Solar Assisted HVAC Market Study

Final Report

ET22SWE0030

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December 23, 2022

Executive Summary

A market evaluation study of solar-assisted heat pumps (SA-HP) was performed. The emerging technology can potentially provide supplemental carbon-free heating to variable speed heat pumps (HP) in the 2-ton to 10-ton range. SA-HP can be grouped into three main categories: direct expansion (DX) SA-HP, indirect expansion (IX) SA-HP, and hybrid SA-HP. Because of its size, the technology is applicable to most residential and small commercial HP applications. The technology uses solar thermal energy to offset a portion of the thermal energy input to the refrigeration cycle that would normally be generated by the compressor. The technology usually consists of a variable speed compressor, solar thermal collector, condenser, evaporator, and often combined with water heating that includes a storage tank. The compressor work is reduced in relation to the amount of solar radiation heat available. Previous research is cited that has shown inconclusive heating mode savings and has recommended further studies to understand SA-HP viability.

The objectives of this study were to identify possible configurations of SA-HP, inventory SA-HP technologies and products available in the residential and commercial market space, size the potential market of SA-HP applications in heating mode, identify the highest benefit applications and locations of the SA-HP technologies in heating mode in CA, identify market opportunities and barriers, and recommend next steps.

The market study and market sizing involved both primary and secondary research. Primary market research was conducted to provide direct data about SA-HP technology for residential and commercial buildings. General searches for existing manufacturers or vendors of this technology were performed. Secondary market research was conducted by surveying journals, articles, catalogs, and peer reviewed studies, as were publicly available. Market sizing methodology involved primary research of CA climate zone data from the American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) (ASHRAE, 2021) to determine the areas of CA that have the most heating loads while also having solar irradiation availability. Additionally, secondary research of HP market potential was conducted, as SA-HP systems would be installed anywhere a traditional HP would be.

The DX SA-HP category has two configurations, basic and dual source. In the basic configuration, the solar collector serves as an additional evaporator. In dual source, the solar collector is parallel to the evaporator and often integrated with a hot water system for space and water heating. The IX SA-HP category also has two configurations, serial and dual source. In the serial configuration, heat exchangers and used to connect a solar collector loop, a refrigerant loop in the HP, and storage water tank loop. In the dual source configuration, the evaporator is parallel to the solar collector water loop and can provide space and water heating. The hybrid SA-HP has one configuration referred to as basic. These systems comprise of solar collector water loops that work independently from the HP.

The associated benefits and drawbacks of the different types and configurations are largely the same but vary with complexity of the system. A more basic DX SA-HP, with COP ranges of 2.5 to 3.5, will be less expensive but will not see the thermal load gains as the indirect expansion systems with integrated thermal energy storage components or systems utilizing phase change materials. The indirect systems, which are more complex and provide thermal energy when solar irradiance drops off in the evening, have shown to have higher heat pump COP ranging from 2.5 to 3.5 in one study

found, and a COP as high as 8.5 in another experimental study. However, these systems have shown 20% lower system COP resulting from power consumed by additional system components like pumps. The consistent finding among prior studies was that the performance of SA-HP is most heavily affected by available solar irradiation. The more solar irradiance on the solar collectors, the higher the COP of the HP system. Low ambient temperatures also affect the efficiency of systems through degraded thermal efficiency of solar thermal collectors and lower COP of the HP. Therefore, SA-HP are likely to only be substantially more efficient than a baseline system in sunny climates that see more mild winters unless combined with thermal energy storage components.

Commercially availability of the SA-HP technology was researched and found only one DX SA-HP product available from a U.S.-based company that offers retrofit options to add solar thermal collectors to existing HP. Another product from a Canadian-based company incorporates thermal energy storage into a hybrid SA-HP design is available in the U.S. as well and can be used for hot water, pool, and space heating.

Climate zone data was researched for the California climate zone with the highest average heating season irradiation and heating degree days. It was determined that climate zone 16 has the highest potential benefit for SA-HP. Market potential was researched and discussed for this emerging technology. HP installations in both residential and commercial buildings are an integral part of the solution to reach decarbonization goals in California. Small commercial facilities, such as offices, retail, and warehouses would be good applications given these buildings typically have packaged and split AC/HP for space conditioning and make up the larger energy users for commercial buildings. Furthermore, the typical operating hours for small commercial facilities coincides with the periods of solar irradiation. The opportunity in residential HP applications also seems to be significant due to aging existing heating equipment for nearly half of the homeowners in the state. Additionally, the technology can be combined with water heating which can help accelerate decarbonization in both single family and multifamily sectors.

There are barriers to the wide-spread adoption of this technology, the largest being a lack of commercially available products that can be retrofitted onto existing HP. Other barriers noted are contractor training, condition of existing roof, required costs of electrical panel upgrades for fuel switching and required modifications to existing ductwork.

Although the SA-HP technology is still immature, it is worth evaluating as it can combine the electrification of both water heating and space heating. With the combination of thermal energy storage, the technology may become the key to optimizing solar electric power, solar thermal energy, and HP operations. The following next steps are recommended when a commercial-ready product is available:

1. Identify a viable vendor.
2. Perform field tests on residential and commercial settings in climate zone 16 to measure savings in the real-world settings.
3. Evaluate the technology’s cost effectiveness in advancing the State of California’s decarbonization agenda.
4. Investigate an incentive mechanism to speed up the technology adoption.

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Abbreviations and Acronyms

Abbreviations and Acronyms	Meaning
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
CA	California
CEC	California Energy Commission
COP	Coefficient of Performance
CPUC	California Public Utilities Commission
CZ	Climate Zone
DX	Direct Expansion
EE	Energy Efficiency
ET	Emerging Technology
GHG	Greenhouse Gas
HDD	Heating Degree Days
HDD65	Heating Degree Days with 65°F Base Temperature
HP	Heat Pump
HVAC	Heating, Ventilation, and Air Conditioning
IX	Indirect Expansion
kWh	Kilowatt-hour
PCM	Phase Change Material
PV	Photovoltaic
PVT	Photovoltaic Thermal
PG&E	Pacific Gas & Electric
SA-HP	Solar-Assisted Heat Pump

Abbreviations and Acronyms	Meaning
TECH	Technology and Equipment for Clean Heating
TES	Thermal Energy Storage
VFD	Variable Frequency Drive

Introduction

California (CA) has targeted to reduce greenhouse gas (GHG) emissions 40% below 1990 levels by 2030 (Pavley, Chapter 249, Statute of 2016). To promote the GHG reduction, the California Energy Commission (CEC) has set a goal of installing at least six million heat pumps (HP) by 2030. Currently, approximately 24 percent of GHG emissions in CA is attributed to existing residential and commercial buildings. Thus, HP installations in existing buildings are encouraged because decarbonization is more challenging in existing homes than new constructions but offers greater potential for emission reductions (California Energy Commission, 2022).

In this report, the market evaluation of solar-assisted heat pumps (SA-HP) was performed. The emerging technology (ET) can provide supplemental carbon-free heating to variable speed HP in the 2-ton to 10-ton range. Because of its size, the technology is applicable to most residential and small commercial HP applications. The technology uses solar thermal energy to offset a portion of the thermal energy input to the refrigeration cycle that would normally be generated by the compressor. The technology usually consists of variable speed compressor, solar thermal collector, condenser, evaporator, and often combined with water heating that includes a storage tank. The compressor work is reduced according to the amount of solar radiation heat available. The technology is expected to work well in climates where the winter is combined with abundant solar radiation. Thus, it has potential in many California climate zones (CZs) that have high solar potential as well as heating loads.

The technology supports CA's goal to achieve decarbonization through energy efficiency (EE), electrification, and load shifting. This technology could also work well with photovoltaic (PV) solar since it would help use electric solar power when there is traditionally less or no demand in the winter from gas heating equipment.

Background

SA-HP technologies were first developed in the 1950s using solar irradiation as the heat source. These systems comprise of a traditional HP that has an integrated solar collector added to the system. When the HP is operating in the heating mode, the heat collected by the solar panel (solar collector) is fed to the condenser. This results in a coefficient of performance (COP) that is greatly improved beyond that of a traditional HP. To better understand the different configurations and corresponding savings potential, many experimental and theoretical studies and system optimizations have been conducted. (Lin, et al., 2022).

Prior studies on technology performance have indicated COP improvements in HP systems serving water heating and combination water heating and space heating, but the savings were primarily estimated from energy modeling simulations. Additionally, a previous field study on a residential HP reported no measured savings in cooling mode, but inconclusive results for the technology's savings in heating mode. The study recommended to conduct further testing in regions with more heating loads (Karasawa & Corradini, 2021). This study is a follow up of the field study and intended to provide an updated review of commercial and pre-commercial technologies, market size, and current feasibility and key barriers, and will provide specific targeting for market segments and climate zones that has the highest potential for SA-HP implementation in heating mode.

Objectives

Understanding the market is a critical first step to assess the potential opportunity of any ET. The following objectives were established in conducting this market study:

- Identify possible configurations of SA-HPs
- Inventory SA-HP technologies and products available in the residential and commercial market space
- Size the potential market of the SA-HP applications in heating mode
- Identify the highest benefit applications and locations of the SA-HP technologies in heating mode in CA
- Identify market opportunities and barriers
- Recommended next steps and utility interventions to advance the ET adoption

Methodology & Approach

The market study and market sizing involved both primary and secondary research.

Primary market research was conducted to provide direct data about SA-HP technology for residential and commercial buildings. General searches for existing manufacturers or vendors of this technology were performed. Secondary market research was conducted by surveying journals, articles, peer reviewed studies as were publicly available, and catalogs.

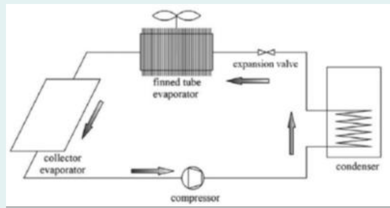
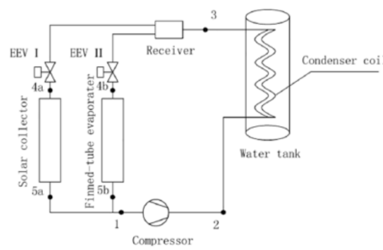
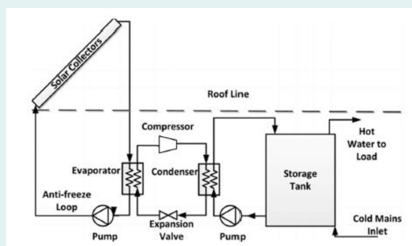
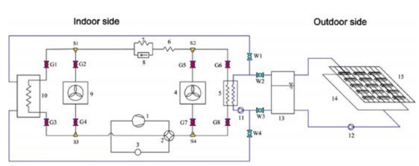
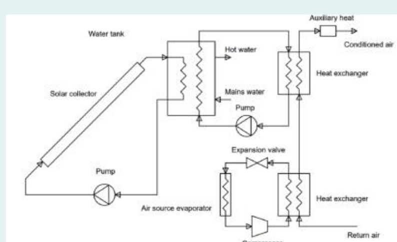
Market sizing methodology involved primary research of CA climate zone data from the American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) (ASHRAE, 2021) to determine the areas of CA that have the most heating loads while also have solar radiation availability. Additionally, secondary research of HP market potential was conducted, as SA-HP systems would be installed anywhere a traditional HP would be.

Findings

Technology Configurations

SA-HP can be grouped into three main categories: direct expansion (DX) SA-HP, indirect expansion (IX) SA-HP, and hybrid SA-HP. Table 1 summarizes the system type and configuration of each system.

Table 1: SA-HP System Types and Configurations

SA-HP Category	System Type	System Configuration
DX SA-HP	Basic	 Solar collector serves as an additional evaporator. COP ranged from 2.5 to 3.5 based on ambient conditions.
	Dual Source	 Evaporator is parallel to the solar collector. COP in solar-source only mode is 30%-50% higher than HP only mode.
IX SA-HP	Serial	 A heat exchanger connects the refrigerant loop and solar HW loop. COP ranged from 2.5 to 3.5 but system COP is about 20% lower due to additional equipment (i.e., pumps).
	Dual Source	 Evaporator is parallel to the solar HW loop. As shown, the HP provides hot water and space heating (multi-functional). With this system, COP increased by 20% with 36°F increase in solar water temperature.
Hybrid SA-HP	Basic	 HP and solar collector water loop work independently.

Source: (Yang, et al., 2021)

The DX SA-HP system typically consists of a solar thermal collector and a refrigerant line that connects the solar thermal collector to a DX system (heat pump) which includes compressor, evaporator, expansion valve, and condenser. The solar thermal collector is added in series (basic) or in parallel to the air-source evaporator (dual source) between the expansion valve and the compressor, by running the refrigerant line from the expansion valve, through the solar collector, and back to the compressor.

The DX SA-HP technology can often be found integrated with a hot water system, as a HP can be used for both space heating and water heating. In this multi-functional configuration, the solar collector works to offset the HP's compressor load while the HP heats the water in a storage tank, reducing the overall electric consumption. Figure 1 shows this hot water heating integration.

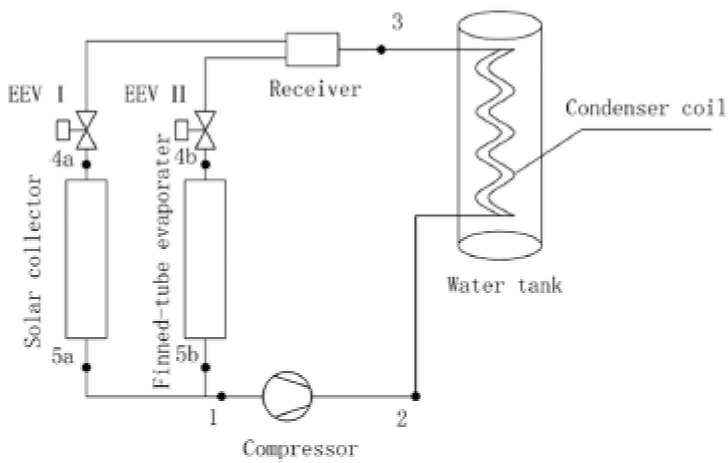


Figure 1: Dual-source DX SA-HP for Water Heating

Source: (Yang, et al., 2021)

Solar thermal collectors can also be integrated with HP systems through indirect expansion (IX SA-HP) configurations. The main difference between a DX SA-HP unit and an IX SA-HP unit is that water instead of the refrigerant carries the thermal energy load collected from the solar thermal collector. Additionally, a heat exchanger is used to transfer the thermal energy to the refrigerant in the HP's evaporator. A diagram of a multi-functional serial IX SA-HP used for both water heating and space heating can be seen in Figure 2. The system absorbs thermal energy from the solar collector, just as in the DX configuration. However, instead of moving that thermal energy directly into a refrigerant loop, it moves through a series of heat exchangers that transfers energy into a water loop that then runs to the evaporator of the HP used for space heating (Yang, et al., 2021).

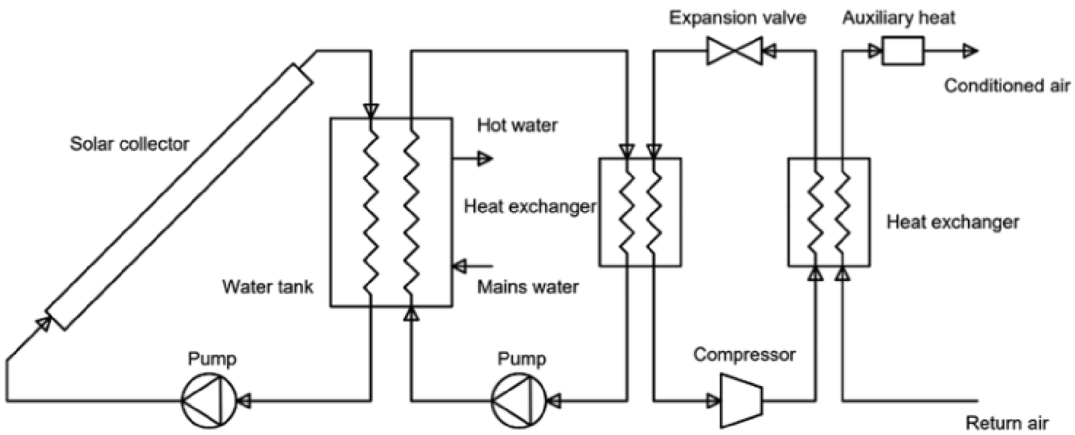


Figure 2: Multi-functional Serial IX SA-HP

Source : (Yang, et al., 2021)

Another version of the IX SA-HP is the dual source IX SA-HP, shown in Figure 3. This system uses both thermal energy collected by the solar collector and thermal energy absorbed from the ambient air in HP's evaporator (Yang, et al., 2021). This configuration adds the ambient air as a source for energy, absorbed from the indoor heat exchanger in the process. Dual source units tend to be more efficient than serial (single source) units due to their ability to draw the thermal energy from multiple sources. This is especially noticeable when the system's solar collector is not experiencing adequate irradiance but can still improve the efficiency of the HP by relying instead on the ambient air energy.

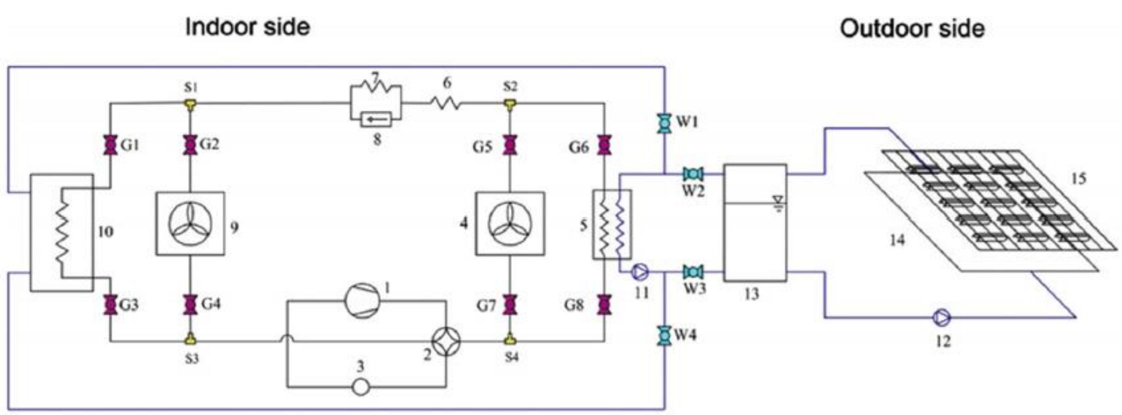


Figure 3: Dual-source IX SA-HP (1 - compressor, 4 – air source evaporator, 5 – heat exchanger, 9 - condenser, 10 – water tank, 13 – water TES tank, 14 and 15 – two solar collectors)

Source: (Yang, et al., 2021)

The biggest drawback of an SA-HP is the mismatching of the peak solar irradiance of a solar collector and the peak demand of a system (Fan, et al., 2021). This would apply more during the winter when the peak heating load occurs at times when solar radiation is unavailable, thus minimizing any potential savings a solar-assisted unit can achieve. To mitigate this issue, advanced SA-HP prototype systems integrated with thermal energy storage (TES) are being developed. Some SA-HP systems are integrated with water as medium for TES while others use phase change material (PCM). These materials can store thermal energy to be discharged later. As it relates to SA-HP systems, TES allows the solar collector to store the excess thermal energy that is gained throughout the day to be used later when the demand exceeds the solar irradiance on the solar collector (Ma, Ren, Lin, & Wang, 2017).

A hybrid SA-HP configuration including the PCM as TES is shown in Figure 4. A theoretical analysis on this system resulted an average COP of 5.21, significantly improving when compared to unmodified HP system efficiency of 3.06 COP. Furthermore, the study determined that the ability of the TES to store some of the thermal energy collected by the solar collector for later use would allow a more effective use of the thermal energy, specifically in the winter. Heating loads are greatest in the evenings and nights during the winter when the daylight hours are shorter, and therefore solar collectors are not able to offset system demands at their peak. With TES to store additional energy, the variability of a solar-assisted unit is reduced and allows for extended use (Ma, Ren, Lin, & Wang, 2017).

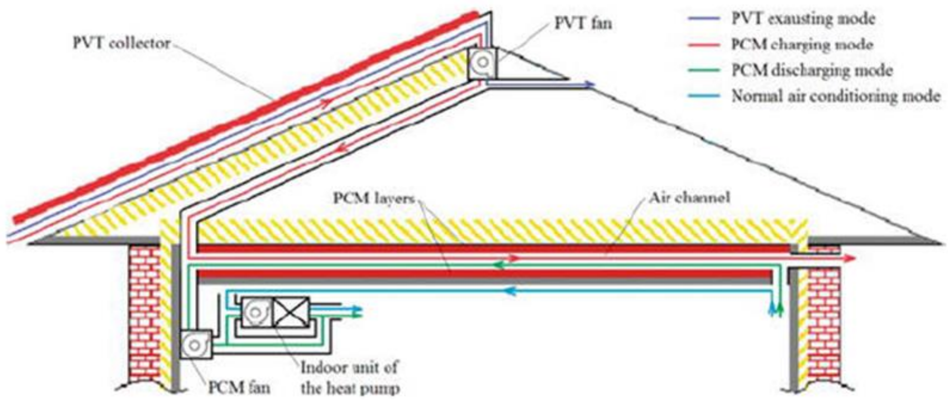


Figure 4: Phase Change Material (PCM) Used as Thermal Energy Storage (TES) in Hybrid SA-HP

Source: (Ma, Ren, Lin, & Wang, 2017)

There is also the distinct opportunity to implement a PV array that both acts as traditional PV system and as a solar thermal collector. The recent research has shown that the technology can not only offset the power demand of HP though the PV power generation but also increase the PV panel efficiency. Since the PV panel efficiency decreases at high temperatures, the solar thermal collector helps lower the temperature of the PV panels by absorbing heat from them. An example of dual source DX SA-HP system with photovoltaic thermal (PVT) collector is shown in Figure 5.

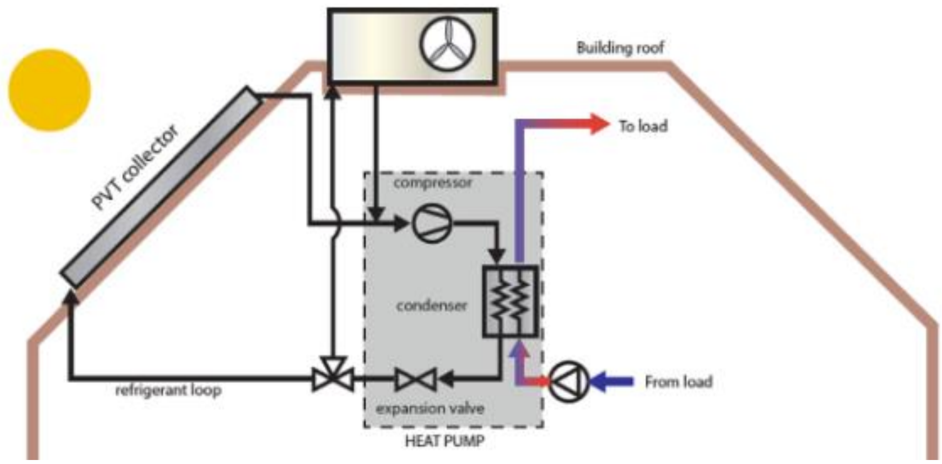


Figure 5: Heat Pump with PVT Collector for Water Heating

Source: (Yang, et al., 2021)

Table 2 below summarizes the system components of SA-HP system examples in this section.

Table 2: System Components of Various SA-HP Configurations

System Type	System Components
Dual-source DX SA-HP – Water Heating (Figure 1)	Solar thermal collector, finned-tube evaporator, compressor, condenser coil, receiver, expansion valve
Serial IX SA-HP – Water and Space Heating (Figure 2)	Solar thermal collector, water tank for water heating, water loop, heat exchangers, refrigeration loop including compressor, condenser, evaporator, and expansion valve for space heating
Dual-source IX SA-HP – Water Heating (Figure 3)	Solar thermal collector, heat exchanger, air-source evaporator, compressor, expansion valve, condenser, water tank, water TES tank
Hybrid SA-HP – PCM – Space Heating (Figure 4)	Phase change material layers (ceiling/roof), photovoltaic flat plate collector (evaporator), compressor, condenser, expansion valve, air channels (to/from PCM)
HP with PVT Collector – Water Heating (Figure 5)	Photovoltaic flat plate collector (evaporator), compressor, condenser, expansion valve, water tank, water inlet, water outlet

Configuration Pros and Cons

The goal of introducing the SA-HP is primarily to reduce the electrical load on a typical house or commercial building. The ability to reduce a building's load with this technology can be an incentive to make the switch from gas heating to an electric HP. Removing more gas heat systems will lead to lower GHG emissions and a reduction in fossil fuel dependence. But that's not to say retrofitting an existing HP with a solar assistance mechanism is without its own merit. Adding a solar thermal collector to reduce the load of the HP it is connected to allows for more efficient operation in the heating mode. The improved efficiency could even prolong the effective lifespan of existing HPs as the operational load on the system would decrease with solar assistance.

The different DX and IX configurations listed in the previous section largely share the same benefits and drawbacks. The degree to which they vary depends on the complexity of the intended system. A more basic DX SA-HP system will be less expensive than an advanced DX SA-HP with an integrated TES. However, the system with TES will be more viable than a regular SA-HP due to the ability to store excess thermal energy for use when the irradiance drops off. Though the TES integrated DX SA-HP systems have their advantages, they also have drawbacks. If the TES is an integral part of a building's roof and/or ceiling as is the case with some PCM, a retrofit may not even be possible in many scenarios and would largely leave this configuration to new construction applications. A SA-HP used for water heating can provide a similar reduction in GHG emissions by switching from a gas water heater the same way a SA-HP space heat system promotes a switch from a gas furnace. There is the extended cost to switch from a gas system to an electric system as opposed to retrofitting an existing electric system.

IX SA-HP systems are generally more complex than their DX SA-HP counterparts. Although the utilization of solar thermal energy increases the HP performance, the system COP is lower than that of the HP due to the power consumed by the additional components. Experimental results of an IX SA-HP system showed the HP COP of 3.8 and its system COP of 2.9. Experimental results of similar IX SA-HP systems showed the HP COP ranging from 2.5 to 3.5, and the system COP to be around 20% lower.

Technology Savings Potential

Figure 6 below illustrates the COP of SA-HP in different configurations used for space heating and water heating documented in published studies. As shown, DX SA-HP systems exhibited great savings potential with high COP values when used in water heating applications. On the other hand, advanced IX SA-HP systems, involving TES and/or innovative aspects of solar collector and system configurations, exceled in both space heating and multi-functional applications. For example, a simulation study found an IX SA-HP system with a seasonal latent heat TES could achieve COP of 8.5 (Yang, et al., 2021). As compared to California Title 24 code baseline performance for a non-solar assisted HP, with COPs of 2.25 to 3.3 based on rating conditions, these technologies have the ability to dramatically improve operating efficiencies.

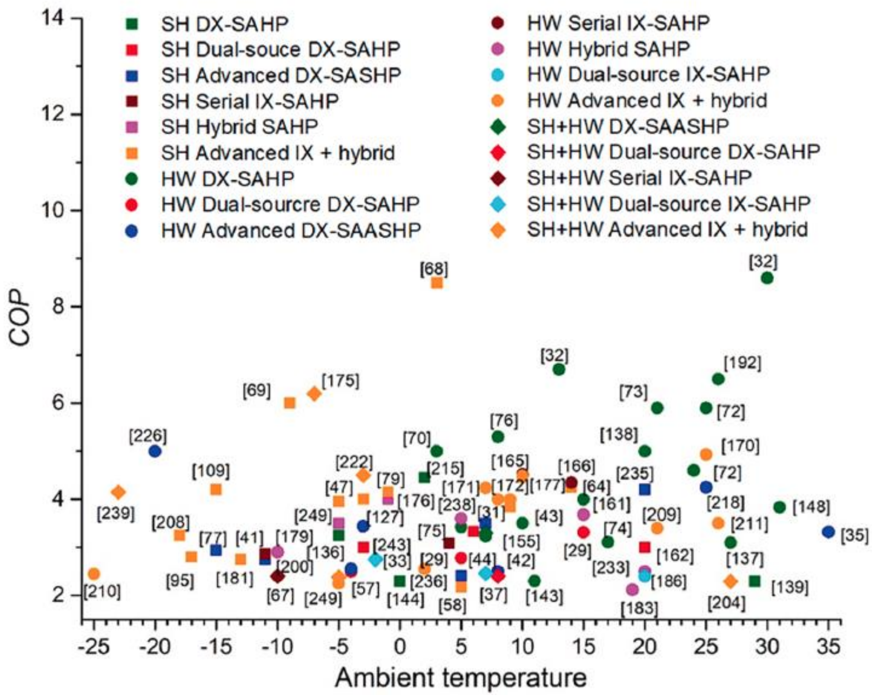


Figure 6: The Effect of Ambient Temperature on COP for SA-HP Used for Space Heating and Hot Water

Source: (Yang, et al., 2021)

Other studies were performed to investigate the effect of solar thermal collector type and configurations on overall efficiency. An experimental analysis was conducted to assess the effect of thermal collector area on the efficiency of a HP used for water heating in a DX SA-HP configuration (Liu, et al., 2022). The study was centered on a value termed Ah/V_{th}, derived as the ratio between the product of the solar collector's area and the convective heat transfer coefficient (h) divided by the volume of the water to be heated (thermal volume). The ratio was between the solar collection area and the reduction of the HP's compressor. Overall, the study found that the higher Ah/V_{th} was, the higher the COP would be. In fact, the study found that doubling the Ah/V_{th} ratio would increase the system COP by 61.3% (from 3.1 to 5.0), which only required increasing the area of solar thermal collector by adding collectors. The study also performed a parallel simulation analysis that saw a maximum error percentage of 6.1% between the instantaneous COP of the system in the experiment and the expected COP based on the theoretical analysis. The experiment setup is shown in Figure 8 and the results of the experiment are detailed in Figure 8. This graphical representation of the experiment compares the COP of the HP and the compressor power with the amount of irradiance the solar collector is subject to. The figure also includes the results of the simulated analysis to demonstrate the accuracy of the simulations given the same parameters measured in the experiment.

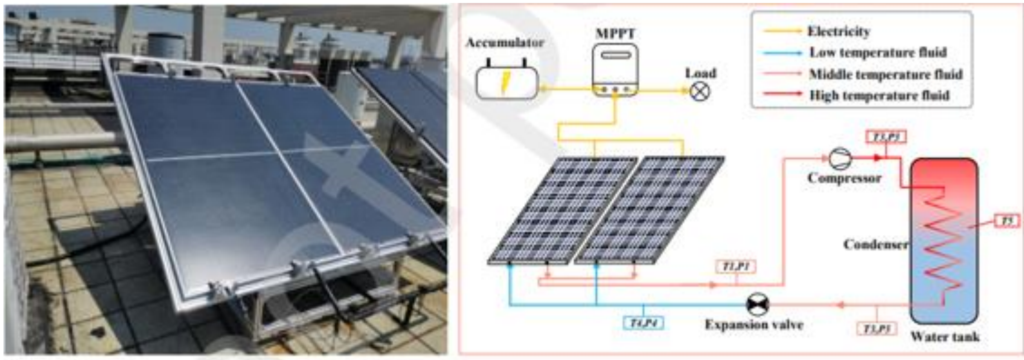


Figure 7: Experimental Setup of Liu, et al. 2022 Study

Source: (Liu, et al., 2022).

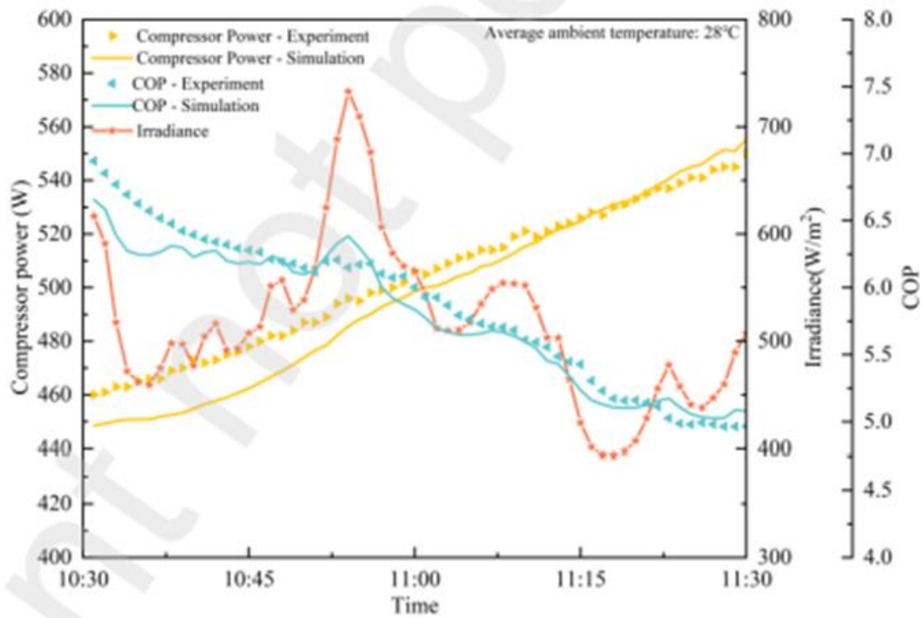


Figure 8: Findings from Liu, et al., 2022 Study

Source: (Liu, et al., 2022).

A similar study was conducted, which investigated the effects of a solar collector integrated into a HP used in water heating (Ćutic, Pasanec, Baleta, Ćurko, & Soldo, 2012) in a DX SA-HP configuration. This experimental setup is shown in Figure 9. The experiment found 79.25 gallons of water was heated from about 60°F to 122°F in just over 4 hours of testing. The system was assisted by the thermal energy from the solar collector for the whole study. The COP of the system ranged between 5.1 and 5.9 for the duration.

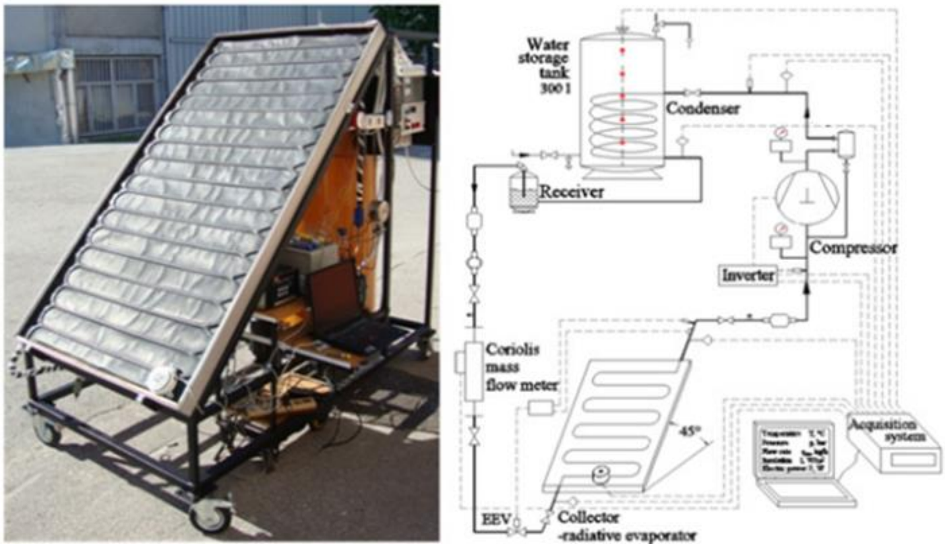


Figure 9: Experimental Setup for Cultic, Pasanec, Baleta, Ćurko, & Soldo, 2012

Source: (Ćutic, Pasanec, Baleta, Ćurko, & Soldo, 2012).

The consistent finding among prior studies was that the performance of SA-HPs is most heavily affected by available solar radiation. The more solar irradiance on the solar collectors, the higher the COP of the HP system will be. A low ambient temperature can also significantly affect the efficiency of systems in several ways. Thermal efficiency of solar thermal collectors and the COP of HPs both decrease as the ambient temperature decreases (Fan, et al., 2021). The lower temperatures also lead to issues beyond the SA-HP such as "reduced volumetric efficiency, elevated compressor discharge temperature, increased compression ratio, reduced refrigerant mass flow rate and decreased operational efficiency," (Fan, et al., 2021). As such, a SA-HP system is likely to only be substantially more efficient than a baseline system in sunny climates that see more mild winters or needs to be combined with TES.

Commercially Available Technologies

Primary research for commercially available SA-HP was conducted through web search and interviews with vendors. There is only one product available in the U.S. that specifically offers retrofit options to add solar thermal collectors to existing HPs. One vendor offers DX SA-HP as a package as well as solar collectors as an add-on to an existing HP system. At the time of this research, these systems' performance has not been independently verified. Their solar thermal collectors can only be combined with air-source HPs at this time. Additionally, to retrofit the technology onto an existing HP, a variable frequency drive (VFD) needs to be added to the compressor. The solar collector adds thermal energy from the solar radiation into the refrigerant, replacing some of the thermal energy the compressor that would otherwise supply mechanically. As the solar thermal collector adds more heat to the system, the VFD slows the compressor to keep the system running at necessary operating pressures. Each solar thermal collector supports systems up to 5 tons and multiple collectors can be connected together to support systems up to 150 tons.

The vendor's solar thermal collector uses a solar film developed by the National Renewable Energy Laboratory (NREL). The solar film redirects the sunlight to a receiver where it is concentrated and converted to heat. With this technology, the solar thermal collectors do not need the direct sunlight, which allows them to collect thermal energy from the sun even on cloudy days. The vendor is currently testing a 5-ton system in Indiana. The technology must be installed by a licensed contractor and is roughly estimated at $10,000 to add a solar thermal collector and VFD to an existing 5-ton system.

A hybrid SA-HP has been developed by a group in Canada, which is commercially available in the U.S. This hybrid SA-HP configuration works in conjunction with a solar storage tank which can store and supply solar thermal energy simultaneously to hot water systems and space heating. An example of this configuration is shown in Figure 10. This vendor's solar thermal collector uses solar vacuum tubes, each consisting of two glass layers and a vacuum separating these layers. The outer layer of the solar tube is Borosilicate glass and allows 98% light energy to pass through. The second inner layer has a coating that can absorb more solar thermal energy while being able to withstand temperatures more than 300°F. The coating converts shortwave solar radiation into longwave heat radiation and is roughly 94% efficient at doing so. The absorbed solar radiation is then diffused in a heat transfer fluid within the tube. The manufacturer uses a water and glycol solution and heat exchanger within the solar storage tank to transfer the thermal energy to hot water and space heating use. Solar water tanks are used to function as TES. When thermal energy from solar radiation is available, the water in the tank is heated and stored for later use, most commonly in the evening and at night.

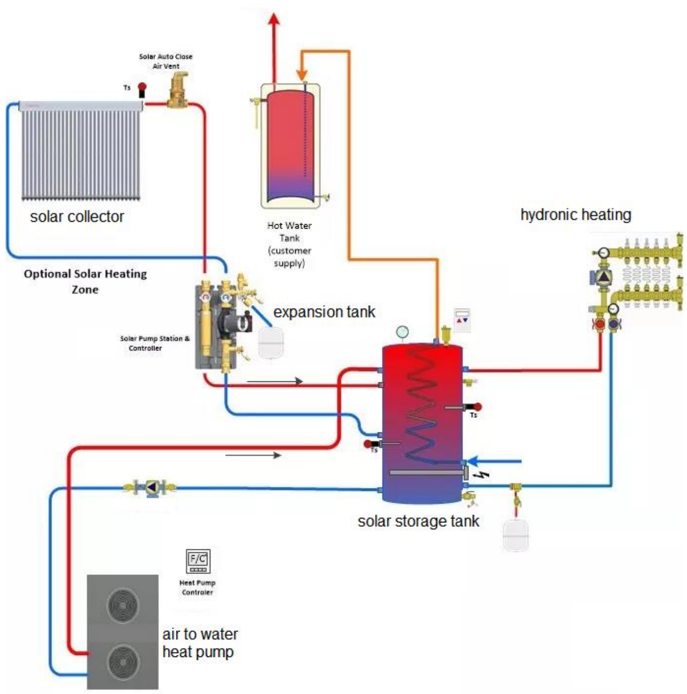


Figure 10: Solar collection to solar storage tank system with heat pump (Hybrid SA-HP)

Source: (Air Source Heat Pump and Solar Water Heating Combined, 2022)

This system can be used for hot water, pool, and space heating. For space heating, the system can work in combination with air-to-water HPs and either radiators, hydronic air handlers, or hydronic floor heating. The integration of this system with an air-to-water HP is simplified because they can both utilize the same glycol heating fluid. The manufacturer claims this combination can supply an average of 44,000 BTU per day per collector.

A single vacuum tube thermal collector is priced at $1,044 while a packaged solar hot water retrofit kit is $5,086. A packaged kit includes: a vacuum tube solar thermal collector, a digital controller, insulated and weather-proof stainless-steel piping with sensor wiring, quick connect fittings, solar heating fluid for the vacuum tube collectors, a positive displacement drill pump, an 18L solar expansion tank, and a heat exchanger. The package does not include a solar storage tank, the minimum cost of which is $3,062. Solar storage tanks range in size and price as do compatible hydronic air handlers. Without installation, the cost for a solar collection retrofit to an existing air-to-water HP and hydronic heating system is a minimum $8,148.

Potential Market Size and Savings

A previous field study of this technology, (Karasawa & Corradini, 2021), suggested that SA-HP systems have the most savings potential in locations where the heating loads are highest, while also having consistent solar irradiation availability during heating hours. To determine locations that have the highest potential for savings, heating degree days with base temperature of 65°F (HDD65) data was collected from ASHRAE (ASHRAE, 2021) for all 16 CZs. Figure 11 illustrates the HDD65 sorted from the highest to the lowest.

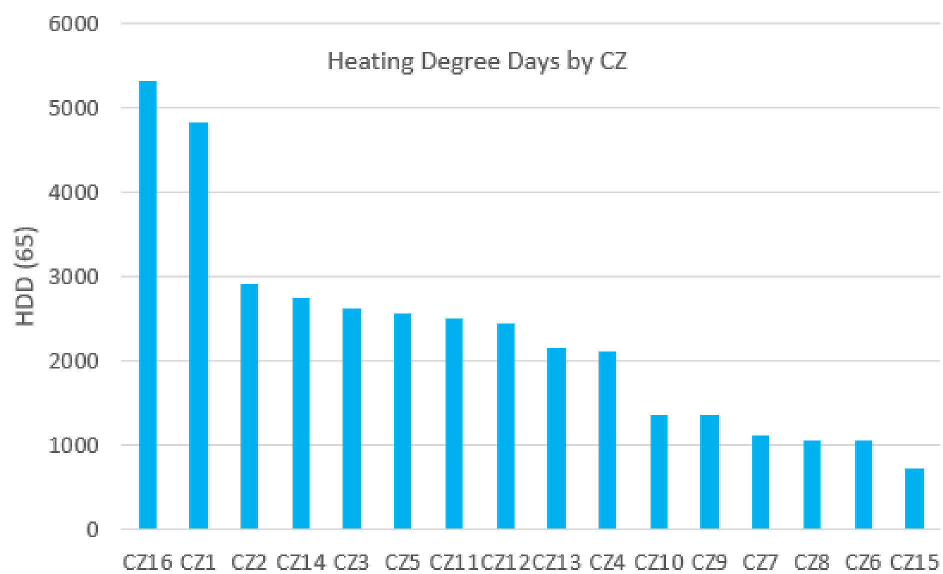


Figure 11: California CZ HDD65

Source: Project Team

From these data, the CZs were grouped into three. The first group consists of CZ1 and CZ16 and has the highest annual heating loads with over 4,000 HDD65. The second group has moderate annual heating loads with 2,000 to 3,000 HDD65. Those locations with the lowest annual heating loads have HDD65 values close to 1,000. Table 3 shows the HDD as groupings.

Table 3: CA CZ HDD Groupings

Group	CZ	HDD65 Range
1	CZ16, CZ1	>4,000
2	CZ2, CZ14, CZ3, CZ5, CZ11, CZ12, CZ13, CZ4	2,000-3,000
3	CZ10, CZ9, CZ7, CZ8, CZ6, CZ15	<1,400

Source: Project Team.

Solar irradiance, defined as a rate at which solar energy is received per unit area, were also obtained from ASHRAE (ASHRAE, 2021), and are plotted with the respective HDD(65) values for all CZs in Figure 12: California CZ HDD and IrradiationFigure 13 and Figure 13 below. The average annual solar irradiation value across all California CZs is 1,667 Btu/ft^2 with only a small variation. Figure 14 below shows the heating season HDD(65) plotted against heating season solar irradiation, and how the average annual solar irradiation compares with the heating season values. These figures indicate that focusing on the CZs with the highest average annual heating loads, represented by HDD(65), would show the general areas in CA with the most savings potential for SA-HP technologies.

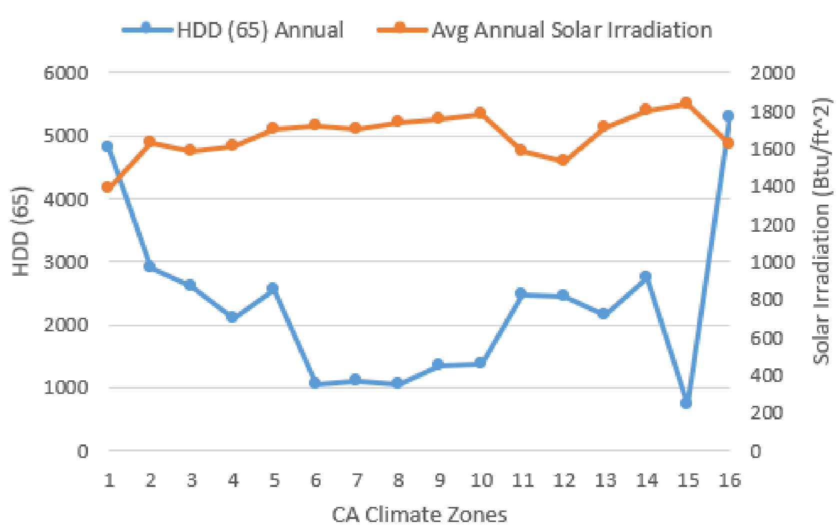


Figure 12: California CZ HDD and Irradiation

Source: Project Team.

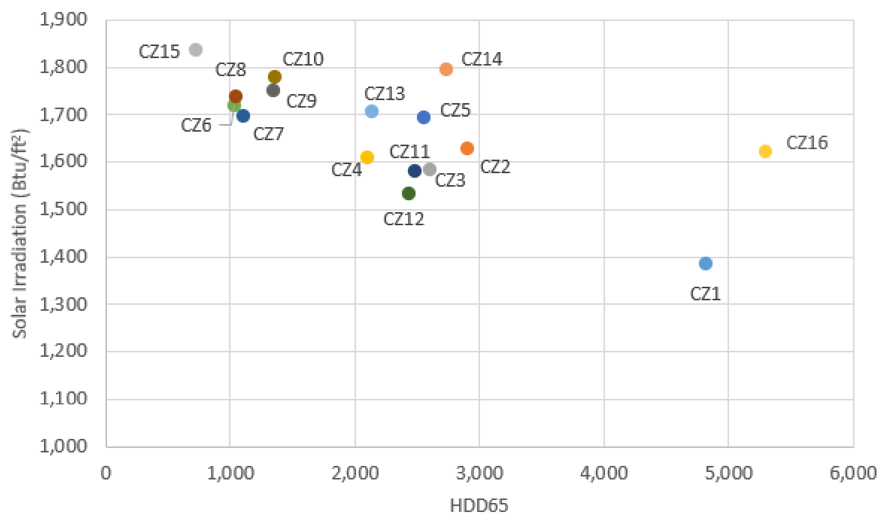


Figure 13: HDD65 vs Solar Irradiation

Source: Project Team.

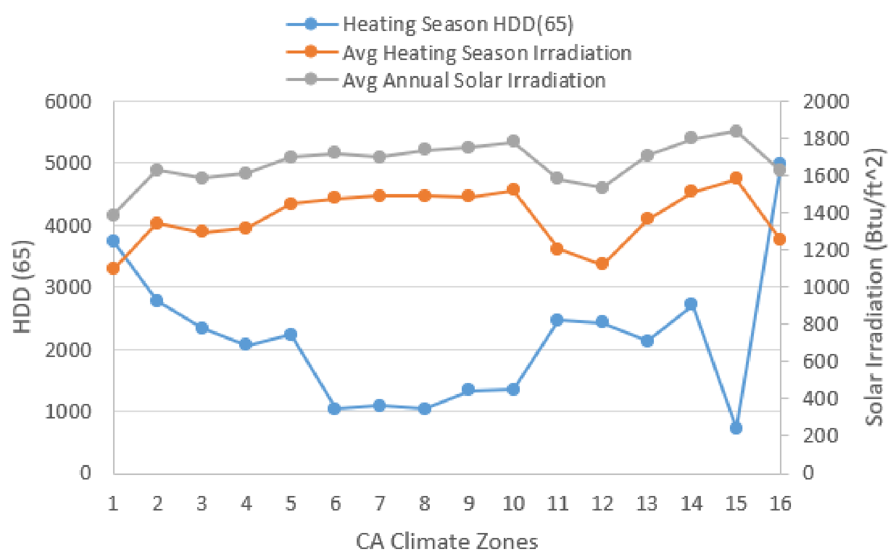


Figure 14: Heating Season HDD and Irradiation

Source: Project Team.

Referencing a map of CA and the respective CZs shown in Figure 15, the northern inland and northern coastal areas have the most heating loads. The rest of the state has moderate heating loads, except for the southern coastal and southmost regions of the state, which have the lowest heating loads. Moderate heating loads, except for the southern coastal and southmost regions of the state, which have the lowest heating loads. Note, Figure 15 is color-coded to help differentiate between the different climate zones. The colors are not indicative of climate-related data.

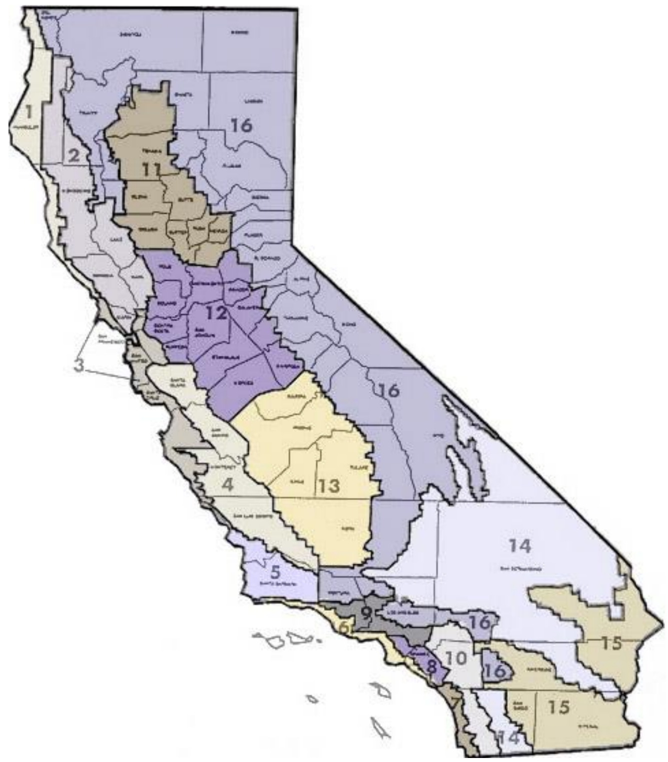


Figure 15 : CA Climate Zone Map

Source: Pacific Gas & Electric (PG&E).

In addition to the regions of CA that SA-HP would have the most potential savings, the size of the market should also be considered in pursuing next steps for the ET adoption. Since the SA-HP technology is added onto or replaces an existing HP, the market potential for the ET would be similar to where typical heat pumps have the highest potential. Due to recent warming trend, many businesses that did not previously have cooling will likely adopt either air-conditioning or HPs (Kenny, Janusch, Neumann, & Jaske, 2021). Although the space heating loads are lower as a percent of total energy use for commercial buildings when compared to either multifamily or residential (Kenny, Janusch, Neumann, & Jaske, 2021), HPs for space heating installations in commercial buildings will be part of the overall most cost-effective decarbonization strategies, along with HPs for water heating and electric vehicles (Fisher & Ziaja, 2018).

In residential HP applications, there is also significant opportunity for installations. A recent study (Tierra Resource Consultants, 2022) was commissioned by the California Public Utilities Commission (CPUC) to provide detail on the CA HP market characterization. Specifically, the study reported that almost half of homeowners in CA with natural gas or electric space heating as their primary heating source have units that are over 14 years old, indicating that a large proportion of homeowners will need to replace their heating systems in the next decade. With CA's ambitious goals for decarbonization to have 6,000,000 HPs installed by 2030 (California Energy Commission, 2022), statewide initiatives like Technology and Equipment for Clean Heating (TECH) Clean CA were designed and are underway to help with low-emissions space heating and water heating in single and multifamily homes for low-income customers and disadvantaged communities. If installed with the new HPs with variable-speed compressor, SA-HPs will complement the initiative well by making the HPs more efficient during the heating operations.

To our knowledge, the energy savings potential of SA-HP for a space heating-only installation has not been recorded in field studies. As previously noted, experimental studies of hybrid SA-HPs have demonstrated increases in COP of 60%-70% with optimal solar collector sizing and addition of PCM, respectively. (Liu, et al., 2022), (Ma, Ren, Lin, & Wang, 2017). The IX SA-HP systems have experimentally shown increased HP COPs ranging from 2.5 to 3.5, but the operation of auxiliary equipment such as pumps lowered the system COP by 20%. The resulting energy savings from these theoretical and experimental COP improvements will vary depending on the location and applications. If an installation utilized the TES technology as well, there could be an opportunity for demand savings during the evening hours. Additional benefit of technology was also documented for SA-HPs with TES, which were able to reduce the frequency of HP start-up and shutdown, increasing the life of equipment (Yang, et al., 2021).

Opportunities and Barriers

HP installations in both residential and commercial buildings are an integral part of the solution to reach decarbonization goals in California. Small commercial facilities, such as offices, retail, and warehouses would be good applications given these buildings typically have packaged and split AC/HP for space conditioning and make up the larger energy users for commercial buildings. Furthermore, the typical operating hours for small commercial facilities coincides with the periods of solar irradiation. The opportunity in residential HP applications also seems to be significant due to aging existing heating equipment for nearly half of the homeowners in the state. Additionally, the technology can be combined with water heating which can help accelerate decarbonization in both single family and multifamily sectors.

The locations in CA with best opportunity to see savings, for both commercial and residential, would be anywhere in the state except for the greater Los Angeles and San Diego areas, which have the lowest average annual heating loads. The climate zones with the lowest opportunity would be CZ 6, CZ7, CZ8, CZ9, CZ10, and CZ15.

The biggest barrier of this technology is commercial availability of SA-HPs. The primary research discovered a lack of products that can be retrofitted onto existing HP systems. One standard configuration and one alternative configuration was found, both being DX SA-HP types, each only compatible with a specific HP type: air-to-air and air-to-water HPs, respectively. Only one company was identified in the US with this specific technology, although the alternative configuration was available from a Canadian company which serves a large market in the northern Midwest. However, this alternative DX SA-HP configuration requires the addition of a solar thermal storage tank and is only compatible with air-to-water HPs. Furthermore, no examples of the ET being retrofit onto a commercial HP system could be found, although full heating system packages with solar collector additions are available commercially. The US-based company has been actively marketing their SA-HP retrofit product and indicated they will continue to do so.

The two biggest drawbacks of an SA-HP depend on the cost and the location of the installation. Switching from a gas heating system to a HP already costs a premium and the infancy of this technology leads it to be more expensive to implement. The location is equally important in terms of the feasibility of such a system. An SA-HP won't be as effective, if at all, in regions with lower levels of sunlight or a high variance in sunlight. Colder climates also reduce the feasibility as reducing the ambient temperature reduces the efficiency of a solar collector. With a greater temperature difference between the ambient air and the refrigerant in the system, the solar collector cannot offset as much load. There is also the practicality of an SA-HP to consider. If an existing HP is already a high efficiency unit, the marginal increase in system efficiency would be vastly outweighed by the incremental cost. Additionally, buildings with large enough PV systems may have little to no need for an additional load offset.

Additional barriers related to the solar collectors also exist. Contractor training regarding best practices for installations, including handling and installation location on the roof where the solar collector would receive the most sun. Availability of solar components and general roof condition and remaining life could cause a customer or contractor to prioritize other projects.

Barriers to the installation of SA-HP would be similar to barriers to standard HP installations. Contractor concerns related to installations are installations in extremely cold and snowy locations, required modifications to existing ductwork, fuel switching required electrical panel upgrades, suitability of HP installation location, and lack of insulation and air tightness. (Tierra Resource Consultants, 2022)

Recommendations

The SA-HP technology is still in the research and developing phase as only one has been commercialized in the U.S. In addition, SA-HP solely for space heating is not well studied. The two major limiting factors of SA-HP in space heating applications is mismatching of heating load and solar availability and low ambient air temperature, which decreases HP efficiency. Thus, in most studies, the SA-HP was examined for water heating only or the combination of water heating and space heating (multi-functional). In a couple of studies, multi-functional SA-HPs have shown promising savings potentials when the technology was combined with TES, which stored solar thermal energy to be used when solar radiation was not available (e.g., in the late afternoons and at night).

Although the SA-HP technology is still immature, it is worth evaluating as it can combine the electrification of both water heating and space heating. In advanced systems, the technology can also combine PV with increased panel efficiency. With the combination of TES, the technology may become the key to optimizing solar electric power, solar thermal energy, and HP operations. The following next steps are recommended when a commercial-ready product is available:

1. Identify a viable vendor.
2. Perform field tests on residential and commercial settings in climate zone 16 to measure savings in the real-world settings.

3. Evaluate the technology's cost effectiveness in advancing the State of California's decarbonization agenda.
4. Investigate an incentive mechanism to speed up the technology adoption.

If, on the other hand, no vendors exist to produce and install a commercial product, no further investigations are recommended at this time.

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