Assessment of Low-Cost Minisplit Heat Pump Connection System

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Disclaimer

EXECUTIVE SUMMARY

This project was funded by SCE's Emerging Technologies Program, and evaluates the feasibility of a connection system that can pave the path to accelerated, cost-effective adoption of high-efficiency Minisplit Heat Pump (MSHP) systems. This report details the characterization of this connection system and a heat pump enabled with this technology in a laboratory setting, and assesses the energy and cost impact applicable to residential buildings in SCE service territory. The energy and economic analysis leverages NREL's ResStock™ modeling approach based on the EnergyPlus® hourly simulation platform.

The connection system can be incorporated into existing MSHP architectures. This reduces installation time from 10 to 20 man hours to approximately one hour or less, dramatically lowering total installation costs without adversely impacting heat pump performance.

This report characterizes the connection system's leakage performance while connected and disconnected, as well as leakage over several connection/disconnection cycles, commensurate with manufacturer specifications for the individual components. The connector was incorporated into an off-the-shelf MSHP. Performance was compared to an identical unmodified heat pump. The connector had no impact on performance.

Large-scale hourly energy simulations were performed for 22,574 homes across 15 counties in SCE service territory. The analysis was performed using baseline assumptions about the penetrations of window air conditioners (~18%) and six upgrade scenarios for these air conditioners. All scenarios assumed 100% adoption of the Connector-Supported Heat Pump (CSHP) in place of window air conditioners: MSHPs at Seasonal Energy Efficiency Ratio (SEER) 17, 25, and 33, and CSHPs at SEER 17, 25, and 33. Results show the increased adoption of high-efficiency heat pumps can result in up to 29% air conditioning energy savings for homes with window air conditioners.

ABBREVIATIONS AND ACRONYMS

CSHP	Connector-Supported Heat Pump
CZ	Climate Zone
EER	Energy Efficiency Ratio
HVAC	Heating, Ventilation, and Air Conditioning
MSHP	Minisplit Heat Pump
NREL	National Renewable Energy Laboratory
RAC	Room Air Conditioner
RASS	Residential Appliance Saturation Study
SCE	Southern California Edison
SEER	Seasonal Energy Efficiency Ratio
VAC	Volts Alternating Current

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INTRODUCTION

The purpose of this multiphase project was to assess the performance of a prototype Heating, Ventilation, and Air Conditioning (HVAC) technology in support of SCE's Emerging Technologies Program. The performance of this technology was evaluated at the NREL Thermal Test Facility (Torcellini et al. 2005).

As California transitions to the next phase of meeting greenhouse gas reduction targets, it is important for utilities to accelerate deployment and adoption of novel technologies. Space cooling accounts for approximately one-third of electric demand and 15% of the annual energy consumption in California. Therefore, enabling technologies that may favorably impact statewide power and energy consumption in space cooling can be beneficial.

BASELINE TECHNOLOGY

For residential buildings that lack the air distribution system necessary for central air conditioning, common technologies to provide space cooling include window and wall-mounted portable Room Air Conditioners (RACs) and Minisplit Heat Pump (MSHPs).

Window air conditioners are the most popular units installed in U.S. homes today, but are inefficient compared to other cooling technologies for several reasons. Most window units do not provide heating. Furthermore, cost and size constraints result in small heat exchangers and low-cost compressors, which lead to low efficiency. Window air conditioners can also suffer from air recirculation between the supply and return grilles, further reducing the overall cooling efficiency[1]. Window units, whether installed in a window or through the wall, significantly reduce building airtightness due to air leakage through and around the unit.[2] Though the air leakage can be reduced when installed per manufacturer instructions, the air leakage is approximately equivalent to a six-inch-square hole based on a study by Steven Winter Associates, Inc. (Zuluaga et al. 2011).

Portable air conditioners are typically located in the center of rooms to provide local, personalized cooling and reject condenser heat to outdoors through an air duct connected to an open window. Portable air conditioners typically have comparable but somewhat lower efficiency than window air conditioners due to the condenser airflow ducts, and portable air conditioners with a single outlet hose significantly increase building infiltration by discharging condenser airflow to the outside, thus depressurizing conditioned space.

MSHPs often use high-efficiency variable-speed compressors to provide room cooling and heating. The indoor and outdoor units are split by a refrigerant line set that must be professionally installed. After connecting the indoor and outdoor units via the field-installed line set, air in the lines must be purged for several hours using a vacuum pump. MSHPs tend to be powered from 240 Volts Alternating Current (VAC), requiring a dedicated electric circuit, which must also be professionally installed. Though MSHPs offer higher cooling and heating efficiency and address many of the shortcomings associated with RACs, high installation costs limit their market share.

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[1] Tests conducted by NREL found that air recirculation can reduce the overall efficiency of a window air conditioner by 10%, although many newer models are attempting to minimize this effect (Winkler et al 2013).

[2] An NREL study by the inventors of this device found that poorly-installed window air conditioners can increase whole-house air leakage by 10%. The NREL study found that air infiltration can be reduced by up to 47 square inches, while performance can be improved by roughly 6 Energy Efficiency Ratio (EER) (Winkler et al 2013).

BACKGROUND

The evaluated technology is a residential-focused, near-to-market, patented joining system that simplifies the connection between the indoor and outdoor units by eliminating the need for a refrigeration line set, brazing of refrigerant connections, and professional electrical installation. The joining system, which includes an adjustable connection attached to the outdoor unit to accommodate various wall thicknesses, provides the structural integration between the indoor and outdoor units and serves as a conduit for the refrigerant, electrical, and condensate connections. The intellectual property focuses on the tight integration of the indoor and outdoor sections allowing for a tool-less, weathertight, low-skilled installation after a single hole is drilled in an exterior wall.

EMERGING TECHNOLOGY/PRODUCT

The connection system addresses many of the expensive labor steps facing conventional MSHP installations. Thus, CSHPs offer a lower-cost option compared to conventional MSHPs by eliminating several hours of installation time.

Figure 1 shows an exploded view of a CSHP, including mounting brackets and mechanical fastening that are integrated into the off-the-shelf MSHP system. The connection system includes functional and mechanical connections to operate and mount the unit all in one.

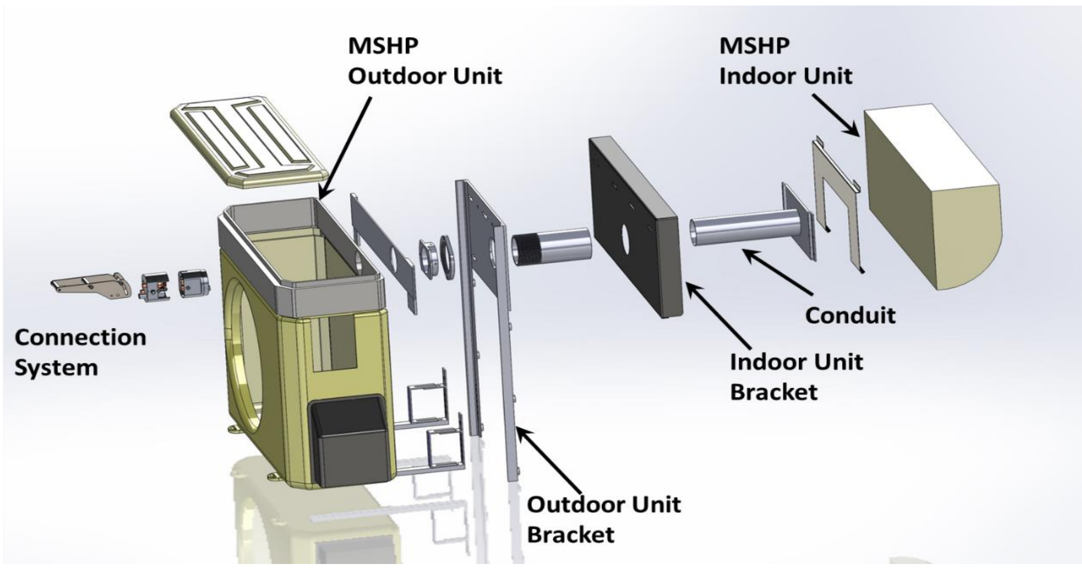


Figure 1. CSHP System Design

The CSHP leverages an off-the-shelf MSHP and includes the patented joining system. The indoor and outdoor unit brackets provide mechanical support, and the connection system allows the installer to join the refrigerant line, electrical wires, and condensate drain in a single action by closing one lever. The yellow components (outdoor and indoor MSHP units) are the original minisplit components and contain the entire vapor compression system. The gray components are the added connector parts and are generally sheet metal or structural members for mechanical integration (except for the integrated connectors on the far left, which house the functional connections and tie the entire system together).

Assessment Objectives

An operational alpha-prototype heat pump was constructed in 2016 using off-the-shelf window air conditioner and MSHP components. The current project has taken this connection system forward on the commercialization path by constructing and characterizing a near-production-ready beta prototype and demonstrating the impact on residential energy use in SCE territory through whole-building energy simulations.

Task 1: Connection System Characterization

Activities: NREL validated performance of a beta-prototype connection system. This included leakage characterization, pressure cycling, pressure loss, durability verification, and installation/interface assessment. The beta-prototype connection system design was completed via different funding sources. Characterization was performed at NREL's Thermal Test Facility.

Deliverables: NREL provided characterization results to SCE for the connection system. This included leakage rate and pressure drop as well as relevant other characteristics (wall thicknesses that can be accommodated, maximum design weight, etc.)

Task 2: Laboratory Characterization of Heat Pump System

Activities: NREL performed laboratory characterization of a complete CSHP air conditioning system. This consisted of efficiency and capacity measurements at multiple environmental operating conditions. Emphasis was placed on conditions representative of SCE service territory; however, multiple climates were represented. Work was performed at NREL's Thermal Test Facility using the HVAC characterization laboratory.

Deliverables: NREL provided approximate energy efficiency and capacity measurements for a fully-integrated CSHP air conditioning system.

Task 3: Impact Analysis – SCE Service Territory

Activities: Whole-building energy models based on EnergyPlus (Crawley et al. 2000) and laboratory performance data from Task 2 were used to estimate energy use in SCE territory. This quantified the impact in SCE territory of different efficiency levels for MSHP and CSHP on energy use relative to replacing window air conditioners.

Deliverables: NREL provided a final report that summarized all efforts under this project. This included all work and results under Tasks 1 and 2 as well as energy modeling methodology and results for all simulations in SCE territory.

CONNECTION SYSTEM CHARACTERIZATION

The integrated connector system is shown in Figure 2. Integrated Connector Schematic – Two Sets of Refrigerant, Electrical, Condensate Connector. The refrigerant, electrical, and condensate connectors are shown. The refrigerant and electrical connectors are commercially available as individual components (Parker Hannifin Corporation 2008). The lever is used to actuate the functional connection as well as the mechanical connection between indoor and outdoor units (not shown).

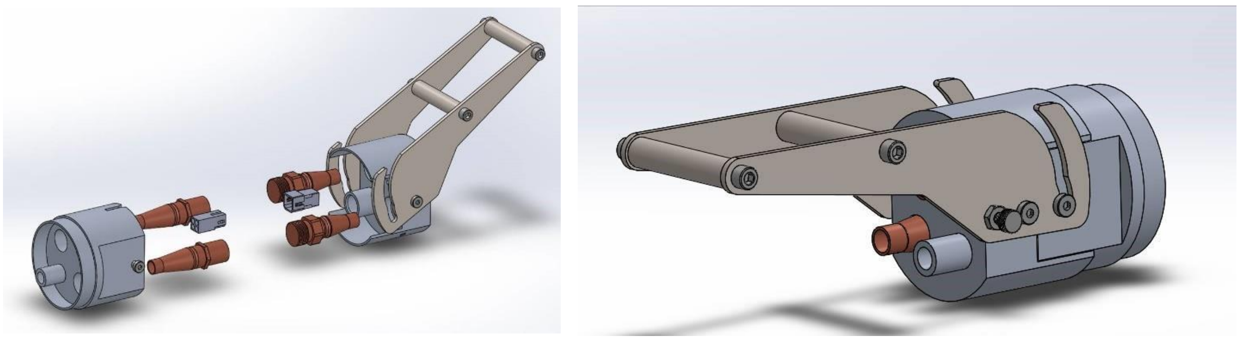


Figure 2. Integrated Connector Schematic – Two Sets of Refrigerant, Electrical, Condensate Connectors

The refrigerant connectors chosen for the beta-prototype were off-the-shelf, refrigerant-compatible, self-sealing brass couplings made by Parker Hannifin, a manufacturer of refrigeration control valves. Parker's 5500-series couplings are specifically design for pre-charged, split air conditioning and heat pump systems that minimize air inclusion and refrigerant loss during connection and disconnection. Male and female couplings were chosen that aligned with the heat pump liquid and suction line diameters to minimize additional pressure drop. Several key specifications are listed in Table 1. The liquid and suction line pressure drops were based on a typical refrigerant mass flow rate of ~120 lbm/h for a 9,000 Btu/h MSHP.

Table 1. Parker Refrigerant Connector Specifications

PARAMETER	SPECIFICATIONS
Operating pressure range, connected	Vacuum – 750 psi
Operating pressure range, disconnected	Vacuum – 750 psi (male) Vacuum – 600 psi (female)
Maximum air inclusion (during connection)	0.15 cc (per connection)
Maximum fluid loss (during disconnection)	0.10 cc (per disconnection)
External leak rate (connected)	<0.1 ounce of refrigerant per year
External leak rate (disconnected, capped)	<0.25 ounce of refrigerant per year
Liquid line pressure drop	<0.1 psi
Suction line pressure drop	~1.0 psi

The as-built apparatus to characterize the connector is shown in Figure 3. Connector Characterization Apparatus. There are fittings for temperature and pressure measurements as well as a pressure release valve. The charging port on the right was used to charge the apparatus with high-pressure argon gas. The other side of the connector was capped to prevent leakage and contain the argon. The apparatus was intentionally designed with a low internal volume to ensure any argon leakage could be easily detected with the pressure measurement. The temperature measurement was used to account for temperature-related pressure fluctuations due to the small changes in the building space temperature.

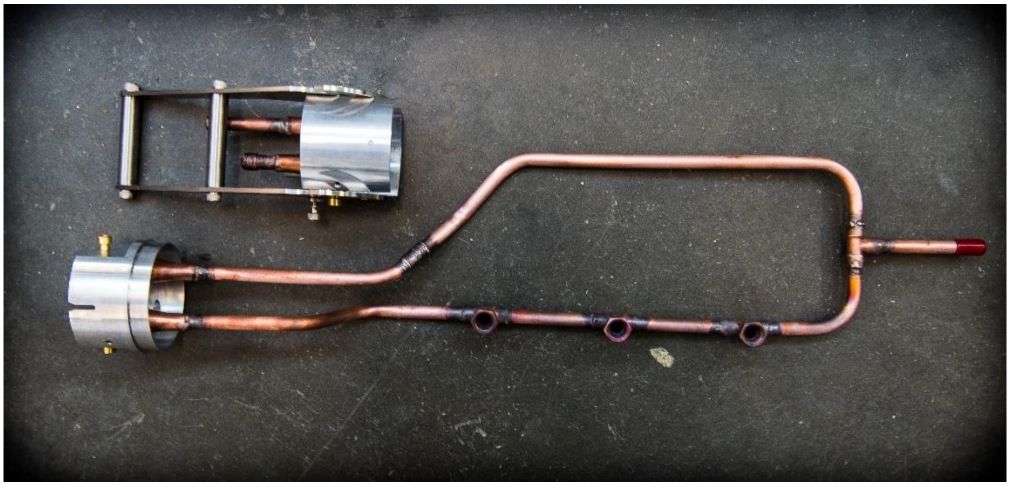


Figure 3. Connector Characterization Apparatus

LONG-TERM LEAK CHARACTERIZATION

The first series of experiments determined the long-term leak rate with the connectors engaged as they would be after installation of a unit. The system was first charged with argon gas to approximately 2.76 MPa (400 psig) and left at room temperature for 11 days. For context, 2.76 MPa corresponds condensing pressure on a hot day (R410A saturation temperature of approximately 46.1°C [~115°F]).

Shortly after charging the apparatus and collecting initial data, data collection was paused for three days due to a software issue. However, the apparatus remained charged during this time. Data collection was restarted and lasted eight additional days, meaning the apparatus was charged for 11 days. The pressure during that time was stable, as can be seen in Figure 4. Normalized Pressure with Connection System Engaged; it is normalized by the average pressure over the test.

The second test was to repeat the same test with the connector disengaged as it would be likely configured during transport and storage prior to installation. Over the 10-day test, there was no observable leakage, as shown in Figure 5. Normalized Pressure with Connection System Disengaged. The standard deviation of the normalized pressure readings was 1.4e-3, while a curve fit of the readings shows a decrease of 3e-5, which is considered statistically irrelevant given the accuracy of the measurements.

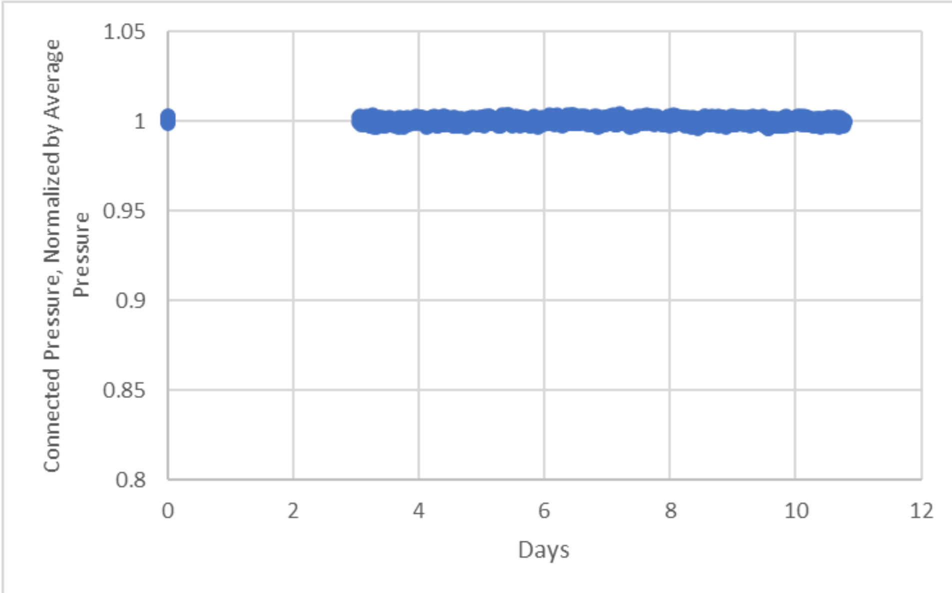


Figure 4. Normalized Pressure with Connection System Engaged

Data collection was paused between Days 1 and 3 due to data acquisition issues. There was no observable leakage at 2.76MPa (400psig).

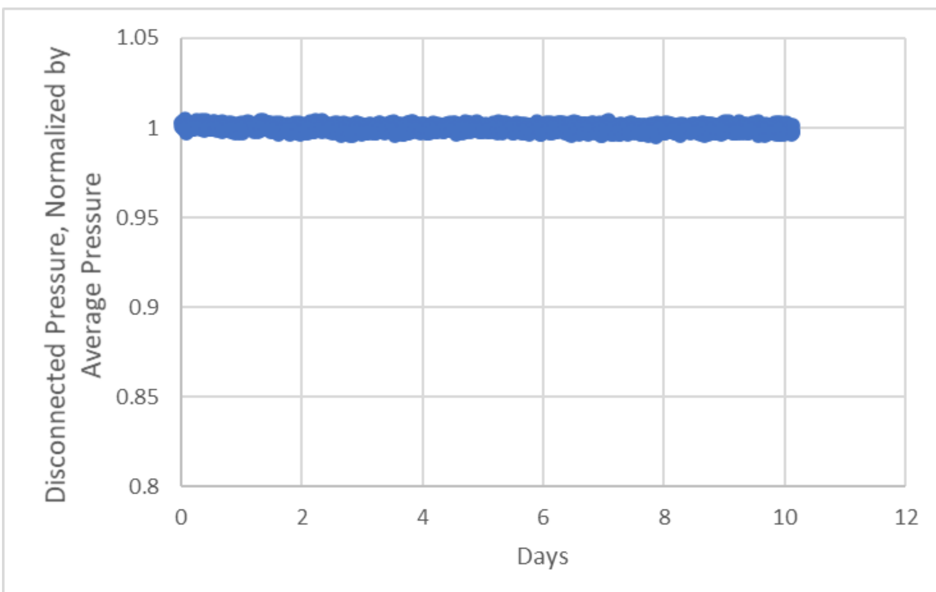


Figure 5. Normalized Pressure with Connection System Disengaged

There was no observable leakage at 2.76MPa (400psig).

CONNECTOR CYCLING PERFORMANCE

The second set of characterization tests involved cycling the connection system. Using the apparatus, the connection system was connected and disconnected for a total of 14 cycles. In typical operation, a heat pump would only undergo a single cycle during its lifetime – connection during installation and then disconnection upon replacement. Therefore, 14 cycles were considered well beyond the expected real-world performance.

The refrigerant connector manufacturer specifies 0.15 cc of air inclusion and 0.1 cc of fluid loss for each connection and disconnection. The combined 0.25 cc loss per cycle can be related to pressure by knowing the internal volume of the test apparatus. The apparatus had an approximate internal volume of 61.5 cc. Each cycle should result in a loss of approximately 0.25/61.5 cc or 0.4% based on manufacturer specifications.

The pressure after n cycles is then:

$$fraction\ of\ starting\ pressure = (1 - 0.004)^n$$

This results in 94.5% of the starting pressure after 14 cycles. This was similar to the measured pressure; thus, the integrated connector design does not degrade the performance of the individual refrigerant connectors, as shown in Figure 6. Normalized Pressure Loss over 14 Connection/Disconnection Cycles. The performance is similar to manufacturer specifications for the refrigerant connectors only, thus the connector design integration does not negatively affect performance.

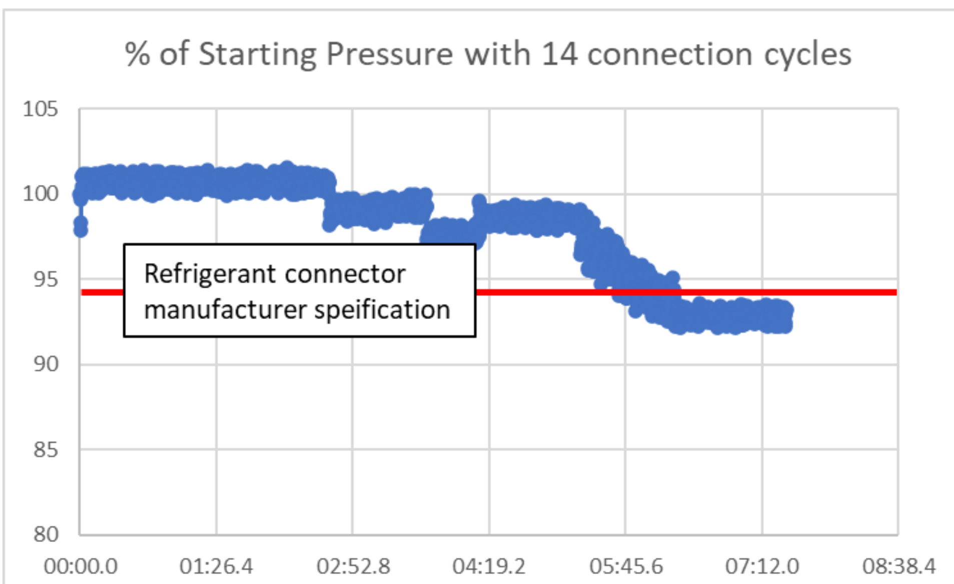


Figure 6. Normalized Pressure Loss over 14 Connection/Disconnection Cycles

CONNECTOR STRENGTH

The third characterization was demonstration of sufficient strength of the integrated system. The connection system (including the frame) was mounted on a demonstration wall, as shown in Figure 7. System Mounted on Demonstration Wall as in Actual Operation (left); Disassembled with Mounting Brackets (right). The hole through which the CSHP was mounted could be at any location between two studs in the wall; the weight of the unit was transferred to the wall by compressing the indoor and outdoor mounting brackets ,which spanned two studs (at 16″ on center). The connector maintained compression to the wall and stability of the unit, including from rotation, and therefore is considered sufficiently strong.

Figure 7. System Mounted on Demonstration Wall as in Actual Operation (left); Disassembled with Mounting Brackets (right)

Photos: Dennis Schroeder

LABORATORY CHARACTERIZATION OF HEAT PUMP SYSTEMS

The purpose of this characterization was to quantify what effect, if any, integration of the connection system may have on heat pump performance. Two identical SEER 22 MSHPs were purchased – one was installed as intended, and the other was modified to accept the connection system. This system was chosen because it operated on a 120-VAC power supply suitable for electrical circuits in most homes in the U.S.

HVAC LABORATORY AND TEST ARTICLES

NREL's Advanced HVAC Systems Laboratory characterizes the performance of HVAC systems and components ranging from 10 to 10,000 cfm. This once-through laboratory (Figure 8. NREL Advanced HVAC Systems Lab, Thermal Test Facility) brings in outdoor air, and conditions it to the desired temperature and humidity for experiments over a wide range of inlet conditions. It includes accurate pressure, temperature, humidity, and flow rate measurements for air, refrigerant, water, and liquid desiccants.

Figure 8. NREL Advanced HVAC Systems Lab, Thermal Test Facility

The baseline and CSHP were installed in a custom chamber that allowed precise measurement and independent control of inlet and outlet air streams for both the indoor and outdoor units using the air streams in the HVAC laboratory. Images of the installed heat pumps are provided in Figure 9. Baseline Unit in Test Chamber; Indoor and Outdoor Units During Installation (left), Outdoor Unit after Installation (right) and Figure 10. CSHP Installed in Test Chamber; Indoor and Outdoor Units During Installation (left), Outdoor Unit with Connection System after Installation (right)

The wooden support for the outdoor unit was an artifact of the test chamber not being able to support a full strength wall; this would not be part of an actual installation.. The CSHP had an approximately three-inch-tall extension mounted to the top of the unit, to house the connector and route the refrigerant lines, which were all internal to the unit instead of exposed to the environment. Before operating the systems, the wall between the indoor and outdoor units was completely sealed, and the supply and return airstreams on each side were separated to prevent mixing and maintain prescribed environmental conditions.

Figure 9. Baseline Unit in Test Chamber; Indoor and Outdoor Units During Installation (left), Outdoor Unit after Installation (right)

Photos: Erin Lewis

Figure 10. CSHP Installed in Test Chamber; Indoor and Outdoor Units During Installation (left), Outdoor Unit with Connection System after Installation (right)

The wooden support for the outdoor unit was an artifact of the test chamber not being able to support a full strength wall; this would not be part of an actual installation.

Photos: Erin Lewis

EXPERIMENTAL TEST MATRIX

Two heat pumps were operated in the laboratory under the environmental conditions listed in Table 2. The tests covered a broad range of conditions for space cooling – space heating was not a primary concern for this comparison; however, based on the results, it is likely that the performance would not change substantially due to the addition of the connection system. The test conditions were chosen to span real-world operating conditions. Three outdoor dry-bulb temperatures were evaluated, ranging from cool to hot weather (23.9°C – 46.1°C) along with three indoor psychrometric conditions. The indoor psychrometric conditions ranged from 26.7°C dry-bulb and 15.8°C dewpoint, the rated condition for split air conditioners, to a common indoor dry-bulb temperature of 25°C, with low humidity to evaluate dry-coil performance.

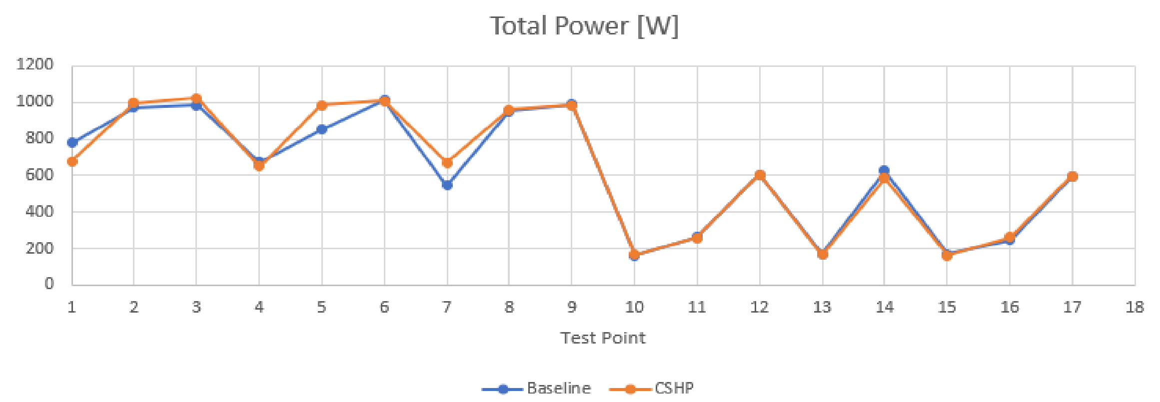
Table 2.Test Conditions

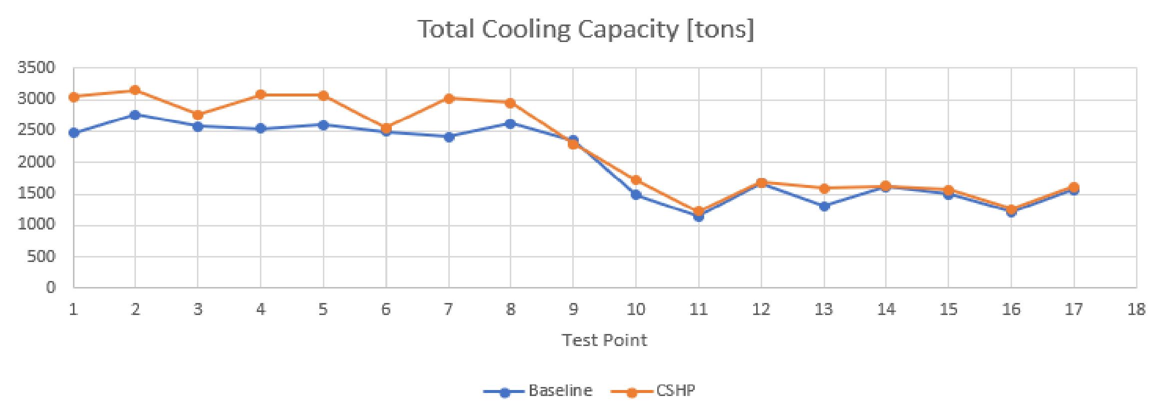
Test Point	Power Setting	Outdoor Dry bulb (°C)	Indoor Dry bulb (°C)	Indoor Dewpoint (°C)
1	High	23.9	26.7	15.8
2	High	35.0	26.7	15.8
3	High	46.1	26.7	15.8
4	High	23.9	23.3	13.3
5	High	35.0	23.3	13.3
6	High	46.1	23.3	13.3
7	High	23.9	25	-[a]
8	High	35.0	25	-[a]
9	High	46.1	25	-[a]
10	Low	23.9	26.7	15.8
11	Low	35	26.7	15.8
12	Low	46.1	26.7	15.8
13	Low	23.9	23.3	13.3
14	Low	46.1	23.3	13.3
15	Low	23.9	25	-[a]
16	Low	35	25	-[a]
17	Low	46.1	25	-[a]

[a] Tests were conducted using low ambient humidity to evaluate dry-coil performance.

BASELINE VS. CSHP PERFORMANCE COMPARISON

The focus of the experiments was to quantify the change in performance from the baseline MSHP unit to the CSHP unit. The performance metrics considered were total power use, total cooling capacity, and coefficient of performance. The comparisons are shown in Figure 11. Comparison of Baseline to CSHP Performance for Conditions in Table 2.. Test points 1–9 were performed at maximum compressor speed, and points 10–17 were performed at the minimum sustainable compressor speed. Note that higher and lower speeds were achievable for short durations, but using the systems' internal control logic, these were the maximum and minimum stable speeds, respectively. The difference between the two units was generally small, and when there were differences, the CSHP unit tended to have higher cooling capacity and coefficient of performance. The conclusion was that integrating the connection system into a heat pump did not have a noticeable negative impact on heat pump performance.





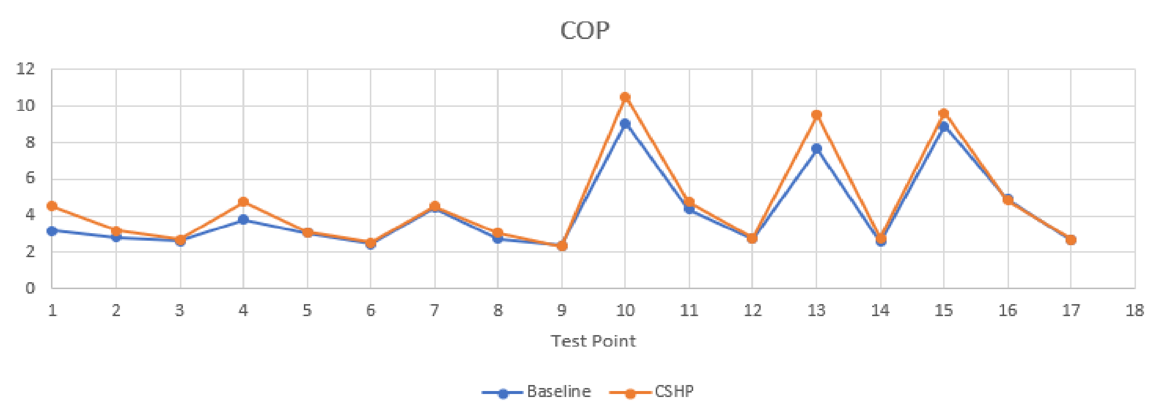


Figure 11. Comparison of Baseline to CSHP Performance for Conditions in Table 2.

ENERGY IMPACT ANALYSIS – SCE TERRITORY

MODELING APPROACH

Modeling was undertaken to determine the impact of replacing all RACs in SCE service territory with either MSHPs or CSHPs, since it was beyond the scope of this work to predict market uptake. The performance of the CSHP units was informed by the laboratory characterization, which showed it was identical to the base MSHP to which the connection system was added. Impact was quantified by energy savings, but a simple payback calculation was included, to help understand economic incentives for homeowners when making air conditioner purchase decisions. Three upgrade scenarios were modeled, to simulate replacement of RACs with higher-efficiency MSHPs and CSHPs; both MSHP and CSHP were modeled with the same three efficiency options:

- Low: SEER 17
- Medium: SEER 25
- High: SEER 33.

In all scenarios, all RAC units in SCE territory were upgraded. The only difference between CSHPs and traditional MSHPs was the installation cost, because the efficiency was identical based on the laboratory characterization.

The simulations were performed using EnergyPlus, for which all simulation input files were generated using NREL's U.S. residential building stock simulation software, ResStock (Wilson 2017). For this analysis, we considered 22,574 simulated homes across 15 counties in SCE service territory. Each home was simulated with local climate conditions for maximum accuracy. Weighting of total energy usage was based on estimates of the percentage of homes in a given county serviced by SCE, which are listed in

Table 3. ResStock simulated 376,610 homes to represent the ~75 million single-family detached homes in the U.S., and 22,574 of those simulated homes resided in SCE service territory. Of these, 4,165 had RACs (18%). Due to the lower efficiency of RACs compared to central split air conditioning systems, RACs represent approximately 38% of the cooling energy used in single-family detached homes in SCE service territory. If a home had a RAC, it was assumed that the total cooling capacity was sufficient to condition the entire home; partial space conditioning of a home was not accounted for in this model, but rather would need to applied in future post-processing. The capacity distribution of RACs is given in Figure 12. RASS RAC Capacity Distribution in SCE Service Territory and is based on Residential Appliance Saturation Study (RASS) (Palmgren et al. 2009).

Table 3.Fraction of SCE-Serviced Homes in Each County (weight) and Home Simulation Distribution in SCE Territory

California County	Weight	# Homes Simulated	# Homes Simulated with RAC
Fresno County	0.42063	1,004	151
Imperial County	0.877672	162	31
Inyo County	0.569207	33	8
Kern County	0.42063	969	175
Kings County	0.42063	147	27
Los Angeles County	0.536699	7,886	1,656
Madera County	0.42063	174	28
Mono County	0.798689	21	6
Orange County	0.435244	2,589	443
Riverside County	0.70091	2,619	417
San Bernardino County	0.402429	2,207	385
San Diego County	0.444035	2,880	511
Santa Barbara County	0.392692	418	75
Tulare County	0.42063	517	94
Tuolumne County	0.349582	86	8
Ventura County	1	862	150
Total		22,574	4,165

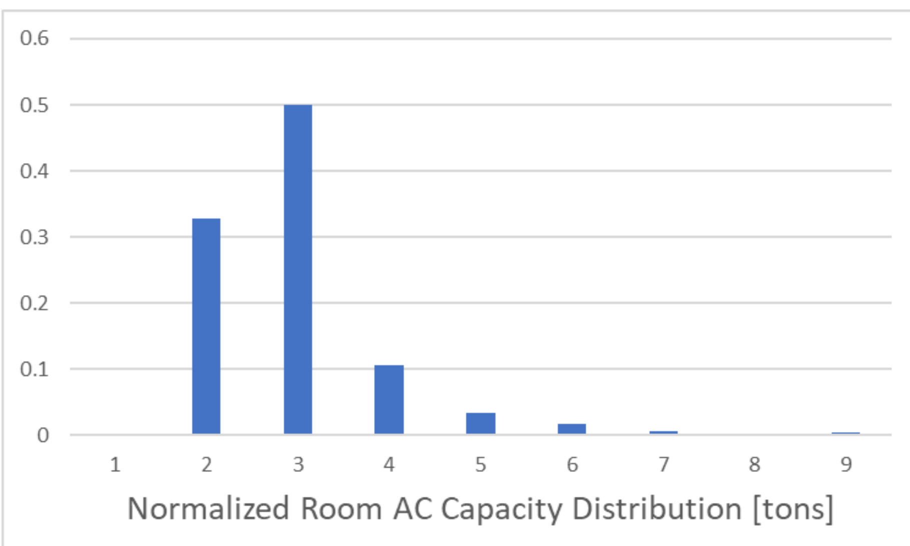


Figure 12. RASS RAC Capacity Distribution in SCE Service Territory

ENERGY SAVINGS

Table 4. Energy Savings from Replacing all RACs in SCE Territory shows the percent energy savings across SCE territory by replacing all the RACs with one of the three MSHP efficiency levels. The savings are expressed as a percentage of total residential cooling energy by upgrading houses with RACs. Thus, even though only 18% of homes were upgraded, the energy savings was much larger. This was to be expected due to the relatively low efficiency of RACs compared to central split systems in other homes (Winkler et al. 2013). Estimates for energy savings with less than 100% upgrading of RACs would follow a linear trend, meaning if 50% of homes were upgraded, 50% of the energy savings would be seen on average. Though it was beyond the scope of this work to estimate what market adoption of MSHP and CSHP could be expected, the impact would be linear with the market adoption of CSHP. For example, if 30% of RACs were replaced by SEER 33 CSHP or MSHP, the energy savings would be 9% (= 30% * 29%)

Table 4. Energy Savings from Replacing all RACs in SCE Territory

UPGRADE SCENARIO	COOLING ENERGY SAVINGS
SEER 17	20%
SEER 25	26%
SEER 33	29%

COST SAVINGS

Installed costs can vary widely, change over time and by location, and relate to proprietary business practices. Therefore, the following cost analysis should be viewed as exemplary rather than definitive.

- RAC $400/ton (baseline if it were to be used for replacement) replaced every 7.5 years. Therefore, when comparing installed costs to MSHP or CSHP, it was assumed that there were two RACs that must have been purchased in 15 years; thus, the cost for this comparison was $800/ton for a 15-year timeframe.
- MSHP costs were from the National Residential Measures Costs Database (replaced every 15 years). A curve fit was used to describe the materials costs:

$$Material\ Costs = (3.5892 * \text{SEER} + 37.465) * \text{Capacity}$$

where capacity was measured in kBtu/hr, while labor costs were assumed to be $1,000/ton (NREL 2020).

- CSHP material costs were identical to MSHP material costs. Labor costs were reduced to $250/ton (replaced every 15 years). This assumed individual units were sized at one ton each, with first-hour billing rates for installation of $250/hr with a one-hour minimum. Because the installation of each one-ton unit would be less than one hour, the labor cost was fixed at $250/ton.

All simulations assumed the cost for electricity was a constant $0.132/kWh, based on inputs for tiered residential pricing in SCE territory from NREL's OpenEI database of utility pricing (Ong and McKeel 2012); no maintenance costs were considered. The distribution of total costs of ownership after 15 years is shown in Figure 13. Total Lifetime MSHP Cost Distribution and Figure 14. Total Lifetime CSHP Cost Distribution for MSHP and CSHP, respectively. Both figures include costs for RACs as the baseline. Because the RACs were assumed to last 7.5 years, those total costs included purchasing two units during the 15-year timeframe. The distribution is much broader for RACs than either MSHPs or CSHPs due to the lower efficiency of the RACs. This means the total cost is more closely related to operating costs on these units than to the purchase price; hence, the distribution is more closely aligned with the distribution of energy use than the distributions of the heat pumps. There are still large variations in costs among different consumers, but the trends in the average costs are made clear in Figure 15. Average 15-Year Lifetime Cost Comparison (window units, MSHPs, and CSHPs) which show that CSHPs have the lowest cost of ownership, whereas RACs and MSHPs are generally quite similar regardless of efficiency.

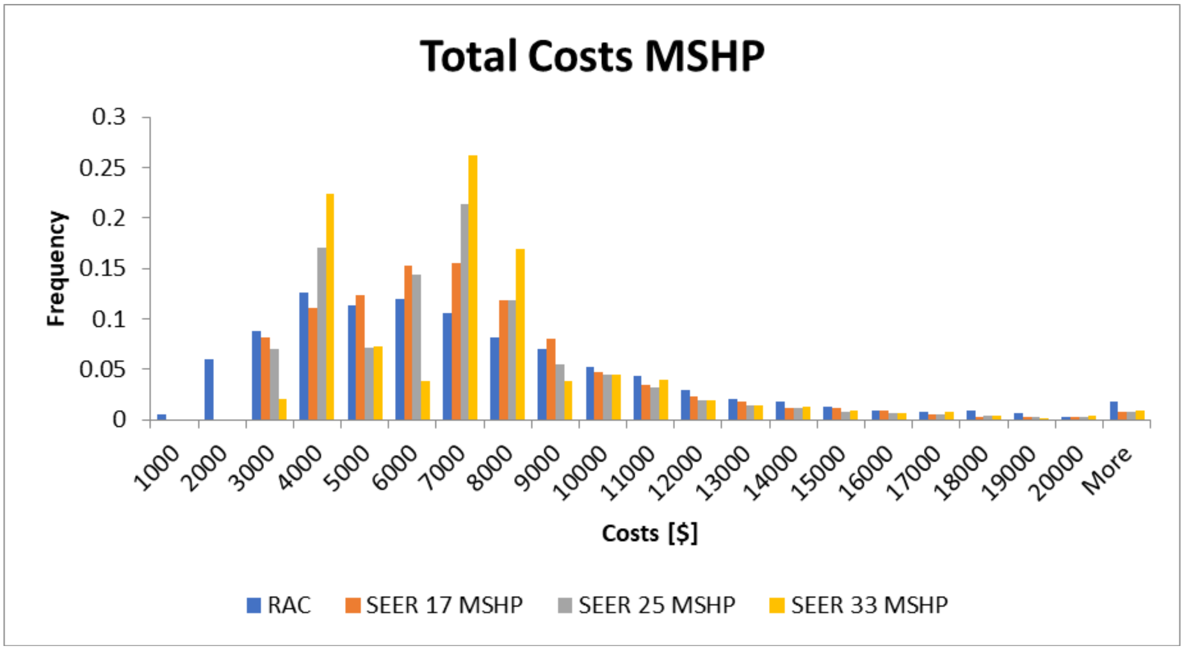


Figure 13. Total Lifetime MSHP Cost Distribution

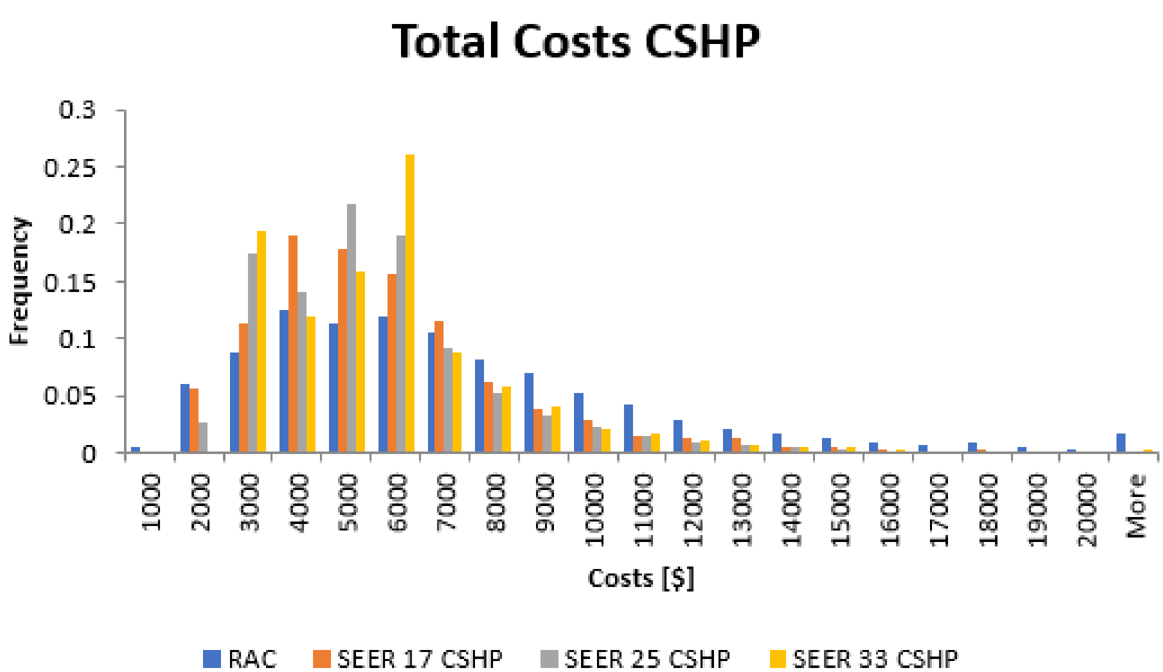


Figure 14. Total Lifetime CSHP Cost Distribution

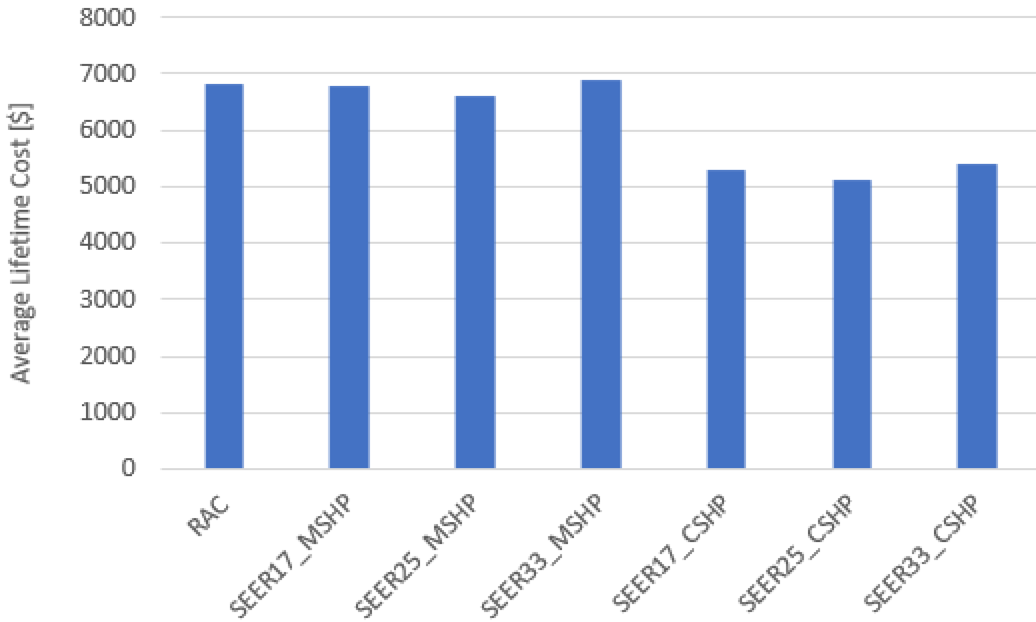


Figure 15. Average 15-Year Lifetime Cost Comparison (window units, MSHPs, and CSHPs)

The median simple payback period relative to a RAC can be calculated from the data in Figure 16. Median Simple Payback of MSHP and CSHP Relative to RACs. MSHP units are the left three bars on the graph, and the CSHP units are the right three bars on the graph. MSHPs have median payback periods in excess of the expected lifetimes of the units (~15 years) regardless of the efficiency.

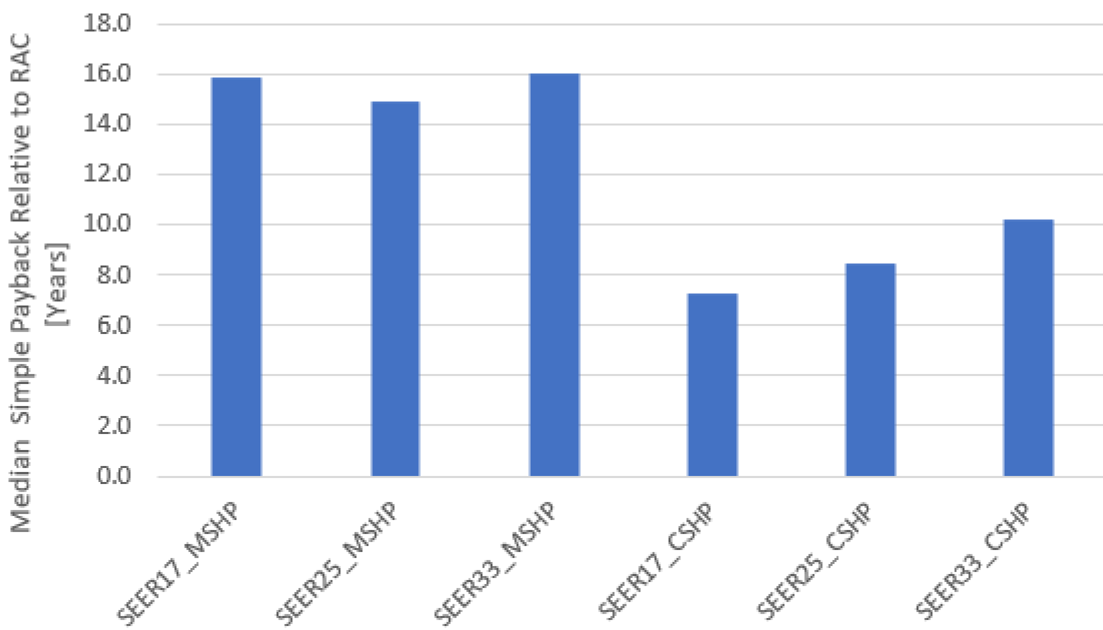


Figure 16. Median Simple Payback of MSHP and CSHP Relative to RACs

CLIMATE SPECIFIC ENERGY SAVINGS

A single-family home was modeled over each Climate Zone (CZ) in SCE territory to provide a quantitative assessment of the impact of climate energy savings the CSHP could provide. Table 5 shows the important house characteristics; it was chosen to be as representative as possible of homes in SCE territory. The percent cooling energy savings is shown in Figure 17. The savings is consistent across all climates and for all CSHP efficiency levels with cooling energy savings > 40% in all but one climate and only for the SEER 17 unit.

Table 5. Building Characteristics of Single-Family Home Simulated in Each CZ

California County	Weight
Vintage	1980s
Floor Area	2000 sf
Wall Insulation	R-11
Ceiling Insulation	R-19 (vented)
Foundation	Slab
Construction	Wood frame
Infiltration	8 ACH50
Garage	2 car
Heating	Electric furnace
Cooling (Baseline)	RAC EER 9.8

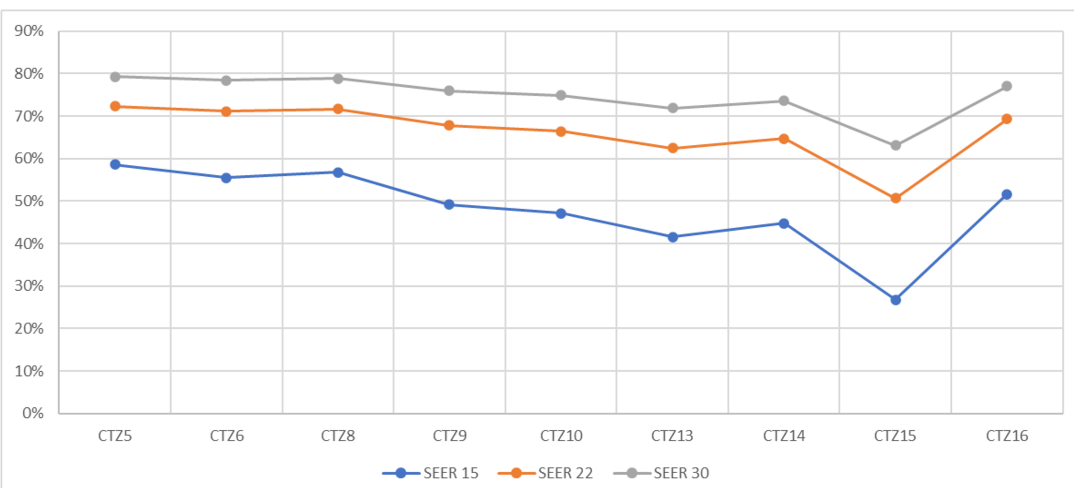


Figure 17. Percent Cooling Energy Savings of Replacing RAC with CSHP in Single-Family Home – All CZs and Three CSHP Efficiencies

CONCLUSIONS

This project evaluated the feasibility of the heat pump connection system technology for accelerating cost-effective adoption of high-efficiency MSHP systems through reduced installation costs. The study involved laboratory characterization and large-scale hourly building energy simulations. Results indicate the potential for significant cost savings without MSHP system performance penalties when the connection system was applied.

The report details the characterization of the connection system and a CSHP in a laboratory setting and assesses the energy and cost impact of high-efficiency CSHPs for residential buildings in SCE service territory. The energy and economic analysis leveraged NREL's ResStock modeling software based on the EnergyPlus hourly simulation platform.

The connection system had no noticeable adverse effects on the underlying refrigerant connection leakage performance while connected or disconnected. The leakage over several connection/disconnection cycles was also commensurate with manufacturer specifications for the individual connector components. When the connector was incorporated into an off-the-shelf MSHP and laboratory performance was compared to an identical, unmodified heat pump, it had no measurable impact on performance. The project shows that the connection system can be incorporated into existing products for notable reductions on installation costs without any negative performance impacts.

Large-scale hourly building energy simulations of 22,574 homes across 15 counties using local climate conditions were performed in SCE service territory. The analysis was based on the assumption that roughly 18% of residential buildings in SCE territory used window air conditioners. Additionally, it assumed that 100% of this population would retrofit their window air conditioners with higher-efficiency MSHP or CSHP units at SEER levels 17, 25, and 33.

The building energy simulations revealed that the increased adoption of high-efficiency heat pumps could result in up to 29% air conditioning energy savings for homes with window air conditioners. The simple payback estimates for CSHP relative to RACs was shown to be between 7 and 10 years, whereas standard MSHP models provided a payback longer than the expected lifetime of the product.

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