Commercial Air-to-Water Heat Pump Market Study

Final Report

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Executive Summary

A market evaluation study was conducted to assess the viability of electrifying heating hot water (HHW) systems in large commercial buildings, with the focus on air-to-water heat pumps (AWHP). Air - to-water heat pumps produce HHW that can be used for space heating applications such as HHW coils in air handling unit (AHU) or terminal variable air volume (VAV) boxes, radiant heating, fan coil units, etc. They can be used by themselves or in combination with other equipment such as water-to-water heat pumps or thermal energy storage to either increase their capacity or recover waste heat.

The objectives of this study were to identify commercial AWHP technologies that are currently available, perform a technology and market assessment to size the potential market in California, estimate energy and greenhouse gas (GHG) savings potentials, identify market barriers and opportunities, and provide recommendations for possible utility interventions to support market adoption.

Market sizing methodology involved primary research from the Commercial Buildings Energy Consumption Survey (CBECS) commercial building stock data and California Energy Commission (CEC) data. Based on data researched, it was estimated that 696 million therms (Mtherms) of natural gas was used for space heating alone in California in 2022. Using heating fuel distribution percentages, it was assumed that 7% of that was used to fuel boilers, providing an opportunity for 48.74 Mtherms to be eliminated from the market. A removal of 48.74 Mtherms from annual gas consumption equates to approximately 257,883 metric tons of CO_2 equivalent or the emissions of 0.65 natural gas fired power plants in one year.

Additionally, the statewide potential for emissions reductions when switching from a natural gas boiler to an AWHP system were evaluated using eQUEST for three large building types. Across the California climate zones, there was a potential to reduce GHG emissions up to 40%. Hospitals presented the most significant and consistent potential for GHG emissions reductions across all climate zones, with reduction values varying from 29% to 32%. Alternatively, office buildings had the largest variance with warmest climate zones showing potential for only an 18% reduction and up to 40% in climate zones with more heating loads.

Through research and manufacturer interviews, multiple market barriers were discussed. The largest barriers were identified as technology cost and its limitation to providing HHW water temperatures up to 140°F. Other barriers noted were lack of contractor training, decreased heat pump performance in cold climate zones, costs of electrical panel upgrades for fuel switching, and required modifications to existing structures.

Abbreviations and Acronyms

Acronym	Meaning
AHU	Air Handling Unit
AWHP	Air-to-Water Heat Pump
CARB	California Air Resources Board
CBE	Center for the Built Environment
CBECS	Commercial Buildings Energy Consumption Survey
CEC	California Energy Commission
CO_2	Carbon Dioxide
CO_2e	Carbon Dioxide Equivalent
COP	Coefficient of Performance
CUP	Central Utility Plant
DAC	Disadvantaged Community
EE	Energy Efficiency
ET	Emerging Technology
EUI	Energy Use Index
GHG	Greenhouse Gas
GWP	Global Warming Potential
HHW	Heating Hot Water
HP	Heat Pump
HTR	Hard-to-Reach
HVAC	Heating, Ventilation, and Air Conditioning
HWS	Hot Water Supply

Acronym	Meaning
IOU	Investor-Owned Utility
IRA	Inflation Reduction Act
kWh	Kilowatt-hour
MBTU	Million British Thermal Unit
OAT	Outdoor Air Temperature
PA	Program Administrator
PCM	Phase Change Material
PG&E	Pacific Gas and Electric
SCE	Southern California Edison
SCG	Southern California Gas Company
SDG&E	San Diego Gas & Electric
SSHP	Storage Source Heat Pump
TES	Thermal Energy Storage
TIER	Time-Independent Energy Recovery
TPM	Technology Priority Map
UC	University of California
VAV	Variable Air Volume
VRF	Variable Refrigerant Flow
WH	Water Heating
WWHP	Water-to-Water Heat Pumps

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Introduction

In large commercial buildings, the largest source of fossil fuel consumption on site typically comes from natural gas boilers or furnaces, which are used primarily for space heating. According to the 2018 Commercial Building Energy Consumption Survey, 30% of commercial building floor area or approximately 27 billion sq. ft. of floor space is heated with boilers in the U.S (EIA 2018). Electrification of these boilers and furnaces at even a fraction of the square footage would prove significant in terms of GHG emissions reduction.

Demand for electrified solutions for buildings of all sizes continues to increase as efforts to reduce GHG emissions are growing at federal and state levels. In California, an aggressive decarbonization target was set to cut GHG emissions by 40% below 1990 levels by 2030 and achieving carbon neutrality by 2045 (CARB 2022). To meet these targets, significant reduction in fossil fuel usage is required across the state, including natural gas used for space heating. The California Energy Commission (CEC) has set a goal of installing at least six million heat pumps by 2030 in residential and commercial buildings, which account for about 24 percent of GHG emissions in the state (CEC 2022).

While heat pump technologies have seen an uptick in the residential market, the technology adoption has not been as prevalent in the commercial market, especially in large commercial buildings. This is because electrification retrofit options for heating systems in large commercial buildings are still limited and not understood well unlike small to medium commercial buildings where electrification retrofit options like air-to-air heat pumps and variable refrigeration flow (VRF) systems are readily available. Thus, there is a need for identifying and evaluating electrification retrofit solutions for large commercial buildings to overcome its unique challenge of complex heating system designs.

This market study will explore options for decarbonizing large commercial buildings through electrifying existing heating systems. The study will primarily focus on opportunities and barriers for electrifying large boilers used for space heating with AWHPs. In addition, the study will assess if there is a sizable market for AWHPs in California by estimating energy and GHG savings for a few large building types.

Background

In the context of building systems, decarbonization is described as “activities that reduce greenhouse gas emissions such as reducing or removing fossil gas use in buildings or replacing fossil fuel generated electricity with renewable sources like solar or wind” (CEC 2021). In building systems, there are several strategies to achieve decarbonization outcomes, including end-use electrification, energy efficiency, grid modernization, refrigeration management (TRANE 2022) (CEC 2021).

The first strategy, energy efficiency, achieves decarbonization of building systems through reduction in energy consumption, both electricity and gas. Energy efficiency was historically motivated by cost savings resulting from the reduced energy usage. Today, however, energy efficiency goals are increasingly driven by carbon footprint reduction because a reduction in energy consumption directly correlates with GHG reduction.

Decarbonization is also achieved through grid modernization. Carbon-free renewable technologies such as solar and wind are increasingly replacing high-emission energy sources such as coal and oil. In turn, electricity is becoming cleaner and less emissions intensive (i.e., grid CO_2 emissions per unit of energy produced are decreasing). California's grid has improved significantly in recent years and more progress is expected to meet its goal to become 100% renewable and zero-carbon resources by 2045 (SB100).

As California's grid continues to decarbonize, electricity is becoming an ideal energy source for GHG emissions reductions. Thus, electrification of end-use equipment that uses fossil fuels as its energy source, such as natural gas boilers and furnaces, is another strategy for decarbonization. Electrification not only removes GHG emissions on site but can also achieve decarbonization through energy efficiency and grid modernization when these measures are combined.

Finally, refrigerant plays a substantial and significant role in decarbonization because the leaked refrigerant releases GHG directly into the atmosphere. Leaks of high global warming potential (GWP) refrigerants (e.g., R-134a, R-410A) are considerably damaging to the environment, even at very low volumes. Thus, the use of low-GWP refrigerants and minimizing leaks are an important part of decarbonization efforts (TRANE 2022).

Heat pump technology is an attractive solution because it decarbonizes buildings utilizing all strategies of decarbonization mentioned above. First, heat pumps provide an efficiency gain over electric resistance-based heating and traditional natural gas heating equipment. This gain in efficiency promotes reduction in GHG emissions. Second, many heat pumps, especially new heat pump products, use low-GWP refrigerants reducing GHG impacts. Finally, heat pumps reduce GHG emissions by removing on-site fossil fuel energy sources (i.e., natural gas) and switching them to electricity. With electricity as the energy source, passive emissions reduction can be achieved over time, as more renewable energy sources continue to come online, and the grid continues to decarbonize (TRANE 2022).

In large commercial buildings, where hydraulic heating systems are predominantly used, electrifying the heating systems requires going beyond traditional solutions such as electric resistance-based space heating. Heat pump technology, specifically AWHPs, may aid in bridging this gap. The hot water produced by the AWHP can be used in many hydraulic heating applications found in large commercial buildings such as radiant heating, fan coils, or hot water coils in AHUs and terminal VAV boxes. Additionally, AWHPs are more efficient than electric boilers and traditional natural gas boilers. These are only some of many aspects that make AWHPs attractive as an electrified heating solution for large buildings but there are also many barriers as the technology is still new to the market.

Objectives

The objectives of this market study are following:

- Identify electrification options for space heating in large commercial buildings.
- Perform a technology and market assessment to size the potential market in California.
- Identify all commercial and pre-commercial AWHP technologies and manufacturers that are currently available.
- Assess expected energy savings and cost effectiveness.
- Identify market barriers and opportunities for electrifying large commercial buildings.
- Recommend possible utility interventions to support market adoption.

Methodology and Approach

To achieve above objectives, the following methodologies and approaches were used:

- Review literature and case studies to identify electrification options for heating systems in existing large buildings.
- Leverage past market research and existing data to size the potential market and identify the highest benefit applications and locations in California.
- Conduct primary research through interviews to inventory existing AWHP technologies and products available in the commercial market space targeting large boiler system electrification. The information gathered included size, features, attributes, claimed benefits (kWh, kW, GHG, operational, maintenance, etc.), product costs, and market/installation barriers.
- Evaluate the feasibility of electrification options and estimate energy savings based on research and interview findings.
- Report on key findings, barriers, and next steps and strategies for utility intervention to advance adoption.

Technology Overview

Electrification Options for HHW System

One of the most prevalent HVAC systems installed in exiting large buildings is the multiple zone system with hot water reheat. In this system, hot water is typically distributed from natural gas boilers located in a central plant to individual zones. With currently available technology, there are few technology options available for electrifying these heating systems in large commercial buildings (Gill 2021). Table 1 summarizes the options available below.

Table 1: HHW System Electrification Options

Technology	Best Applications	Max HW Supply	Size (MBH[1])	COP	Limitations
Electric Resistance Heating	Baseboard heating, electric furnace, radiant heater	N/A	Up to 13.6	1.0	· Not suitable for large electrical load
Electric Boiler	Backup heating, high temperature applications	220°F	Up to 10,000	0.97	· Low efficiency · Large electrical load · May require electrical infrastructure upgrade
Air-to-Water Heat Pump	Distributed HW generation, in mild/warm climate	145°F	300 - 5,000	2.7 – 3.6 @ 44°F ambient	· Standard unit supplies HW at 130°F · Recommended design temp at 115-120°F with 10-15°F ΔT · Limited output capacity at low ambient temperature
Water-to-Water Heat Pump	Distributed HW generation, direct boiler replacement	170°F	400 - 40,000	3.0 – 4.0 @ 130°F HW	· Standard unit supplies HW at 130°F · Recommended design temp at 130-135°F with 20-25°F ΔT · Requires additional heat source · High first cost

Source: (CSU 2019)

Electric Resistance Heating

Electric resistance heating can replace hot water coils in terminal zone units, eliminating the need for a HHW distribution system and associated boilers. However, California Title 24 prohibits the installation of electric resistance reheat for both new construction and replacements with few exceptions (CEC 2022). Moreover, the efficiency of electric resistance heating is only slightly better than natural gas boilers whose efficiency typically ranges from 80% to 95%. While electric heating is

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[1] MBH = thousands of Btu per hour

a simple affordable option for small-scale heating system or supplemental heating, it is not scalable for larger heating loads. For larger applications, electrical infrastructure upgrades may also be required to support the additional demand (CSU 2019).

Electric Boiler

Electric boilers use electricity to produce hot water and can produce water temperatures up to 220°F. An electric boiler can replace an existing natural gas boiler directly, but they have relatively low efficiencies, similar to that of electric resistance heating. Replacing an existing gas boiler with an electric boiler will increase the energy cost significantly due to the high cost of electricity when compared to natural gas cost in California. Electrical infrastructure upgrades are likely required to support the added load, further increasing the cost. Therefore, electric boilers are best used for backup heating to meet peak demand or for applications where high hot water temperatures are required (CSU 2019).

Air-to-Water Heat Pump

Air-to-water heat pumps work by extracting heat from the ambient outdoor air and transferring it to a fluid medium, typically a water-glycol mixture, used for space heating. The process begins with the heat pump's evaporator coil absorbing thermal energy from the surrounding air, causing a refrigerant inside the coil to evaporate. This low temperature, low pressure vapor is then sent to the compressor which raises the temperature and pressure. The hot high-pressure refrigerant is then passed through a condenser coil located in the indoor heating system or in a hot water tank where heat is exchanged to the water. This hot water can then be used for various space heating applications such as radiant floor heating, sent to individual fan coil units, etc. Once the heat is transferred, the refrigerant condenses back into a liquid. Standard AWHPs produce hot water up to 130°F. Some AWHPs can produce water temperatures up to 145°F but that comes with a cost premium. The AWHPs typically have a COP of 3 making them approximately three times or more efficient than natural gas boilers. Because heat pumps use electricity instead of natural gas, they are ideal candidates for decarbonization. While the installation of an AWHP may also require electrical upgrades like that of an electric boiler, the increase in efficiency and energy savings over time will net a much quicker payback.

Air-to-water heat pumps can be configured to provide hot water (heating) only or hot water and chilled water (heating and cooling) simultaneously. In addition, the AWHPs can be configured to recover heat either partially or fully from cooling processes. The sections below briefly describe each configuration.

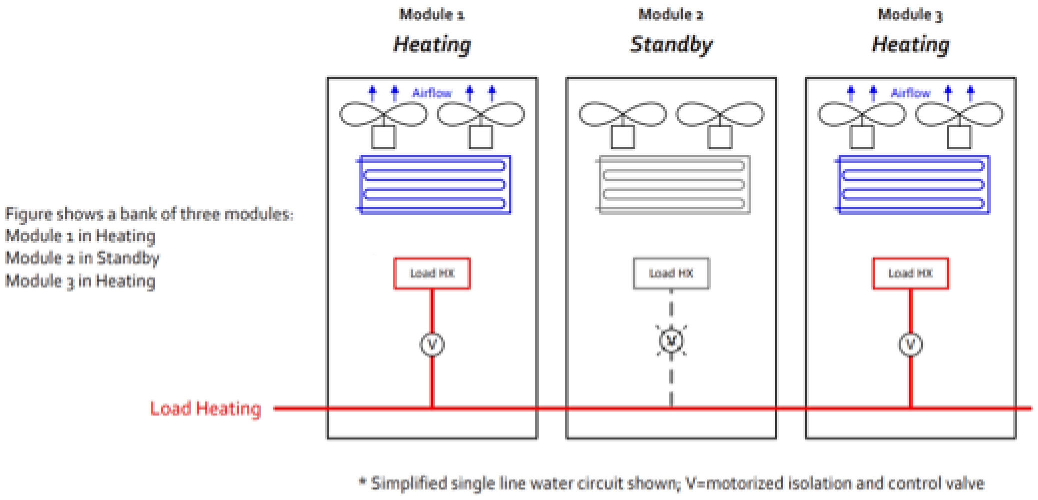
HEATING ONLY (TWO-PIPE SYSTEM)

A two-pipe system is an HVAC configuration that is widely used for heating and cooling. The system employs a singular set of pipes for both heating and cooling. It can only cool or heat at a given time and switching between modes is done by using a reversing valve.

Air-to-water heat pumps in two-pipe configuration provide hot water (heating) only and the reversing valve is solely used during the defrost cycle. The best applications for heating only AWHPs are the following (CSU 2019):

- Replacing boilers in a HHW distribution system
- Systems with little to no cooling/chilled water demand

- Systems with limited heat recovery potential



* Simplified single line water circuit shown; V=motorized isolation and control valve

Figure 1: Heating Only AWHPs

Source: (CSU 2019)

SIMULTANEOUS HEATING AND COOLING (FOUR-PIPE SYSTEM)

A four-pipe system is an HVAC configuration that features two separate sets of pipes and coils: One for heating and one for cooling. The configuration enables simultaneous heating and cooling in different zones of a building for precise temperature controls, in addition to cooling-only and heating-only modes. A four-pipe unit has three main heat exchangers: a condenser that heats water for space heating, an evaporator that cools water for space cooling, and a balancing air coil. The balancing coil works as either a condenser in cooling mode or an evaporator in heating mode to balance the difference between heating and cooling demands.

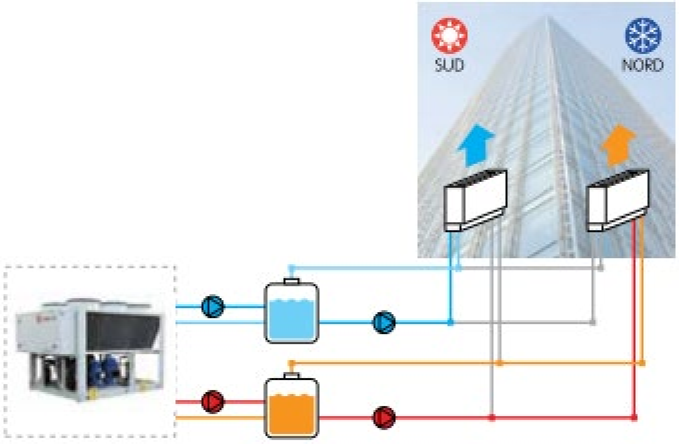


Figure 2: Simultaneous Heating and Cooling of a Four-Pipe System

Source: (TRANE 2022)

The piping diagram below illustrates how simultaneous heating and cooling can occur in a four–pipe system with two AWHP modules. With this configuration, either heat pump can serve heating or cooling load at any time.

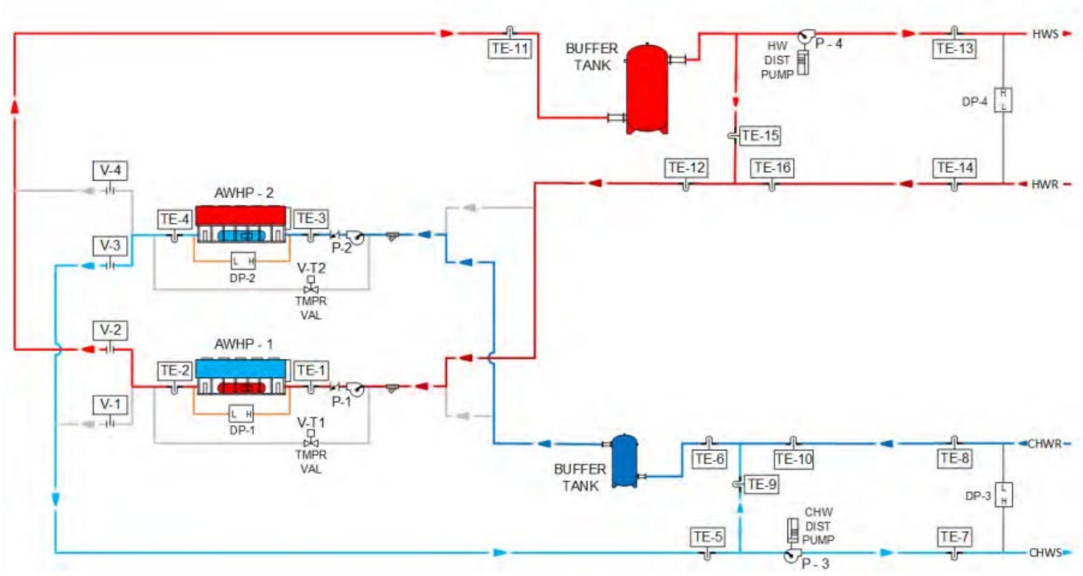


Figure 3: Four-Pipe Distribution, Dual-Feed Chiller-Heater System[2]

Source: (TRANE 2022)

HEAT RECOVERY

A heat recovery system can utilize waste heat from cooling processes that would otherwise be wasted in other parts of the building, making it an effective way to electrify heating systems in large commercial buildings. A four-pipe AWHP can simultaneously produce chilled and hot water via heat recovery when there is concurrent cooling and heating demand. The heat recovery AWHPs have the highest efficiency because it can satisfy both cooling and heating load with one power input (CSU 2019). There are two types of heat recovery units:

- **Partial Heat Recovery:** An application where only the heat of compression is recovered. In practice, this is achieved by the addition of a “desuperheater”, an intermediate heat exchanger, between the compressor and condenser in the refrigeration cycle. The heat captured is limited by the desired hot water temperature and frequency/length of cooling loads.
- **Full Heat Recovery:** A system with the main function of providing cooling where all the rejected heat from the condenser is used to satisfy heating loads. This system utilizes a heat exchanger in parallel with the system rather than in series like a partial recovery system. Heat energy can then be used for hot water or building heating.

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[2] TRANE refers to this system as a chiller-heater system, which has the flexibility to accommodate a mix of chillers and heat pumps in a common production system.

The heat recovery AWHP system may be implemented as a replacement for a boiler/chiller system used in a building and can offer great energy savings if a building has simultaneous heating and cooling demands. However, these systems are more complex and costly to implement than a traditional boiler/chiller system and requires detailed load analysis to make sure there is adequate simultaneous heating and cooling. Thus, a full energy and economic analysis is needed to quantify the cost and benefits of installing the system prior to design and implementation.

Water-to-Water Heat Pump

Water-to-water heat pumps (WWHPs) extract heat from water and move it to another fluid medium, typically a water-glycol mixture in a hydronic distribution system to be used for heating. Typical WWHPs produce hot water at 130°F but premium products can produce hot water temperatures up to 170°F. They are more efficient than AWHPs with a COP range between 3.0 and 4.0 because water can transfer heat better than air, but they require an additional heat source. Additionally, WWHPs' performance is more stable than AWHPs because the source (water) temperature is kept relatively constant and does not fluctuate as much as ambient air temperature (CSU 2019). The WWHP most commonly uses condenser water from chillers as a heat source. It converts waste heat to usable heat by recovering heat from condenser water that is otherwise rejected to the atmosphere by cooling towers.

Like AWHPs, WWHPs can be configured to provide heating only (two-pipe) or heating and cooling simultaneously (four-pipe). Partial or full heat recovery is also viable with WWHPs. The following sections describe WWHP systems in four-pipe and six-pipe heat recovery configurations.

FOUR-PIPE HEAT RECOVERY SYSTEM

A heat recovery WWHP can recover heat generated from cooling processes that would otherwise be rejected out to the atmosphere by cooling towers. As shown in Figure 4, a WWHP connects to both the chilled water and hot water loop in a four-pipe heat recovery configuration. While producing chilled water in the chilled water loop, the heat from the condenser side is captured in the hot water loop. Because WWHPs operate similarly to conventional chillers, WWHPs with heat recovery capability are often referred to as heat recovery or heat reclaim chillers (CSU 2019). Heat recovery WWHPs are different from chillers in that they are designed to generate high-pressure refrigerant to produce higher temperature refrigerant at the condenser (Carrier 2022).

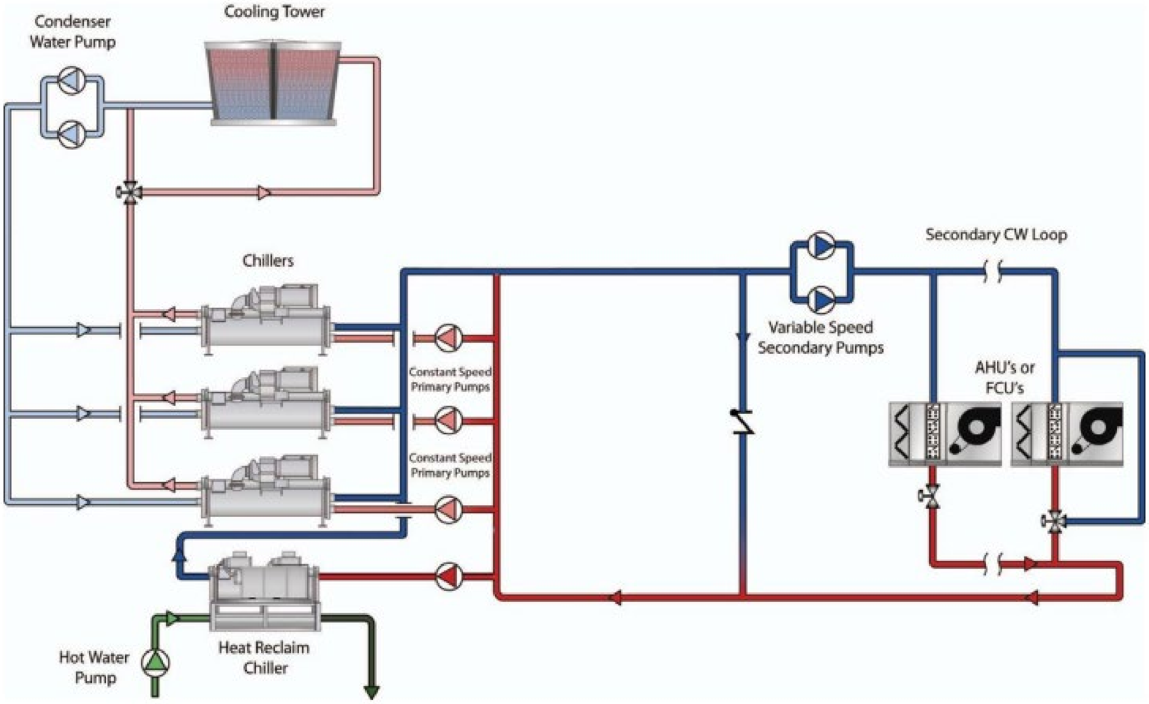


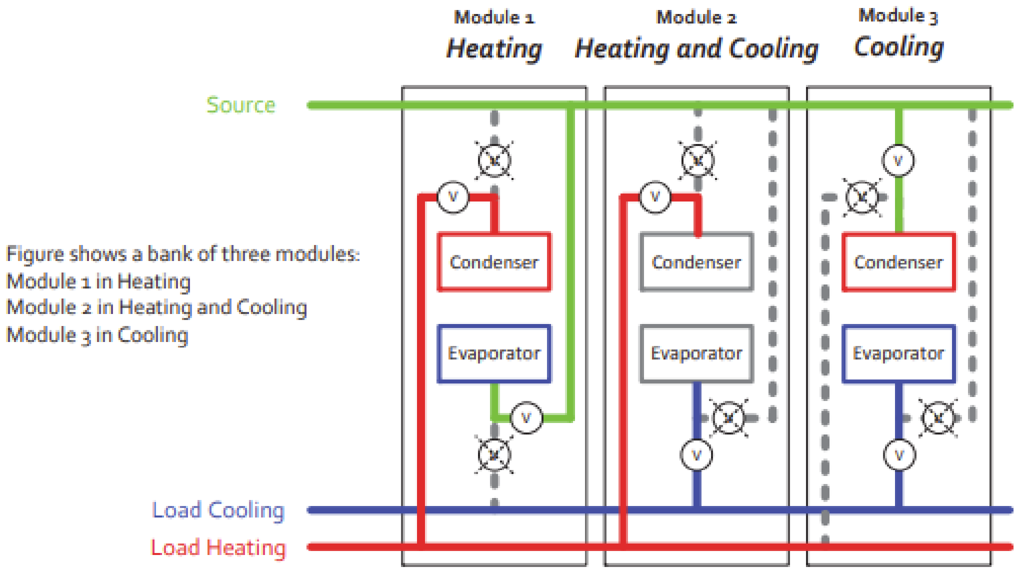
Figure 4: Primary/Secondary Chilled Water System with Heat Recovery Chiller

Source: (Carrier 2022)

Simultaneous cooling and heating is required for heat recovery as it does for AWHPs. In four-pipe configuration, the WWHP can recover 80-90% of cooling capacity when it is providing both cooling and heating (CSU 2019). In cooling-only mode, the heat recovery WWHP operates less efficiently than traditional chillers because it operates with higher lift and therefore requires more compressor power to reach the higher temperature at the condenser. Thus, the four-pipe configuration should only be considered in cases where there is significant simultaneous cooling and heating load.

SIX-PIPE HEAT RECOVERY SYSTEM

To remedy the energy penalty incurred by the heat recovery WWHP in cooling-only mode, the WWHP can be installed in six-pipe configuration. In this configuration, the WWHP is piped to the condenser water loop in addition to the chilled water and hot water loop. When only cooling is required, the condenser water from the heat recovery WWHP is routed to the cooling tower via the condenser water loop so that heat is rejected to the air. This allows the WWHP to operate at a lower condenser water temperature, reducing the compressor lift and increasing capacity. While there are energy benefits to the six-pipe configuration, it is more expensive than the four-pipe configuration requiring more piping and an additional heat rejection device such as a cooling tower.



*Simplified single line water circuit shown; V=motorized isolation and control valve

Figure 5: Six-Pipe System for WWHP with Heat Recovery

Source: (Climacool 2015)

AWHP Design Limitations

Within the large commercial building sector, the electrification of heating systems is still in its infancy. While AWHPs are more efficient than traditional heating equipment such as boilers and furnaces, they do have different constraints and require thoughtful design and implementation to properly match the heating needs of various commercial buildings. In the subsequent sections, the limitations to electrifying existing HHW systems with AWHPs are discussed.

HHW Supply Temperature

The typical HHW design supply temperature is 180°F for HHW systems utilizing a boiler as a heat source (CBE 2022). However, AWHPs are generally limited to design supply temperatures between 120°F and 130°F. Because of this limitation, it is generally accepted that current AWHP technology cannot meet or match the design supply temperature of existing HHW systems. To meet the same heating load with a lower HHW supply temperature, heating coils need to be resized and/or hot water flow must be increased, in some cases significantly. Reducing HHW temperature also poses challenges in existing buildings as it may impact system pipe sizing. Resizing pipework could be a barrier for adoption as it would result in increased first costs for retrofitting.

Capacity

Since the heat output of an AWHP is limited to 5,000 MBTU with current technology, AWHPs are generally not a viable one-for-one replacement option for natural gas boilers in large commercial buildings. Additionally, at least two AWHPs are needed per system as they require redundancy to ensure uninterrupted operations (CBE 2022).

Due to the limited heat output of an individual AWHP, the installation often involves multiple heat pumps in series and a buffer tank or thermal energy storage (TES). Thus, AWHPs typically take up more space than existing boilers. The available space both on the roof and in utility rooms can be an obstacle for AWHP installations in existing buildings although right sizing equipment, implementing energy efficiency measures, and optimizing space may help reduce the footprint.

Specifying right-sized equipment may also pose challenges. It is a common practice to simply replace the boiler that has reached the end of life with equipment with the same capacity without any consideration to changes in building occupancy or building upgrades. However, HHW boilers are often oversized in existing buildings (CBE 2022). There are many factors for this tendency of oversizing, such as design standards used when the boiler was installed, lack of building load data, and generous safety factors.

Another potential obstacle for upgrading boilers with AWHPs is that more electrical capacity is likely necessary to serve the needs of an all-electric system. If existing capacity does not allow for the retrofit, an incremental approach where partial electrification is implemented (e.g., AWHP with gas furnace for peak heating loads in winter) or long-term planning to perform electrical upgrades when equipment is at the end of life may be required.

Performance

The performance of AWHP depends greatly on the outdoor air temperature (OAT) and design HHW temperature. Figure 6below shows that the AWHP efficiency declines with OAT, especially below 40°F. Heat pumps are typically designed to operate at OAT above 40°F, unless specifically designed for cold climates. Minimizing the design HHW temperature is also important to optimize the equipment efficiency. For instance, at 50°F OAT, the efficiency of a unit delivering 105°F HHW is approximately 30% more efficient than the same unit when delivering 135°F HHW.

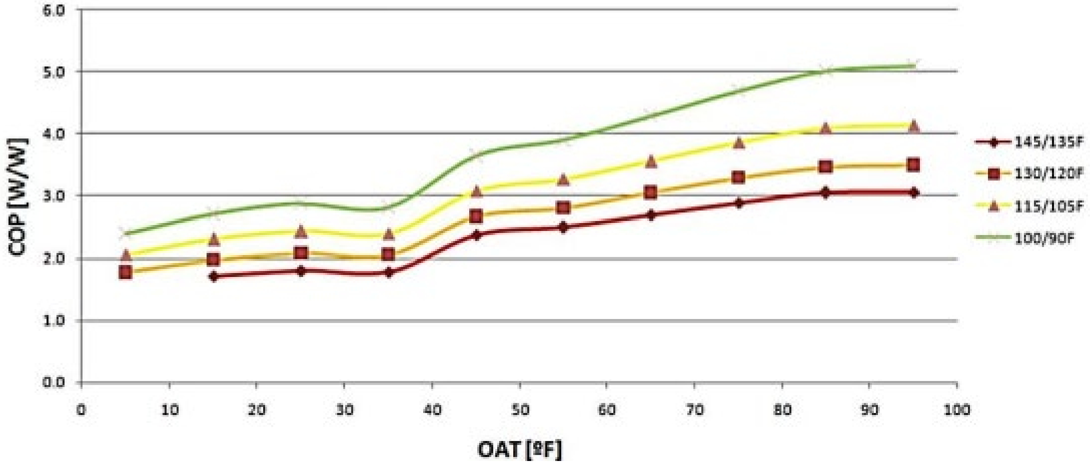


Figure 6: AWHP Performance with Respect to Outdoor Air Temperature and Design HHW Temperatures

The AWHP performance also varies with its operational profile. In general, heat pumps perform the best with constant load. The performance deteriorates significantly with frequent cycling and therefore it is best used as a base-load unit or for buildings with relatively constant heating load.

AWHP Design Opportunities

Although a one-for-one retrofit of a HHW boiler is not feasible with current AWHP technology, various alternative systems that incorporate AWHP technology have been introduced to leverage the heat pump's efficiency benefits. Some of the technologies and components that can complement AWHPs include, but are not limited to, condensing boilers, electric boilers, TES systems, and heat recovery chillers (CBE 2022). A successful combination of technologies and components alongside AWHPs presents opportunities for electrification in large buildings.

Partial Electrification

Pairing AWHPs with existing or complimentary technologies such as natural gas boilers allows building owners and operators to begin taking partial but critical steps towards electrification and decarbonization. In cases where a full electrification project is not possible, retaining existing boiler equipment while still installing an AWHP can achieve partial electrification outcomes with significant carbon savings. For example, base load heat pumps can be designed to meet approximately 30% of peak building heating demand and the rest can be covered by natural gas boilers on cold days. It is estimated that the base load heat pumps alone can cover 60% of annual heating hours, resulting in a significant reduction in carbon emissions (CBE 2022). It is generally agreed that even partial electrification is still a critical step for electrifying existing buildings, and that it is an option that should be strongly considered in retrofit and upgrade discussions (CBE 2022).

Heat Recovery WWHP

Air-to water heat pumps can be combined with heat recovery WWHP(s) to take advantage of waste heat from cooling processes. The biggest driving characteristic for successful application of this is simultaneous heating and cooling. Stanford University investigated this opportunity in 2008 when their existing cogeneration plant was approaching its end-life in 2015. By analyzing the campus-wide annual heating and cooling loads, they were able to identify a significant heating and cooling overlap throughout the entire year. Today, they boast an impressive central plant system driven substantially by heat pump technology (J. C. Stagner 2016).

Thermal Energy Storage (TES)

Air-to-water heat pumps can also be combined with thermal energy storage (TES) to store energy to be used later. By adding TES systems alongside AWHPs, energy can be stored in thermal storage during off-peak hours, increasing overall effectiveness. A TES system allows a HP system, even an undersized HP system, to accumulate hot water for peak load when they occur. Hot water storage also allows HPs to operate during daytime hours when the grid is typically supplied by more renewable energy sources, decreasing associated carbon emissions. Moreover, AWHPs operate at higher efficiency when the OAT is warmer (CBE 2022). Thermal energy storage is not limited to hot water or chilled water. A successful TES system for HP applications can also be consist of condenser water storage, ice storage, or phase-change material (PCM) storage (Gill 2021).

The Storage-Source Heat Pump (SSHP) system from Trane is an example of how a combination of AWHPs, WWHPs (named as chiller heaters), and TES tanks can overcome some of the typical limitations of AWHPs such as reduced capacity and inability to produce hot water in cold climates. At its core, the SSHP is a four-pipe system that can provide simultaneous heating and cooling, with the addition of TES storage. The SSHP system's TES tanks store excess energy to be used later for cooling or heating, depending on the operating conditions. Figure 7 shows a diagram of the system implemented in a multi-use commercial building. At the top of the building are the AWHPs, on the bottom left are the chiller-heaters, and to the bottom right are the TES tanks.

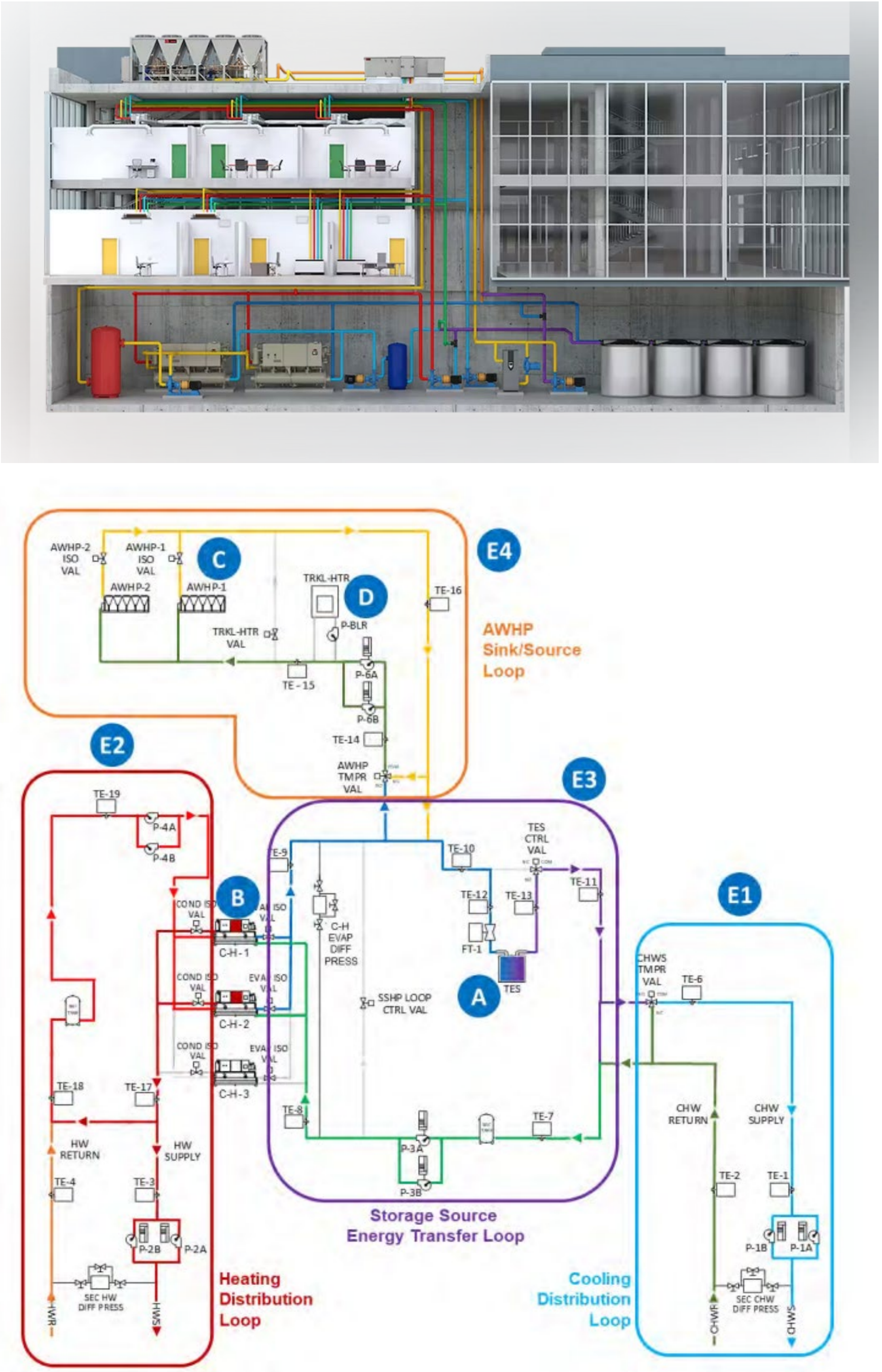


Figure 7: Storage-Source Heat Pump (SSHP) System with TES

Source: (TRANE 2022) (TRANE 2023)

This technology is relatively new to the market. However, the benefits to implementing TES with AWHPs are significant as this can overcome some of the AWHP limitations and increase energy savings for buildings that have simultaneous heating and cooling loads.

HHW Supply Temperature

A common misconception about lowering HHW temperature is that it is perceived to increase the risk of leaks in pipework and that seals at couplings can become brittle and fail because of additional expansion or contraction in the system due to temperature changes. However, the leaks are typically caused by HHW temperatures falling close to ambient temperatures (e.g., <100°F) during key events such as system maintenance, equipment failure, or power outage, not from lowering the HHW supply temperature. While some boiler plants operate 24/7 with the intention of reducing the risk of system leaks, this incurs a large energy penalty and delays the eventuality of a system needing downtime.

Instead of waiting for the unexpected, a HHW reset strategy could be adopted to test run the system with a lower HHW temperature and check for leaks in a controlled environment. If leaks are discovered, fixing them will offer very quick paybacks to building operators. Energy savings generated from the HHW reset could even be used to replace the faulty fittings. Performing regular pipe maintenance combined with other load reducing measures can be implemented prior to the installation of a heat pump and can be part of a long-term facility electrification plan. Moreover, incrementally reducing the HHW supply temperature not only prepares the building for future electrification, but also allow building operators to gain valuable insight into which zones may require additional heating capacity, which may be accommodated in the form of larger reheat coils in terminal boxes or a small, localized HP (e.g., wall-mounted split unit), reducing the capacity required by the AWHP.

Heating hot water systems operating at a lower HHW supply temperature also has its advantages. By lowering HHW temperature, distribution losses in the HHW system are reduced as they are directly proportional to the HHW temperature. The reduction in distribution losses can be significant as one study estimated that distribution losses account for 44% of heat output of a boiler (Raftery, Geronazzo, et al. 2018).

Contrary to the popular belief, recent studies have also shown that HHW systems could operate at supply temperatures below 180°F, and with relatively small delta T. For example, a HHW system at the Cal State Long Beach campus operates with a HHW supply of 165°F using non-condensing boilers, even though the system was originally designed for a 180°F supply. The system currently operates with a return temperature of 150°F, a delta T of 15°F (Glumac 2018). The possibility of operating a HHW system with a lower HHW temperature in existing buildings was also discussed in a 2022 study conducted by the Center for the Built Environment (CBE). In this study, 17 HVAC design engineers were interviewed to explore opportunities and limitations of electrifying central natural gas-fired boilers used for space heating in existing large commercial buildings. Many engineers interviewed believed that most buildings in mild climates, such as those found in the San Francisco Bay Area (and more generally across California), can meet their heating needs at HHW system temperatures below 180°F without any modifications to their existing system. (CBE 2022).

Energy Savings

As discussed previously, the pipe leak is such a big concern that it is common for boiler plants to operate 24/7, even if 24/7 operation is not required. Plants that currently operate 24/7 are good candidates for electrification with AWHPs because energy savings can be significant just from deploying an operating schedule and reset strategy. These savings can be used to offset the costs of new fittings and couplings, increased pump, and flow rates, and/or any re-piping that might be required with electrification (CBE 2022).

Case Study

Stanford's central plant is a great example to help illustrate how heat pump technology, and by extension, AWHP technology, can fit into alternative HHW systems. Despite AWHP technology not being mature enough to allow for a one-for-one boiler replacement, this case study demonstrates that heat pumps are a key component of electrification.

Stanford's central plant is supported largely by heat pump technology, but not completely. Due to limited heat capacity of heat pump technology, Stanford's central plant design included three natural gas-fired hot water generators alongside heat pumps. The generators are the only non-electric piece of equipment in the plant and used to boost HHW output for peak days, while the heat pumps handled the base heating loads for most of the year (J. Stagner 2016). Stanford states that the hot water generators are only used in a part-time manner, from November through February, and serve less than 10% of annual system heating load. The remaining 90% of annual system heat is handled by the plant's heat pumps.

Although simultaneous heating and cooling is a critical ingredient for successful heat pump implementation, rarely, if ever, is a large commercial building (or campus) perfectly energy balanced in terms of heating load and cooling load. Even more rarely is there a balance with respect to heating and cooling demand timing. To bridge this gap, it is necessary to consider a TES system when deploying a heat pump system. Stanford did this with both a cold-water (chilled water) TES tank (two tanks totaling 9.5M gallons; 90,000 Ton-Hr) and a hot water TES tank (one tank totaling 2.3M gallons; 600 MMBTU). Both tanks work in concert to allow Stanford to store excess cooling or heating and dispatch it in an efficient and time-independent fashion. Similarly, the tanks allow for TES charging when solar is overproducing, or when electricity rates are at their lowest (J. C. Stagner 2016).

Title 24 Code Requirements

In 2022, Title 24 mandated heat pumps for all single-zone systems under 20 tons across many building types in most of the state. Offices, financial institutions, retail, groceries, and schools within this cooling capacity are required to have all-electric heat pumps, with exceptions of buildings within climate zones (CZ) 2 and 16, which are allowed to have dual-fuel heat pumps. While California Title 24 has some other requirements for heat pumps, there are no specific requirements related to AWHPs used for space heating (ICC 2022).

There is also a set of requirements for HHW systems in Title 24. In most CZs (all excluding CZ7 and CZ15), there are strict design requirements regarding boiler efficiency of 90% or more, design return water temperature of 120°F, and minimum design flow rate that is less than 20% of the maximum design flow. The goal is to minimize natural gas consumption as much as possible by requiring the most efficient boilers possible (i.e., condensing boilers) in large new construction buildings. While these two pieces of legislation do not directly focus on large commercial buildings or AWHPs, it is very likely that similar requirements will appear in the next few years as technology continues to evolve and more systems are implemented across the California building stock. In fact, to prepare buildings for future electrification, the HHW supply design temperature limit of 130°F is being proposed for new construction buildings and additions and alternations in the Title 24 code change for the 2025 cycle (Boyce, et al. 2023).

It should also be noted that Title 24 largely prohibits the use of electric resistance heating for space heating applications with some exemptions. For instance, electric resistance heating is allowed if it is used as a supplement to a heat pump that supplies at least 75% of the design load or if 60% of heating system energy is provided by onsite solar or recovered energy.

Market Sizing

To gauge the potential energy savings of electrifying large commercial buildings, it is necessary to understand the current natural gas usage in California and what portion of that energy is being used for space heating in buildings. In 2022, commercial buildings in PG&E, SDG&E, and SCG territories consumed 1,913 Mtherms of natural gas (CEC 2022). From data captured in the 2006 California Commercial End-Use Survey, it is estimated that 36.4% of natural gas usage in California commercial buildings is dedicated to space heating, 31.8% for water heating and 31.8% to all other uses.

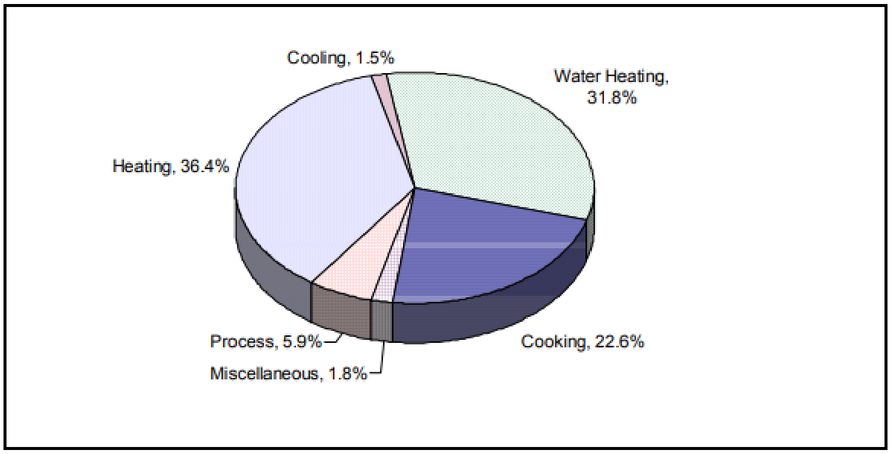


Figure 8: Natural Gas by End Use by Commercial Building in California

Source: (Itron 2006)

Using the above percentages of natural gas end use and the recorded natural gas utility data, it can be estimated that 696 Mtherms of natural gas was used for space heating alone in California in 2022. Assuming 7% of this was used to fuel boilers, there is an opportunity for 48.74 Mtherms to be eliminated from the market. This equates to boilers using approximately 19.2% of natural gas used for space heating in surveyed commercial buildings in California. A removal of 48.74 Mtherms from annual gas consumption equates to approximately 257,883 metric tons of CO_2 equivalent or to the emissions of 0.648 natural gas power plants fired in one year (EPA GHG Calculator, 2023).

It is important to note that the amount of electrically heated buildings is equal to or exceeds gas heated buildings in Southern California. Figure 9 illustrates that most customers in this part of the state, particularly those served by SDG&E, primarily use heat pumps for space heating or have no heating at all. This data also shows that only 7% of natural gas space heating in the commercial market is fueled by boilers in California and most of this use comes from the PG&E service area. (Itron 2014). This means the market potential for heating decarbonization in Southern California is smaller than the rest of the state. However, electrification in warmer climates is still important, especially once equipment reaches its end of useful life.

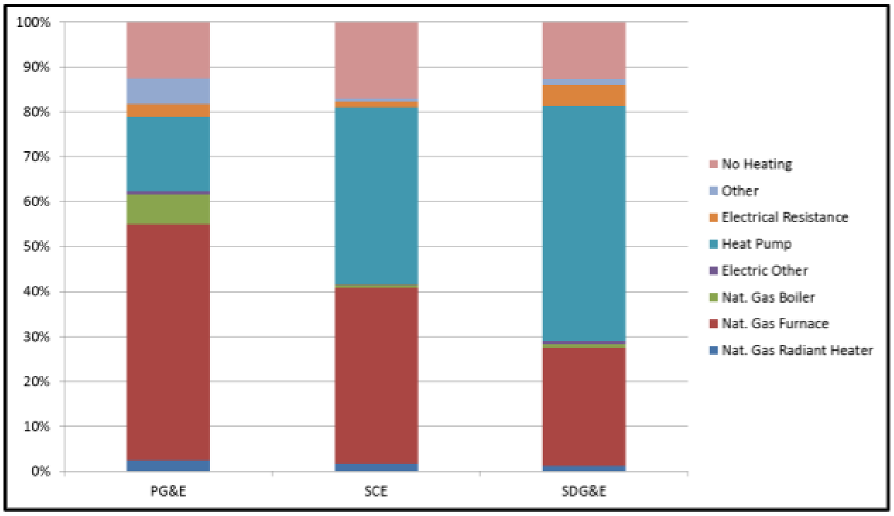


Figure 9: Heating Fuel Distribution by Utility

Source: (Itron 2014)

California is the nation's second largest consumer of natural gas. Several interstate natural gas pipelines enter California from Arizona, Nevada, and Oregon and bring natural gas into California from the Southwest, the Rocky Mountain region, and western Canada. Since approximately 45% of natural gas consumed by California is used for generation, it's also important to consider the impact that this increased electric load would have on the existing energy generation infrastructure of the state.

Energy Savings Estimate

To approximate the energy savings potential for replacing natural gas boiler(s) in a large commercial building with AWHP(s), an energy model was created in eQUEST. Three different building types were selected for the estimate: a hospital, a university, and a mid-rise office building. The prototypical building model was used for each building type to estimate boiler energy usage across all 16 CZs in

California. The results from the energy simulations were used to estimate GHG emissions for the baseline. Table 2 illustrates key assumptions used in the energy models.

Table 2: Key Model Assumptions

Building Type	Hospital	University	Office
Facility Size	250,000 ft^2	250,000 ft^2	150,000 ft^2
Operating Hours	24/7	M-F 8am-8pm (Breaks in spring, summer, and winter)	M-F 8am-5pm
HVAC type	Dual Duct VAV	Single Duct VAV with Hot Water Reheat	Single Duct VAV with Hot Water Reheat
Annual HVAC Operating Hours	8,760	2,660	2,860
Boiler Type	Natural Draft Boiler (Natural Gas)	Natural Draft Boiler (Natural Gas)	Natural Draft Boiler (Natural Gas)
Boiler Efficiency	80%	80%	80%
HHW Design Temperature	180°F	180°F	180°F

Source: Project team

Next, the boiler type was revised to a condensing boiler with a 91.5% efficiency for each model to roughly estimate the energy consumption (in Btu/hr) of a HHW system with AWHPs. The condensing boiler was selected because the system typically runs with a HHW design temperature of 140°F, the closest to the design temperature of AWHPs (which is typically 130°F). After the simulations were completed, the resulting heating energy was converted with the COP of 2.9, the average of AWHP efficiency values collected from interviewed manufacturers, to estimate the heating usage.

The results of simulations are shown in the figures below. It was found that with a COP of 2.9, the replacement of a natural gas boiler with an AWHP could yield GHG emissions savings of 20% to 40%, depending on the CZ. Note that the assumed COP could be higher or lower depending on the technology used, system configuration, etc. and therefore the actual GHG savings would vary. The detailed simulation results can be referenced in Appendix B.

For the hospital model, the overall heating energy usage was higher than other building types because it had higher outside air intake and operated 24/7. In addition, the hospital saw the smallest deviations in GHG emissions savings across all climate zones. Its higher heating energy consumption and the 24/7 load profile could potentially see benefits from more complex hybrid AWHP systems with thermal storage and heat recovery since simultaneous heating and cooling is often occurring. Figure 10 shows the emission reduction between a natural gas boiler baseline and AWHP. Overall, the GHG emission savings for the hospital was greatest among the three building types modeled because it consumes a lot of energy for heating and would see the greatest benefit from AWHP systems.

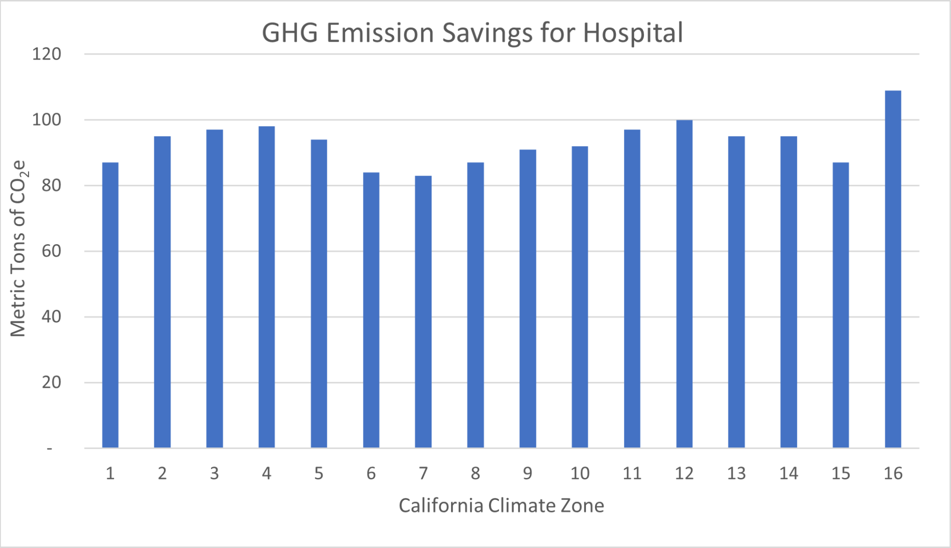


Figure 10: CO_2e Savings by CZ for Hospital Model

College and office buildings presented a range of heating energy consumptions by CZs and therefore also saw variations in GHG emission savings. With both college and office models, the savings were greatest in CZ16 followed by CZ1 and CZ2, as shown in Figure 11 and Figure 12. These areas have the largest potential for electrification and are all served by PG&E for their gas service. Alternatively, CZ6 though CZ10 saw little savings because the heating requirements in these mild climate zones are minimal. These CZs encompass regions along the southern coast, including greater Los Angeles and San Diego, served mostly by SCG and SDG&E. This aligns with the small utility gas usage for space heating shown earlier in Figure 9.

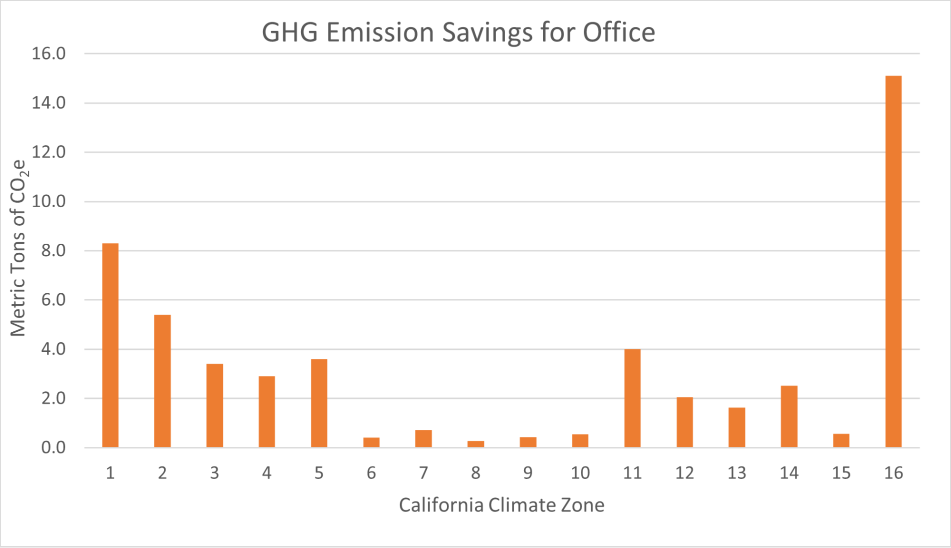


Figure 11: CO_2e Savings by Climate Zone for Office Model

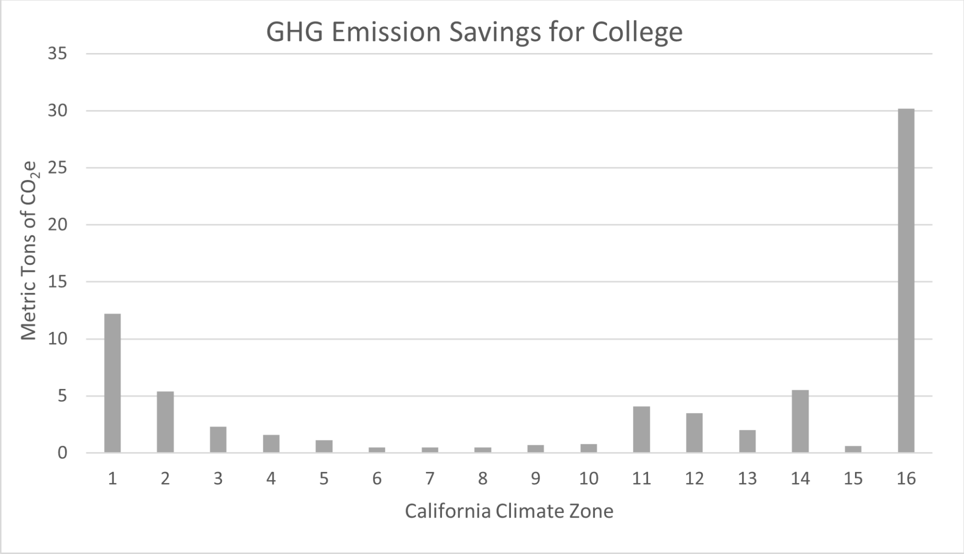


Figure 12: CO_2e Savings by Climate Zone for College Model

Additionally, the total number of hours when heating and cooling were simultaneously occurring were calculated and displayed in Figure 13. Since the hospital model was built with a dual duct system, both heating and cooling were on as long as the HVAC system was in use. This meant that the hours for simultaneous operation were the same across every CZ and therefore was omitted from the figure. Still, the hospital model presented a great opportunity for heat recovery systems since there were almost always heating and cooling demands in different spaces within a larger facility. For the office model, the amount of simultaneous cooling and heating hours was the largest for CZ1 with 2,541 hours or 88% of annual HVAC operating hours but other CZs such as CZ2, CZ3, CZ4, CZ5, and

CZ16 also showed significant amounts. Colleges had the least potential for heat recovery with the smallest simultaneous cooling and heating hours.

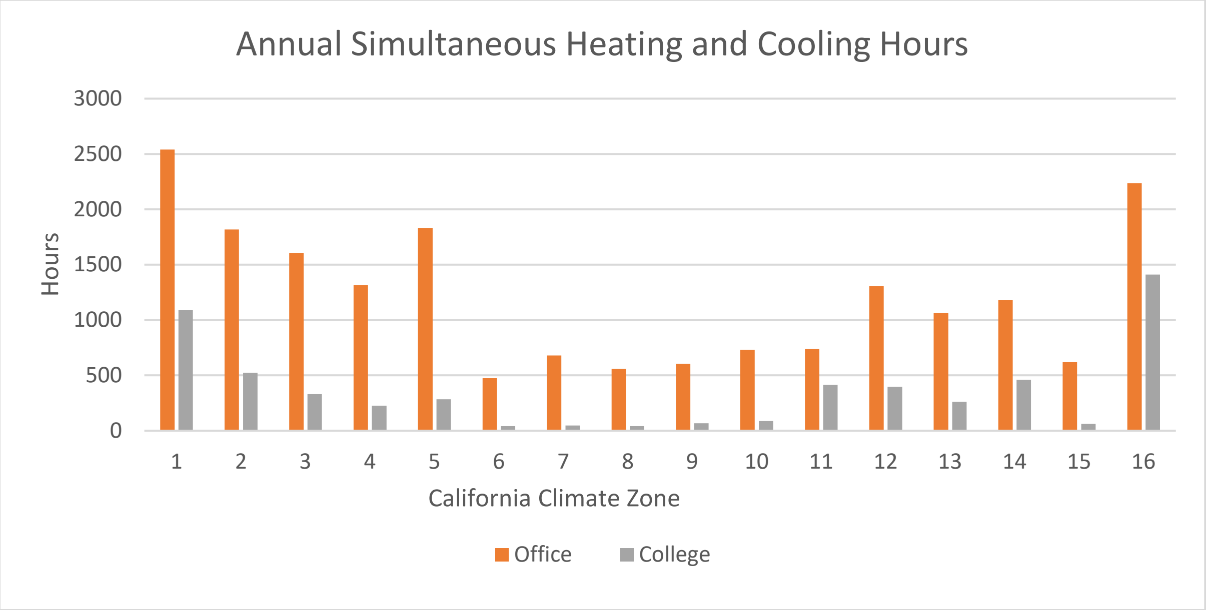


Figure 13: Annual Simultaneous Heating and Cooling Hours by Climate Zone

Overall, there is a market for AWHPs in California but the energy and GHG savings potential varies with climate as well as existing building HVAC system type and operations. In general, CZ1, CZ2, and CZ16 have the largest heating loads and have the greatest opportunity for electrification. California's mild climate is suited for AWHP because even mountainous areas like CZ16 typically don't see temperatures below 0°F, a common operating limit for heat pumps. These results indicate that there is enough opportunity within the existing commercial building market to pursue more aggressive decarbonization targets.

Commercial Air-to-Water Heat Pump Manufacturers and Products

Various heat pump manufacturers were identified and contacted for this study to obtain additional information about the current market landscape and product offerings. Manufacturers were contacted both inside and outside the U.S. In some cases, the same manufacturer offered products outside the U.S. (abroad) but did not offer any products within the U.S. For these cases, both the manufacturer's foreign office and U.S. office were contacted separately. These contacts were treated as separate and individual to each other, even though they fell under the same brand. In turn, this allowed for easier parsing and organization of manufacturer data, and enabled insights into U.S. market maturity versus international market maturity.

Table 3 shows a list of commercial AWHP products sorted by the location (country) of manufacturer brand. Additional details such as the general technology used by the heat pump, the maximum hot water supply temperature, the capacity of the model, COP at maximum hot water supply temperature, the ambient air temperature range for unit operation, and the refrigerant utilized are included. As shown, most products currently available are modular types with capacities less than 2,000 MBH. The maximum hot water supply temperature is limited to 140°F in most cases except for a few products that can supply hot water temperature up to 180°F. The COP varied from 1.8 to 4.5.

Table 3: Manufacturer Product List

Mfr.	Location	Technology	Max HW Supply	Size (MBH)	COP @ Max HW Supply	Ambient Air Temp Range & Refrigerant
A	United Kingdom	Monobloc AWHP (Hybrid DHW & HHW Capabilities)	140°F	307	N/A	-4°F to 95°F R410A Refrigerant
B	U.S.	High Temperature AWHP (Fixed-Speed Screw Compressor)	180°F	1,398	1.90	-4°F to 95°F R1234yf Refrigerant
C	United Kingdom	Monobloc AWHP (Hybrid DHW & HHW Capabilities)	149°F	84 to 351	2.42 – 2.68	-4°F to 104°F R407C Refrigerant
D	U.S.	Modular Inverter AWHP	140°F	541	N/A	-22°F to 109°F R410A Refrigerant
E	North America	AWHP (Variable Volume Ratio Scroll Compressor)	140°F	1,500 to 2,500	2.77	0°F to 95°F R410A Refrigerant
F	Canada	Modular AWHP (Also Dedicated DHW Capabilities)	140°F	95 to 723	2.3 to 4.2	-30°F to 95°F No Refrigerant Given
G	Canada	Modular AWHP (Also Dedicated DHW Capabilities)	140°F	96 to 713	1.8 to 3.2	-30°F to 95°F No Refrigerant Given
H	Canada	Modular AWHP (Also Dedicated DHW Capabilities)	180°F	250 to 540	N/A	10°F to 120°F No Refrigerant Given
I	Canada	Modular AWHP Utilizing CO_2 Refrigerant (Also Dedicated DHW Capabilities)	190°F	121 to 640	2.2 to 4.5	-20°F to 120°F

Mfr.	Location	Technology	Max HW Supply	Size (MBH)	COP @ Max HW Supply	Ambient Air Temp Range & Refrigerant
J	U.S.	Modular Inverter Scroll AWHP	140°F	451 to 1,803	3.55	-13°F to 109°F
K	U.S.	Modular Inverter Scroll AWHP	140°F	458 to 1,834	3.45	-13°F to 109°F

Source: Project team

Many of the manufacturers we contacted could not provide the estimated cost of an AWHP installation because the cost depended on multiple factors such as existing HHW supply temperature, system configuration, and space availability. A few estimates we received ranged between $2,000 and $6,000 per ton, which roughly translates to $170 to $500 per MBH. The numbers are comparable to the information collected from the literature review, which is shown in Table 4. As shown, the first cost for an AWHP is significantly more than an electric boiler or a condensing boiler.

Table 4: Estimated System Costs

System Type	Estimated First Cost per MBH
AWHP	Heat Pump w/o Recovery: $90-170 Full Heat Recovery: $150-200
WWHP	Heat Pump w/o Recovery: $60-270 Full Heat Recovery: $100-450
Electric Boiler	$18-$36
Condensing Gas Boiler	$15-$30

Source: (CSU 2019)

Interviews with Manufacturers and Collaborators

Stakeholder interviews were also conducted to obtain a deeper understanding of specifying, installing, owning, and operating commercial AWHPs. The interviewed stakeholders included heat pump manufacturers, distributors, energy service companies (ESCOs), and energy efficiency and engineering consultants.

The questionnaires developed and used for interview discussion can be found in Appendix A. Interview responses were broken down into three insight categories (barriers, opportunities, and policy considerations) and are discussed in the following sections.

Barriers

Table 5 summarizes the comments from manufacturers regarding barriers. Comments were largely divided into three main categories: design parameters, refrigerant constraints, and implementation requirements.

Table 5: Barriers Identified during Manufacturer Interviews

Category	Manufacturer Comments
Design Parameters	· Most available AWHP technologies cannot produce hot water more than 140°F. High temperature products and applications are not yet at maturity. · There are no industry standards for HHW design temperatures. · The performance of an AWHP degrades significantly with decreasing ambient temperature, especially for those that operate at low temperature conditions (below 0°F). · Outdoor ambient temperature drives the AWHP capacity. As ambient temperatures decrease, less heat capacity is available.
Refrigerant Constraints	· R-134a is difficult to leverage at locations with lower ambient temperatures, and can only make hot water up to 150-160°F even if entering air is above 50°F. · CO_2 as a refrigerant requires trans-critical states and is not straightforward to use for space heating and cooling. · R-410 can only make 120°F water in design conditions. · Staying up to date with refrigerant rules, regulations, and policy changes can be challenging. · The change in regulations can require potentially difficult and/or expensive system tweaks or reworks (e.g., coil resizing due to new refrigerant heat capacities).

Category	Manufacturer Comments
Implementation Requirements	· Substantial electrical and structure rework may be required. · Additional equipment and components are required to convert a gas boiler system to an electric AWHP system (e.g., electric boilers, especially in colder climates; buffer tanks; thermal storage tanks). · High initial/capital cost is required (roughly estimated between $2,000 and $6,000 per ton). · AWHP require additional space that may not be available in existing buildings.

Source: Project team

Opportunities

Overall, most manufacturers agreed that the existing products in the market today could enable the electrification of commercial hydronic heating systems to some extent, but the market was not quite there yet. However, states like California with its warmer climate and aggressive electrification goals present a great opportunity to accelerate adoption of AWHPs. Below are some of the opportunities discussed during the interview:

- AWHPs can operate efficiently in California's moderate climate.
- Most existing AWHP designs are modular, which can provide significant flexibility to both short-term and long-term electrification goals. For example, it can be combined with another equipment such as an electric boiler to pursue partial electrification. In addition, the facility can install additional modular AWHPs if the building heating loads change over time.
- Commercial AWHPs can also be installed in a cascade system where AWHPs are used in the first stage to get water up to a certain temperature. A WWHP or electric boiler can be used in the second stage to get the water up to a higher temperature. This is especially useful if the HHW temperature is a big constraint.
- Manufacturers are focusing on, and working towards, releasing more products that allow simultaneous heating and cooling (heat recovery) and products that can provide higher temperature supply. European factories are expanding in these areas especially and making these systems available.

Other Considerations

The interviewees acknowledged that policy pressure from state and municipal organizations for electrification was largely driving market demand for AWHP in the commercial sector. National and state decarbonization goals are also encouraging technology innovations and some manufacturers have begun to broaden their product offerings.

While the policy and goal setting are important, those alone can't drive the market. All interviewed manufacturers agreed that, besides certain design constraints, initial cost is the main barrier for the AWHP implementation and that there was a need to lower its first cost by offering incentives for installations or subsidizing the cost of equipment. It was also suggested that keeping the differential in the cost per kWh fixed would help stabilize energy costs for end users.

Multiple interviewers also indicated that the Inflation Reduction Act (IRA) was a step in the right direction, but that there needed to be more specific action focused on incentives and rebates for heat pumps. The IRA recently reworked a long-standing federal tax provision that provided tax deductions for energy efficient buildings meeting ASHRAE 90.1-2007 standards. The tax deduction for owners of new and improved energy-saving commercial buildings now ranges from $0.50 to $5.00 per square foot of floor area. This is dependent on the percentage of energy savings and if the contractor pays prevailing wages. For building retrofits, there is an alternative route based on the actual site energy use index (EUI) of the site compared to the EUI prior to the retrofit. Since technology like heat pumps are significantly more efficient than other heating sources when considering only the energy use onsite, this helps better qualify electrification projects for deductions (Ungar and Nadel 2023).

Another key suggestion was to provide focused education for all levels of engagement (owners, operators, designers, as well as sales representatives). Providing clear instructions for operators is essential for systems to achieve the best efficiency possible.

Conclusion

This market study explored the barriers and opportunities associated with electrifying natural gas boilers used for HHW systems in existing large commercial buildings, with the focus on AWHPs. Currently, there are only a few options available to electrify these heating systems and AWHPs present the most potential for decarbonization without the need for heat recovery (Gill 2021). However, the AWHP technology and its applications in HHW systems in existing buildings are still in its infancy. Thus, there are many barriers that need to be addressed before it is widely adopted to the market. Table 6 below highlights the main barriers discussed in this study and potential solutions for them, based on research and the interviews conducted with various stakeholders.

Table 6: Market Barriers Summary

Category	Barrier	Potential Solutions
Technological	Unable to produce HHW temperatures above 140°F	· Install cascade system (Use AWHP for first stage and WWHP or electric boiler for second stage) · Lower HHW design supply temperature · Prioritize pipe and building envelope upgrades to reduce heat losses throughout the system · Redesign HHW system

Category	Barrier	Potential Solutions
	Cannot operate efficiently at low ambient temperatures	· Install dual-fuel system for colder climates · Refrigerant improvements
Cost	High initial cost	· Use AWHP for both cooling and heating · Apply federal Incentives and tax deductions · Utility rebates and incentives
	High operational cost when compared to natural gas boilers	· Install heat recovery system with TES · Utility rate incentive · Perform routine maintenance to ensure optimum operation
	Requires substantial building upgrades	· Utility incentive for electrical infrastructure upgrades · Establish clear requirements needed for system prior to project. · Encourage small incremental energy efficiency upgrades to prepare for eventual retrofit. · Implement energy efficiency measures to reduce heating load to minimize the size of upgrades
Market Readiness	Lack of awareness and education	· Provide up-to-date education for service contractors, owners, designers, and sales representatives through classes and seminars. · Make resources available for building operators to ensure proper maintenance is performed (service contracts, SOPs etc.)

Source: Project team

The fact that current AWHP technology is limited to HHW temperatures below 140°F is one of the main technological and design barriers existing in the market. Most existing HHW systems tend to use design temperatures above 140°F, especially those with natural gas boilers. Existing building operators are often hesitant to lower operating temperatures to avoid impacts on pumps, pipework, and terminal coil sizing.

Another key barrier for AWHP integration is the impact on infrastructure, particularly in retrofit scenarios. This was discussed both with interviewed manufacturers and found through research. When converting from a natural gas boiler to an AWHP, substantial electrical and structural rework in a building may be required. Heat generation at scale does take up more room, and buildings may also need to perform structural upgrades to accommodate the new system. The solution to this problem is multi-faceted and could involve manufacturers providing adequate resources for contractors to gain familiarity with new technologies, federal entities and utilities providing larger incentives and building owners planning for change. With new construction, it is important to consider these issues early in the design process.

Finally, high first cost presents a significant barrier to the widespread adoption of AWHPs. While there are some incentives available for high efficiency buildings, there is no incentive specific to AWHP. These barriers are preventing the widespread adoption of AWHPs as a replacement for natural gas boilers, most manufacturers interviewed believed this would change as the technology continues to evolve.

Recommendations

The market study and analysis confirmed the energy efficiency potential and emission benefits of AWHP systems, on a per system and statewide basis. The technology provides a large increase in efficiency, a decrease in energy usage, and GHG emission reductions over many existing natural gas-fired systems. However, there are many nuances to AWHP systems, and AWHPs are not ideal for a one-for-one replacement for existing boilers and should not be treated as such. The broader adoption of AWHPs in the commercial space will require a multi-faceted approach to combat the barriers discussed in previous sections.

Successful market adoption will require efforts such as:

- Pilot projects and field demonstrations to provide further data on the energy saving potential for AWHPs in various configurations and applications.
- Utility rebates and rate incentives to encourage fuel-switching and support potential structural and electrical upgrades needed to convert from gas to electric heating in a large building.
- The support of federal and state regulatory agencies to provide larger financial assistance to offset large first costs.
- Increased focus on building long-term electrification plans that encourage incremental energy projects and partial electrification to prepare for more capital-intensive projects such as equipment replacement.
- Development of larger system packages that function solely with AWHP(s) and/or in combination with TES and heat recovery chiller(s).
- Continued research and development on AWHP technology for flexibility with colder temperature operations and ability to produce hot water temperature above 140°F.
- Focused education and training for industry professionals participating in the design or installation of AWHPs.
- General education and training for building owners and operators to spread the technology knowledge across all stakeholders.

Appendix A: Interview Questions

The below questions were initially formulated and posed to a subset of manufacturers and manufacturer contacts. In some cases, interview contacts were not immediately available, and a memo version of the below questionnaire was created for ease of electronic transmittal. A copy of this memo version questionnaire can be seen further below.

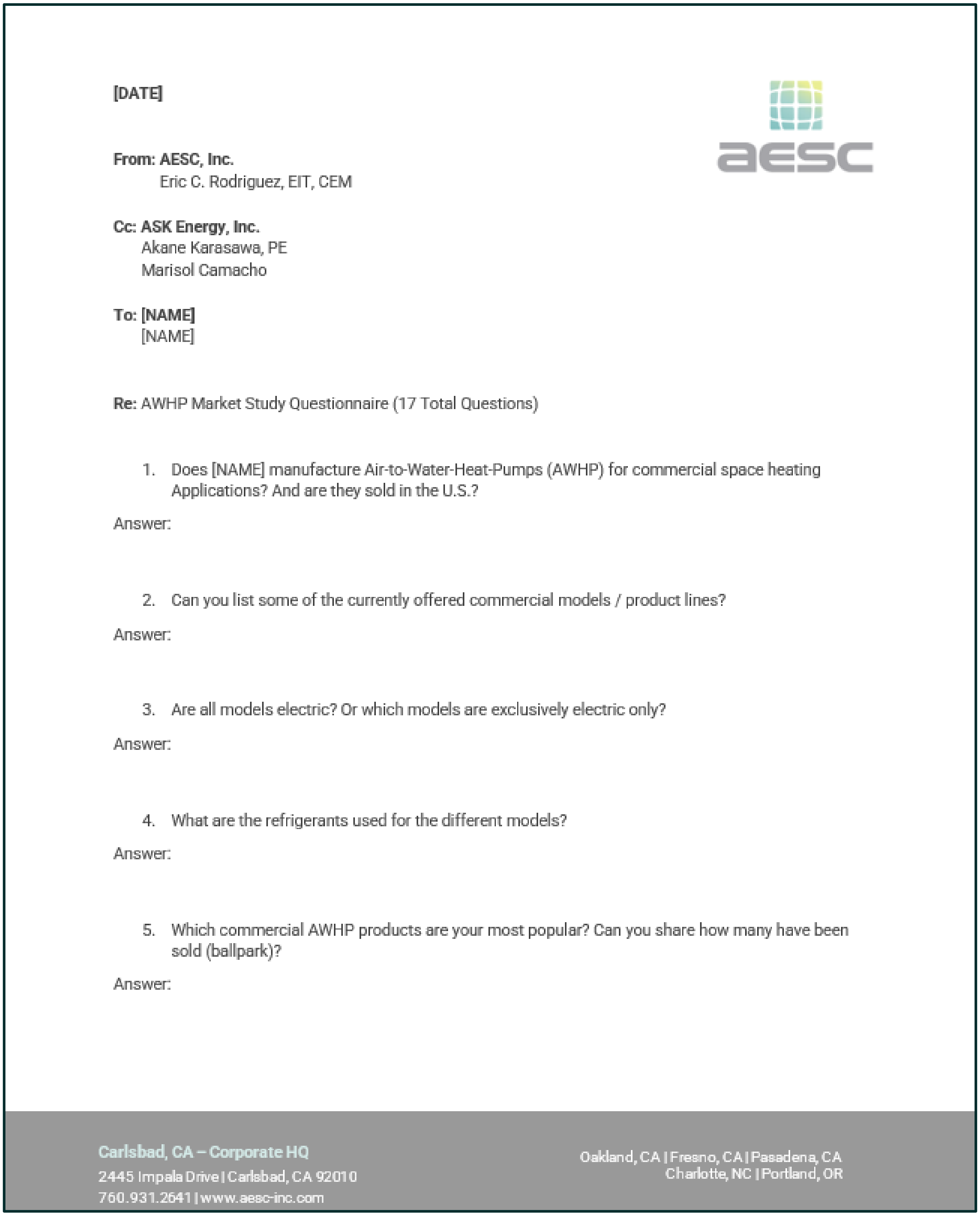
1. Does [COMPANY NAME] manufacture Air-to-Water-Heat-Pumps (AWHP) for Commercial space heating Applications? And are they sold in the U.S.?

If Question #1 is “Yes”

2. Can you direct me to some of the currently offered commercial models or product lines?
3. These are electric commercial-level AWHP’s correct?
4. What is the refrigerant used for the AWHPs?
5. Which commercial AWHP products are your most popular? Can you share how many have been sold?
6. How are your AWHP typically installed?
7. Do you typically find that customers are looking for additional system components to support or go along with their AWHP products and purchases? (e.g. Electric boiler, Hot Water Storage Tanks, Cold Water Storage Tanks, TES Tanks Generally, PTHPs, Heat Recovery Chillers, etc. to go with AWHPs)
8. What is the typical cost/payback?
9. When customers inquire about, or purchase, AWHP products, is electrification ever cited as a reason for the purchase? What reasons (if any) are usually cited, or have been cited in the past, for purchases?
10. Are any rebate programs cited, or have any rebate programs been cited, when customers purchase AWHP products?
11. What challenges have you encountered while specifying or installing AWHP?
12. Are there any design tool available for AWHP? Do you know of any?
13. Would you be able to provide me with a project reference for recently purchased or installed commercial AWHPs? **I’m ideally looking for existing building or retrofit projects, rather than new construction projects.**
14. Are there any plans to expand manufacturing or product line offerings for AWHPs? If yes, why or why now? If no, why not?
15. How are AWHPs differentiated from Heat Recovery Chillers?
16. Do you have any recommendations for CA utility programs to accelerate the adoption of AWHP?

If Question #1 is “No”

17. Are there any plans to manufacture or offer Air-to-Water-Heat-Pumps in the near or distant future? If yes, why now? If no, why not?



[DATE]

From: AESC, Inc.
Eric C. Rodriguez, EIT, CEM

Cc: ASK Energy, Inc.
Akane Karasawa, PE
Marisol Camacho

To: [NAME]
[NAME]

Re: AWHP Market Study Questionnaire (17 Total Questions)

1. Does [NAME] manufacture Air-to-Water-Heat-Pumps (AWHP) for commercial space heating Applications? And are they sold in the U.S.?

Answer:

2. Can you list some of the currently offered commercial models / product lines?

Answer:

3. Are all models electric? Or which models are exclusively electric only?

Answer:

4. What are the refrigerants used for the different models?

Answer:

5. Which commercial AWHP products are your most popular? Can you share how many have been sold (ballpark)?

Answer:

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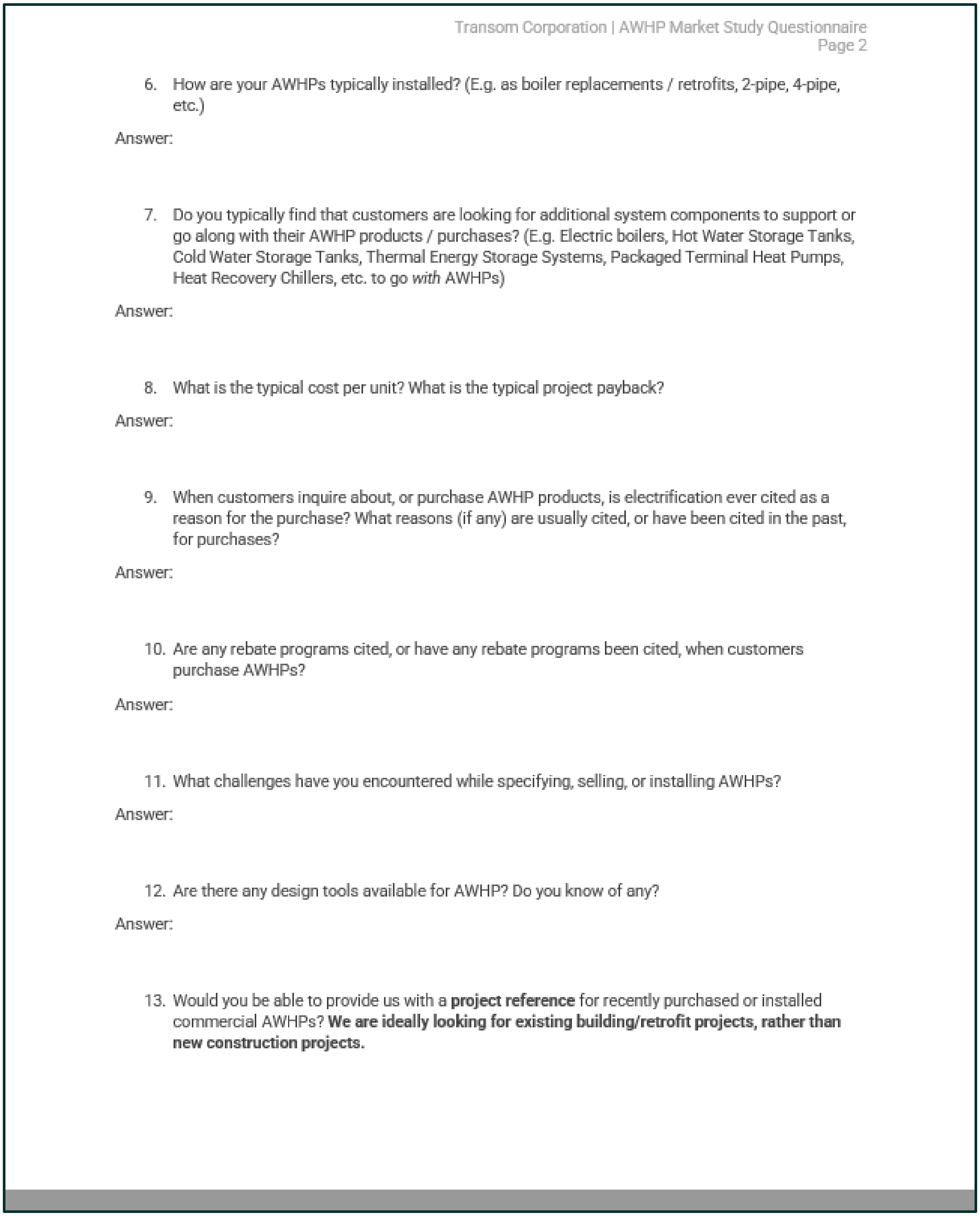
Oakland, CA | Fresno, CA | Pasadena, CA
Charlotte, NC | Portland, OR



Transom Corporation | AWHP Market Study Questionnaire
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6. How are your AWHPs typically installed? (E.g. as boiler replacements / retrofits, 2-pipe, 4-pipe, etc.)

Answer:

7. Do you typically find that customers are looking for additional system components to support or go along with their AWHP products / purchases? (E.g. Electric boilers, Hot Water Storage Tanks, Cold Water Storage Tanks, Thermal Energy Storage Systems, Packaged Terminal Heat Pumps, Heat Recovery Chillers, etc. to go *with* AWHPs)

Answer:

8. What is the typical cost per unit? What is the typical project payback?

Answer:

9. When customers inquire about, or purchase AWHP products, is electrification ever cited as a reason for the purchase? What reasons (if any) are usually cited, or have been cited in the past, for purchases?

Answer:

10. Are any rebate programs cited, or have any rebate programs been cited, when customers purchase AWHPs?

Answer:

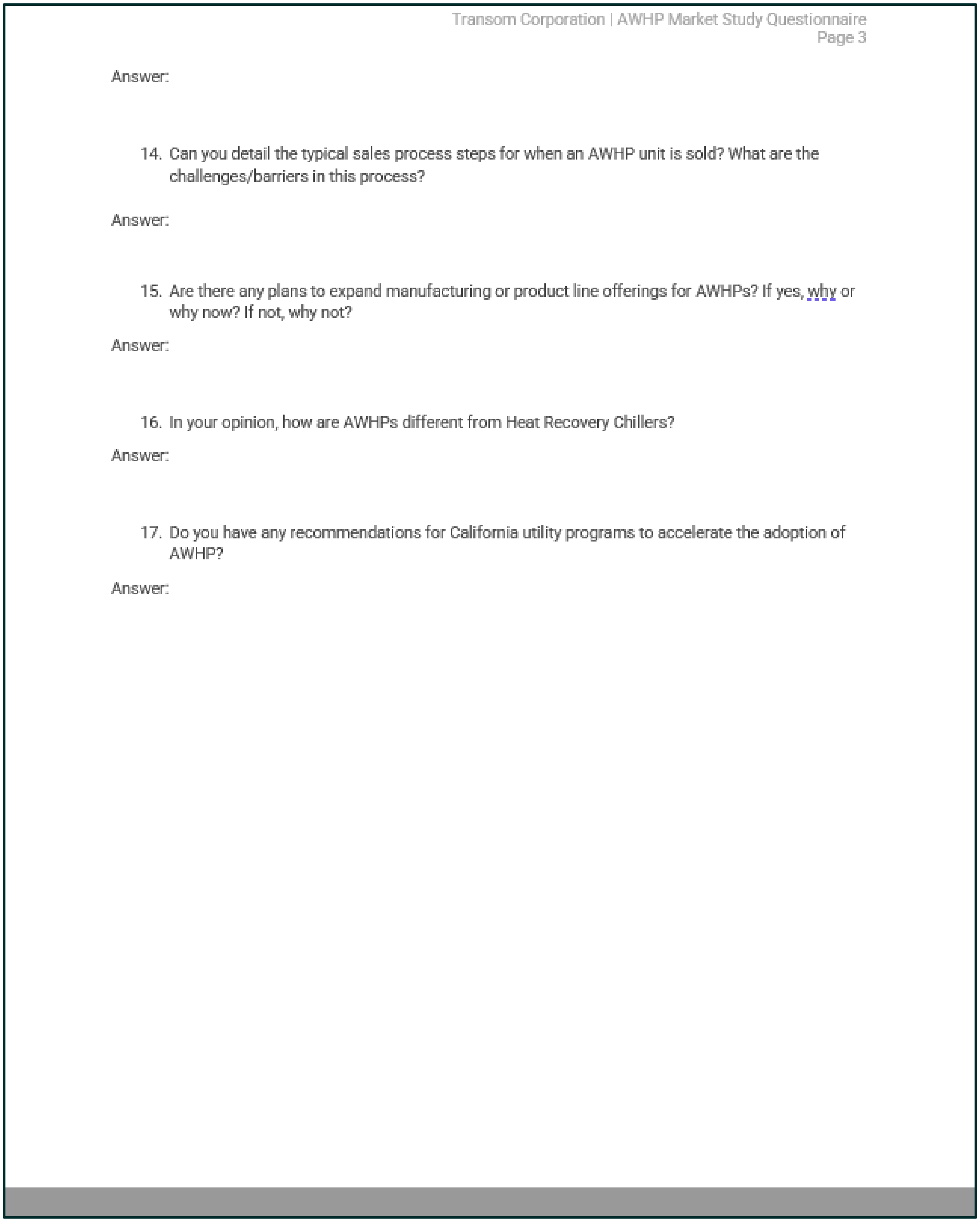
11. What challenges have you encountered while specifying, selling, or installing AWHPs?

Answer:

12. Are there any design tools available for AWHP? Do you know of any?

Answer:

13. Would you be able to provide us with a **project reference** for recently purchased or installed commercial AWHPs? **We are ideally looking for existing building/retrofit projects, rather than new construction projects.**



Answer:

14. Can you detail the typical sales process steps for when an AWHP unit is sold? What are the challenges/barriers in this process?

Answer:

15. Are there any plans to expand manufacturing or product line offerings for AWHPs? If yes, why or why now? If not, why not?

Answer:

16. In your opinion, how are AWHPs different from Heat Recovery Chillers?

Answer:

17. Do you have any recommendations for California utility programs to accelerate the adoption of AWHP?

Answer:

Appendix B: Boiler and AWHP Energy Usage Comparisons

Table 7: Energy Consumption and GHG Emissions for Hospital

CZ	Baseline Energy (therms/yr)	AWHP Energy (kWh/yr)	Baseline GHG Emissions (tonnes CO_2e/yr)	AWHP GHG Emissions (tonnes CO_2e/yr)	GHG Emissions Savings (tonnes CO_2e/yr)	Savings (%)
1	58,600	515,765	310	223	87	28%
2	64,100	564,024	339	244	95	28%
3	60,100	510,738	318	221	97	31%
4	60,500	512,749	320	222	98	31%
5	58,300	494,652	308	214	94	31%
6	49,200	407,384	260	176	84	32%
7	48,900	405,976	259	176	83	32%
8	51,000	423,772	270	183	87	32%
9	53,800	448,203	285	194	91	32%
10	54,800	457,854	290	198	92	32%
11	58,700	495,657	311	214	97	31%
12	61,800	524,813	327	227	100	31%
13	57,800	486,609	306	211	95	31%
14	58,100	490,630	307	212	95	31%
15	50,600	417,940	268	181	87	32%
16	71,600	624,347	379	270	109	29%

Table 8: Energy Consumption and GHG Emissions for Office Building

CZ	Baseline Energy (therms/yr)	AWHP Energy (kWh/yr)	Baseline GHG Emissions (tonnes CO_2e/yr)	AWHP GHG Emissions (tonnes CO_2e/yr)	GHG Emissions Savings (tonnes CO_2e/yr)	Savings (%)
1	4,325.4	33,640.3	22.9	14.6	8.3	36%
2	2,761.6	21,377.6	14.6	9.2	5.4	37%
3	1,634.6	11,956.1	8.6	5.2	3.4	40%
4	1,338.9	9,714.1	7.1	4.2	2.9	41%
5	1,623.8	11,511.7	8.6	5.0	3.6	42%
6	198.3	1,242.7	1	0.5	0.4	41%
7	284.7	1,782.6	1.5	0.8	0.7	49%
8	287.1	1,902.2	1.5	0.8	0.3	18%
9	448.9	3,103.6	2.4	1.3	0.4	18%
10	560.0	3,930.1	3	1.7	0.5	18%
11	2,144.0	16,790.0	11.3	7.3	4.0	35%
12	2,152.6	16,740.7	11.4	7.2	2.1	18%
13	1,708.2	13,336.5	9	5.7	1.6	18%
14	2,653.6	21,403.7	14	9.3	2.5	18%
15	593.5	4,262.9	3.1	1.8	0.6	18%
16	9,163.0	77,193.8	48.5	33.4	15.1	31%

Table 9: Energy Consumption and GHG Emissions for College/University

CZ	Baseline Energy (therms/yr)	AWHP Energy (kWh/yr)	Baseline GHG Emissions (tonnes CO_2e/yr)	AWHP GHG Emissions (tonnes CO_2e/yr)	GHG Emissions Savings (tonnes CO_2e/yr)	Savings (%)
1	6,461	50843	34.2	22	4.7	36%
2	2,881	22722	15.2	9.8	2.2	36%
3	1,483	12668	7.8	5.5	1.2	29%
4	1,038	8948	5.5	3.9	0.8	29%
5	1,464	11864	6.2	5.1	1.1	18%
6	323	2795	1.7	1.2	0.3	29%
7	339	2925	1.8	1.3	0.2	28%
8	360	3157	1.9	1.4	0.3	26%
9	396	3293	2.1	1.4	0.3	33%
10	431	3519	2.3	1.5	0.4	35%
11	2,055	15634	10.9	6.8	1.4	38%
12	1,927	15584	10.2	6.7	1.5	34%
13	1,216	10203	6.4	4.4	1	31%
14	2,704	20364	14.3	8.8	1.9	38%
15	421	3720	2.2	1.6	0.4	27%
16	15,073	114,574	79.8	49.6	10.7	38%

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