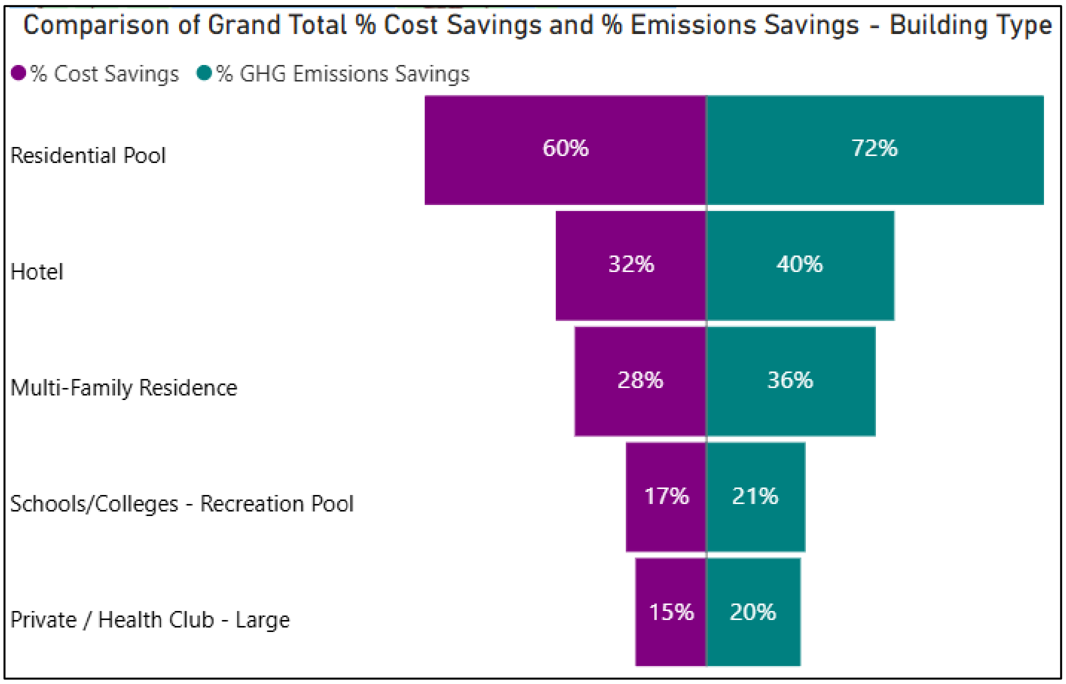
Figure 7: Comparison With Technology Types–Multifamily Outdoor Pools



2. **Comparison of % Cost Savings and % Emissions Savings With Pool or Building Types**

Figure 8 shows the comparison of percent cost savings and percent emissions savings of GAHP for different pool or building types. The average percent cost savings for GAHP across all climate zones in California is the highest for the residential sector, followed by hotel and multifamily sectors. Average percent emissions savings also follow the same trend.

Figure 8: Comparison With Building Type–GAHP for Outdoor Pools



3. **Comparison of Normalized Costs and Therms Savings of GAHP With Climate Zone and Building Type**

Figure 9 illustrates the comparison of normalized therms and normalized cost savings of GAHP for multifamily sector. The energy consumption and costs are normalized with respect to pool surface area (sq. ft.). CZ07 (San Diego) has the highest normalized cost savings for multifamily sector. Figure 10 illustrates the climate zone wise comparison for hotel sector, and the plot follows the same trend.

Figure 9: Comparison With Climate Zone–GAHP for Multifamily Sector

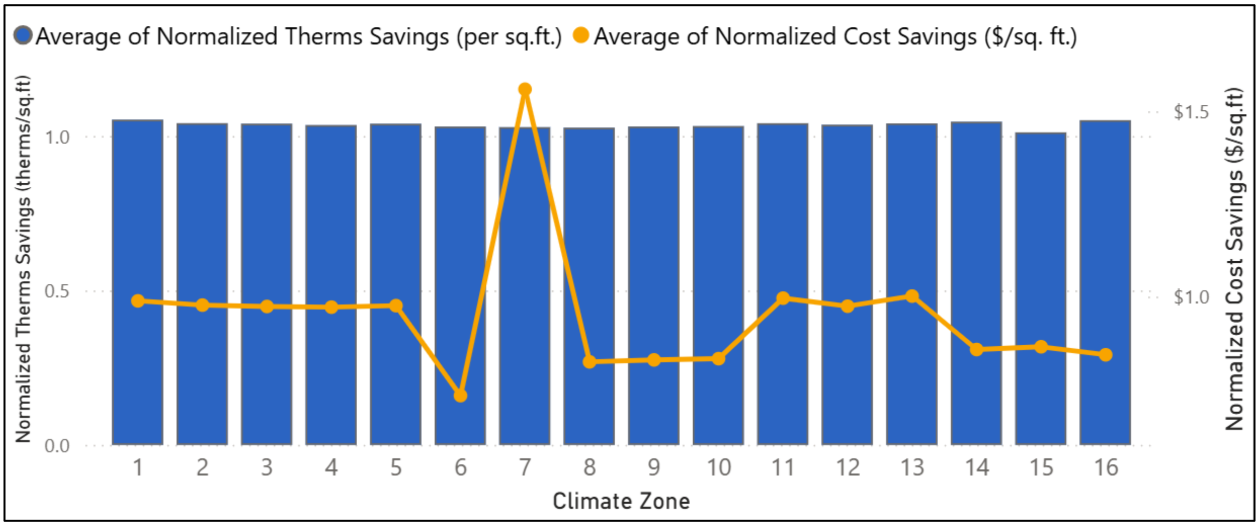
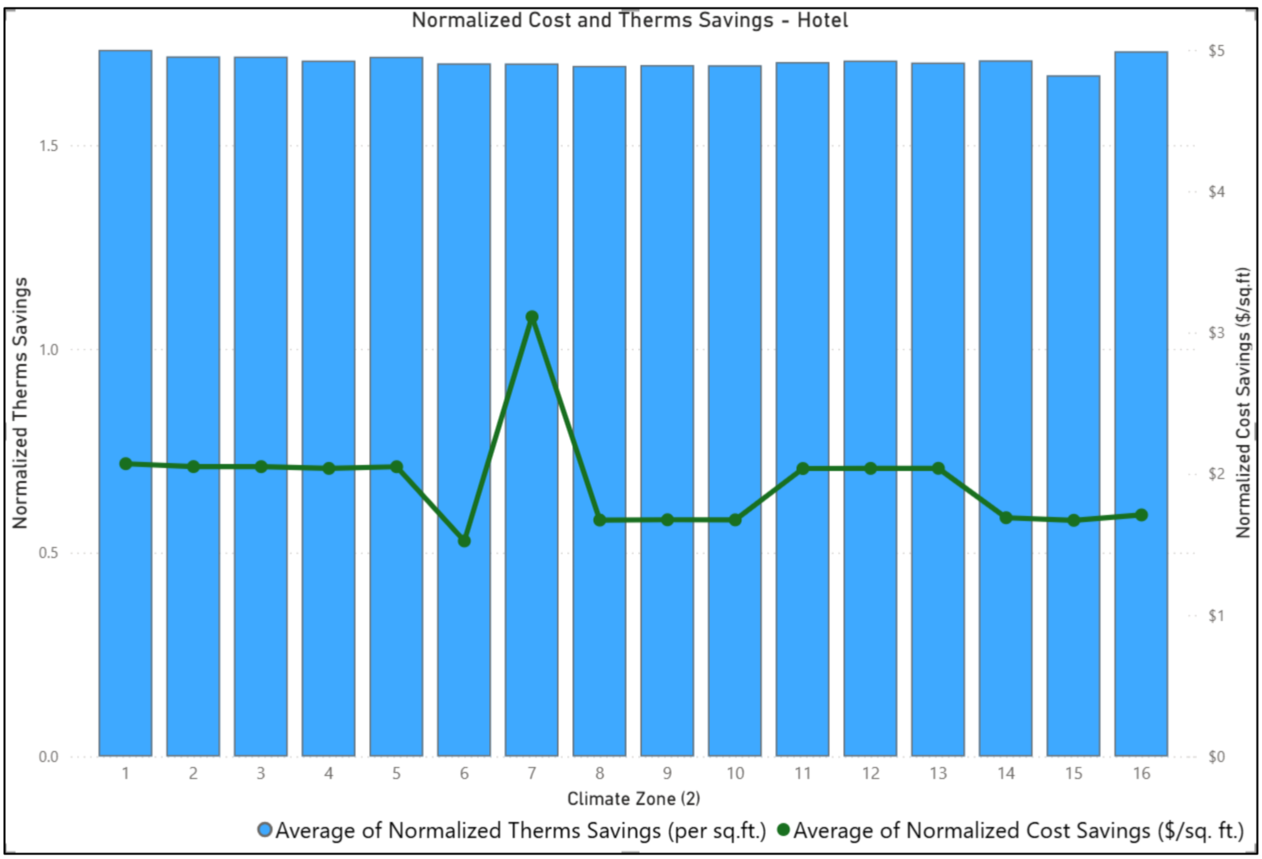


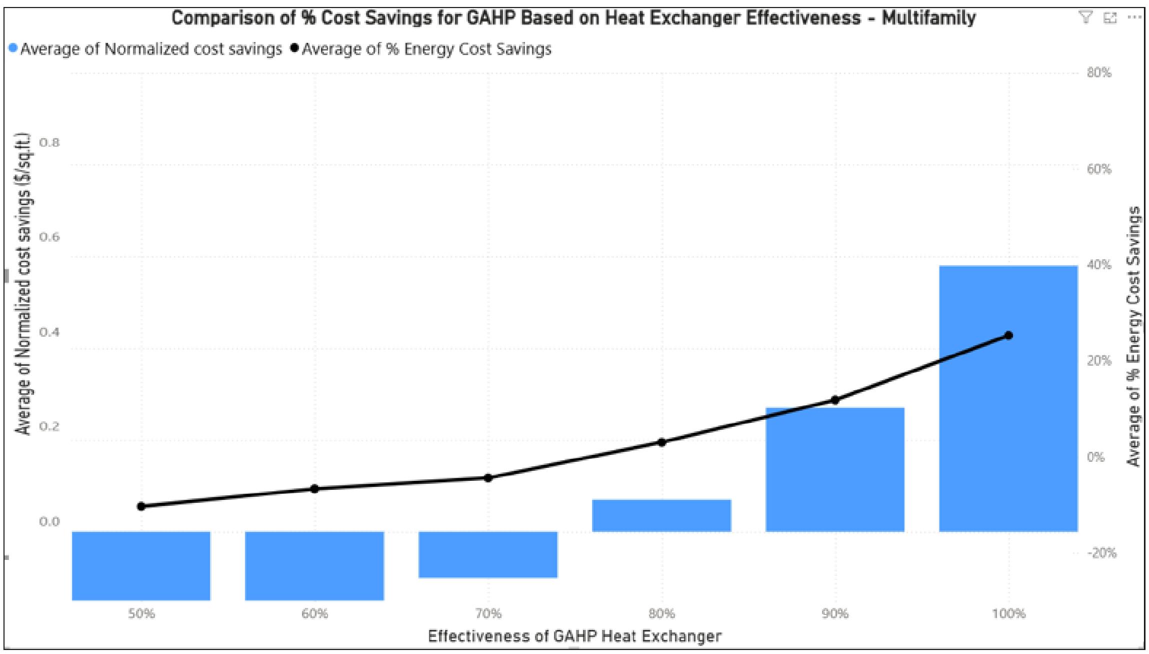
Figure 10: Comparison With Climate Zone–GAHP for Hotel Sector



4. **Impact of Effectiveness of GAHP Heat Exchanger**

Figure 11 highlights the impact of effectiveness of GAHP heat exchanger on percent energy cost savings. The energy cost saving potential of GAHP technology increases with increase in effectiveness of heat exchanger. The effectiveness of the heat exchanger needs to be higher or equal to 0.8 for positive energy savings. Average percent energy cost savings of GAHP technology in Multifamily sector increases from 17% to 25%, if the effectiveness of heat exchanger is increased from 0.8 to 0.9. This highlights the fact that cost saving potential of GAHP technology would increase significantly if GAHPs are designed with integrated heat exchanger, like the hybrid pool heater. Note that these energy savings are averaged out for all 16 climate zones.

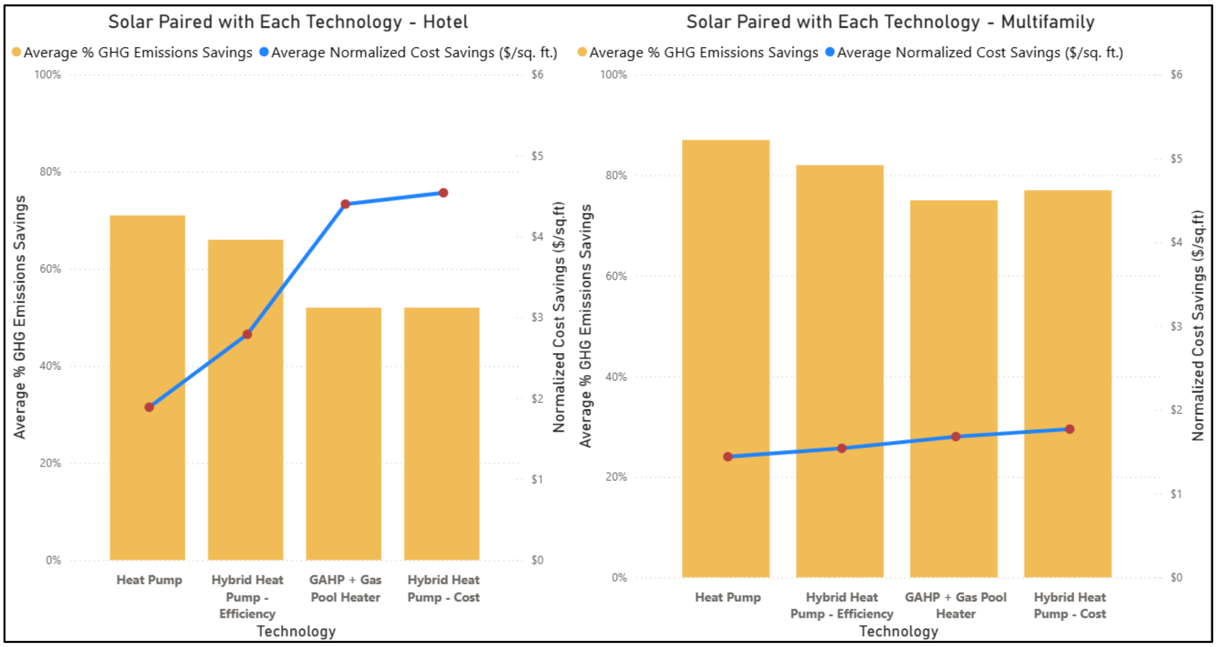
Figure 11: Effectiveness of GAHP Heat Exchanger



5. **Comparison of Emissions and Energy Savings of Solar Paired With Each Technology–Multifamily and Hotel**

Figure 12 shows the comparison of emissions and energy savings of solar paired with each technology for multifamily and hotel building types- based on two metrics- percent GHG emissions and normalized cost savings. It can be inferred that hybrid heat pump, when run on minimum cost mode, has the highest normalized cost savings, followed by GAHP paired with existing pool heater. As anticipated, the heat pump and the hybrid heat pump (when run on efficiency mode) has the highest percentage GHG emissions savings. Both multifamily and hotel sectors follow the same trend. However, the hotel building type shows higher normalized costs compared to multifamily building type.

Figure 12: Comparison of Energy and Emissions Savings–Solar Paired With Each Technology



6. **Pool Cover**

Figure 13 shows the distribution of different heat losses in an outdoor pool over a typical swimming season. Evaporation heat loss contributes to 55% of the total, whereas radiation heat loss contributes to 40% of the total. Having a negligible impact on total heat loss, conduction heat loss can be neglected.

Figure 13: Distribution of Pool Heat Losses

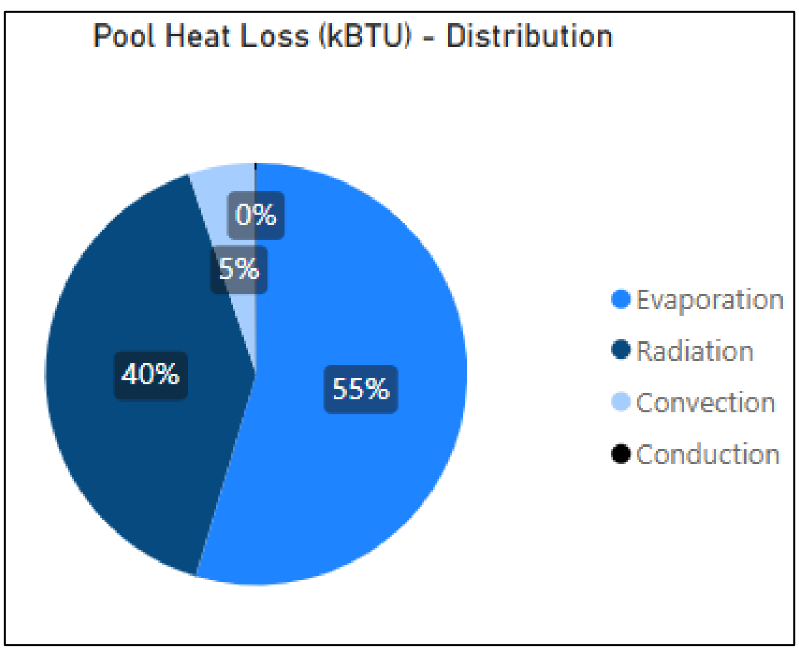


Figure 14 shows the impact of pool cover on the pool heat losses for outdoor pool in multifamily building type. For both the pool cover types (vinyl and bubble/solar), there is significant reduction (~50%) in evaporation heat loss when the pool cover is in place during the unoccupied hours.

Figure 14: Impact of Pool Cover on Total Heat Losses

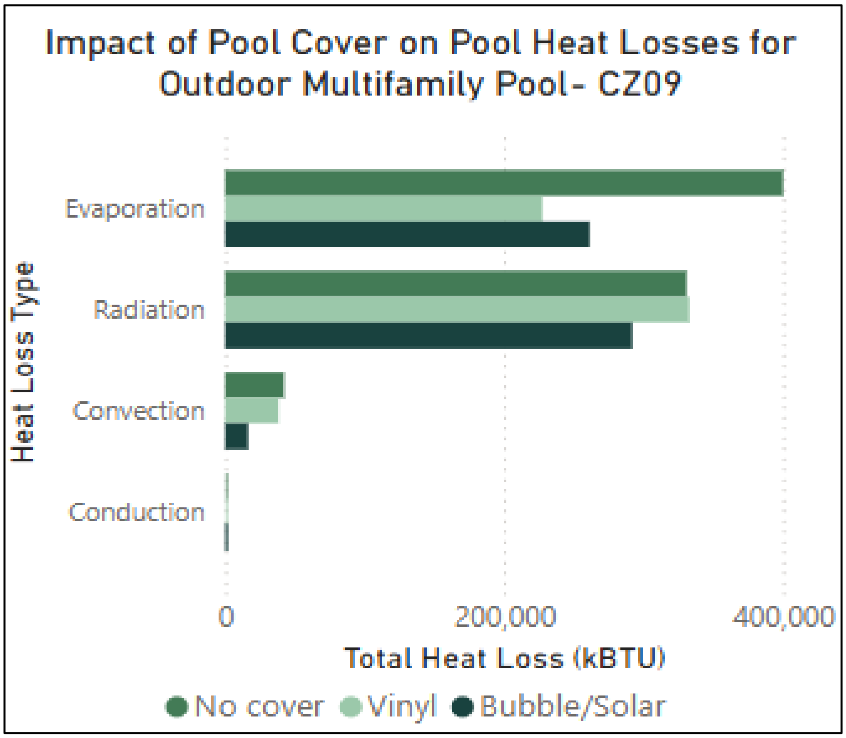
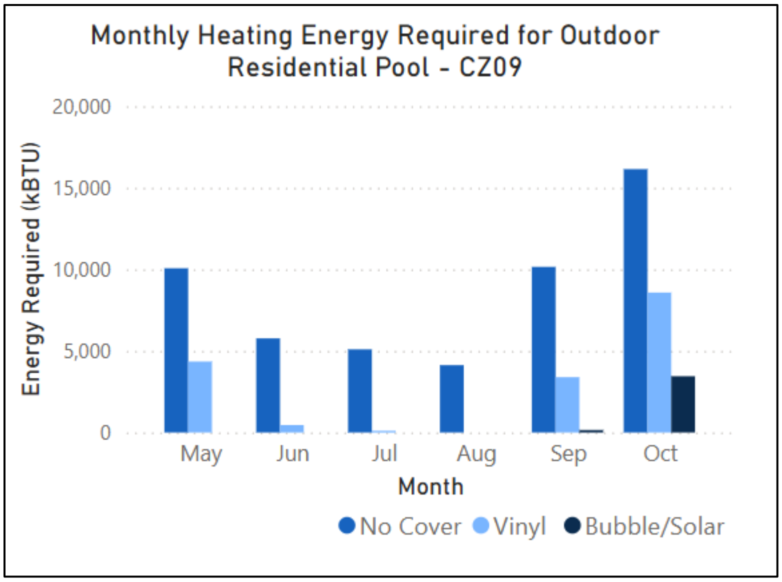


Figure 15 shows the difference in monthly heating energy required for an outdoor residential pool- with and without pool cover. It can be inferred from the plot that there is no or minimal pool heating required for months except October. This highlights the impact of keeping pool cover ON during the unoccupied hours on total heat losses and energy savings.

Figure 15: Monthly Heating Energy Required for Outdoor Residential Pool—CZ09



Final Plots and Data Analysis—Indoor Pools

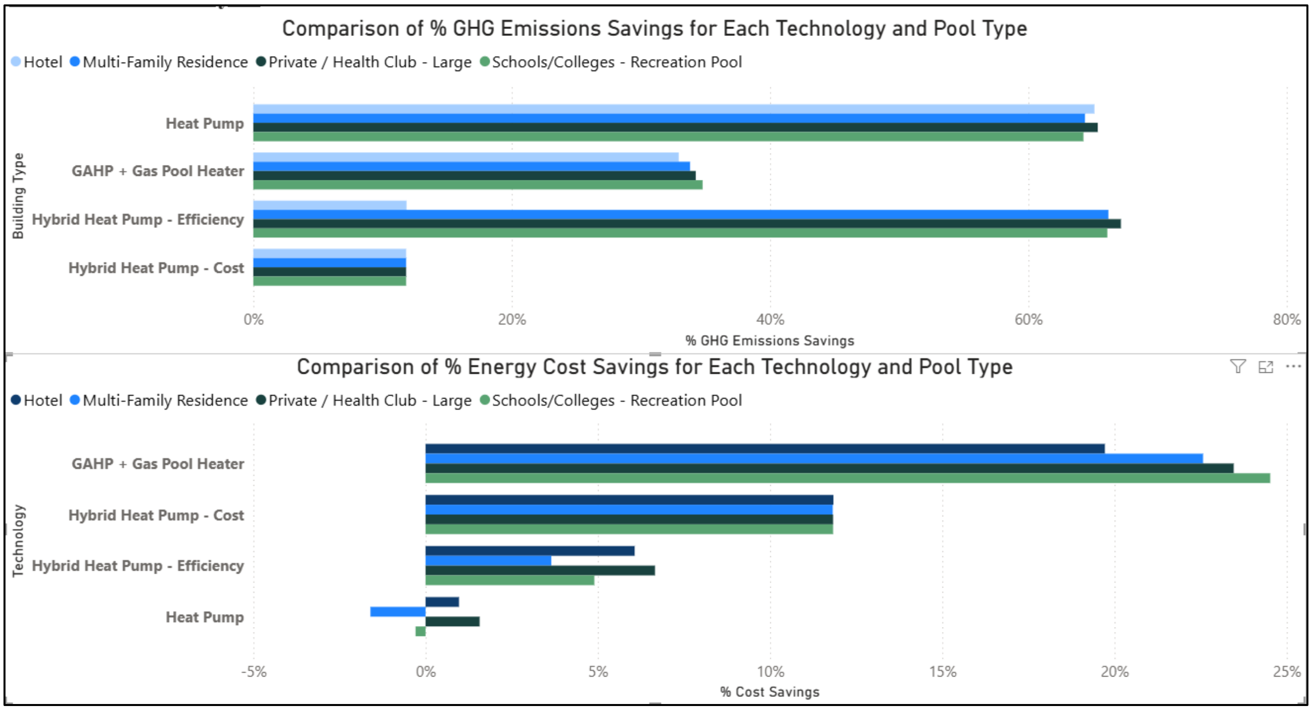
Similar parametric analysis is conducted for indoor pools.

Figure 16 shows the comparison of percent GHG emissions and percent cost savings for each technology and building type. Indoor pools are assumed to run year-round.

GAHP paired with the existing gas pool heater shows the highest percentage cost savings for all indoor pool types, followed by hybrid pool heater when run on minimum cost mode. Due to predictable and steady heating loads for indoor pools, there is comparatively less cycling of GAHP and higher cost savings. GAHP has the highest cost saving potential for larger pool types, such as Private Health Club-Large and Schools/Colleges - Recreation Pools. On the other hand, heat pump pool heaters have negative or negligible cost savings.

Heat pump and hybrid pool heater (when run on maximum efficiency mode) shows the highest percentage GHG emissions saving potential for all the indoor pool types (more than 60%). This trend is similar to outdoor pools.

Figure 16: Comparison of Percent Cost Savings and Percent GHG Emissions Savings—Indoor Pools



Note that the data sets are compiled in **Appendix C: Datasets**.

Conclusions

This study investigates energy, utility costs, and GHG emissions savings potential of pool heating technologies in California based on modeling and tool development. This includes traditional gas fired pool heaters, heat pump pool heaters, hybrid pool heaters, GAHPs, and solar thermal pool heaters for both indoor and outdoor pools.

First, the study synthesized findings from literature review and SME interviews. Previous research highlighted that pool covers greatly reduce evaporation heat loss and heating energy requirements but are underutilized in commercial settings. Solar-assisted heat pumps can achieve significant energy savings in favorable climates. Hybrid pool heating systems combining alternative technologies with gas pool heaters can optimize performance as well as GHG emissions.

The SME interviews revealed that traditional gas heaters are still a popular choice among customers due to their ability to heat up the large volume of pool water quickly; alternative technologies like electric or hybrid pool heaters, and GAHPs are not yet widely installed for pool heating applications. Some of the barriers include- lack of awareness, contractor training, and higher upfront costs of alternative technologies compared to conventional gas fired pool heaters.

The existing ICF pool cover calculation tool was updated to evaluate new pool heating technologies. The tool models hourly energy use, costs, and emissions based on inputs such as climate zone, pool type, temperature setpoints, pool cover type, and heater operation schedules.

Following are the key findings from tool development and parametric analysis:

- There is significant reduction in evaporation heat loss (up to 50%) when pool cover is in place during the unoccupied pool hours. For a residential pool, there is minimal, or no heating energy required to heat up a pool when pool cover is ON.
- Gas absorption heat pump (GAHP) paired with existing gas pool heaters, has the average highest % cost savings (28%) in multifamily sector, when all climate zones in California are considered. The hybrid pool heater, when run on minimum cost mode, has 25% average cost savings.
- Heat pump pool heater and hybrid heat pump (when run on efficiency mode) have the highest GHG emissions saving potential for the multifamily sector (more than 50%).
- The effectiveness of GAHP heat exchanger is a critical design parameter.
  The effectiveness of the heat exchanger needs to be higher or equal to 0.8 for positive energy savings. Average percent energy cost savings of GAHP technology in multifamily sector increases from 17% to 25%, if the effectiveness of heat exchanger is increased from 0.8 to 0.9. This highlights the fact that cost saving potential of GAHP technology would increase significantly if GAHPs are designed with integrated heat exchanger, like the hybrid pool heater.
- Hybrid pool heater, when run on minimum cost mode and paired with solar thermal pool heating, has the highest normalized cost savings, followed by GAHP paired with existing pool heater. As anticipated, heat pump and hybrid heat pump (when run on efficiency mode) has the highest % GHG emissions savings. Both multifamily and hotel sectors follow the same trend.
- GAHP paired with the existing gas pool heater shows the highest percentage operating cost savings for all indoor pool types (up to 25%), followed by hybrid pool heater when run on minimum cost mode (up to 12%). Heat pump and the hybrid pool heater (when run on maximum efficiency mode) show the highest percentage GHG emissions saving potential for all the indoor pool types (more than 60%).

Recommendations

The comprehensive analysis of pool related parameters and scenarios will further guide the pool heating technology to reduce GHG emissions and increase utility cost savings. The tool development and application of the updated analytical tool have demonstrated that GAHP and hybrid pool heating technologies offer significant potential for reducing both energy costs and GHG emissions. The study recommends updating the Excel-based tool for field tested data of the GAHP unit researched as well as performance data provided by other GAHP manufacturers. The study also recommends conducting comprehensive techno-economic analysis to determine energy saving potential of GAHP and hybrid heating technology for pool heating applications. Additionally, the study recommends conducting field demonstrations of these technologies to gather real-world equipment performance data and evaluate actual energy cost savings of GAHP and the hybrid pool heater for both indoor and outdoor environments.

Appendix A: Interview Questionnaire

Note: These questions were modified depending on the manufacturer or specialist interviewed to reflect their product and expertise. The specific questions asked to each SME can be found in the interview notes in Appendix B.

1. Can you tell us more about your product?
2. Can you tell us more about your product as it is or would it be used for pool heating?
3. Can you share your thoughts on the current most used pool heating technologies?
4. What are the biggest positive/advantages of using your product? What are the biggest barriers or challenges with installing and using your units?
5. What are the biggest differentiators between your product and other pool heaters?
6. Are there any pre-qualifications for installing or using your specific product? Are there any limitations to using your product?
7. How would sequencing your product with a traditional gas pool heater work, and optimization of controls with a backup heater for baseload and peak load requirements?
8. Can you share more insights into the cost impact or the initial price for your system for an average-sized pool (20'x40')? Do you have an estimate of installation costs?
9. Can you share your thoughts about emissions savings from your systems in the near term (5-10 years)?
10. Do you have data on performance curves or performance metrics of your product? Would you be able to share them with us?
11. What are the installation and usage best practices for your product?
12. What are some market challenges preventing the adoption of your product — primarily for pool heating applications?
13. Can you share more insights on the market presence of your product in CA?
14. Do you have any other contacts in the pool heating industry that you are comfortable sharing?

Appendix B: Interview Notes

[1] Interviewee: SME 1 and 2

Organization: Organization A and B

Date of interview: 07/08/2024

Background of Interviewees:

SME 1 is a contractor who works at organization A. This organization A is based out of Southern California with roots in Mechanical Contracting, Engineering and Utility Programs.

SME 2 is a CEO of organization B, which manufactures Wi-Fi, cellular, cloud-connected controls and sensors with a platform of applications optimized for the building controls industry. The SME is on the Consumer Technology Association committee managing the CTA-2045 EcoPort standard, the co-head of the Advanced Water Heater Initiative (AWHI) sub-committee on connectivity and control, and the head of the subcommittee on commercial load control. The SME is also working with NEEA, ACEEE, Energy Star, and National Laboratories on regulatory and policy initiatives, where the SME's focus is enabling buildings and electric loads to lower grid costs, decrease carbon emissions and increase the use of renewable energy.

Interview Questions and Notes:

1. Can you share your thoughts on the most used pool heating technologies currently?
    a. Mostly gas pool heaters for both residential and commercial. Some heat pumps are underway, but most of the pool heaters are primarily gas.
    b. Only traditional gas heaters have been installed. No GAHP or electric heat pumps in my experience (currently). Most of the pools use gas heaters. An exception is the case of using boilers for primary heating and using waste heat to heat pool. The largest water heater in my experience is for a large pool in San Diego utilizing two Raypak heaters of capacity 2 million BTU, using only one at a time.
    The average 20-foot x 40-foot pools in SoCal typically use 399,000-500,000 BTU/hr heater.
2. What are the biggest positives with using traditional gas pool heaters?
    a. The traditional gas pool heaters have larger heat capacity than both GAHP and electric heat pumps, and one heater comes close to matching the maximum hourly input required by an average pool. They also heat the pool very quickly compared to other types. However, the traditional gas water heater can be used as a backup for every other system.

3. What are the typical installation costs/first costs of traditional gas heaters?
    a. The traditional gas heaters are cheap to put in. The first cost is around $3,000 to replace the existing pool heater. Currently, I don't have any estimates for GAHP or otherwise. GAHPs have system and pre-qualification requirements.
4. Are there any differences in prequalification's for gas heaters and other pool heating systems?
    a. The heating capacity of heat pump pool heater is around 125,000 BTU/hr. For an average pool size, we would need about 9-10 electric [heat pump] pool heaters. GAHP appears to be a good alternative considering the heating capacity in comparison with the gas heaters. Gas heaters are good for both indoor and outdoor pools.
5. What are the biggest installation challenges with commercially available pool heating equipment?
    a. GAHPs have pre-qualification requirements regarding space and location, such as they need to be installed outside. Gas heaters don't have many challenges; however, you are not allowed to vent gas 10 feet away from or below an openable window.

    Any solar uses/ applications?

    I believe that solar thermal doesn't seem to be a good option for heating pools, most of the evaporation heat loss occurs at night. The solar thermal doesn't have a storage tank while domestic hot water does, so it doesn't heat water while the pool is losing heat energy. However, it may be a good option for the residential (small) sector. The solar pool heating may be able to use solar thermal as supplemental heating.
6. How would the system configuration change for retrofit or additions of various pool heating systems?
    a. The customers can replace less efficient gas heaters with high efficiency units, from 82% to 87%. There is an increased cost usually for higher efficiency. In my experience so far, I have not seen condensing water heaters commonly implemented for pool heating applications. I would primarily advise installing a GAHP to meet the base loads and leverage existing gas pool heaters for meeting peak loads in the system.
7. What are the potential barriers or challenges of installing higher efficiency heaters, GAHP, or why don't they recommend condensing water heaters?
    a. I am unsure why a condensing water heater is not used but it may be because of the presence of chlorine. Electric heaters and heat pumps are too small to

reasonably use, so the heating capacity and number of units required just make it not feasible.

8. Any insights that you've gotten with your current program with SCG?
    a. We're just working on controls and not heaters.
9. Are you aware of any code changes for pool heating systems?
    a. Not aware of anything right now.
10. Are you aware of the general energy savings or payback costs for pool heating systems?
    a. Higher efficiency pool heaters have no additional maintenance costs and only save 3-4% considering the jump from 82-86% efficiency.
    b. Organization B is primarily for connecting data monitoring and controls using Modbus and BACnet to connect to pool heating systems.
11. Are there any opportunities for controls optimization or sequencing for a combination of a GAHP and gas heater?
    a. I am working on a program that would ideally shut down pool heater when pool closes and calculate when it would have to be turned back on to raise it back to the ideal temperature. This could also be done by using a GAHP, but due to low rate of heating, GAHPs would have to come online earlier.
12. Would you advise installing gas meters separated from the gas heaters to understand energy usage?
    a. I would advise monitoring the efficiency and run time of the heater and calculating energy assumption accordingly. Some gas meters are installed for whole pools or the general hot water system as well.
13. Which factor is the most impactful when it comes to pool energy loss/ heat consumption?
    a. Most significant factor in pool heating is the difference in pool temperature/setpoint and outside air temperature, as well as humidity and wind speed. Higher humidity means lesser evaporation. Cloud cover reduces evaporation and solar gain. The activity factor is also a significant factor.
14. What is the impact of passive heating or reducing heat loss, such as pool covers?
    a. Pool covers essentially eliminate evaporation losses, and are inexpensive to purchase, install, and use. The liability is very high for safety and drowning risks. I have never seen a pool cover on any commercial or multifamily property in my experience so far. Installation of a pool cover might be a pain point for customers as it must be tight around the edges to work properly. Indoor pools have a

different issue with evaporation of pool water–the evaporation takes chlorine, so pools must have ventilation to take chlorine out from the air.

[2] Interviewee: SME 3

Organization: Organization C

Date of interview: 07/12/2024

Background of Interviewee:

SME 3 is uniquely qualified to bring gas absorption heating into the mainstream, combining world-class absorption technology development with executive leadership in the high-volume water and space heating appliance manufacturing industry. The SME served as Director of Engineering for A.O. Smith residential products and brands (including State, Kenmore, Reliance, and Whirlpool), representing 50% of residential water heater sales in the United States. Mr. Garrabrant was VP of Engineering for American Water Heater Company before it was acquired by A.O. Smith. Previously, as VP of Engineering for Cooling Technologies, Inc., the SME led the development of a high-efficiency gas-fired absorption cooling product, which was a spin-off from technology developed at Ohio State University.

The SME earned the SME's BS and MS degrees in Mechanical Engineering from Ohio State, is a registered Professional Engineer (Ohio), and has earned twelve U.S. patents. The SME served as the Chairman of the Gas Appliance Manufacturing Association (GAMA) Residential Water Heater Efficiency Test Harmonization Working Group and served on the Air-Conditioning, Heating & Refrigeration Institute (AHRI) Certification Programs & Policy Committee. The SME was awarded the 2008 AHRI Richard C. Schulze Award for distinguished service and commitment to AHRI's goals and objectives.

Interview Questions and Notes:

1. Will you share more about GAHP technology and your product?
    a. My company produces an air-to-water gas absorption heat pump. This runs with an absorption unit with combustion/heat instead of compressor using a thermal compression type cycle. This is similar to an electric heat pump but uses heat with combustion. A key difference between electric heat pump and GAHP is that the GAHP can operate down to low temperatures (-40 °F @ 65% of rated efficiency).

2. How would your product be used for pools?
   a. The nominal efficiency (COP) for space heating is 1.4-1.5 at 120°F supply water temperature and 45°F outside air temperature. The pool temperature stays at 80 °F and doesn't usually get too low, so COP may be higher (1.5-1.6). This system can still be used to heat pools well at lower ambient temperatures and may have a COP around 1.35-1.4.
3. Has your product been installed for use in a pool?
   a. Not yet but interested in a demonstration project.
4. What are your general thoughts on current pool heating systems?
   a. Most systems are natural gas or propane and sit outside. Non-condensing heaters have an efficiency at around 80% efficiency. However, gas inputs tend to be large, roughly 150,000-300,000 BTU/hr. These heaters can heat water very quickly compared to other heating systems.
   b. Electric heat pumps are a growing market but can generally only have applications in warmer climates. These have sizes around 75-125,000 BTU/hr.
   c. The GAHP intro model has an output of 80,000 BTU/hr and provides quick heating, although not as quick as gas heaters.
5. What are the biggest differentiators between your product and typical pool heaters?
   a. The biggest differences are the much higher efficiency of the GAHP and the largely decreased gas bill (about half). The GAHP also has lower expenses than electric heat pumps due to lower electrical costs and fewer associated systems.
6. Would your system need an external heat exchanger, and can it be modulated to use multiple GAHP together?
   a. Yes — it could use any titanium pool heat exchanger between the pool pump and GAHP.
   b. The system would be able to modulate 4 units together into one heating system.
7. What are the biggest challenges in using your product?
   a. It has a straightforward installation, but costs more than a gas heater due to novel technology and installation. Customers would ideally get payback within a couple of years due to lower gas bills. Because it's condensing, condensate must be neutralized and piped to a drain or the frost line.
8. What are the biggest differentiators between your product and other GAHPs?
   a. The other GAHP manufacturer produces a model of output around 123,000 BTU/hr. However, the Anesi model has higher efficiency, especially at colder temperatures. However, the unit also does not modulate so they cycle on-off and are non-condensing.

    b. The difference between electric heat pumps and GAHP is that electric models use “forever chemicals” for refrigerants, whereas Anesi GAHP models use 100% natural refrigerants.

9. How do you use modulating to prevent short cycling?
    a. For water-heating, the model will run at full capacity to reach the set point temperature.
10. What are the pre-qualifications to using your system for pool heating?
    a. The system needs a natural gas or propane line and an external heat exchanger between the unit and the pool pump. In addition, the unit can only be installed outside and requires a place to drain condensate.
11. Would your product be able to be sequenced with a traditional gas heater?
    a. The system would consist of a multistage thermostat. Once the pool decreased to a lower set-point, the GAHP would turn on. If the temperature were to continue to drop, the gas heater would turn on. The two units would run concurrently.
12. What is the initial cost impact and installation costs of your system?
    a. Not a lot of data, as this information comes from distributors. The total installed cost would range $10-15,000, and the individual unit has no indication of cost yet for the consumer, but it may be between $7-10,000.
13. What are the GHG savings of your product over a traditional gas heater?
    a. This comparison is based on a heater with 80% efficiency and a GAHP COP of 1.4. This would reduce GHG emissions by nearly 40-50%. If you were to have a higher efficiency gas heater, the emissions savings would be closer to 30% reduction.
14. What is the general COP for your product?
    a. The COP would be higher for pool heating than space heating. The unit has 1.4 COP for space heating.
15. Should we consider return temperatures above 80°F considering heat exchanger and other heat losses?
    a. The supply water temperature would likely be around 90°F.
16. What are the best practices for using your system?
    a. The unit should be installed on level ground on a concrete or heavy-duty plastic pad. The condensate would need to be routed correctly, and the system would need to be accurately sized.

17. Are there any market adoption issues?
    a. Only if there were to be gas bans.
18. What is your market presence in CA?
    a. No, units are currently installed commercially, as they started shipping to distributors 3 weeks ago. They are now available to purchase and install, as they have distributors and have trained installers.

[3] Interviewee: SME 4, SME 5

Organization: Organization D

Date of interview: 07/19/2024

Background of Interviewee:

SME 4's interests in energy efficiency and focus on Solar Thermal technologies have helped organization D maintain the US leading position in Glazed Flat Plate Solar manufacturing. The SME's dedication to ensuring every solar thermal installation is a success is echoed by the organization's contractor and distributor base. As energy efficiency standards and requirements throughout the United States, and the world, advance to make better utilization of the resources we all share. The SME believes that documented and verifiable benefits for solar thermal technology will pave the way for its ultimate acceptance and adoption as a preferred method of energy production and conservation.

The SME has held the previous Solar Industry positions: SEIA Solar Heating and Cooling Alliance, Chairman CALSSA, Board Member.

The SME currently holds the following Solar Industry Positions. IAPMO Uniform Solar Energy and Hydronics Code, Technical Committee Member, The Solaray Corporation, Vice President and Board Member.

Interview Questions and Notes:

1. Can you share more about your product–pool heating?
    a. My company produces solar heating pool collectors. Residential, or seasonal, pools are outdoors and primarily use unglazed collectors. These are made of polymers and have no insulation with transparent covering. The polymer is usually plastic or made of copper for wildfire resistance. Commercial, or indoor non-seasonal, pools use glazed collectors with insulation.
2. What typically comprises a solar pool heating system?
    a. The solar co 0.5"llector, controller, and valve set.
3. What are your thoughts on current pool heaters?
    a. Gas heaters are the most common and are incumbent technology. However, they are expensive to run so many consumers do not use them to consistently heat the pool. They quickly heat water and are used as a backup system when combined with other technology. Solar pool heating is a passive system and relatively common. Heat pumps are less common. These systems work like solar, and heat slowly compared to gas heaters.

4. What about a combination of gas and solar?
   a. Most pools that use solar also have a gas heater as a backup, just a matter of whether the gas heater is regularly used. They run concurrently, using the gas heater to supply peak heating or quickly heat the pool.
5. What are the efficiencies/performance metrics of the tech?
   a. There is no added energy into pumping through collectors. For smaller pools, the pool pump system is strong enough to achieve the required flow. Because of this, solar thermal systems have COPs over 50. The efficiency /sq. Ft. Is about 90% (i.e. 90% of the solar energy hitting collector is transferred to water running through it).
6. Biggest positives for using your product?
   a. There is no additional energy input into the system, only energy output to pool water. The collectors are made of recycled materials and are able to recycle post use and utilize no GHG emitting materials or parts. The DOE states that solar pool heating is the most efficient form of pool heating. The equipment has a long lifespan, about 20 years, and quick payback due to no energy or maintenance input.
7. Biggest challenges of using your product?
   a. The largest challenge is the high upfront cost. Residential solar pool heating is the only technology that doesn't have federal tax credit or programs for reducing the installation cost. Another barrier is the available training & sizing for the product, as it ranges broadly by location and user comfort. The market is run by dealers/distributors, so training is mostly run through them and location dependent. Finally, pools need a massive amount of energy to heat by a couple of degrees, and this system may not be able to supply the necessary amount, or at a comfortable pace for the user.
8. Are there prequalification's to installing/using your product?
   a. The system must be outside and in the sun. Other changes to the system are location dependent. However, it does not need external HX, as pool water can run through polypropylene.
9. What are the cost impacts/installation costs?
   a. The installed cost is about $5-8,000 for an average sized pool. The product is likely 30% of installation cost but is dependent on installer/distributor.

10. Other differentiators between your product and other pool heating systems?
    a. The only pool heating system that can run for free and has an ROI. It is also the most efficient, highly recyclable, and has a long lifespan.
11. Sequencing for use with a pool heater?
    a. Most automated pool pumps have solar settings built in. Basic pools pumps use a timer, and heaters have an on/off switch. For sophisticated systems, solar will "pre-heat" the water, then it will run through the gas heater to reach the set point. The solar pool heater runs for base load to maintain pool temp, and the gas heater is used for peak load.
12. Greenhouse gas emission savings?
    a. It is unknown how often gas pool heaters are run, so it is difficult to understand the GHG emissions from current systems. Inherent emissions from the solar thermal system are only from the pool pump that also pushes the water through collectors. Because of this, it has complete savings over heaters or heat pumps.
13. Total energy output range?
    a. The system outputs about 250 BTU/hr./sq. ft. depending on solar energy. It has a 6-7 hr. heating day for seasonal pools, depending on location.
14. Installation and usage best practices?
    a. The layout depends on the installation location but is largely adaptable.
15. Market challenges with adoption?
    a. The first cost is expensive, and there is a lack of market knowledge. This technology is also not federally supported, as there is no energy star rating from DOE or federal tax credits.
16. Market presence in CA?
    a. There is a market across CA, solar thermal systems are used frequently and run by distributors.

[4] Interviewee: SME 6

Organization: Organization E

Date of interview: 08/01/2024

Background of Interviewee:

SME 6 has over 13 years of experience in the energy industry and is currently a Program Manager at organization E. There, he launches pilots with innovative technologies, such as gas heat pumps and dual fuel heating systems. These pilots aim to transform the market by increasing energy efficiency and reducing emissions, while supporting the climate action goals of the province of British Columbia in Canada. The SME holds an MBA and a Master of Engineering Leadership in Clean Energy Engineering from the University of British Columbia, Canada.

Interview Questions and Notes:

1. Could you give a short background on yourself and your work?
    a. I work with a leading dual-fuel energy provider. I run pilot programs for gas heat pumps and dual-fuel heat heating systems.
2. Could you give a short explanation of gas heat pumps and dual fuel heating systems?
    a. GAHP are more than 100% efficient (130-140%), while gas boilers are less than 100%. Other non-gas systems have decreased performance at colder temperatures, while GAHPs still perform at high efficiency. Gas boilers are highly reliable, but GAHPs also have high reliability and reduce GHG emissions.
    b. Dual fuel heating systems also reduce emissions and are a hybrid electric and gas heater system. These are optimal as an intermediate solution.
3. How does/would using GAHPs for pool heating work?
    a. It has not been done yet but would be a good use. Large pools typically require significant heating and utilize boilers, and the baseload could instead be supplied by GAHPs. This would improve the efficiency of the heating system from 80% to 130%.
4. Thoughts on other heating systems?
    a. Gas boilers are easy to use and well understood by maintenance teams and have lower upfront costs. GAHPs are much more efficient and use a lower amount of gas.

5. How does sequencing GAHP with other systems work?
    a. A gas boiler would provide peak heating to reach high temperatures that GAHP may struggle to reach, or to quickly heat as required. There may be installation issues if the boiler is older, incorrectly sized, or unable to be connected to a controller.
6. How does on/off cycling effect system performance?
    a. Short cycling reduces the efficiency of the system. Ideally, the unit would be running at full capacity for a long period of time.
7. How is the system sized in conjunction with a boiler?
    a. Best practice is to size the GAHP as high as possible for one (or more) unit to run at full capacity, typically about 70% of the load, and the remainder supplied by the boiler.
8. Can systems be modulated together?
    a. Modulating is more necessary for residential as the heat requirements of these buildings change throughout the day and usage. Commercial heat requirements stay relatively consistent, so the heating system does not require modulation.
    b. Robur units are non-modulating while Anesi units are [modulating].
9. What manufacturers do you work with?
    a. The manufacturers of GAHPs are Robur, Anesi, and Vicot. Gas heat pump manufacturers include Yanmar.
10. What are the biggest barriers to using GAHP?
    a. Outdoor units are bulky and have a large footprint compared to traditional heaters, and some consumers may have issues with the sizing and location. These units are also noisy and may produce up to 60 dB, so special design considerations should be made with the location to ensure occupant comfort and code adherence. The contractor costs are large due to their unfamiliarity with the technology. The system cost is lower than the installation. The refrigerant system used is ammonia and water, which some consumers may be uncomfortable with, but has 0 GWP.
11. Have there been any challenges in integrating GAHP with gas heaters in the pilot program?
    a. Only one system where the boiler had to be replaced due to age. The boiler must be able to be integrated with the boiler. If there is a rooftop unit, it must meet structural requirements.

12. What are the first cost impacts?
    a. The technology and installation are more expensive than the incumbent technology.
13. What are the emissions savings from the unit?
    a. The system can save up to 50% of emissions from a standard efficiency boiler.
14. What are installation and usage best practices?
    a. The system should be designed for the unit to take a high percentage of the total load, must be integrated with the control system, and must be located outside.
15. What are the most prominent market adoption challenges?
    a. The largest challenges are building policy requirements for systems, and any issues with installing or using gas-based equipment. As mentioned earlier, lack of market awareness or training is also a large issue.
16. What is the market presence of GAHPs?
    a. GAHPs are not yet a mainstream choice. FortisBC launched the rebate program in 2022 and had 0 applications that year. Consumer and contractor education are the most important actions to change that. Since 2023, there have been about 10-15 installations under FortisBC. It is a slow process from the first conversation to the final installation, about a year.
17. What is the comparison of GAHP with electric or solar heaters?
    a. We have not made a side-by-side comparison. A 100% electric heater or heat pump used on a clean grid has very low emissions but typically has high electric costs and operations. Thet also perform with lower efficiency in cold climates compared to GAHP. For a residential home, the electric panel may have to be upgraded to use an electric hp. The GAHP can be run with solar panels or solar thermal but has not been investigated for performance or controls.

[5] Interviewee: SME 8

Organization: Organization E

Date of interview: 08/06/2024

Background of Interviewee:

SME 8 is a Service Technician for organization E. The SME's certifications and professional experience include an HACR technical degree and 25+ years' experience in multi-family housing maintenance and he is a certified pool operator.

Interview Questions and Notes:

1. Can you tell us more about GAHPs, manufactured by your company?
    a. Electric consumption of 0.9 kW and output of 123,000 BTU/hr for space heating. This technology is often used to bridge any heat production gap by being added onto existing boiler system**.**
2. Can you tell us more about these units as they are/would be used for pool heating?
    a. It would need to be placed outside and have an external heat exchanger for the pool water. Depending on the energy requirement of the pool, several units may need to be modulated together. The unit may need to be run overnight to prevent an extreme temperature drop
3. Can you share your thoughts on the current most used pool/water heating technologies (gas heaters, heat pumps)?
    a. Some pools use electric heaters. For pools that I worked on, they often used a 3-phase electric heater that required a 240-amp breaker. The bills for this average sized multifamily pool—roughly 34,000 gallons or 25' x 50' to 92 degrees was about $5,000, located indoors in southern Indiana. This electric draw and expense were very high.
4. What are the biggest positives of using a GAHP? What are the biggest barriers/challenges with installing and using your units?
    a. The units have very few moving parts—a fan motor and hydronic pump. This makes the simple to use, install, and maintain. Understanding the hydronic side and using the heat exchanger may be the most challenging parts of using these systems.

5. What are the biggest differentiators between your product and other pool heaters/other GAHP manufacturers?
    a. The low electric draw is one of the standout differentiators between GAHPs and other types of heaters, as well as the low gas use when comparing to traditional gas heaters. When compared to competing GAHPs, other GAHP manufacturers produce GAHPs suitable for residential and not commercial sizing.
6. Are there pre-qualifications for installing/using these units? Are there any limitations to using them?
    a. Must be placed outside and understanding the hydronic loop with the pool, as it must be separated from the heat pump by heat exchanger.
7. How would sequencing the unit with a traditional gas pool heater work, and optimization of controls with a backup heater [baseload and peak load]? In addition, how are these units modulated together to prevent over/under sizing?
    a. These units can be modulated together via an RB200 controller and a direct digital controller. This will turn units on and off based on the need. It can be sequenced in with a traditional gas heater for requirements with the speed of heating, etc., but several GAHP units would be capable of providing all the required heat.
8. What affects the efficiency of these units? How does short-cycling work and how would this affect efficiency?
    a. Dirty coils affect efficiency strongly. The coils must be cleaned once a year to prevent efficiency from decreasing. Short cycling is when the unit kicks on and off frequently and does not effectively cool or heat. By altering the inlet and outlet temperature with the controller, short cycling can be prevented or decreased.
9. Could you share more insights into the cost impact or the initial price for a Robur system? Do you have an estimate for installation/maintenance costs?
    a. The maintenance is about an hour per year to check the components and for cleaning. Unfortunately, as the manufacturer, we do not have many figures on the installation cost or individual product cost. The installation may change drastically depending on the system and requirements. However, I have heard of ROIs in the range of 1.5-3 years on space heating. The highest ROI comes from the heat recovery chiller, which can be used very well for domestic hot water and space heating/cooling.
10. What are the installation and usage best practices for the Robur units?
    a. They require a low electric connection, a gas supply, and a location outside. The spacing requirements are 18”, 32.5”, and 24” on each side for optimal airflow.

11. What are some market challenges preventing the adoption of the Robur units?
    a. A lack of knowledge of the Robur product is the largest challenge — many consumers do not know what options are available. Robur has been producing absorption heat pumps for around 50 years–but the number of units installed has been taking off and likely will continue to do so with education and focus on cleaner technology. We currently have over 100,000 units installed for heating and cooling in North America.
12. Can you share more insights on the market presence of the Robur units for pool usage?
    a. They have not yet been used for heating pools, but they have been used for domestic hot water. The application would be similar.
13. Selection tool discussion
    a. I do not feel the selection tool would be applicable, and other equations would be more appropriate. The heat exchanger is not included as far as I am aware, especially for pools as it is an external heat exchanger. The spec sheet of the heat exchanger would provide the best information to understand the effect on the supply temperature needed from the unit. The flow is typically 14 gallons/minute and usually has a 10-degree temperature differential between the inlet and outlet.

Appendix C: Datasets

Appendix C: Datasets (Table 12-20) compile tool output data of various scenarios or parametric combinations. This output data was primarily used to generate Power BI plots discussed in 'Parametric Analysis' section. The parametric analysis was conducted to determine which pool or equipment related parameters play a significant role in total energy consumption, utility costs, and GHG emissions. Also, a comparative analysis of different pool heating technologies for various building types was conducted.

The average electric and natural gas utility rate assumptions for multifamily and commercial sectors are compiled in Table 11. Similarly, the rate assumptions for residential sector are compiled in Table 12.

Table 11: Average Electric and Natural Gas Utility Rates for Different CA Climate Zones (Multifamily and Commercial Sector)

Climate Zone	Name of electric utility	Name of gas utility	Average rate [$/kWh]	Average rate [$/therm]
CZ01	PG&E	PG&E	$0.41	$1.69
CZ02	PG&E	PG&E	$0.41	$1.69
CZ03	PG&E	PG&E	$0.41	$1.69
CZ04	PG&E	PG&E	$0.41	$1.69
CZ05	PG&E	PG&E	$0.41	$1.69
CZ06	SCE	SoCalGas	$0.30	$1.26
CZ07	SDG&E	SDG&E	$0.50	$2.44
CZ08	SCE	SoCalGas	$0.30	$1.35
CZ09	SCE	SoCalGas	$0.30	$1.35
CZ10	SCE	SoCalGas	$0.30	$1.35
CZ11	PG&E	PG&E	$0.41	$1.69
CZ12	PG&E	PG&E	$0.41	$1.69
CZ13	PG&E	PG&E	$0.41	$1.69
CZ14	SCE	SoCalGas	$0.30	$1.35
CZ15	SCE	SoCalGas	$0.30	$1.35
CZ16	SCE	SoCalGas	$0.30	$1.35

Table 12: Average Electric and Natural Gas Utility Rates for Different CA Climate Zones (Residential Sector)

Climate Zone	me of electric utility	Name of gas utility	Average rate [$/kWh]	Average rate [$/therm]
CZ01	PG&E	PG&E	$0.41	$1.68
CZ02	PG&E	PG&E	$0.40	$1.70
CZ03	PG&E	PG&E	$0.41	$1.68
CZ04	PG&E	PG&E	$0.40	$1.70
CZ05	PG&E	PG&E	$0.41	$1.68
CZ06	SCE	SoCalGas	$0.34	$1.54
CZ07	SDG&E	SDG&E	$0.49	$2.21
CZ08	SCE	SoCalGas	$0.34	$1.54
CZ09	SCE	SoCalGas	$0.33	$1.53
CZ10	SCE	SoCalGas	$0.33	$1.55
CZ11	PG&E	PG&E	$0.39	$1.75
CZ12	PG&E	PG&E	$0.39	$1.74
CZ13	PG&E	PG&E	$0.39	$1.76
CZ14	SCE	SoCalGas	$0.34	$1.52
CZ15	SCE	SoCalGas	$0.32	$1.55
CZ16	SCE	SoCalGas	$0.33	$1.54

Table 13: GAHP for Outdoor Pools–All Building Types

GAHP- Outdoor Pools			
Building Type	Average of % GHG Emissions Savings	Average of % Energy Cost Savings	Average of Normalized Cost Savings ($/sq. ft.)
Hotel	40%	32%	$2.93
Multi-Family Residence	36%	28%	$0.65
Private / Health Club - Large	20%	15%	$2.07
Residential Pool	72%	60%	$1.00
Schools/Colleges - Recreation Pool	21%	17%	$1.64

Table 14: Impact of GAHP Heat Exchanger Effectiveness

GAHP HX Effectiveness	% Energy Cost Savings	Normalized cost savings
0.5	-10.34%	-0.24
0.6	-6.68%	-0.15
0.7	-4.42%	-0.10
0.8	2.99%	0.07
0.9	11.81%	0.27
1	25.27%	0.58

Table 15: Outdoor Pools in Multifamily Sector

Multi-Family Residence- Outdoor			
Heater Type	Average of % GHG Emissions Savings	Average of % Energy Cost Savings	Average of Normalized Cost Savings ($/sq. ft.)
GAHP + Gas Pool Heater	36%	28%	$0.65
Heat Pump	60%	-9%	($0.22)
Hybrid Heat Pump - Cost	25%	25%	$0.58
Hybrid Heat Pump - Efficiency	50%	1%	$0.03

Table 16: Indoor Pools in Multifamily Sector

Multi-Family Residence- Indoor			
Heater Type	Average of % GHG Emissions Savings	Average of % Energy Cost Savings	Average of Normalized Cost Savings ($/sq. ft.)
GAHP + Gas Pool Heater	34%	23%	$0.94
Heat Pump	64%	-2%	($0.07)
Hybrid Heat Pump - Cost	12%	12%	$0.49
Hybrid Heat Pump - Efficiency	66%	4%	$0.15

Table 17: Outdoor Pools in Hotel Sector–Paired With Solar

Hotel-Outdoor-Solar		
Heater Type	Average of % GHG Emissions Savings	Average of Normalized Cost Savings ($/sq. ft.)
GAHP + Gas Pool Heater	52%	$4.40
Heat Pump	71%	$1.89
Hybrid Heat Pump - Cost	52%	$4.54
Hybrid Heat Pump - Efficiency	66%	$2.79

Table 18: Outdoor Pools in Multifamily Sector–Paired With Solar

Multifamily-Outdoor-Solar		
Heater Type	Average of % GHG Emissions Savings	Average of Normalized Cost Savings ($/sq. ft.)
GAHP + Gas Pool Heater	75%	$1.68
Heat Pump	87%	$1.44
Hybrid Heat Pump - Cost	77%	$1.77
Hybrid Heat Pump - Efficiency	82%	$1.54

Table 19: Indoor Pools–Average % GHG Emissions Savings

Indoor Pools- Recommended Qty				
	Average of % GHG Emissions Savings			
Building Type	Hotel	Multi-Family Residence	Private / Health Club - Large	Schools/Colleges - Recreation Pool
GAHP + Gas Pool Heater	32.93%	33.81%	34.25%	34.78%
Heat Pump	65.11%	64.38%	65.37%	64.26%
Hybrid Heat Pump - Cost	11.83%	11.83%	11.83%	11.83%
Hybrid Heat Pump - Efficiency	11.86%	66.19%	67.16%	66.11%

Table 20: Indoor Pools–Average % Energy Cost Savings

Indoor Pools- Recommended Qty				
	Average of % Energy Cost Savings			
Building Type	Hotel	Multi-Family Residence	Private / Health Club - Large	Schools/Colleges - Recreation Pool
GAHP + Gas Pool Heater	19.72%	22.57%	23.46%	24.52%
Heat Pump	0.97%	-1.60%	1.57%	-0.29%
Hybrid Heat Pump - Cost	11.84%	11.82%	11.83%	11.83%
Hybrid Heat Pump - Efficiency	6.07%	3.65%	6.66%	4.90%

Table 21: Multifamily Outdoor Pool–Types of Heat Losses

	No cover	Bubble/Solar	Vinyl
Evaporation	450,312	261,519	227,571
Radiation	330,735	291,750	332,597
Convection	42,275	16,278	38,349
Conduction	487	1,863	845

Table 22: Monthly Heating Energy Required–Outdoor Pool Multifamily

Month	No Cover	Vinyl cover	Bubble/Solar
May	10,069	4,352	-
Jun	5,770	457	-
Jul	5,098	104	-
Aug	4,129	-	-
Sep	10,152	3,393	151
Oct	16,146	8,579	3,451
	Energy required- Kbtu		
CZ09, Residential outdoor pool, GAHP			

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