Light Commercial Variable Speed Heat Pump Performance Map

Final Report

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Disclaimer

Executive Summary

This project endeavored to fulfill the ambitious goal of the California Government of deploying six million heat pumps by 2030. In the process, the project team has partnered with the California investor-owned electric utilities (PG&E, SCE, and SDG&E) to conduct modeling and collect performance data of commercial Variable Capacity Heat Pumps (VCHP), i.e., unitary, single-split, and multi-split equipment with three or more steps of capacity, of greater than 5.4 Ton capacity, which will be used for aggressive incentive promotion efforts.

To accurately forecast VCHP savings levels, understanding the performance characteristics of high-efficiency VCHP equipment for use in energy modeling software is essential. This is best achieved through expanded performance maps. Accurately modeled savings estimates will lead to significantly higher incentives, which allows manufacturers to sell more high-efficiency VCHP equipment, which should lead to higher profits.

The project team collaborated with VCHP manufacturers and distributors to acquire advanced equipment performance data and entertained nondisclosure agreements (NDAs) to provide assurance that sensitive business information will remain confidential. The team will share such data only in an anonymized form with the state public utility commissions for review but will take appropriate steps to ensure that there is no way to trace the data back to the relevant manufacturer.

The market for 3-speed or higher speed VCHPs is dominated mainly by two manufacturers in North America, that offer a limited number of products. There are several manufacturers of two-speed unitary HPs, though this product was not the primary focus of research. This made the data sourcing effort a challenging exercise, although the team explored numerous avenues to source data including National Laboratories, AHRI/DOE sites, and other public databases. In 2024 the manufacturers are preoccupied with the development and optimization of their products, particularly, to comply them with DOE standards and the low GWP refrigerant changeover, which has impacted progress on VCHP data collection efforts. The gratifying news is that this research is now on the manufacturers' roadmaps and in one case has helped the manufacturer better organize its own data in-house. Efforts to acquire manufacturer data are ongoing that may result in the conversion of this data in the future into anonymized curve coefficients for use in appropriate DEER measure packages.

Variable speed/capacity VCHPs have experienced a little marginalization since the focus has so far been devoted to Air-Conditioning Units without a reversing value as against the HPs. This resulted in the VCHPs being in the early stage of Emerging Technology. While VCHPs offer immense potential of revolutionizing the landscape of energy efficient heat pumps, the uptake of this technology in the market is growing and is in the early stages of market integration.

One of the successes of the project is that the project team processed the publicly available data of three two-speed VCHPs and modeled them in EnergyPlus. The performance curves were then compared with BeOpt performance curves (DEER curve) in the DEER prototype as a proof of concept and to explain the methodology to be exercised in this project. The significant outcome of this modelling effort is that it resulted in the determination of the correlation of COPs at stage 1 and stage 2 and simplifying the 2 speed VCHP modeling option in the DEER prototype. It is recommended

to maintain the DUAL-EQUAL option while phasing out the TWO-SPEED and DUAL model options for the 2-speed DX coil model in the DEER prototype.

This project, while challenging, has been a learning exercise not only for the project team but also for wider stakeholders. Some of these pertinent aspects that are worth sharing with the broader audience, who would benefit while exercising such projects in the future, include the following-

1. Data gathering, particularly for VCHPs, can be a challenging exercise since it involves numerous datapoints involving various compressor speeds, temperatures, flow rates and capacities. The manufacturers are willing to be a part of such initiatives, however, it is a time-consuming and challenging undertaking, and one must be extremely patient in the process and allow enough time.
2. One must not solely rely on proprietary OEM data but should also explore all possible options. Unlike residential VCHPs (<65,000 Btu/h), there don't seem to be any online expanded performance maps that one could access as a workaround.
3. While conducting this type of work in the future, researchers may simultaneously explore alternative "out of the box" approaches and strategies. These may include and but not limited to the following -
    a. Continue discussions with CPUC ex-ante DEER team to streamline and update unitary LC HP equipment in DEER, including 1-speed, 2-speed, and VCHPs,
    b. Exercise "theoretical modelling or reverse engineering" to develop performance maps based on equipment ratings, engineering judgment and on theoretical VCHP performance,
    c. Scope out the possibility of conducting component-level modeling efforts with a software program such as VapCyc® or similar. This software is capable of producing results that are considered accurate and able to predict equipment efficiency ratings such as IEER or COP. It may be possible to use this software to create expanded performance maps as well, for generating the necessary curve coefficients for use in EnergyPlus, or similar. This software is capable of producing results that are considered accurate and able to predict equipment efficiency ratings such as IEER or COP. It may be possible to use this software to create expanded performance maps as well, for generating the necessary curve coefficients for use in EnergyPlus,
    d. Seek pathways to collaborate with manufacturers and other stakeholders in California that may allow testing of such products in test laboratories to collect independent test data to alleviate high test costs while sharing benefits,
    e. Look out for other aspects as the market continues to evolve with low-GWP refrigerants, additional OEMs adding LC VCHPs, cold climate VCHPs, etc., and
    f. Consider the possibility of combining the above approaches with a field data monitoring effort, potentially in conjunction with another ongoing California effort, to validate the EnergyPlus modeling results, and ultimately LC VCHP performance curve coefficients for DEER.

Abbreviations and Acronyms

Acronym	Meaning
AC	Air-conditioning
AHRI	Air-conditioning, Heating and Refrigeration Institute
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.
BLDC	Brushless Direct Current
CARB	California Air Resource Board
COP	Coefficient of Performance
CPUC	California Public Utility Commission
DAC	Disadvantaged Communities
DEER	Database of Energy Efficient Resources
DOE	Department of Energy
EE	Energy Efficiency
EER	Energy Efficiency Ratio
EPA	Environmental Protection Agency
ES	Energy Solutions
ET	Emerging Technology
GHG	Greenhouse Gas
GWP	Global Warming Potential
HP	Heat Pump
HSPF	Heating Seasonal Performance Factor

Acronym	Meaning
HTR	Hard-to-Reach
HVAC	Heating, Ventilation, and Air-Conditioning
IEER	Integrated Energy Efficiency Ratio
IOU	Investor-Owned Utility
IWBT	Indoor Wet Bulb Temperature
kWh	Kilowatt-hour
LBNL	Lawrence Birkley National Laboratory
MCLU	Multi Capacity Large Unitary
NEEA	Northwest Energy Efficiency Alliance
NREL	National Renewable Energy Laboratory
ODBT	Outdoor Dry Bulb Temperature
OEM	Original Equipment Manufacturer
ORNL	Oak Ridge National Laboratory
PA	Program Administrator
PG&E	Pacific Gas & Electric
PNNL	Pacific Northwest National Laboratory
REEO	Regional Environmental and Energy Organization
RTU	Roof Top Unit
SCE	Southern California Edison
SDG&E	San Diego Gas & Electric
SEER	Seasonable Energy Efficiency Ratio

Acronym	Meaning
TPM	Technology Priority Map
UL	Underwriters Laboratory
VCHP	Variable Capacity Heat Pump
VRF	Variable Refrigerant Flow
WH	Water Heating

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Introduction

The California Public Utilities Commission (CPUC) published its Database of Energy Efficient Resources (DEER) Resolution E-5221, containing information and direction to the California Investor-Owned Utilities (CA IOUs) regarding research activities to be undertaken to support future high efficiency DEER offerings. Section R of E-5221 directed the San Diego Gas and Electric (SDG&E), the lead HVAC program administrator (PA), to gather performance information for variable capacity equipment (CPUC 2022) and understand how VCHPs perform in the field relative to their fixed speed compressor counterparts.

CPUC Resolution E-5221 (DEER2024) governs updates to the EE portfolio measures, and Section R directed program administrators to collect and update performance data for a variety of high efficiency VCHP equipment types. The data can be with and without heat recovery and was requested to be ready for inclusion in the deemed portfolio for Program Year 2026-27. Our interpretation of Resolution E-5221 Section R is that light commercial VCHPs are in-scope equipment.[1]

Initially, coordination with the CPUC and SDG&E focused on residential (less than 65,000 BTU/h capacity) equipment in 2023. Equipment was required to be tested in accordance with 10 CFR 430 Appendix M1 and rated using the new SEER2/EER2/HSPF2 metrics. Due to updates required by the new U.S. Department of Energy (DOE) appliance standards effective January 1, 2024, VRF equipment was initially excluded from data collection. Additionally, the CPUC sought data for equipment charged with low-GWP refrigerants.

The project team began the first phase of this project in 2023 and gathered data ton equipment under 65,000 Btu/h, which was classified as "SEER2 class." In 2024, the focus has shifted to commercial-grade equipment, including variable refrigerant flow (VRF) systems and light commercial unitary heat pumps with capacities greater than 65,000 Btu/h. SDG&E, as Measure Lead, identified this as a pressing measure need, similar to other CalNEXT Fast Track projects performed previously on CPUC-requested measures. The Energy Solutions team has been coordinating with SDG&E, CPUC, and other measure developers as stakeholders to collect the remaining performance data called for under E-5221.Light commercial (LC) VCHPs are an important emerging technology for energy-efficient building electrification, offering a promising replacement for current rooftop unit (RTU) air conditioners with gas furnaces. LC VCHPs use variable-speed compressors and fans to increase efficiency. LC VCHP-specific performance maps, essential for proper modeling in EnergyPlus, are required for these systems. Existing DEER performance maps only capture equipment features such as two-speed compressors and fans, which field data suggests, perform differently than variable-speed units. Our characterization of this equipment as "emerging technology" is based on the number of manufacturers (two) that produce the equipment relative to the array of manufacturers who produce single and two-speed unitary light commercial heat pumps (over 10 manufacturers based on the AHRI database).

[1] Any equipment having capacity greater than 65,000 BTU/h but less than 240,000 BTU/h is generally termed as "light commercial".

Table 1summarizes the basic attributes of various direct expansion HVAC equipment, the relevant AHRI test procedures and the specific projects investigated by Energy Solutions during 2023 and 2024.

Table 1: Major DX HVAC Equipment Categories and VCHP Data Collection Timing

VCHP Type/Attributes	AHRI Test Procedure	Data Collection Timing
"SEER2-class" equipment which is <65,000 Btu/h cooling capacity, mini or multi split, ducted or ductless[a]	AHRI 210/240	2023
Light commercial unitary, packaged heat pumps (IEER rated)	AHRI 340/360	2024
Commercial Variable Refrigerant Flow (IEER rated)	AHRI 1230	2024

[a] Multi-split VRFs under 65,000 Btu/h are included in this category. However, due to performance characteristics that are more similar to commercial VRFs, this product category will be studied in conjunction with VRF data gathering efforts in 2024.

The overall intent of this project is to gather more information and data for inverter driven VCHPs across different size categories, model them in EnergyPlus and update DEER prototypes.

Background

To support California's goal of deploying six million heat pumps by 2030, the project team has partnered with the state's investor-owned electric utilities (PG&E, SCE, and SDG&E) to gather performance data on Variable Capacity Heat Pumps (VCHPs), including unitary, single-split, and multi-split systems with three or more capacity stages. This data will help document energy savings and drive aggressive incentive programs. As building decarbonization becomes increasingly important, the HVAC industry faces a pivotal moment. Electrifying space heating presents a key business opportunity for HVAC manufacturers, with rising demand anticipated for vapor-compression cycle equipment.

Existing deemed light commercial heat pump measure packages (SWHC013, SWHC043, SWHC046) in the eTRM do not currently include variable capacity measure offerings. The measure package with features closest to a variable capacity offering is SWHC043, where the highest Integrated Energy Efficiency Ratio (IEER) tiers are designed for equipment that includes multiple unequally sized fixed-speed compressors on a single refrigerant circuit (a form of variable capacity, but not variable speed). Furthermore, these packages cover only air conditioner offerings with no deemed offerings for variable capacity or variable speed heat pumps. Refer to the savings increase of the Multi Capacity Large Unitary (MCLU) offerings (SWHC043) vs the 2-speed RTU offerings (SWHC013) in the eTRM for an indication of the potential increase in savings. VCHPs reduce cycling losses, enable compressor lift reductions during off-design conditions, and provide better customer comfort. Adding

VCHP offerings to impacted measure packages would enable programs to claim greater savings for each VCHP and correspondingly offer greater incentives, which should have the impact of shifting the market toward light commercial VCHPs.

Objectives

The objectives of this project were to collaborate with market actors, including manufacturers and distributors, to collect performance map data on light commercial VCHPs and to model it in EnergyPlus. Efforts were devoted to collect data of low GWP refrigerant as much as possible to meet the upcoming California Air Resource Board (CARB)/Environmental Protection Agency (EPA) regulations, from multiple manufacturers and in accordance with the ASHRAE 205 specification, wherever possible. Note that data collection can be difficult for a variety of reasons, including technical complexity of the request and sensitivity around protecting confidential data. In addition to manufacturers, other nationally recognized entities such as regional energy efficiency organizations (REEOs), National Laboratories (e.g., LBNL, ORNL) and other relevant stakeholders were engaged to either provide data or insights regarding other existing datasets that could be used to satisfy the goals of this effort.

One project goal was to update unitary measure packages to include both AC and HP options, with IEER as the key metric for AC and IEER and COP for HP. The overall objective was to pursue high efficiency tiers for VCHPs to help the market to achieve high efficiency, where capturing part load performance of a variable capacity compressor was the heart of the process. Each available VCHP model was to be modeled in EnergyPlus, including part-load operation under various operating conditions and across different building types. This was to ensure that any equipment meeting the required IEER values is qualified for incentives. The primary objective was to gather performance maps of inverter-driven light commercial VCHPs and analyze their EnergyPlus modeling outputs.

VCHP Technology, its Advantages and Unique Features[2]

VCHPs capture the modulation feature of the compressor speed to meet space conditioning needs. The VCHP has been appropriately defined by AHRI 210/240 – 2024, described below.

- Variable Capacity System (Variable Capacity Air-conditioner or Variable Capacity Heat Pump): An air-conditioner(s) or heat pump(s) that has either a i) a *variable capacity compressor*, or ii) a *digital compressor*, and that controls the system by monitoring system operation and automatically modulating the compressor output, indoor air flow, and other system parameters as required in order to maintain the indoor room temperature.
- *Variable Speed Compressor:* A compressor that has capability of varying its rotational speed in non-discrete stages or steps from low to full using an inverter or variable frequency drive.
- *Multiple Capacity (Multiple Stage) Compressor.* A compressor having three or more stages of capacity that has neither an inverter, nor variable frequency drive, or a group of compressors with three or more stages of capacity.

[2] Adapted from *Adding SEER2 VCHP Offerings to DEER, SDGE Report*, 2023

VCHPs vs Constant Speed Heat Pumps

VCHPs are growing in popularity and employ strategies (usually an inverter driven compressor and fans) that enable capacity and power modulation during part load conditions. VCHPs may operate at part load when the outdoor temperature is mild or internal building loads are less than the design loads (e.g., the zone is empty on a very hot day). While a fixed speed or a two-speed heat pump may cycle and over compress the refrigerant when it is not necessary, a VCHP should be capable of employing more advanced controls and capacity modulation techniques to better match the HVAC equipment capacity to the building load. The ability to cycle and match equipment capacity to zone loads manifests in two basic energy efficiency measures as described below.

REDUCED CYCLIC LOSSES

Fixed-speed and two-speed heat pumps must frequently cycle between a few discrete capacity levels, typically 100%, 75% or 66%, to meet the indoor temperature setpoint, since it is rare for the load to perfectly match a capacity level. On the contrary, VCHPs are capable of more closely matching the equipment capacity delivered to the zone load, resulting in significantly reduced "cycling losses". Note that all compressors do have a low-speed limit (our research suggests this to be roughly 25-33% of full speed for VCHPs) and below this point, the unit must cycle.

REDUCED COMPRESSOR LIFT

VCHPs can result in reduced compressor "lift" in certain conditions (i.e., the pressure difference between the suction and discharge ports) of the compressor. For example, at design conditions (95°F ambient), the refrigerant running through the condenser coil must exceed this temperature by a meaningful amount (on the order of 10°F) so that heat transfer can occur. However, if it is only 75°F ambient, the condenser head pressure (and corresponding saturation temperature) can be "reset" to a lower value (e.g., down from 105 to 85°F), which can save significant compressor energy.

Methodology & Approach

The current set of deemed heat pump incentive offerings are based on decades-old equipment performance data based on single and two-stage equipment. Outdated heat pump performance data results in inaccurate modeling of equipment energy consumption. This leads to utility program incentive offerings that fail to appropriately reward the efficiency and greenhouse gas emissions reduction potential that VCHPs provide. The use of outdated heat pump performance data slows the pace of market transformation and obstructs the goals set by the state of California and the nation.

DEER recently migrated its modeling system to EnergyPlus and in the process, the CPUC ex-ante team assembled a set of modeling options and objects for unitary HPs that are confusing to navigate and excludes VCHPs. In order to add value, our team has taken a pass at consolidating and recommending the simplification of 2 speed DX coil option for the performance curves, and ratio of COP2/COP1 vat compressor speeds to accurately model unitary HPs.

To close the LC VCHP data gap in DEER, the approach involved reaching out to OEMs and acquiring performance data directly from them. A key lesson learned in 2023 was not to rely solely on proprietary OEM data. However, unlike residential SEER2 VCHPs, no online expanded performance maps were available as an alternative solution.

The engagement efforts with Original Equipment Manufacturers (OEMs) were highly time consuming, challenging and required a high level of perseverance and patience. One major OEM signed the NDA and agreed to share the data but due to their pressing internal requirements, they were not able to share it before the submission of this report to CalNEXT. There is, however, some silver lining in that the OEM has promised to share the data before the end of 2024 (see further details later in the "Stakeholders Engagement" section).

Emerging VCHP Systems and Novel Designs

A review of recent literature highlights several noteworthy advancements from various manufacturers, which are summarized below.

Manufacturer 1

A commercial-packaged rooftop system was launched in the market in 2024 with capacities varying from 45-75 tons, air flow of up to 29,000 cubic feet per minute (cfm) and featuring a lower GWP A2L refrigerant. The design uses an inverter driven scroll compressor, electronic expansion valve, variable speed ECM fan motors or VFDs on all fans. These features result in improved temperature/humidity control and energy efficiency. Such a system can deliver an Integrated Energy Efficiency Rating (IEER) of over 20.0. These systems are ideal for any low-rise commercial buildings like schools, retail, offices, and medical facilities, as well as in dedicated outdoor air applications.

Manufacturer 2

A wide range of air-source heat pumps (ASHP) are currently available in capacities ranging from 6-70 tons with variable capacity and variable speed compressors, and other features such as energy recovery, modulating hot gas reheat, as well as auxiliary supplemental heat to allow a unit to operate in heat pump mode. Currently, such VCHPs are available with refrigerant R410A compressors, while systems with low GWP refrigerants are expected to be released soon.

Manufacturer 3

A newer VCHP design has been introduced that uses a brushless DC (BLDC) inverter motor in both the compressor and the fans that resulted in the energy efficiency improvement by 11% compared with the AC inverter compressor. The BLDC design has no slip losses while the noise is also reduced due to its low torque ripple design. The compressor is a high-pressure type that smoothens oil lubrication. The BLDC fan motor consumes 35% less power and improves motor output by 75%, as compared with the normal induction motor.

Data Collection and Engagement Strategy

To gather comprehensive performance data for VCHP units, the project team employed a multifaceted engagement strategy. This strategy involved both direct communication with manufacturers and leveraging existing professional relationships through Energy Solution contacts.

1. Direct Manufacturer Engagement:
    a. Email correspondence and conference calls: The project team contacted manufacturers via email and scheduled conference calls to discuss the project's objectives. These communications aimed to build rapport and encourage manufacturers to share their performance data.

    b. Highlighting Benefits: During these interactions, the team emphasized the advantages of integrating the manufacturer's data into the Investor-Owned Utility (IOU) energy efficiency

(EE) portfolio, highlighting potential energy savings, the key benefits of efficiency improvements, and how it may help OEMs to capture more market share by selling more high efficiency units as a result of higher incentives.

2. Leveraging Professional Networks:
    a. Energy Solution Contacts: Utilizing established relationships through its Trade Ally Management (TAM) team, the team accessed a broader network of manufacturers. These contacts, developed over time, were instrumental in facilitating introductions and securing meetings with key industry players.
3. Stakeholder Engagement:
    a. **Market Actors**: The team hosted calls with relevant VCHP market actors, including manufacturers and distributors, to explain the project scope and request necessary data.
    b. **National and Regional Organizations**: The project team also approached Lawrence Berkeley National Laboratory (LBNL) and Oak Ridge National Laboratory (ORNL); however, they didn't have any data to support the project's goals.

Data Request and Template Utilization

1. Data Solicitation:
    a. **Structured Calls**: The team organized and hosted calls where the project scope was thoroughly explained to participants. Following these explanations, a formal request for data was made, targeting specific performance metrics and datasets from manufacturers and other market actors.
    b. **Existing Datasets**: Engagement with entities like national labs and REEOs helped identify and utilize existing datasets, which could be integrated into the project's data repository to enhance comprehensiveness and reliability.
2. ASHRAE 205 Template:
    a. Leveraging Standards: The ASHRAE 205 template was employed extensively to standardize the data collection process. This template provided a structured format for data submission, ensuring consistency and ease of integration across different data sources.

By combining direct engagement with manufacturers, leveraging established professional networks, and collaborating with key national and regional organizations, the project team tried all possible options to gather essential data systematically.

Communication and Coordination Efforts

Data Collection

The project team exercised the following strategies to source data from a range of outlets to overcome the challenges and mitigate the data gap issues.

METHOD 1: SOURCING DATA DIRECTLY FROM THE MANUFACTURERS

The team believed that this was potentially a viable option to source the data directly from the manufacturers in a tight time frame and to process it with EnergyPlus to draw performance maps for inclusion in the DEER modeling framework. The project team established contacts with numerous manufacturers to secure data before the submission date of this project in November, 2024. However, the project team managed to source only some data on 2-speed VCHPs from other sources, including AHRI and/or DOE EERE, manufacturers' websites and data published at third-party websites.

This method served as the primary mechanism for obtaining data. To address concerns about data accuracy, collaboration with manufacturers was aimed at understanding how expanded performance maps related to DOE/AHRI-rated conditions, which were third-party validated. The plan involved sourcing manufacturer attestations on this issue.

METHOD 2: SOURCING DATA FROM AUTHENTICATED NON-OEM SOURCES

This method was suggested as a potential mechanism for validating OEM data. However, for the specific equipment under study in 2024 (i.e., LC unitary VCHP), no promising leads were identified in this area. Nonetheless, some preliminary thoughts on this method are shared.

1. National Laboratories (e.g. ORNL, LBNL) either don't have such data or are unwilling to share. Despite several outreach attempts, the team hasn't succeeded in penetrating the firewall thus far. The team was not optimistic that this would be a viable option for our projects.
2. Independent Research Test Laboratories (Intertek, UL, etc.): These laboratories seemed to have specific NDAs with most clients that prohibit them to share any data with outside parties, such as ES, and hence it was not possible for ES team to penetrate this firewall in any meaningful way.
3. Public Sources (such as ASHRAE, NEEA, etc.) didn't seem to have any data that they could share with us. The ES team had exhausted all such options but without any success.

METHOD 3: TESTING VCHP AND VRF UNITS AT TESTING LABORATORIES

This path would indeed be most valuable in obtaining the most reliable equipment performance data via an independent source under a range of operating conditions that could be trusted by all stakeholders. However, by no means can it be considered a meager task, and it would require a significant amount of funding (of the order of a few million dollars), co-ordination, commitment, planning and teamwork. This is something that all stakeholders may consider for future projects as it promises to overcome all barriers that the current projects are currently undergoing, however, under the current prevailing circumstances, it was not considered to be feasible.

METHOD 4: OUT OF THE BOX APPROACH;" THEORETICAL MODELLING EXERCISE"

The project team had considered to exercise "theoretical modelling or reverse engineering" to develop performance maps based on equipment ratings, engineering judgment and on theoretical VCHP performance. The team approached this cautiously and did not feel comfortable pursuing it further at this stage due to challenges with numerous unknowns, the risks of extrapolating a curve that cannot be adequately validated, and concerns about its potential inaccuracy. However, this is something the team may consider exploring in the future.

Stakeholder Engagement

The project team reached out to numerous stakeholders, including equipment manufacturers, distributors, National Laboratories (e.g., ORNL, LBNL) and regional energy efficiency alliances (e.g., NEEA). In addition, the team facilitated monthly interactive Zoom meetings with personnel of CPUC, DNV, Big Ladder Software and other consulting firms (e.g., TRC Companies, Solaris Technical). The team presented their progress on the data search, modelling efforts and the other relevant pressing issues and challenges of the project. These meetings were cordial, productive and generated numerous useful ideas and pathways to resolve issues and the way forward. Some of this feedback includes:

4. Risks with the manufacturer-centric approach (including data accuracy, the likelihood of manufacturers following through, and ability to work with confidentially obtained data) were discussed
5. There were follow-up questions about past collaboration and technical discussions, including engagement with EnergyPlus experts, as well as future coordination.
6. Interest was expressed in improving modeling for this sector incrementally.

To engage OEMs and demonstrate the value of partnering with Energy Solutions, the team developed a one-page business case document (see Appendix A). This document outlines the key benefits and rationale for sharing data with Energy Solutions. Key highlights of the business case include:

1. Participating with Energy Solutions will allow the OEM to leverage enhanced incentive programs based on accurate performance data resulting in increased sales of high efficiency VCHPs,
2. The proprietary data of the OEM will be fully protected after signing of NDA,
3. By contributing performance data, the OEM gains a strategic advantage to influence the structure of incentive programs, leading to higher sales of their premium products.
4. Success in California will be replicated across 14 additional states where Energy Solutions operates, scaling the benefits.
5. This partnership offers the OEM a unique opportunity to lead the HVAC market into the future, driving both short-term sales and long-term strategic gains.

In the process, Energy Solutions reached out to several OEMs about their LC VCHP products in the United States.

It was revealing that the market is dominated by only two major OEMs making outreach challenging. Both these manufacturers, however, responded to our inquiry with interest. Discussions with the manufacturers continue as of the submission time of this report in November 2024. However, they have so far been unable to provide the necessary performance data in time for this project report. In this context, the OEM faced some underlying challenges and shared the following sentiments:

1. The OEM had several other organizations requesting similar types of information and support, which is often challenging for the OEM to prioritize.
2. The thoughtful explanation of how DOE and other Federal regulatory requirements are impacting team's capacity, and
3. The earliest that the OEM would be able to share the performance data information with the project team would be the very end of 2024.

Unfortunately, though we do not have performance data of VCHPs in time for this deliverable, the project team processed the publicly available data of a two-speed VCHP and modeled it in EnergyPlus. The performance curves were then compared with BeOpt performance curves (DEER curves) in the DEER prototype as a proof of concept and to explain the methodology to be exercised in this project. In addition, this data validated the existing 2-speed DEER curves, which implies that the 2-speed DEER curves may not need to be replaced. Of course, this does not resolve the issue that DEER is without dedicated LC VCHP performance curves, and this data gap remains unresolved as of this report.

Validation of Accuracy of Manufacturer Performance Data

A given manufacturer's catalog data typically includes AHRI-rated heating/cooling capacity and efficiency, as shown in Table 2. Figure 1 shows AHRI certification from AHRI database as reference. Additionally, the catalog data provides the performance data under various indoor and outdoor conditions, as listed in Table 3 (in Appendix B). This allows us to compare the AHRI-rated data with the extended performance data to validate its accuracy. This comparison can give us some confidence in the accuracy of the manufacturer's catalog data, even if it is based on just one data point for heating or cooling.

Table 2: Example of AHRI System Matches

Model	Cooling BTU/h	IEER	EER	High Heating (BTU/h)	Low Heating (BTU/h)	High Heat COP	Low Heat COP
A	69,000	14.1	11	66,000	41,000	3.4	2.25
B	88,000	14.1	11	87,000	50,000	3.4	2.25
C	115,000	14.1	11	114,000	70,000	3.4	2.25
D	178,000	13.5	10.6	170,000	98,000	3.3	2.05

NOTES:

1. Net capacity includes indoor blower motor heat deduction, while gross capacity does not.
2. AHRI certified to AHRI Standard 230/240
3. Cooling Ratings: 95ºF outdoor air, 80ºF (db)/43ºF (wb) indoor air
4. High Temperature Heating Ratings: 47ºF (db)/43ºF (wb) outdoor air, 70ºF (db) indoor air
5. Low Temperature Heating Ratings: 17ºF (db)/15F (wb) outdoor air, 70ºF (db) indoor air

AHRI CERTIFIED®
www.ahridirectory.org

Certificate of Product Ratings

AHRI Certified Reference Number : [redacted] Date : 05-20-2024 Model Status : Active

Brand Name : [redacted]

Model Number : [redacted]

Indoor Unit Model Number : [redacted]

Series Name : [redacted]

AHRI Type : HRCU-A-CB

Refrigerant Type : R-410A

Hertz : 60

Sold In? : USA, Canada, Outside USA and Canada

Rated as follows in accordance with the following test procedures and subject to verification of rating accuracy by AHRI-sponsored, independent, third-party testing:

-AHRI Standard 340/360-2022, Performance Rating of Commercial and Industrial Unitary Air-Conditioning and Heat Pump Equipment

-AHRI Standard 365-2009, Commercial and Industrial Unitary Air-Conditioning Condensing Units

Cooling Capacity 95F/Cooling Capacity 95F at 230v : 69000/69000

EER 95F/EER 95F at 230v : 11.00/11.00

Heating Capacity 47F/Heating Capacity 47F at 230v : 66000/66000

COP 47F/COP 47F at 230v : 3.40/3.40

Heating Capacity 17F/Heating Capacity 17Fat 230v : 41000/41000

COP 17F/COP 17Fat 230v : 2.25/2.25

IEER/IEER at 230v : 14.1/14.1

The following data is for reference only and is not certified by AHRI

Full Load Indoor Coil Air Quantity (scfm) : 2600

Figure 1 AHRI certification for MODEL 3

Appendix B shows the cooling capacity at full load. So far, the project team has used the performance data from publicly available data of a two-speed Heat pump unit to generate the multiple performance curves (OEM curve in the figures below). The performance curves were compared with BeOpt two-speed performance curves (DEER curve) in the DEER prototype. The results show that both sets of performance curves exhibit a similar trend as shown in the following figures. The heating capacity increases, and the heating energy efficiency ratio (EIR) decreases as the outdoor temperature rises. In contrast, the cooling capacity decreases while the EIR increases with rising outdoor temperatures.

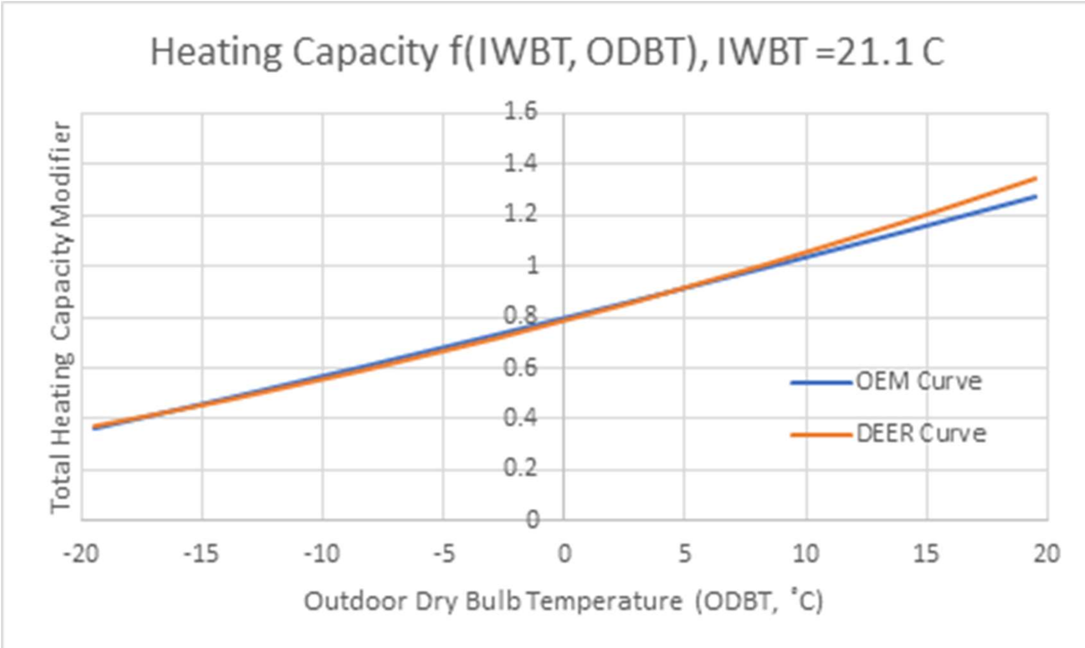

Figure 2 Heating EIR f(IDB, ODB), Model 3 vs DEER

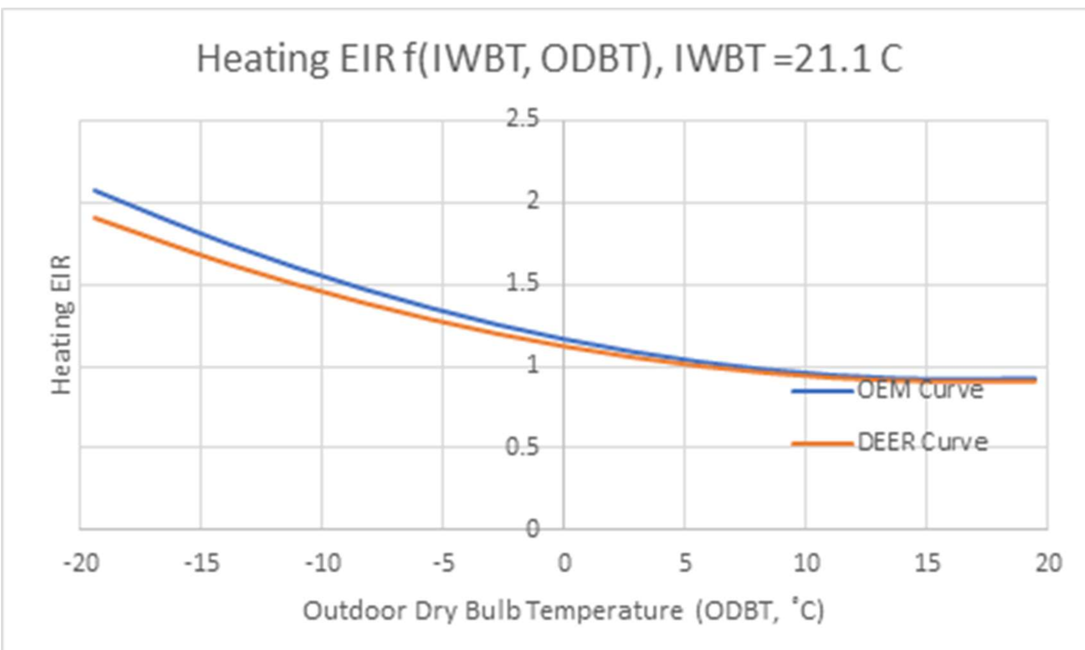

Figure 3 Heating Capacity f(IDB, ODB), Model 3 vs DEER

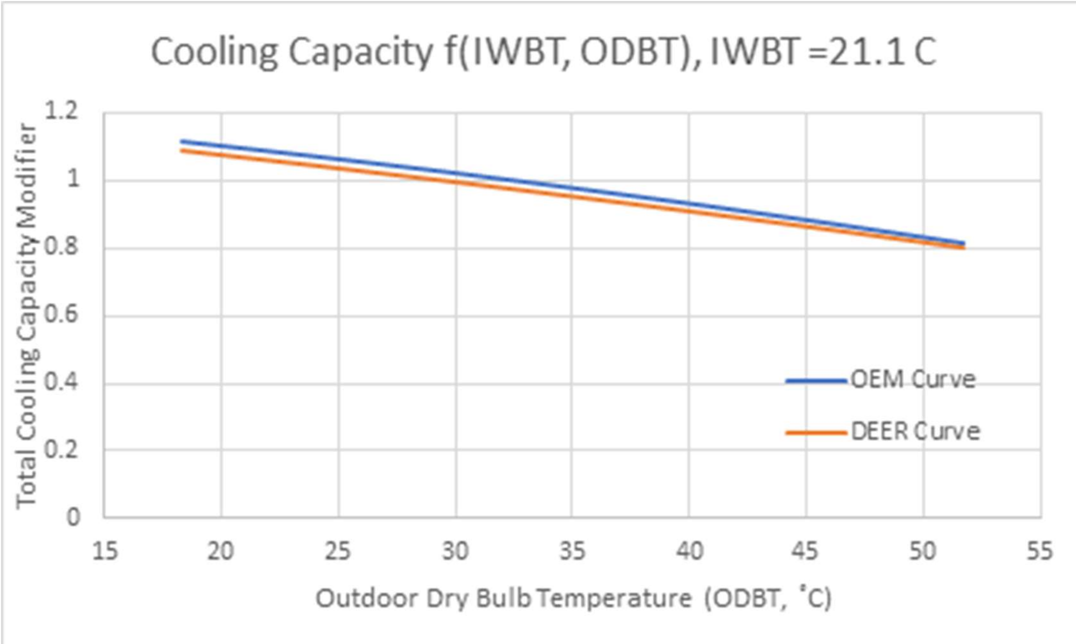

Figure 4 Cooling Cap f ID & OD Temps, Model 3 vs DEER

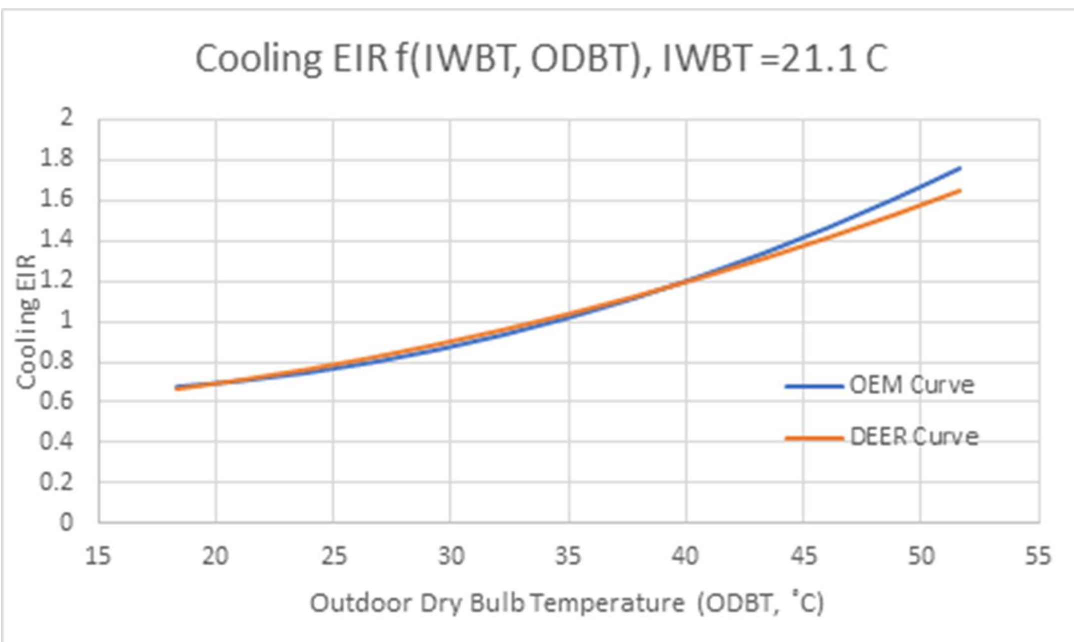

Figure 5 Cooling EIR f ID & OD Temps, Model 3 vs DEER

Findings

Currently, DEER prototypes use EnergyPlus objects (Coil:Cooling:DX:Multispeed and Coil:Heating:DX:Multispeed) to model VCHP. The multispeed DX coil can have from two to four compressor speeds. For each compressor speed, the multispeed DX object uses performance information at reference conditions along with the curve fits for cooling/heating capacity and efficiency to determine VCHP operation at off-reference conditions as shown below. VCHP performance curves can be generated by fitting manufacturer's catalog data. One set of the performance curve coefficients (Model 1) is listed below in Table 4.

Total Cooling Capacity Function of Temperature Curve:

$$TotCapFTemp_{clg} = a + b(T_{wb,i}) + c(T_{wb,i})^2 + d(T_{db,o}) + e(T_{db,o})^2 + f\,(T_{wb,i})(T_{db,o})$$

Cooling Energy Input Ratio Function of Temperature Curve:

$$EIRFTemp_{clg} = a + b(T_{wb,i}) + c(T_{wb,i})^2 + d(T_{db,o}) + e(T_{db,o})^2 + f\,(T_{wb,i})(T_{db,o})$$

Total Cooling Capacity Function of Flow Fraction Curve:

$$TotCapFTemp_{clg} = a + b(FF) + c(FF)^2$$

Cooling Energy Input Ratio Function of Flow Fraction Curve:

$$EIRFTemp_{clg} = a + b(FF) + c(FF)^2$$

Heating Capacity Function of Temperature Curve:

$$TotCapFTemp_{htg} = a + b(T_{db,i}) + c(T_{db,i})^2 + d(T_{db,o}) + e(T_{db,o})^2 + f\,(T_{db,i})(T_{db,o})$$

Heating Energy Input Ratio Function of Temperature Curve:

$$EIRFTemp_{htg} = a + b(T_{db,i}) + c(T_{db,i})^2 + d(T_{db,o}) + e(T_{db,o})^2 + f\,(T_{db,i})(T_{db,o})$$

Heating Capacity Function of Flow Fraction Curve:

$$TotCapFTemp_{htg} = a + b(FF) + c(FF)^2$$

Heating Energy Input Ratio Function of Flow Fraction Curve:

$$EIRFTemp_{htg} = a + b(FF) + c(FF)^2$$

where:

$TotCapFTemp_{clg}$ is Total cooling capacity factor, equal to 1 at reference conditions.

$T_{wb,i}$ is Indoor wetbulb temperature (°C).

$T_{db,o}$ is Outdoor entering drybulb temperature (°C).

$EIRFTemp_{clg}$ is Energy input ratio to cooling output factor.

$TotCapFTemp_{htg}$ is Heating capacity factor, equal to 1 at reference conditions.

$T_{db,i}$ is Indoor drybulb temperature (°C).

$EIRFTemp_{htg}$ is Energy input ratio to heating output factor.

FF is Ratio of actual air flow rate across the heating/cooling coil to the rated air flow rate.

DEER prototype has three options for 2 speed DX coil including TWO-SPEED, DUAL, and DUAL-EQUAL DUAL-As indicated IN Table 3, each option has different default settings for cooling and heating COPs at stage 1 and stage 2. Table 4 list default settings of VARIABLE for 4 speed DX coil.

Table **3**: Existing DEER 2 Speed DX Coil Options

2 Speed DX Coil	Cooling		Heating	
	COP1	COP2	COP1	COP2
TWO_SPEED	cool_coil_cop[1]*1.0149	cool_coil_cop	heat_coil_cop*1.0149	heat_coil_cop
DUAL	cool_coil_cop / 0.9	cool_coil	heat_coil_cop / 0.9	heat_coil_cop
DUAL-EQUAL	cool_coil_co	cool_coil_co	heat_coil_cop / 0.9	heat_coil_cop

[1]: cool_coil_cop is default or user defined cooling COP

[2]: heat_coil_cop is default or user defined heating COP

As shown above in Table 3, the ratio of COPs at stage 2 and stage 1 (COP2/COP1) are 0.9 and 0.98533 (1/1.0148883375) for existing 2 speed DX coil in the DEER prototype. However, based on our data collection and analysis, 3 models of 2 speed DX coil have an average ratio of 0.627904 COP2/COP1. The COP2/COP1 ratio should be adjusted to 0.627904 to more accurately reflect the performance of the two-speed DX coil.

Table **4**: Existing DEER 4 Speed DX Coil Option

4Speed DX Coil	Cooling				Heating			
	COP1	COP2	COP3	COP4	COP1	COP2	COP3	COP 4
VARIABLE	cool_coil_cop[1]/0.7	cool_coil_cop/0.75	cool_coil_cop/0.9	cool_coil_cop	heat_coil_cop[1]/0.7	heat_coil_cop/0.75	heat_coil_cop/0.9	heat_coil_cop

[1]: cool_coil_cop is default or user defined cooling COP

[2]: heat_coil_cop is default or user defined heating COP

Table 5: Ratio of COPs at stage 1 and stage 2 for 2 Speed DX Coils

2 Speed DX HP	COP1	COP2	COP2/COP1	Mean COP2/COP1
Model 1	7.62	5.05	0.662126	
Model 2	7.15	4.28	0.598754	0.627904
Model 3	7.20	4.49	0.622832	

Tables 6 -11 below list the performance curve coefficients for models 1-3.

Table 6: Model 1 (72kBtu/h) VCHP Performance Curve Coefficients at Stage 1

Curve	Curve Coefficient					
	a	b	c	d	e	f
$TotCapFTemp_{clg}$	0.425358	0.033392	0.000138	0.0054251	-0.0001	-0.00028
$EIRFTemp_{clg}$	0.964966	-0.02378	0.000626	0.001994	0.000725	-0.00103
$TotCapFff_{clg}$	0.524752	0.772277	-0.29703			
$EIRFff_{clg}$	1.686176	-1.19342	0.507242			
$TotCapFTemp_{htg}$	0.800427	0	0	0.023313	0.000056	0
$EIRFTemp_{htg}$	1.164950	0	0	-0.029723	0.000891	0
$TotCapFff_{htg}$	0.859497	0.217142	-0.076638			
$EIRFff_{htg}$	1.869039	-1.606058	0.737019			

Table 7: Model 1 (72kBtu/h) VCHP Performance Curve Coefficients at Stage 2

Curve	Curve Coefficient					
	a	b	c	d	e	f
$TotCapFTemp_{clg}$	1.135048	-0.02791	0.001815	0.004621	-4.7E-05	-0.00056
$EIRFTemp_{clg}$	0.226983	0.059637	-0.00166	-0.0096	0.000718	-0.00045
$TotCapFff_{clg}$	0.662698	0.551587	-0.21429			
$EIRFff_{clg}$	1.370512	-0.63632	0.265809			
$TotCapFTemp_{htg}$	0.800427	0	0	0.023313	0.000056	0
$EIRFTemp_{htg}$	1.164950	0	0	-0.029723	0.000891	0
$TotCapFff_{htg}$	0.859497	0.217142	-0.076638			
$EIRFff_{htg}$	1.869039	-1.606058	0.737019			

As indicated above, collected data from the manufacture was utilized to generate the following performance curves for 2 speed DX coil in in EnergyPlus:

- Cooling capacity function of indoor/outdoor temperature
- Cooling energy input ratio function of indoor/outdoor temperature
- Cooling capacity function of flow fraction
- Cooling energy input ratio function of flow fraction
- Heating capacity function of indoor/outdoor temperature
- Heating energy input ratio function of indoor/outdoor temperature
- Heating capacity function of flow fraction
- Heating energy input ratio function of flow fraction

The project team determined that the other input fields needed to describe the HVAC system could remain the same as what is used for DEER default settings. Figure 6 through Figure 9 show the comparison of one of the OEM VCHP curve sets, Model 3, against the DEER baseline two speed BeOpt curve.

Table 8: Model 2 (96 kBtu/h) VCHP Performance Curve Coefficients at Stage 1

Curve	Curve Coefficient					
	a	b	c	d	e	f
$TotCapFTemp_{clg}$	0.670919	0.019585	0.000525	0.00154753	-4.9E-05	-0.00036
$EIRFTemp_{clg}$	0.437762	0.008481	-3.6E-05	0.006164	0.000769	-0.00109
$TotCapFff_{clg}$	0.57377	0.672131	-0.2459			
$EIRFff_{clg}$	1.51622	-0.8101	0.293882			
$TotCapFTemp_{htg}$	0.806153	0	0	0.022804	3.87E-5	0
$EIRFTemp_{htg}$	1.111213	0	0	-0.025136	0.000902	0
$TotCapFff_{htg}$	0.8216887	0.276855	-0.09854			
$EIRFff_{htg}$	1.8690394	-1.60606	0.737019			

Table 9: Model 2 (96 kBtu/h) VCHP Performance Curve Coefficients at Stage 2

Curve	Curve Coefficient					
	a	b	c	d	e	f
$TotCapFTemp_{clg}$	0.881453	-0.00053	0.001068	0.004516	-6.5E-05	-0.00052
$EIRFTemp_{clg}$	0.549776	0.024065	-0.00076	-0.00718	0.000581	-0.00028
$TotCapFff_{clg}$	0.626927	0.613566	-0.24049			
$EIRFff_{clg}$	1.305661	-0.53704	0.231378			
$TotCapFTemp_{htg}$	0.806153	0	0	0.022804	3.87E-05	0
$EIRFTemp_{htg}$	1.111213	0	0	-0.025136	0.000902	0
$TotCapFff_{htg}$	0.8216887	0.276855	-0.09854			
$EIRFff_{htg}$	1.8690394	-1.60606	0.737019			

Table 10: Model 3 (120 kBtu/h) VCHP Performance Curve Coefficients at Stage 1

Curve	Curve Coefficient					
	a	b	c	d	e	f
$TotCapFTemp_{clg}$	0.712119	0.008328	0.000661	0.005077	-0.000118	-0.000233
$EIRFTemp_{clg}$	0.489348	0.022456	-0.000348	-0.002933	0.000861	-0.001097
$TotCapFff_{clg}$	0.575626	0.698585	-0.27421			
$EIRFff_{clg}$	1.568232	-0.98724	0.419008			
$TotCapFTemp_{htg}$	0.821257	0.000000	0.000000	0.021542	-0.000007	0.000000
$EIRFTemp_{htg}$	1.088401	0.000000	0.000000	-0.022207	0.000875	0.000000
$TotCapFff_{htg}$	0.820990	0.287972	-0.108963			
$EIRFff_{htg}$	1.882497	-1.516539	0.634042			

Table 11: Model 3 (120 kBtu/h) VCHP Performance Curve Coefficients at Stage 2

Curve	Curve Coefficient					
	a	b	c	d	e	f
$TotCapFTemp_{clg}$	1.211816	-0.0356	0.001987	0.00480332	-6E-05	-0.00054
$EIRFTemp_{clg}$	0.227108	0.064075	-0.0017	-0.00995	0.000672	-0.00045
$TotCapFff_{clg}$	0.649351	0.584416	-0.23377			
$EIRFff_{clg}$	1.335507	-0.59203	0.256522			
$TotCapFTemp_{htg}$	0.821257	0.000000	0.000000	0.021542	-0.000007	0.000000
$EIRFTemp_{htg}$	1.088401	0.000000	0.000000	-0.022207	0.000875	0.000000
$TotCapFff_{htg}$	0.820990	0.287972	-0.108963			
$EIRFff_{htg}$	1.882497	-1.516539	0.634042			

Table 12 shows the set of inputs used for the modeling exercise that was conducted to compare the annual electric consumption. DEER default heating and cooling COPs were fixed across the four sets of performance maps.

Table 12: EnergyPlus Modeling Case Input Description for Final Runs to Determine Median Curves

Modeling Case (Performance Curves)	Cooling COP	Heating COP	Coil Type	Number of Coil Speeds	Cycling loss enabled?
DEER 2-speed BeOpt (DAUL EQUAL)	3.9	3.59	Multi-speed	2	Yes
Model 1	3.9	3.59	Multi-speed	2	Yes
Model 2	3.9	3.59	Multi-speed	2	Yes
Model 3	3.9	3.59	Multi-speed	2	Yes

As depicted in Figure 6, the annual electricity consumptions are very similar among four sets of performance curves including DEER 2-speed BeOpt (DUAL-EQUAL) and three manufacturer's curves. This indicates the current DEER prototype uses the appropriate performance curves for 2 speed DX coil. Since the DEER DUAL-EQUAL 2-speed model closely aligns with the manufacturer's performance data and serves as the default option for 2-speed DX coils, it is recommended to keep the DUAL-EQUAL model while phasing out the TWO-SPEED and DUAL model options. This would simplify the modeling approach for 2-speed DX coils in the DEER prototype.

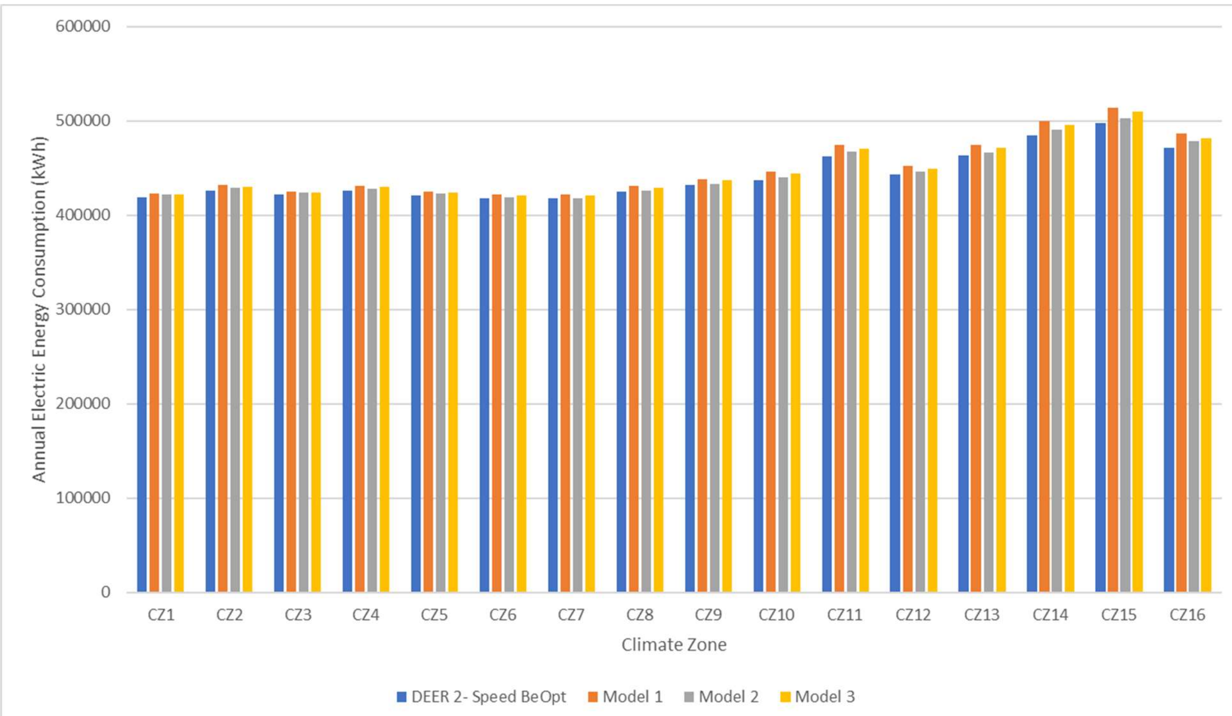

Figure 6: Annual Electric Energy Consumption Comparison between DEER 2 speed BeOpt and OEM curves

Conclusions

This project summarizes the outcome of the background research and modelling results on the viability of LC VCHPs for incentives promotion efforts. To accurately forecast VCHP savings levels, understanding the performance characteristics of high-efficiency VCHP equipment for use in energy modeling software is essential. This is best achieved through expanded performance maps. Accurately modeled savings estimates lead to significantly higher incentives, which allows manufacturers to sell more high-efficiency VCHP equipment, which should lead to higher profits.

There were three OEMs of LC VCHPs with two being the major shareholders. The team reached out to OEMs and other stakeholders to collect performance data. Discussions with OEMs are ongoing and will continue after this report. For this deliverable, we modeled a 2-speed unitary HP with used the publicly available data of a two-speed DX HP and modeled it in EnergyPlus.

After analyzing three sets of 2 speed DX coil performance curves from the manufacturer, the major outcomes of the modelling exercise are two-fold-

1. The COP2/COP1 ratio be adjusted to 0.627904 to more accurately reflect the performance of the two-speed DX coil.
2. The team recommends the DUAL-EQUAL option be maintained while phasing out the TWO-SPEED and DUAL model options for the 2-speed DX coil model in the DEER prototype.

Next Steps

- Continue discussions with VCHP OEMs to successfully acquire expanded performance maps. One OEM has indicated a target date of the end of 2024 to be able to find time to deliver information.
    - The team will seek to develop a set of performance curves based on their data and compare them to current curves in the DEER prototypes.
    - Then, the team will update the DEER prototype template to include the new performance curves.
    - Following this, energy modeling will be conducted to compare new performance curves against VCHP existing curves across 16 climate zones.
    - The team will assess whether the new performance curves and COPs at different stages can be updated in DEER prototypes.
    - Finally, if the team deems this data valuable and worthy of being shared with CPUC; the team will initiate discussions with CPUC ex ante staff to work to get the information into the DEER prototypes
- Continue discussions with CPUC ex-ante DEER team to streamline and update unitary LC HP equipment in DEER, including 1-speed, 2-speed, and VCHPs. At this point, these changes would become effective for DEER2028, and based on the most recent timing from CPUC, these recommendations would be needed by December 2025.
- Seek a pathway to conduct laboratory testing efforts with unitary LC VCHP equipment. Ideally, manufacturer participation would be encouraged. Given the cost of such an undertaking, efforts to share benefits with other stakeholders in California may be pursued. Lab testing would need to be scoped in a way that results in expanded performance maps for VCHPs, meaning that labs that can only test to standard AHRI rating conditions would not be sufficient.
- Scope out the possibility of conducting component-level modeling efforts with a software program such as VapCyc® or similar. This software is capable of producing results that are considered accurate and able to predict equipment efficiency ratings such as IEER or COP. It may be possible to use this software to create expanded performance maps as well, for generating the necessary curve coefficients for use in EnergyPlus. The challenge with this

approach would be to ensure that whatever product/component-level model is created is representative of actual equipment performance and is not too far removed. Therefore, it might be ideal to pursue a component-level modeling effort alongside a lab testing effort to help calibrate the component-level model with lab tests. Then the full performance map could be generated using software.

- Consider the possibility of combining the above approaches with a field data monitoring effort, again potentially in conjunction with another ongoing California effort, in order to provide a source to validate the EnergyPlus modeling results, and ultimately LC VCHP performance curve coefficients for DEER. For example, the TECH Clean California program is delivering a population-level database that includes information about compressor speed. However, this approach would be of limited utility for light commercial VCHPs since the dataset is for residential equipment less than 5.4 tons.

References

1. DEER 2024 Resolution E-5221, Nov 4, 2022
2. ASHRAE 205 Development and Maintenance, 2023
3. Cutter et al., 2013, Improved Modeling of Residential Air Conditioners and Heat Pumps for Energy Calculations, Technical Report, NREL/TP-5500-56354, January 2013
4. Issac Smith, Variable Speed Heat Pump Product Assessment and Analysis, NEEP, REPORT #E22-32, April 2022
5. Bryan Boyce, Shaojie Wang, Sean Steffensen, Jim Hanna, Pradeep Bansal, Energy Solutions, Adding SEER2 VCHP Offerings to DEER- VCHP Performance Maps Final Report, SDGE Report, November 2023

Appendix A

Business Case for Data Sharing

Executive Summary
California's goal of deploying six million heat pumps by 2030 presents a unique, time-sensitive opportunity. XXX (company name) can gain a first-mover advantage in this rapidly expanding market by partnering with Energy Solutions and California's investor-owned utilities (PG&E, SCE, SDG&E). Immediate collaboration on performance data sharing for Variable Capacity Heat Pumps (VCHPs) will drive market transformation and position XXX (company name) as an industry leader, with direct benefits in California and beyond.

Why Act Now?

1. Regulatory and Market Shift: The HVAC industry is at a critical juncture as building decarbonization becomes a national priority. Delaying action could result in lost market share to competitors who move swiftly to meet new regulatory standards and customer demands.
2. Immediate Sales Growth: Participating now will allow XXX (company name) to leverage enhanced incentive programs based on accurate performance data. This will increase the sales of high-efficiency VCHPs, which are more profitable and align with market demand for sustainable solutions.
3. Confidentiality Assured: Energy Solutions is prepared to sign a nondisclosure agreement (NDA) to protect XXX (company name)'s proprietary data. We will anonymize the data shared with state utility commissions, ensuring that XXX (company name)'s competitive edge remains secure.

Strategic Benefits

- Increased Profit Margins: By contributing performance data, XXX (company name) can influence the structure of incentive programs, leading to higher sales of premium products.
- Market Leadership: Early participation positions XXX (company name) as a critical player in the national effort to decarbonize buildings, strengthening brand reputation and market influence.
- Scalable Impact: Success in California will be replicated across 14 additional states where Energy Solutions operates, multiplying the benefits.

Next Steps

1. Immediate Action Required: We request XXX (company name) to provide expanded performance data for its VCHP product lines by [specific date]. This data will be used to secure enhanced incentives, driving near-term sales growth.
2. Kickoff Meeting: We propose a meeting within the next two weeks to finalize the data-sharing agreement and outline the implementation plan.

Conclusion

This partnership offers XXX (company name) a unique opportunity to lead the HVAC market into the future, driving both short-term sales and long-term strategic gains. By acting now, XXX (company name) can secure its position as a leader in the decarbonization of buildings, with tangible benefits across multiple states.

We urge the XXX (company name) leadership team to act promptly to capitalize on this strategic opportunity.

Appendix B

Table 13: Performance data under various indoor and outdoor conditions

Entering Wet Bulb Tem-perature	Total Air Volume	Outdoor Air Temperature Entering Outdoor Coil																			
		85°F					95°F					105°F					115°F				
		Total Cooling Cap	Comp. Motor Input	Sensible to Total Ratio (S/T) Dry Bulb			Total Cooling Cap	Comp Motor Input	Sensible to Total Ratio (S/T) Dry Bulb			Total Cooling Cap	Comp Motor Input	Sensible to Total Ratio (S/T) Dry Bulb			Total Cooling Cap	Comp Motor Input	Sensible to Total Ratio (S/T) Dry Bulb		
	CFM	kBTUh	kW	75°F	80°F	85°F	kBTUh	kW	75°F	80°F	85°F	kBTUh	kW	75°F	80°F	85°F	kBTUh	kW	75°F	80°F	85°F
63°F	1920	69.6	3.83	0.74	0.87	1.00	66.2	4.35	0.75	0.89	1.00	62.6	4.94	0.77	0.92	1.00	58.8	5.62	0.79	0.95	1.00
	2400	73.0	3.85	0.79	0.95	1.00	69.5	4.36	0.81	0.97	1.00	65.7	4.95	0.83	1.00	1.00	61.9	5.62	0.86	1.00	1.00
	2880	75.8	3.86	0.85	1.00	1.00	72.3	4.37	0.86	1.00	1.00	68.0	4.96	0.89	1.00	1.00	65.1	5.63	0.93	1.00	1.00
67°F	1920	74.2	3.85	0.58	0.71	0.84	70.7	4.37	0.59	0.73	0.86	66.7	4.95	0.60	0.74	0.89	62.7	5.63	0.62	0.77	0.92
	2400	77.5	3.87	0.62	0.77	0.92	73.6	4.38	0.63	0.79	0.94	69.5	4.96	0.64	0.81	0.97	64.9	5.63	0.65	0.84	1.00
	2880	79.8	3.88	0.65	0.82	0.98	75.6	4.39	0.66	0.84	1.00	71.5	4.97	0.68	0.87	1.00	66.9	5.64	0.69	0.90	1.00
71°F	1920	78.4	3.87	0.44	0.56	0.68	74.8	4.38	0.44	0.58	0.71	70.8	4.97	0.45	0.58	0.72	66.5	5.64	0.45	0.60	0.75
	2400	82.0	3.89	0.45	0.60	0.74	78.0	4.40	0.46	0.61	0.76	73.8	4.98	0.46	0.63	0.79	69.1	5.65	0.47	0.65	0.81
	2880	84.5	3.91	0.47	0.64	0.80	80.2	4.42	0.47	0.65	0.82	75.6	4.99	0.48	0.67	0.85	70.7	5.65	0.49	0.69	0.88