Central Valley Research Homes

Variable Compressor Speed Heat Pumps

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Project Managers: Marshall Hunt, Codes & Standards
Jeff Beresini, Emerging Technologies
Pacific Gas and Electric Company

Prepared by: Bruce Wilcox, P.E.

Abram Conant
Proctor Engineering

Rick Chitwood
Chitwood Energy Management

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Pacific Gas and Electric Company®

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LEGAL NOTICE

ABBREVIATIONS AND ACRONYMS

ACCA	Air Conditioning Contractors of America
ACH	Air changes per hour
Btu	British thermal unit
CFM	Cubic feet per minute
CT	Current transducer
EER	Energy efficiency ratio
HERS	Home energy rating system
HP	Heat pump
HSPF	Heating seasonal performance factor
HVAC	Heating, ventilating, and air conditioning
kWh	Kilowatt hour
RH	Relative humidity
SEER	Seasonal energy efficiency ratio
SHGC	Solar heat gain coefficient
U	U-factor (thermal transmittance)
VCHP	Variable-capacity heat pump
VRF	Variable refrigerant flow

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EXECUTIVE SUMMARY

PROJECT GOALS

This project evaluated the installed performance of variable capacity heat pump (VCHP) mini- and multi-split systems in three (3) California research homes in Stockton, California. The two primary areas of focus were:

1) Energy performance: VCHP systems with SEER ratings as high as 38 and HSPF ratings as high as 15 are now available. The current federal code minimum efficiency central forced air split system heat pumps are rated 14 SEER and 8.2 HSPF. This project measured the installed energy performance of VCHP systems in comparison to minimum efficiency single speed forced air heat pump units to determine if the standard efficiency rating metrics are a reliable predictor of energy use in California homes.
2) Comfort: VCHP mini- and multi-split systems may be ducted or ductless. The ductless systems offer the promise of energy savings through reduced air handler fan power and elimination of duct losses. However, comfort may be comprised in rooms without a ductless fan coil. Additionally, variable-speed systems have complex controls some of which are not accessible in the field. The controls modulate fan and compressor speeds in ways that may affect comfort performance relative to the single-speed ducted systems that are typically used in California residences.

PROJECT DESCRIPTION

The project installed VCHP systems and minimum efficiency reference forced air heat pump systems into three existing houses in Stockton, California. The houses ranged in vintage from 1948 to 2005. The houses received shell improvements through a previous research project (Wilcox) and are more efficient with lower heating and cooling loads than the typical existing house of the same vintage. Heating and cooling loads approach those being achieved by new houses built to current efficiency standards. The houses were unoccupied, and internal gains from simulated occupancy were provided by electric heaters and humidifiers controlled by the data acquisition system to follow the sensible and latent gains magnitude and schedule specified in Title 24.

A flip/flop experimental design was applied, with the VCHP and reference systems alternating every three days during the cooling season and every two days during the heating season. The first day of the three-day cooling season cycle simulated a daytime thermostat setup and evening recovery schedule, while days two and three held a constant 76°F thermostat setpoint throughout the day. To simulate common best practice in Stockton's hot dry central valley climate a whole house fan was enabled during the cooling season between sunrise and 11:00PM (see page 19 for details). A constant thermostat setpoint was used at all times during heating season.

The Reference heat pump systems were single-speed, single-zone, standard ducted split systems with ductwork entirely inside the conditioned space. The systems were installed and commissioned according to Title 24 standards, with refrigerant charge verified to be correct based on the manufacturer specified amount of subcooling. Airflow was tested and confirmed to be between 403 and 456 cfm/ton.

The VCHP system designs were specified by the manufacturers, installed by the manufacturers' preferred contractors, and commissioned with controls settings specified by the manufacturers. The VCHP system configurations varied by house:

- Mayfair House (one-story, 1,104 ft^2): Ducted single-zone mini split
- Grange House (one-story, 848 ft^2): Ductless single-head mini split with a ducted transfer fan supplying air to the two unconditioned bedrooms which had open doors
- Caleb House (two-story, 2,076 ft^2): Ductless single-head mini split on the first floor, and ductless two-head multi split on the second floor with two ducted transfer fans supplying air to the two unconditioned bedrooms which had open doors

The houses and HVAC systems were instrumented and monitored through one cooling and one heating season, summer 2015 and winter 2015-16. Energy performance was evaluated by characterizing daily energy use of each system as a function of daily average outdoor temperature and then projecting the results to the Title 24 weather file for Stockton. The projected annual energy consumption of the VCHP and reference systems were then compared to their relative efficiency ratings to evaluate the reliability of ratings as a predictor of installed energy performance.

Comfort performance was evaluated by comparing the monitored performance to ACCA Manual RS (ACCA 2015) guidelines for room temperature delta-to-setpoint and room-to-room temperature difference. Each system's ability to maintain indoor relative humidity below 60% maximum was also evaluated.

PROJECT FINDINGS/RESULTS

The project found mixed results with respect to VCHP system comfort. Findings include:

- Despite an optimistic experimental design that kept the interior doors to all rooms open at all times and used constantly-operating transfer fans to deliver air to rooms not directly served by an indoor terminal unit, the ductless VCHP systems did not maintain temperature comfort levels equivalent to the reference systems.
    - The ductless VCHP system at the 848 ft^2 single-story Grange house provided good temperature control during cooling season, but in heating season was only able to meet ACCA Manual RS guidelines for room-thermostat temperature 32% of the time.
    - The ductless VCHP systems at the 2,076 ft^2 two story Caleb house was only able to meet Manual RS guidelines for room-thermostat temperature 52% of the time during cooling season and 20% of the time in heating season.
- The ductless VCHP systems experienced longer temperature recovery times following a thermostat setup in cooling than the reference systems. Compliance with Manual RS guidelines for room-thermostat temperature fell to 66% at the Grange house and 32% at the Caleb house when a setup and recovery schedule was used. The rooms not directly served by an indoor terminal unit were especially problematic during recovery.
- The ducted VCHP system (Mayfair house) provided better temperature comfort levels than the reference system when a constant thermostat setting was used, but did so by running the indoor fan constantly at high speed during the cooling season. The constant high speed fan operation caused two problems:

  - The VCHP system predominantly ran at low compressor speeds. With the compressor on low speed and the fan on high speed, the system provided little or no latent cooling. Indoor humidity levels exceeded 60% relative humidity 23% of the time.
  - Energy use was significantly increased.

- The ductless mini-split system at the Grange house also provided very little latent cooling during the cooling season, with indoor humidity levels exceeding 60% relative humidity 39% of the time. The lack of latent capacity appears to be related to controls programming that did not modulate indoor fan speed with compressor speed.
- Problems were experienced with VCHP system controls. The Mayfair system required a controls setting modification due to inability to meet cooling load on hot days. The Caleb VCHP systems experienced ongoing temperature control problems throughout the heating season. Temperatures in rooms where the thermostatic controls were located were recorded falling to as much as 6°F below setpoint.
- The lack of latent cooling provided by the VCHP systems at two houses, Grange and Mayfair, led to indoor relative humidity exceeding 60% for a significant number of hours, as noted above. At the third house, Caleb, the VCHP system did not provide quite as much latent cooling as the reference system but succeeded in keeping relative humidity below 60% for most hours.

VCHP energy performance relative to their efficiency ratings was also mixed when compared to performance of the reference systems. Table 1 shows that estimated annual cooling energy savings for the VCHP systems relative to the minimum efficiency reference systems ranged from 10% better than expected (Caleb) to 31% below expectations (Mayfair) based on relative efficiency ratings. Table 2 shows annual heating energy savings exceeded expectations at all three houses, ranging from 14% to 16% better.

TABLE 1. VCHP ANNUAL COOLING ENERGY SAVINGS

SITE	SYSTEM	SEER	SEER PREDICTED COOLING ENERGY SAVINGS	MONITORED SAVINGS, UNADJUSTED	PERFORMANCE NORMALIZED SAVINGS **
Caleb	Reference HP	14			
	VCHP	20.9*	33%	43%	41%
Grange	Reference HP	14			
	VCHP	25.5	45%	41%	33%
Mayfair	Reference HP	14			
	VCHP	16	13%	-18%	-21%

*Capacity weighted average of the two VCHP systems at Caleb.

** Normalized savings include adjustments for differences in latent cooling and indoor air temperature.

TABLE 2. VCHP ANNUAL HEATING ENERGY SAVINGS

SITE	SYSTEM	HSPF	HSPF PREDICTED HEATING ENERGY SAVINGS	MONITORED SAVINGS
Caleb	Reference HP	8.2		
	VCHP	10.5*	22%	37%
Grange	Reference HP	8.2		
	VCHP	11.5	29%	45%
Mayfair	Reference HP	8.2		
	VCHP	10	18%	32%

*Capacity weighted average of the two VCHP systems at Caleb

The energy consumption of constantly operating VCHP fans is a major concern.

- The ducted VCHP system (Mayfair house) operated the air handler fan constantly during cooling season, and as a result the projected seasonal cooling energy use was 18% higher than the reference system. Based on SEER ratings, the VCHP system was expected to use 13% less energy than the reference system, and the constantly operating fan was the primary contributor to the shortfall of 31%.
- The transfer fans that were installed with the ductless VCHP systems (Caleb and Grange houses) are not commercially available for use in that application, and they provided significantly lower energy use than would be possible with standard commercially available products. The ducted transfer fans used in this study operated at 0.12 W/cfm (Grange) and 0.04 cfm (Caleb). Efficiency of standard through-the-wall transfer fans is roughly 1.5 W/cfm. Standard transfer fans are estimated to increase energy use such that VCHP cooling energy savings would fall to approximately 40% below expectations at both of the houses with ductless systems.

The VCHP systems provided significant summer peak HVAC electricity demand reductions of 44% to 64% when the systems were operated with a constant thermostat setpoint, compared to the reference systems under similar outdoor temperature conditions. Demand reductions with a thermostat setup and recovery schedule were uncertain due to varying comfort conditions and the potential that occupants would force the systems into higher speeds than were observed during recovery periods in this study.

PROJECT RECOMMENDATIONS

Based on the results of this study, additional research is recommended to:

- Develop a better understanding of ductless VCHP system comfort performance under different scenarios, including with interior doors closed and without constantly operating transfer fans.
- Monitor ductless VCHP energy performance when standard transfer fans are used.
- Perform a direct comparison of ducted and ductless VCHP system comfort and energy performance in the same house.
- Develop efficiency ratings and methods of test that are more applicable to the dynamic capabilities of VCHP systems than the current DOE test methods, which lock variable-speed systems at fixed speeds. The DOE ratings are not demonstrated to be

representative of installed performance. Improved test methods are needed which allow these systems to modulate as instructed by their control programming, thereby functioning as they would in field installations.

INTRODUCTION

Variable Compressor Speed Heat Pump (VCHP) systems are an emerging technology in California and the rest of North America even though they are common in many parts of the world. Prior research has focused primarily on heating mode, while the cooling mode performance is also of concern in California.

VCHP systems with very high SEER and HSPF ratings based on current test methods (AHRI 210-240) are now available. However, these VCHP systems are currently not credited with improved energy performance in the California Title 24 building standards due to a number of areas of uncertainty regarding installed performance. These include:

- The efficiency ratings are not demonstrated to reliably represent installed performance.
    - Phase I of the Central Valley Research House (CVRH) project (described below) found VCHP system performance well below expectations based on efficiency ratings.
    - Efficiency rating test procedures require locking variable-speed equipment at a set of constant speeds, thereby defeating the controls logic and producing results substantially different from real world installations.
- Ductless VCHP efficiency ratings do not reflect supplemental air distribution systems which may be required to achieve comfort or comply with building code requirements for heat delivery.
- At present it is not possible to verify proper installation and that performance is meeting expectations.

Evaluation of VCHP system installed performance is needed to develop a better understanding of this emerging technology, appropriate installation practices, and more reliable estimates of energy consumption in California homes.

BACKGROUND

CENTRAL VALLEY RESEARCH HOMES PROJECT

The houses used in this study are three of four houses studied in the CVRH project, a multi-year effort to test residential energy efficiency measures and technologies in four unoccupied, highly instrumented homes of different vintages in Stockton, California.

The CVRH project began with funding from the California Energy Commission to perform three experiments.

1) Develop packages of envelope and HVAC efficiency retrofits that achieve 50% to 75% savings in heating and cooling energy in the experimental homes.
2) Compare measured energy consumption at the four experimental homes with energy consumption estimates by six HERS Raters at each of the four homes.

3) Compare monitored energy use of variable compressor speed heat pumps (VCHP) to reference heating and cooling systems installed in the experimental homes.

Project timeline:

- Four homes leased in 2011
- 2012-2013 collected baseline data
- 2013-2014 installed first package of upgrades and collected data
- 2014-2015 second package of upgrades and data collected

Among the findings of the CVRH project was that the all four of the VCHP systems installed during that study underperformed by a very large margin in the cooling mode, and two of the four systems seriously underperformed in heating mode.

EMERGING TECHNOLOGY

Starting with the Summer of 2015, the PG&E Codes & Standards and Emerging Technology programs provided funding for the next phase of CVRH. The subject of this study is an emerging HVAC technology: variable capacity heat pumps (VCHP), which are also known as mini-split and multi-split heat pumps. In some configurations these systems are called variable refrigerant flow (VRF) systems. These systems are commonly used in Asia and Europe but have not been widely adopted in the United States. These machines have the potential to provide more efficient heating and cooling than conventional single-speed heat pumps.

This study uses three of the original four homes to install and test three configurations of VCHP systems.

1) One house has a single outdoor unit with single wall-mounted indoor unit.
2) A second house has a single outdoor unit with a short-duct indoor unit mounted in a crawlspace.
3) The third house has two systems: the lower floor has a single outdoor unit and single wall-mounted indoor unit, and the upper floor has a single outdoor unit connected to two indoor wall-mounted units.

ASSESSMENT OBJECTIVES

The objectives of this study are:

- To assess energy savings performance of VCHP systems compared to standard split system heat pumps in support of annual performance simulation as required by the CEC Title 24 Part 6 Building Energy Efficiency Standards (Title 24).
- To assess the ability of the systems to control indoor temperature and relative humidity to provide comfort equivalent to existing central ducted forced air systems

- To identify best practices for VCHP system design, installation, and performance verification.

TECHNOLOGY EVALUATION

The project compares the cooling and heating performance of conventional minimum-efficiency central ducted split system heat pumps to VCHP systems. The study was conducted in three of the Stockton CVRH research houses. In these unoccupied and extensively instrumented houses, occupants were simulated with computer controlled equipment producing sensible and latent internal gains to match the Title 24 schedules. In the cooling season the previously installed whole house fans are enabled each night. In the hot dry Stockton climate, night time temperatures are in the 60s and the air is low in humidity, making night ventilation a long-standing cooling strategy. The control strategy for the whole-house fans is described on page 19.

Each house has both a reference system, which is installed within the conditioned space, and a VCHP system. During both the cooling and heating seasons, the HVAC units were operated on a flip/flop schedule. Details are described in the section below titled *Test Plan*.

The study was designed to produce the best possible installed VCHP performance. The VCHP system models and sizing were specified by the manufacturers. Installation and commissioning was conducted by the manufacturer's preferred contractor, under the guidance of the manufacturer. Room to room custom transfer fans were installed to provide the cooling and heating to rooms not directly served by a terminal unit.

TEST METHODOLOGY

TEST LOCATIONS

The three houses in this study - referred to as Grange, Mayfair, and Caleb - are located in Stockton, California. Stockton is located in California Climate Zone 12, in the middle part of California's Central Valley. This inland region is characterized by cooler winters and hotter summer's than the San Francisco Bay Area to its west. The winter rainy period extends from November to April, but is generally fairly mild. Summer high temperatures can exceed 110°F but averages 93 in August. Daily lows average 58 in August due to a mesoscale sea breeze which cools the area into the 60s except when a peak hot spell occurs. On an annual basis, there are more Heating Degree Days (HDD) than Cooling Degree Days (CDD). A good summary of Climate Zone 12 characteristics can be found in "The Pacific Energy Center's Guide to California Climate Zones." (Pacific Energy Center, 2006).

Each of the homes received energy efficiency upgrades as part of an earlier study (Wilcox, to be published as a final research report by the California Energy Commission). Therefore, the envelope performance is improved compared to original construction so that it approaches what is required by Title 24 for new dwellings.

GRANGE

Built in 1948, the Grange Avenue house is the oldest of the test houses. At 848 ft^2, it is also the smallest. It is a two-bedroom, single-story rectangular house with slab on grade construction.

FIGURE 1. GRANGE TEST HOUSE

TABLE 3. GRANGE HOUSE CHARACTERISTICS (AS TESTED)

Floor Area	848 ft^2
Year Built	1948
Stories	1
Bedrooms	2
Floor type	Slab on grade
Air Leakage	438 CFM50 (3.8 ACH50)
Attic Insulation	852 ft^2, R-49 loose fill fiberglass
Attic Ventilation	15.5 ft^2 (1 ft^2 vent / 55 ft^2 ceiling area)
Wall Insulation	R-10 loose fill fiberglass
Windows	78 ft^2, vinyl, double-pane, low-E^2, U 0.30, SHGC 0.25
IAQ Ventilation	ASHRAE 62.2 compliant bath exhaust fan, 39 CFM, 5.5 watts
Whole-house fan	Two whole-house fans installed in ceiling. Total 1213 CFM and 141 watts
Heating Load	12,775 Btu/hr (see Appendix A)
Cooling Load	10,253 Btu/hr (see Appendix A)

MAYFAIR

The house on West Mayfair in Stockton is the second oldest test home. This three-bedroom home was built in 1953 and has a floor area of 1,104 square feet. It is a simple one-story rectangular building over a crawlspace

FIGURE 2. MAYFAIR TEST HOUSE - FRONT

FIGURE 3. MAYFAIR HOUSE – REAR (SHADE STRUCTURE REMOVED BEFORE EXPERIMENTS)

TABLE 4. MAYFAIR HOUSE CHARACTERISTICS (AS TESTED)

Floor Area	1,104 ft^2
Year Built	1953
Stories	1
Bedrooms	3
Floor type	Crawlspace
Air Leakage	1,248 CFM50 (9.3 ACH50)
Attic Insulation	1,104 ft^2, R-49 loose fill fiberglass
Attic Ventilation	20 ft^2 (1 ft^2 vent / 55 ft^2 ceiling area)
Wall Insulation	R-13 loose fill fiberglass
Crawlspace Efficiency	Uninsulated, plastic membrane on floor, code-minimum vent area
Windows	197 ft^2, vinyl, double-pane, low-E^2, U 0.30, SHGC 0.25
IAQ Ventilation	ASHRAE 62.2 compliant bath exhaust fan, 50 CFM, 3.0 watts
Whole-house fan	Three whole-house fans installed in ceiling. Total 1,638 cfm and 202.5 watts
Heating Load	15,583 Btu/hr (see Appendix A)
Cooling Load	16,175 Btu/hr (see Appendix A)

CALEB

Built in 2005, the four bedroom, 2,076 ft^2 house on Caleb Circle is the newest and largest of the test houses. It is a two-story rectangular home with a portion of the second story overlapping the garage

FIGURE 4. CALEB TEST HOUSE – FRONT AND SIDE VIEW

FIGURE 5. CALEB TEST HOUSE – REAR VIEW

TABLE 5. CALEB HOUSE CHARACTERISTICS

Floor Area	2,076 ft^2
Year Built	2005
Stories	2
Bedrooms	4
Floor type	Slab on grade
Air Leakage	1,615 CFM50 (5.4 ACH50)
Attic Insulation	R-30 loose fill fiberglass + PolyFoam (3M) PolySet spray foam system under roofing tiles
Attic Ventilation	16.7 ft^2 (1 ft^2 vent / 66 ft^2 ceiling area)
Wall Insulation	R-17
Windows	Vinyl, double-pane, low-E, U 0.35, SHGC 0.30
IAQ Ventilation	ASHRAE 62.2 compliant bath exhaust fan, 64 CFM, 12.1 watts
Whole-house fan	Four whole-house fans installed in ceiling. Total 2,075 CFM and 275 watts
Heating Load	21,577 Btu/hr (see Appendix A)
Cooling Load	25,084 Btu/hr (see Appendix A)

TEST PERIOD

Systems were installed during spring 2015.

Cooling season data cover the period of July 2015 through October 2015.

Heating system data cover the period of December 12, 2015 through March 8, 2016.

REFERENCE SYSTEMS

The reference systems are standard split-system forced air heat pumps with the air handlers and ducts installed within the conditioned space suspended from the ceiling. Figure 6 illustrates the typical installation. Table 6 lists reference system specifications for each of the three houses. These systems represent minimum efficiency equipment allowed by Title 24 building energy standards. Spiral-wire helix plastic ducts with factory insulation were used, with duct runs equal to those commonly found in new construction. Routing of the ducts is similar to what is commonly found in California homes.

FIGURE 6. TYPICAL REFERENCE HEAT PUMP SYSTEM INSTALLATION WITHIN CONDITIONED SPACE

FIGURE 7. TYPICAL REFERENCE HEAT PUMP SYSTEM OUTDOOR UNIT INSTALLATION

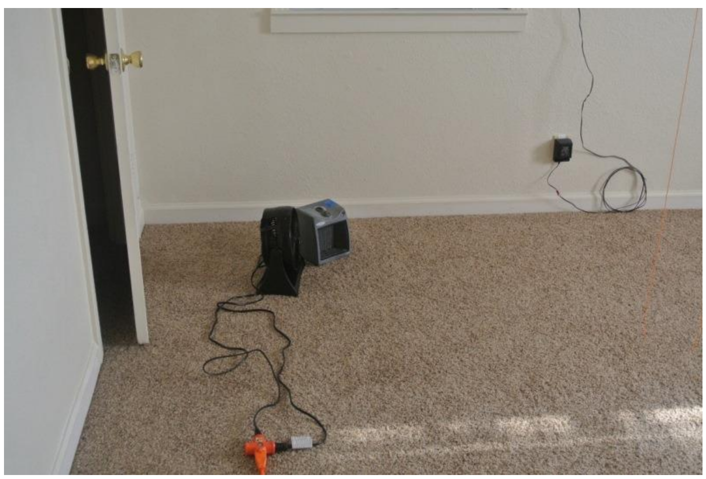


FIGURE 8. ELECTRIC RESISTANCE HEATERS IN EVERY ROOM

TABLE 6. REFERENCE SYSTEMS

House	Description	Location	Equipment specifications	
Grange	1.5 ton split system heat pump	Living Room - ducts hung from ceilings	SEER: EER: Rated Cooling Capacity: HSPF: Rated Heating Capacity:	14 11.5 17,600 Btu/hr 8.2 18,000 Btu/hr
Mayfair	2 ton split system heat pump	Dining Room - ducts hung from ceilings	SEER: EER: Rated Cooling Capacity: HSPF: Rated Heating Capacity:	14 11.5 23,200 Btu/hr 8.2 23,200 Btu/hr
Caleb	2.5 ton split system heat pump	2nd Floor Landing - ducts hung from ceilings	SEER: EER: Rated Cooling Capacity: HSPF: Rated Heating Capacity:	14 12 28,000 Btu/hr 8.2 27,800 Btu/hr

VCHP SYSTEMS

Table 7 lists the type and basic specifications for the VCHP systems installed in each house.

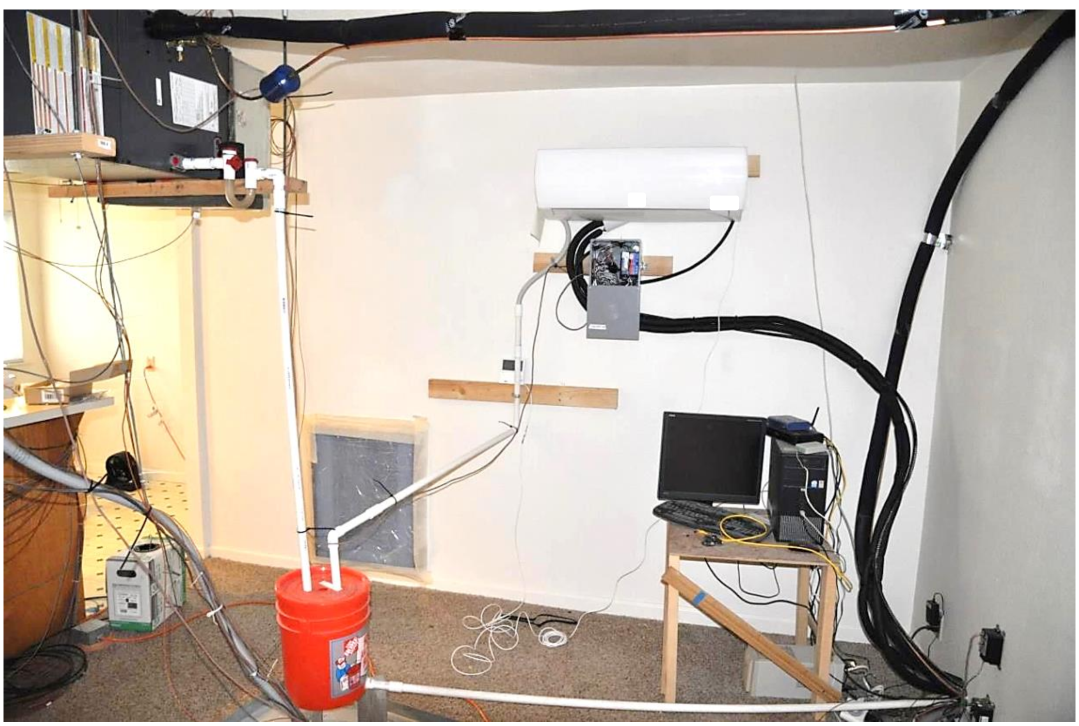


FIGURE 9. WALL-MOUNTED VCHP FAN COIL AND REFERENCE SYSTEM AIR HANDLER AT GRANGE HOUSE

FIGURE 10. CRAWLSPACE-MOUNTED VCHP DUCTED AIR HANDLER AT MAYFAIR HOUSE

FIGURE 11. WALL-MOUNTED VCHP FAN COIL AT CALEB HOUSE (1 OF 3) & SUSPENDED, SHIELDED SENSORS

TABLE 7. VCHP SYSTEMS

House	Description	Location of Air Handler	Equipment Specifications	
Grange	1 ton mini-split w/air transfer fan to bedrooms	Living Room (17 ft piping)	SEER: EER: Rated Cooling Capacity: HSPF: Rated Heating Capacity:	25.5 13.8 11,000 11.5 12,000
Mayfair	1 ton mini-split with ducted air handler	Crawlspace (22.2 ft piping)	SEER: EER: Rated Cooling Capacity: HSPF: Rated Heating Capacity:	16 12.5 11,500 10 13,600
Caleb 1st Floor	1 ton mini-split	Dining Room (30 ft piping)	SEER: EER: Rated Cooling Capacity: HSPF: Rated Heating Capacity:	23 12.8 12,000 12.5 14,400
Caleb 2nd Floor	1.5 ton multi-split with 2 heads w/air transfer fans to bedrooms	M.Bed and Landing (45.5 and 68 ft piping)	SEER: EER: Rated Cooling Capacity: HSPF: Rated Heating Capacity:	19.5 12.6 18,000 9.2 22,000

The air transfer fans at the Grange and Caleb houses were not standard commercially available products for this application. They were high efficiency bathroom exhaust fans that were customized to function as room-to-room air transfer fans with extremely low watt draw. At Grange, measured performance for the single transfer fan is 9 watts at 75 cfm (0.12 W/cfm). At Caleb, two transfer fans draw a combined total of 10 watts and move a total of 230 cfm (0.04 W/cfm). Transfer fan products that are currently available on the market have power draws that are 5 to 10 times greater than the customized fans used in this study. Power for standard through-the-wall fans was measured at 50 watts each in a separate study. Because these fans are typically installed to operate constantly, their power draw is a significant contributor to annual energy consumption.

SYSTEM SELECTION AND SIZING

Cooling and heating load calculations results for each house are included as an attachment to this report. Result are summarized in Table 8.

Reference system selection and sizing was performed by the research team. Systems were selected as the smallest available that was rated to meet the calculated cooling loads.

VCHP systems were selected by the manufacturers. The manufacturers were provided with load calculations and information about the houses. Equipment combinations and sizing were specified by the manufacturer.

TABLE 8. COOLING AND HEATING LOAD CALCULATION SUMMARY (DETAILS IN APPENDIX A)

HOUSE	COOLING LOAD (BTU/HR)	HEATING LOAD (BTU/HR)	AIRFLOW (CFM)
Grange	10,253	12,775	499
Mayfair	16,175	15,583	863
Caleb	25,084	21,577	1,191

SYSTEM INSTALLATION

Reference systems were installed and commissioned by the research team during the spring of 2015. Airflow to each room was adjusted following initial operation to provide even room temperatures. Commissioning reports for the reference systems are included in Appendix B.

TABLE 9. SUMMARY OF REFERENCE-SYSTEM COMMISSIONING DATA

HOUSE	NOMINAL CAPACITY (TONS)	MODE	MEASURED AIRFLOW (CFM)	MEASURED AIRFLOW (CFM/TON)	MEASURED FAN POWER (WATTS)	MEASURED FAN POWER (WATTS/CFM)
Grange	1.5	Cooling	684	456	201	0.29
		Heating	642	428	195	0.30
Mayfair	2.0	Cooling	827	414	283	0.34
		Heating	824	412	277	0.34
Caleb	2.5	Cooling	1057	423	426	0.40
		Heating	1008	403	412	0.41

VCHP systems were each installed by contractors selected by the equipment manufacturers. Operating mode and other controls options were specified and set by the installing contractors and equipment manufacturers, and are not necessarily the factory default configurations. VCHP system manufacturers do not provide information or test methods that would allow measured performance verification. The research team attempted to measure VCHP system installed performance, but results were inconclusive due to transient controls behavior, lack of detailed performance data, and lack of information regarding correlation of any performance data that is available to specific speeds or control modes. Systems were inspected by a licensed HERS rater using an inspection verification checklist proposed by AHRI. Completed checklists are included in Appendix C. Inspectors weighed refrigerant charge and measured inlet and outlet air temperatures for the indoor cooling in both heating and cooling modes.

TEST PLAN

OPERATION SCHEDULE

COOLING MODE

The project applied a flip/flop experimental design. In cooling mode, the data acquisition system (DAS) control system alternated between the VCHP and Reference HP systems every three days. System changeover occurred at midnight. The following control schedule was applied to both systems:

1) Day One - Daytime thermostat setup and evening recovery schedule. Heat pump systems were disabled and house temperatures were uncontrolled until 5PM. At 5PM the systems were enabled with a 76°F thermostatic setpoint, which remained constant through the end of the day.
2) Days Two and Three - Heat pump systems were enabled all day, with a constant 76 °F setpoint.

On all days, the whole house fan was enabled between sunrise and 11PM to align with Title 24 simulation assumptions. The whole house fan was controlled to operate if the outdoor temperature was at least 10.8 °F cooler than the indoor temperature, and the indoor temperature was above 68 °F. Figure 12 shows photos of a whole-house fan system installation at one of the houses.

FIGURE 12. WHOLE-HOUSE FAN IN ATTIC AND SIDEWALL OUTSIDE AIR INLET AUTOMATIC DAMPER AT CALEB

On days where the ductless VCHP systems at the Caleb and Grange houses were active, the transfer fans were operated constantly (drawing 10 and 9 watts, respectively).

HEATING MODE

In heating mode, the DAS control system alternated between the VCHP, Reference HP, and electric resistance heaters every two days. System changeover occurred at 7AM. The 7AM changeover was designed to minimize solar heating and storage effects that could carry over from a warm afternoon into the morning of the next day. The heating systems were enabled all day, with a constant 68 °F setpoint.

On days where the ductless VCHP systems at the Caleb and Grange houses were active, the transfer fans were operated constantly.

OCCUPANT SIMULATION

Internal heat gains due to occupants and appliances are simulated using electric heaters and a humidifier. The equipment is programmed to produce heat and moisture to match sensible and latent heat gain profiles used in Title 24-2013 compliance software. The sensible heat gain profiles are shown in Table 10 and the latent heat gain profiles are shown in Table 11. The gains are assumed to vary monthly per the multipliers in Table 12. The algorithms used to develop the profiles are described in the document *2013 Residential ACM Algorithms* (CEC 2013).

The electric heaters that simulate the sensible heat gain are turned on each 5 minutes for the amount of time necessary to provide the desired average heat rate for the hour.

The humidifier that simulates the latent heat gain is turned on every 15 minutes and runs for the amount of time necessary to provide the desired average latent heat rate for the hour. The humidifier is run only during the summer season for this study.

FIGURE 13. EQUIPMENT USED TO SIMULATE OCCUPANTS

TABLE 10. INTERNAL SENSIBLE HEAT GAIN PROFILES

HOUR	CALEB (KWH)	GRANGE (KWH)	MAYFAIR (KWH)
1	0.47278	0.30891	0.33244
2	0.44589	0.29463	0.31648
3	0.42572	0.28454	0.30471
4	0.43160	0.28707	0.30807
5	0.42824	0.28454	0.30555
6	0.57110	0.39883	0.42404
7	0.72908	0.51816	0.55009
8	0.64925	0.43244	0.46522
9	0.47866	0.29715	0.32404
10	0.38034	0.22404	0.24757
11	0.38202	0.22572	0.24841
12	0.37614	0.22320	0.24505
13	0.35681	0.21312	0.23328
14	0.36438	0.21732	0.23833
15	0.39715	0.24253	0.26522
16	0.45429	0.28538	0.31059
17	0.57110	0.37026	0.39967
18	0.72740	0.47530	0.51228
19	0.92992	0.59883	0.64925
20	1.09463	0.70387	0.76522
21	1.09547	0.70555	0.76606
22	0.98791	0.63160	0.68623
23	0.76942	0.49127	0.53328
24	0.57950	0.36438	0.39547

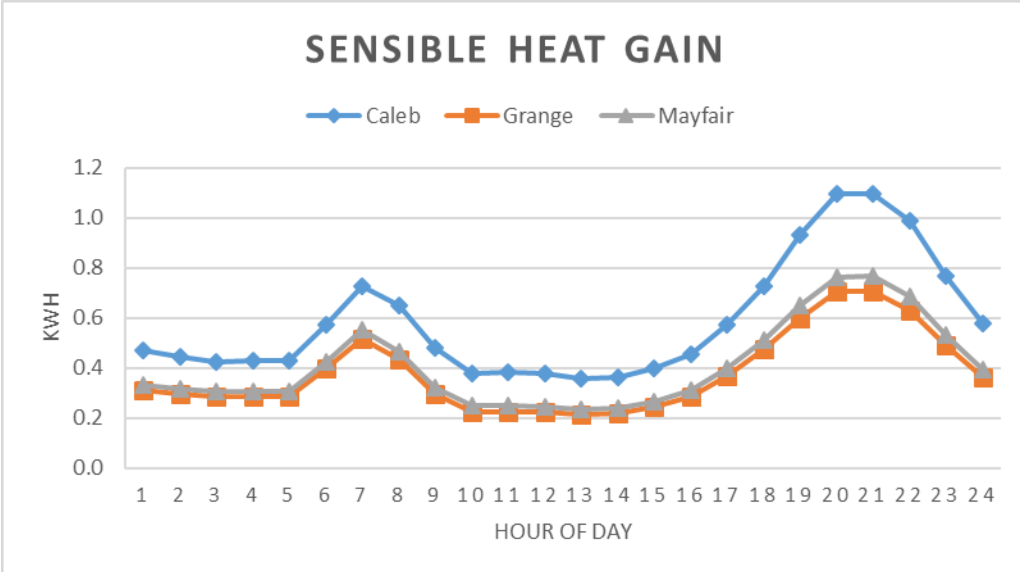


FIGURE 14. SENSIBLE HEAT GAIN PROFILE

Table 11. Internal Latent Heat Gain Profiles

Hour	Caleb (kWh)	Caleb (liters)	Grange (kWh)	Grange (liters)	Mayfair (kWh)	Mayfair (liters)
1	0.14874	0.21825	0.12353	0.18126	0.12521	0.18372
2	0.14538	0.21331	0.12101	0.17756	0.12269	0.18002
3	0.14454	0.21208	0.12017	0.17632	0.12185	0.17879
4	0.14454	0.21208	0.12017	0.17632	0.12185	0.17879
5	0.14118	0.20715	0.11849	0.17386	0.12017	0.17632
6	0.20840	0.30579	0.18319	0.26880	0.18571	0.27250
7	0.27731	0.40690	0.24790	0.36374	0.24958	0.36621
8	0.21092	0.30949	0.18067	0.26510	0.18319	0.26880
9	0.12857	0.18865	0.10252	0.15043	0.10420	0.15290
10	0.08739	0.12823	0.06496	0.09531	0.06655	0.09766
11	0.08908	0.13070	0.06588	0.09667	0.06748	0.09901
12	0.08908	0.13070	0.06588	0.09667	0.06748	0.09901
13	0.08739	0.12823	0.06496	0.09531	0.06655	0.09766
14	0.08908	0.13070	0.06588	0.09667	0.06748	0.09901
15	0.10504	0.15413	0.08042	0.11800	0.08218	0.12059
16	0.12857	0.18865	0.10252	0.15043	0.10420	0.15290
17	0.17563	0.25770	0.14454	0.21208	0.14706	0.21578
18	0.22605	0.33168	0.18908	0.27743	0.19160	0.28113
19	0.26723	0.39210	0.22689	0.33292	0.22941	0.33662
20	0.30588	0.44882	0.26387	0.38717	0.26723	0.39210
21	0.30924	0.45375	0.26639	0.39087	0.26891	0.39457
22	0.27563	0.40443	0.23361	0.34278	0.23613	0.34648
23	0.21933	0.32182	0.18319	0.26880	0.18571	0.27250
24	0.16218	0.23797	0.13025	0.19112	0.13277	0.19482

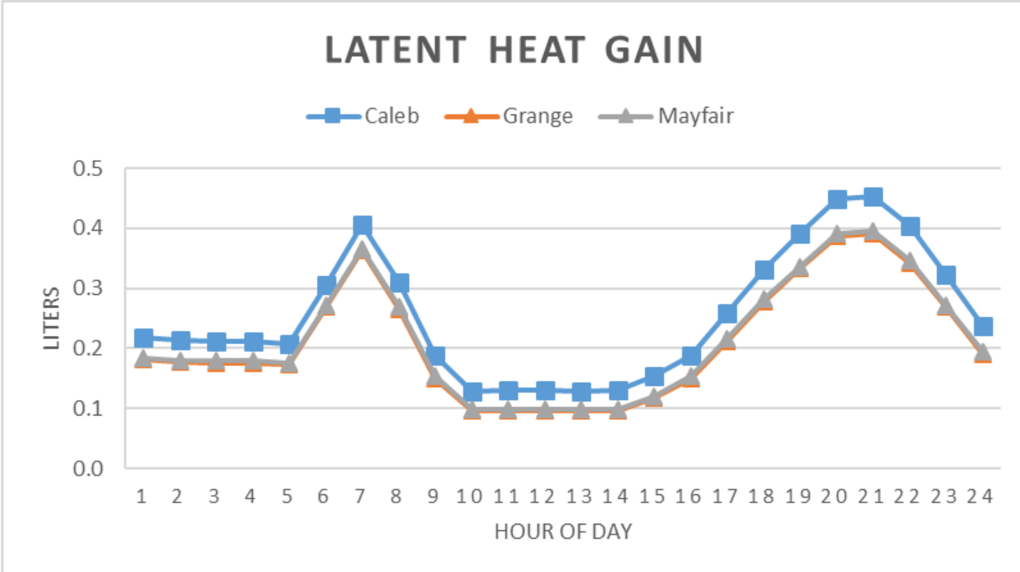


FIGURE 15. LATENT HEAT GAIN PROFILE

TABLE 12. INTERNAL HEAT GAIN MONTHLY MULTIPLIERS – USED FOR BOTH SENSIBLE AND LATENT HEAT GAINS

MONTH	MULTIPLIER
1	1.19
2	1.11
3	1.02
4	0.93
5	0.84
6	0.80
7	0.82
8	0.88
9	0.98
10	1.07
11	1.16
12	1.21

KEY MONITORED DATA POINTS

These monitored data points were used in the analysis.

- Dry bulb air temperature in each conditioned room
- Indoor relative humidity
- Outdoor temperature
- Outdoor humidity
- Supply and return plenum temperatures of the Reference HP system

- Electrical energy of each HVAC systems' individual components separately from each other and all other house electrical loads
- Electrical energy of electric resistance heaters and other interior electrical loads applied as sensible gains
- Liters of water added through the humidifier as latent gains
- Liters of condensate removal from each HVAC system
- Pressure difference from the house to outside

INSTRUMENTATION PLAN

The team installed monitoring and control systems in each home. These systems control the operation of the HVAC and internal gain systems and allow for switching between the house and reference HVAC systems. The team instrumented the research homes to provide hourly and minute-by-minute data. The monitoring equipment also controlled the humidifiers and heaters that simulated latent and sensible heat gain from simulated occupants.

SENSOR SPECIFICATIONS, LOCATIONS, AND CALIBRATION

The measurements made for this study are listed in the following three tables along with sensor specifications and sensor locations. The rooms listed in these tables can be identified in the floorplans: Figure 16 through Figure 19.

TABLE 13. SENSOR SPECIFICATIONS AND LOCATIONS - CALEB

MEASUREMENT	SENSOR	LOCATION(S)
Air temperature	Shielded and aspirated thermocouple – Type T. Omega 24 ga TW SH STR	Mounting height 48 in., center of room • Living room • Kitchen • Laundry • Bedroom 1 • Bedroom 2 • Bedroom 3 • Master bedroom • Master bath • Bonus room • Garage • Attic (mounted at midpoint between ceiling and roof) • Thermostat 1st floor • Thermostat 2nd floor • Supply air, reference system (8) • Return air, reference system

Air temperature & relative humidity	Vaisala HMP60 Relative humidity • 0 to 40C • +/-3% RH (0 to 90% RH) • +/-5% RH (90 to 100% RH) Temperature: 10-30C, +/-0.5C	Mounting height 48 in. • Living room • Bonus room
Air temperature & relative humidity	Vaisala HMP110 Relative humidity • 0 to 40C • +/-1.5% RH (0 to 90% RH) • +/-2.5% RH (90 to 100% RH) Temperature: 0-40C, +/-0.2C	Mounting height 48 in., center of room • Dining room • Laundry • Bedroom 1 • Bedroom 2 • Bedroom 3 • Master bedroom • Master bath • Outdoors
Differential air pressure	Setra 264 very low pressure differential transducer. 0-150F. +/- 1% full scale	• Indoor at floor level to outdoors • Attic to outdoors
Electric energy	Watt Node – WNB-3D-240-P Accuracy: +/-0.5% (CT current 5% - 100% of rated current)	• 50A CT: House total, not including old outdoor unit, reference outdoor unit, and reference air handler • 15A CT: old outdoor unit & downstairs mini-split system • 5A CT: downstairs mini-split head unit • 30A CT: reference AC outdoor unit • 15A CT: reference AC air handler • 15A CT: upstairs mini-split outdoor unit • 5A CT: upstairs mini-split head unit, landing • 5A CT: upstairs mini-split head unit, master bedroom
Electric energy	Watt Node – WNB-3Y-208-P	• 5A CT: transfer fan
Water flow to humidifier	Water meter	• Kitchen
Air conditioner condensate	Tipping bucket	

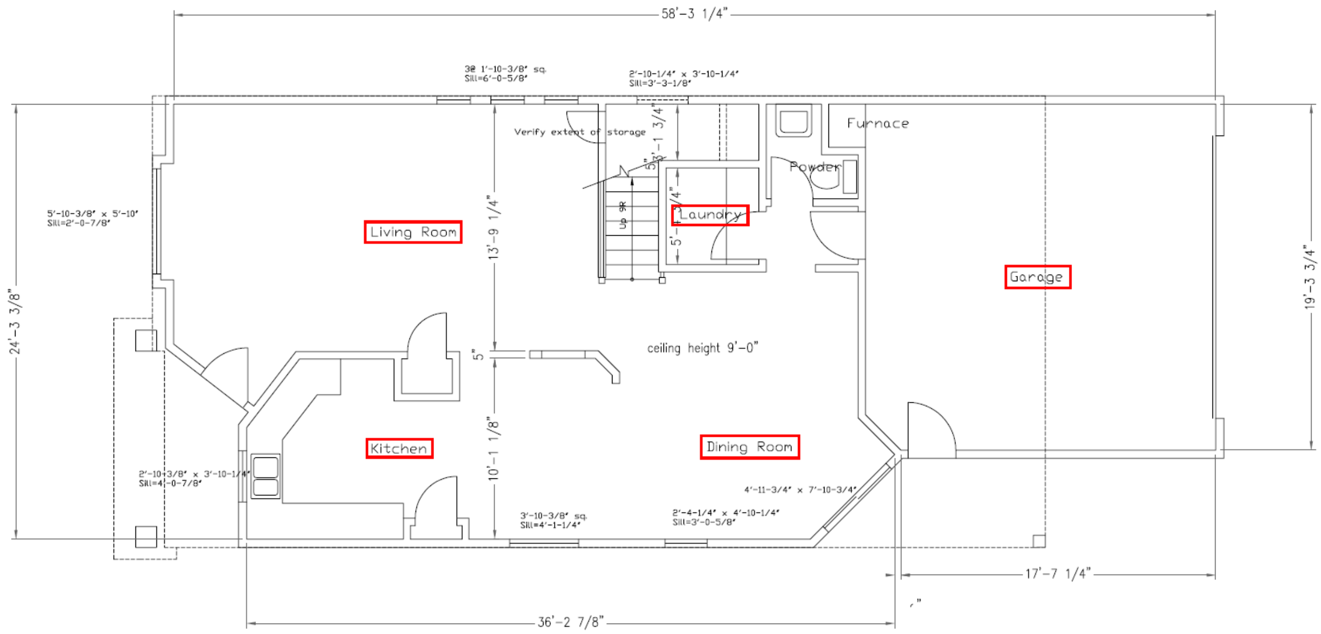


FIGURE 16. CALEB FLOOR PLAN – LOWER FLOOR

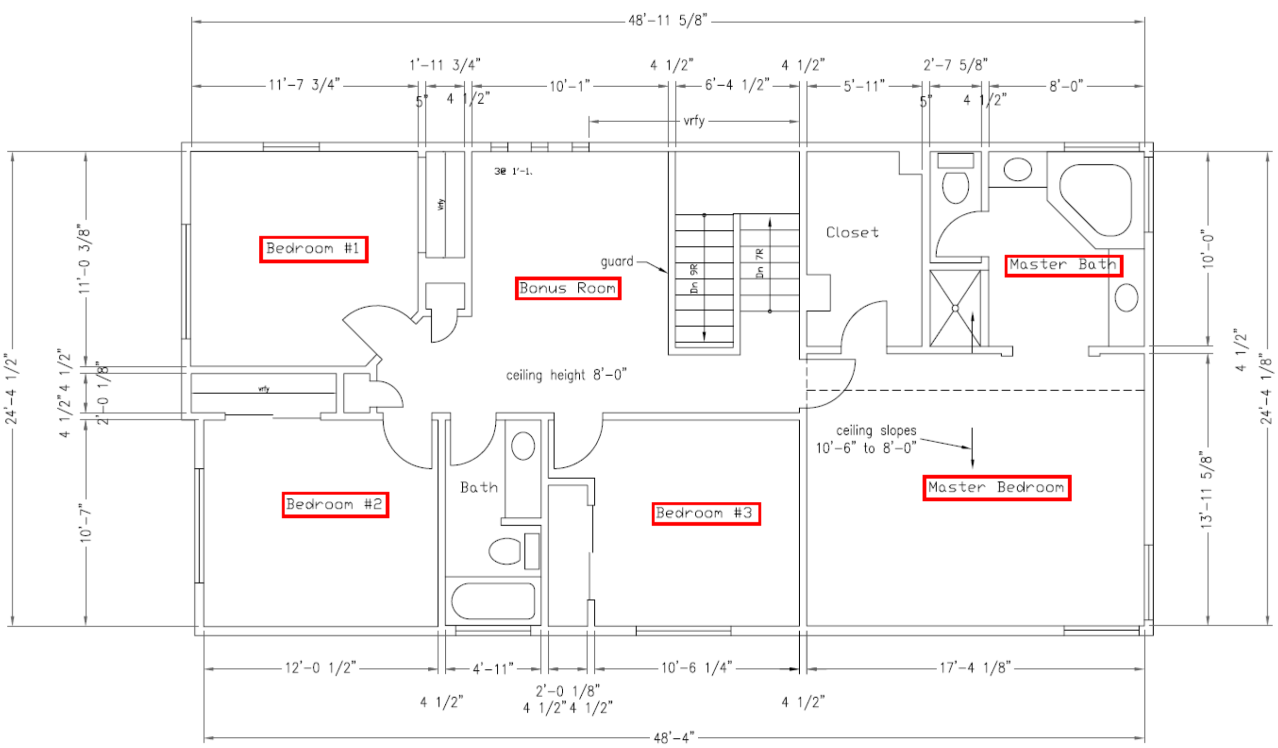


FIGURE 17. CALEB FLOOR PLAN – UPPER FLOOR

TABLE 14. SENSOR SPECIFICATIONS AND LOCATIONS - GRANGE

MEASUREMENT	SENSOR	LOCATION(S)
Air temperature	Shielded and aspirated thermocouple – Type T. Omega 24 ga TW SH STR	Mounting height 48 in., center of room • Living room • Kitchen • Bedroom 1 • Bedroom 2 • Bath • Garage • Attic (midpoint between ceiling and roof) • Thermostat • Supply air, reference system (8) • Return air, reference system
Air Temperature & relative humidity	Vaisala HMP60 Relative humidity • 0 to 40C • +/-3% RH (0 to 90% RH) • +/-5% RH (90 to 100% RH) Temperature • 10-30C, +/-0.5C	Mounting height 48 in. • Living room • Return air, reference system
Differential air pressure	Setra 264 very low pressure differential transducer. 0-150F +/- 1% full scale	• Indoor at floor level to outdoors • Attic to outdoors
Electric energy	Watt Node – WNB-3D-240-P Accuracy: +/-0.5% (CT current 5% - 100% of rated current)	• 100A CT: House total, not including old outdoor unit, reference outdoor unit, and reference air handler • 15A CT: old outdoor unit & mini-split system • 5A CT: old air handler & mini-split head unit • 30A CT: reference AC outdoor unit • 15A CT: reference AC air handler
Electric energy	Watt Node – WNB-3Y-208-P	• 5A CT: transfer fan
Water flow to humidifier	Water meter	• Kitchen
Air conditioner condensate	Tipping bucket	

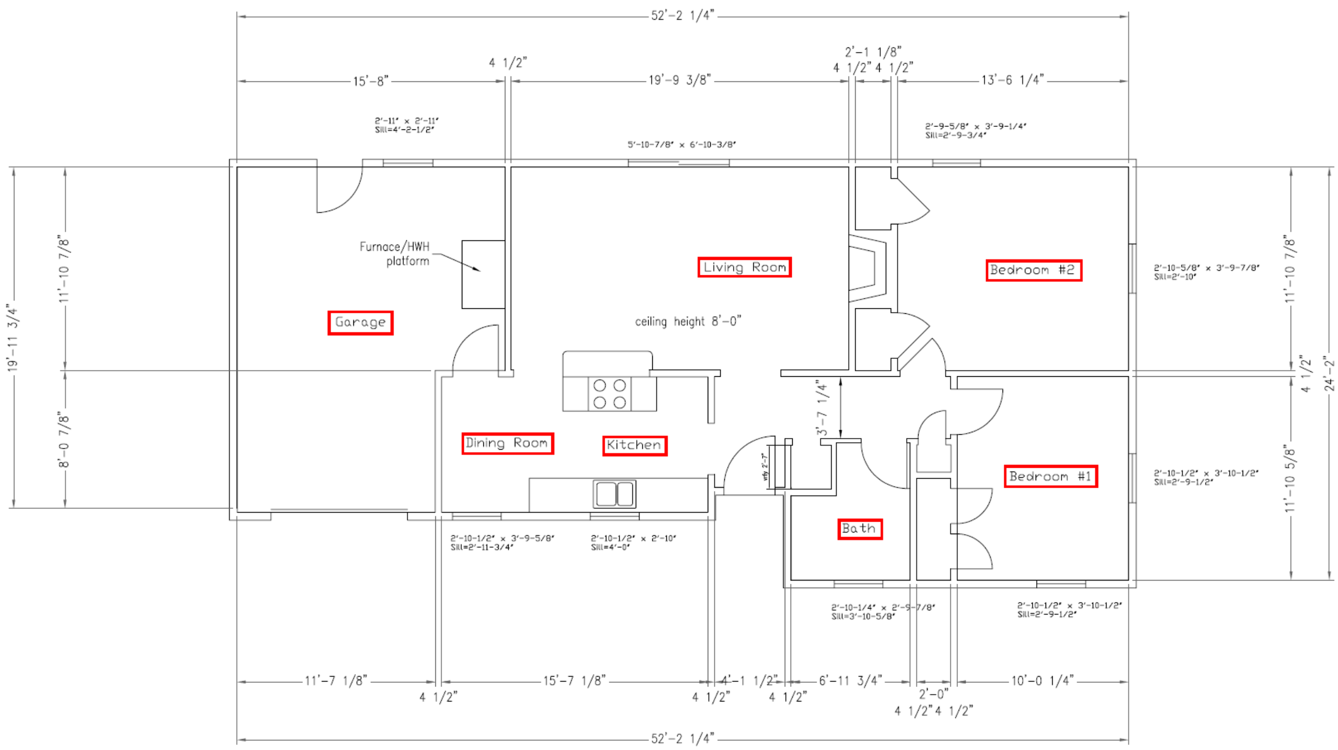


FIGURE 18. GRANGE FLOOR PLAN

TABLE 15. SENSOR SPECIFICATIONS AND LOCATIONS - MAYFAIR

MEASUREMENT	SENSOR	LOCATION(S)
Air temperature	Shielded and aspirated thermocouple – Type T. Omega 24 ga TW SH STR	Mounting height 48 in., center of room • Dining room • Living room • Kitchen • Bedroom 1 • Bedroom 2 • Bedroom 3 • Bath • Garage • Attic (midpoint between ceiling and roof) • Thermostat • Supply air, reference system (8) • Return air, reference system
Air Temperature & relative humidity	Vaisala HMP60 Relative humidity • 0 to 40C • +/-3% RH (0 to 90% RH) • +/-5% RH (90 to 100% RH) Temperature • 10-30C, +/-0.5C	Mounting height 48 in. • Living room • Crawlspace
Differential air pressure	Setra 264 very low pressure differential transducer. 0-150F +/- 1% full scale	• Indoor at floor level to outdoors • Attic to outdoors
Electric energy	Watt Node – WNB-3D-240-P Accuracy: +/-0.5% (CT current 5% - 100% of rated current)	• 100A CT: House total, not including old outdoor unit, reference outdoor unit, and reference air handler • 15A CT: old outdoor unit & mini-split system • 5A CT: old air handler & mini-split head unit • 30A CT: reference AC outdoor unit • 15A CT: reference AC air handler
Water flow to humidifier	Water meter	• Kitchen
Air conditioner condensate	Tipping bucket	

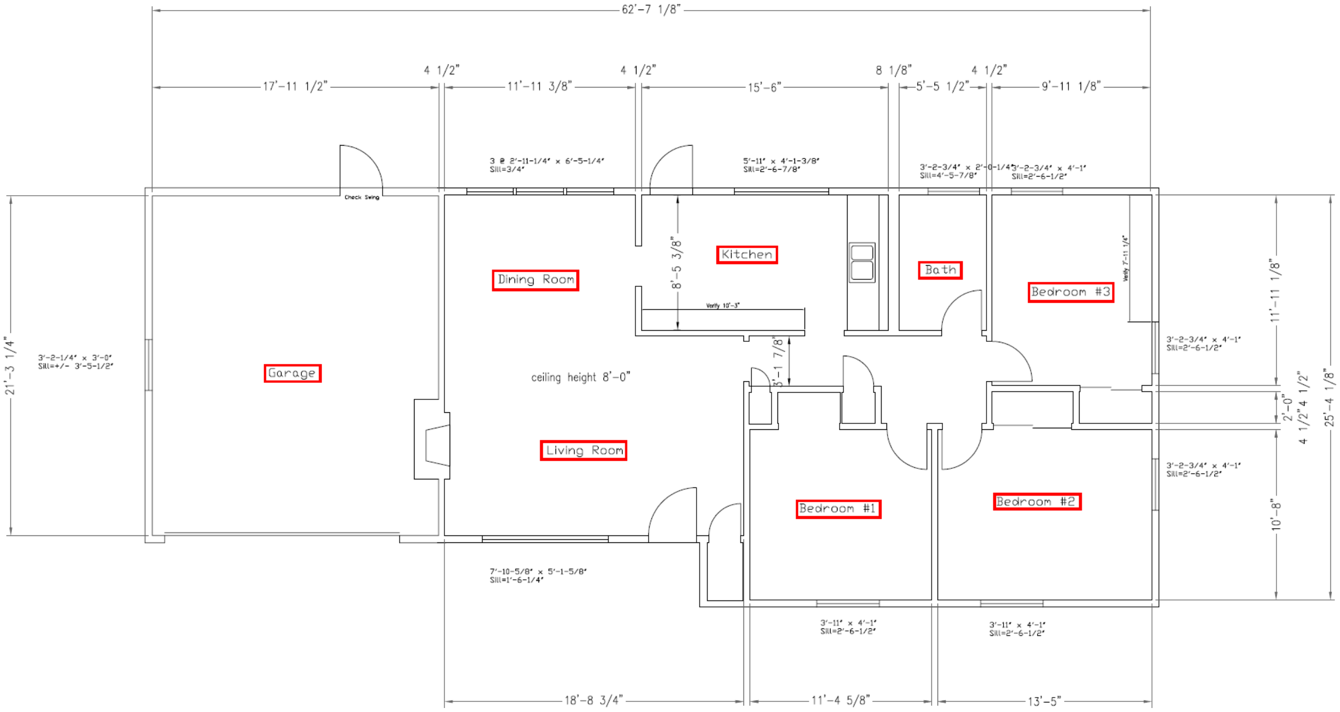


FIGURE 19. MAYFAIR FLOOR PLAN

DATA LOGGER SPECIFICATIONS AND PROGRAMMING

Data were collected using the following set of Campbell Scientific equipment at each site.

- (1) CR1000 Measurement and Control System
- (2) AM16/32 multiplexer
- (2) SDM-SW8A 8-Channel Switch Closure Input Module
- (1) SDM-CD16AC 16-Channel AC/DC Relay Controller

The monitored data points were read every 20 seconds and the average (or sum as appropriate) was recorded every minute. Data were automatically downloaded by a remote server every 20 minutes.

The role of the system included equipment control as well as data collection. Outputs from the monitoring equipment controlled all the equipment. The system turned on and off the humidifier and heaters that simulated latent and sensible heat gain from typical occupancy. The system also controlled whole house fans, transfer fans, and electric space heaters. The system enables power to the VCHP system and the reference air conditioner, which are each then controlled by their stand-alone controls.

Monitoring Equipment Installation and Calibration

Much of the monitoring and control equipment was installed and commissioned in a previous phase of the CVRH project (Wilcox). Updates to the system were installed and commissioned prior to the 2015 cooling season.

Electric Energy

New revenue-grade electrical energy meters were installed prior to the 2015 cooling season. The accuracy was verified by comparing 1 week totals to the utility electricity meter, and were found to be within 1%.

Air Temperature

Room air temperature thermocouples were verified using an ice bath to be accurate within 0.05°F.

Relative Humidity

Relative humidity sensors were checked by co-locating sensors for several hours and verifying that the sensors provided the same reading.

Humidifier Water Flow

The water meter was verified using a graduated cylinder to be accurate within 1%.

Results

Cooling Performance with Constant Thermostat Setpoint

Cooling season energy use analysis was performed for days the HVAC systems operated at a constant thermostat setpoint. reference system and VCHP system temperature control performance was sufficiently similar on constant setpoint days to develop energy use comparisons. Observations of performance during recovery from thermostat setup are discussed in a later section, but long recovery times for the VCHP systems resulted in indoor temperature differences too large for a meaningful energy use comparison to be made.

Annual Cooling Energy

Energy consumption for cooling includes three components: 1) compressor and supply fan, 2) constant standby energy for HVAC electrical components, and 3) constant transfer fans for the ductless VCHP systems.

The estimate of annual cooling energy use is based on a linear regression model of daily HVAC system energy use against daily average outdoor temperature. Figure 20 shows the relationship between daily cooling energy and daily average outdoor temperature for both the reference system and the VCHP system for each of the three houses.

Prior to performing the regressions, energy use resulting from constant power draws from HVAC system electrical components (standby power) and constantly operating transfer fans was subtracted from the daily energy use. The values for those constant power draws are shown in Table 16. The total daily HVAC energy use is calculated as the sum of the regression-predicted energy use plus energy use resulting from constant power draws. It was assumed that half of the energy consumption due to constant power draw (standby power and transfer fans) is attributed to the cooling season (4,380 hours) and the other half attributed to the heating season (4,380 hours).

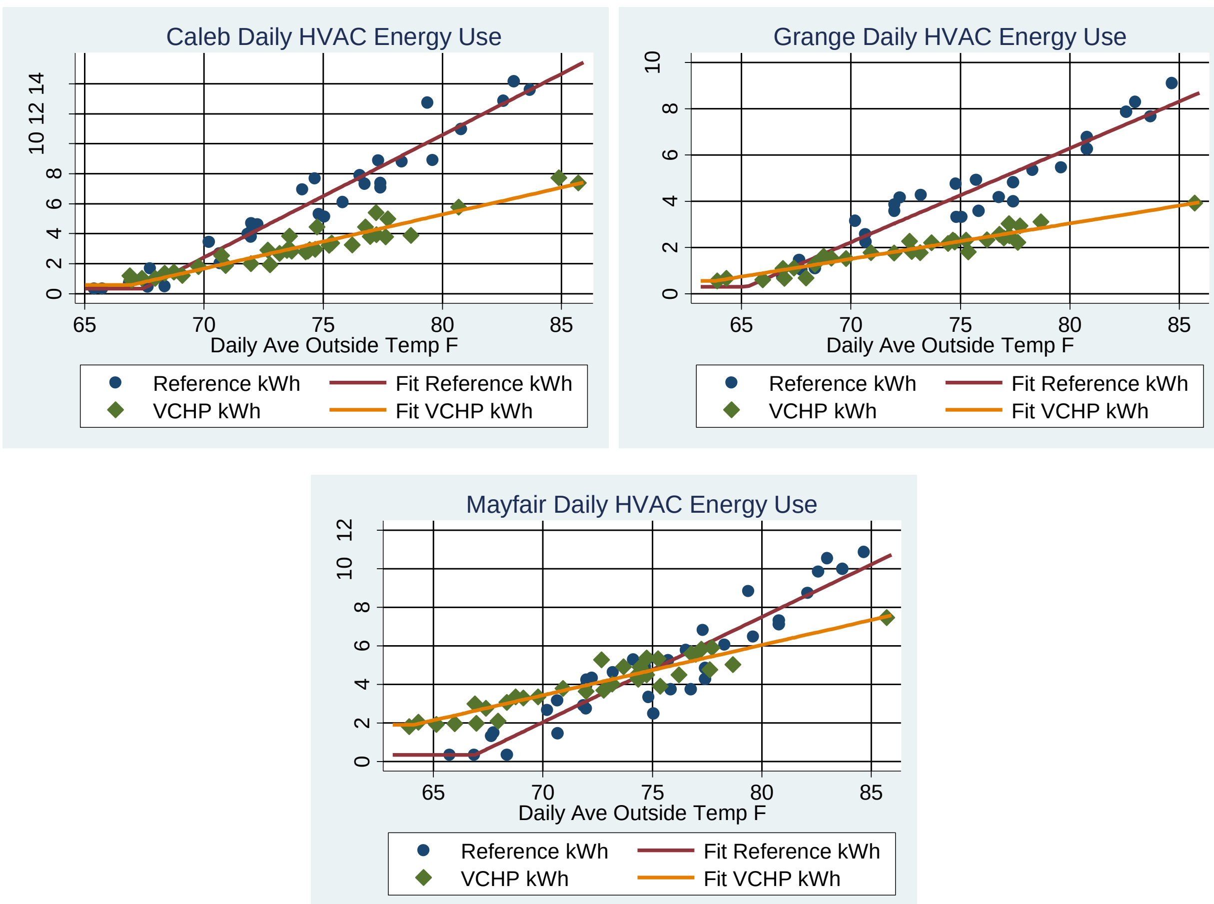


FIGURE 20. COOLING ENERGY LINEAR REGRESSIONS (PLOTTED VALUES ALSO INCLUDE CONSTANT POWER DRAW)

TABLE 16. CONSTANT POWER DRAWS

Site	System	Constant Power: Combined Indoor & Outdoor Units (watts)	Transfer Fans (watts)
Caleb	Reference system	14	
	VCHP	14	10
Grange	Reference system	10	
	VCHP	14	9
Mayfair	Reference system	14	
	VCHP	79*	

* Mayfair constant power for the VCHP system includes constantly-operating indoor supply fan power.

Annual cooling energy use was calculated as:

$$kWh_{COOL} = \sum_{i=1}^{365} (Max(0, T_i \times E_T + C1) + \frac{C2 + C_{TF}}{2})$$

Where:

T_i = Daily average outdoor temperature (°F) for day i, for each of 365 days in a year

E_T = Linear regression daily energy use (kWh) slope against daily average outdoor temperature (°F)

C1 = Linear regression constant

C2 = Heat pump daily energy use (kWh) due to constant power draws, half of which is attributed to cooling season

C_{TF} = Transfer fan daily energy use (kWh), half of which is attributed to cooling season

Coefficients for this equation are listed in Table 17.

TABLE 17. COOLING ENERGY REGRESSION COEFFICIENTS

Site	System	E_T	C1	R^2	C2	C_{TF}
Caleb	Reference HP	0.817	0.817	0.94	0.33	-
	VCHP	0.360	0.360	0.90	0.33	0.24
Grange	Reference HP	0.406	0.406	0.90	0.30	-
	VCHP	0.154	0.154	0.88	0.34	0.21
Mayfair	Reference HP	0.547	0.547	0.86	0.33	-
	VCHP	0.261	0.261	0.82	1.90	-

The linear regression results were applied to the Title 24 weather file for Stockton to develop annual cooling energy use estimates. The results are shown in Table 18.

These results assume equivalent Reference HP and VCHP system performance with respect to temperature and humidity control. However, the monitored data showed significant differences in temperature and humidity control between the reference systems and the VCHP systems. A discussion of observed differences and estimated energy impacts follows.

TABLE 18. ANNUAL COOLING ENERGY PROJECTIONS (UNADJUSTED FOR INDOOR CONDITIONS)

SITE	SYSTEM	AC UNITS (KWH/YR)	TRANSFER FAN(S) (KWH/YR)	TOTAL, UNADJUSTED (KWH/YR)
Caleb	Reference HP	807	-	807
	VCHP	413	44	457
Grange	Reference HP	547	-	547
	VCHP	281	39	320
Mayfair	Reference HP	600	-	600
	VCHP	707	-	707

The annual cooling energy use levels monitored in this study are not necessarily representative of the average California home. These houses received substantial building shell upgrades during a prior research project, and cooling loads may be lower than the average existing house of similar vintage. Dwellings complying with the 2016 version of Title 24 will likely have loads that are even lower that the CVRH houses. Relative energy performance of the VCHP vs. Reference HP systems can be expected to scale with cooling load.

DEHUMIDIFICATION PERFORMANCE

The VCHP systems provided significantly less dehumidification than the reference systems at the Grange and Mayfair houses. The Caleb VCHP system also provided less dehumidification, but the difference was smaller than at the other two houses. Figure 21 shows the daily volume of moisture removed from the air, measured as condensate from the cooling coils, plotted against daily average outdoor air humidity ratio. These plots show that the amount of moisture removed by the reference systems increases as moisture content of the outdoor air increases. The plots also show very little moisture removal by the VCHP systems at Grange and Mayfair. The VCHP system at Caleb does provide some dehumidification, but the volume is less than for the reference system under similar conditions.

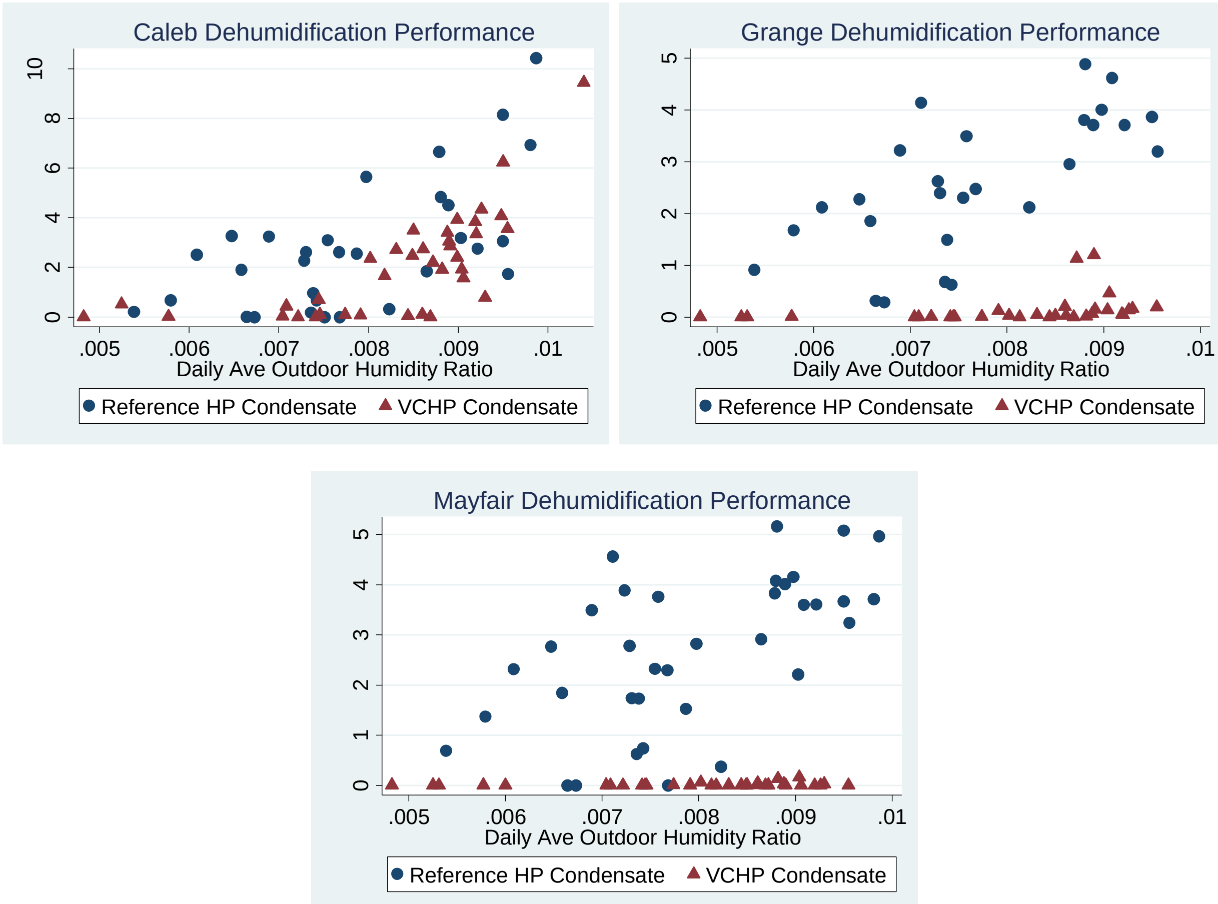


FIGURE 21. DEHUMIDIFICATION PERFORMANCE

Reduced cooling system dehumidification is only a problem if indoor humidity becomes too high. It is generally accepted within the HVAC industry that indoor relative humidity should be maintained below 60% in residential buildings to provide occupant comfort and reduce the potential for condensation and mold growth. The monitored data show indoor relative humidity exceeding 60% a significant fraction of the time at the Grange and Mayfair houses. The reference systems at all three houses, and the VCHP system at the Caleb house maintained indoor humidity at acceptable levels.

Indoor relative humidity control characteristics for each system are shown in Table 19 and Figure 22. The values shown represent only the last day of the flip/flop control cycle, allowing for any impacts from the first recovery day to be isolated by a full day of constant setpoint operation. Dehumidification differences between the systems caused indoor humidity levels to trend upward while the VCHP system was running, and downward while the reference system was running. The last day of the control cycle most closely approximates the humidity levels that each system would maintain over long-term operation. The values shown in Table 19 and Figure 22 are likely a conservative representation of indoor humidity differences since humidity levels may not be fully stabilized after 3 days.

TABLE 19. INDOOR HUMIDITY CONTROL CHARACTERISTICS

SITE	SYSTEM	MEAN INDOOR RH ON LAST DAY OF CYCLE	% OF TIME ABOVE 60% RH ON LAST DAY OF CYCLE
Caleb	Reference HP	50%	2%
	VCHP	51%	2%
Grange	Reference HP	50%	1%
	VCHP	58%	39%
Mayfair	Reference HP	49%	1%
	VCHP	56%	23%

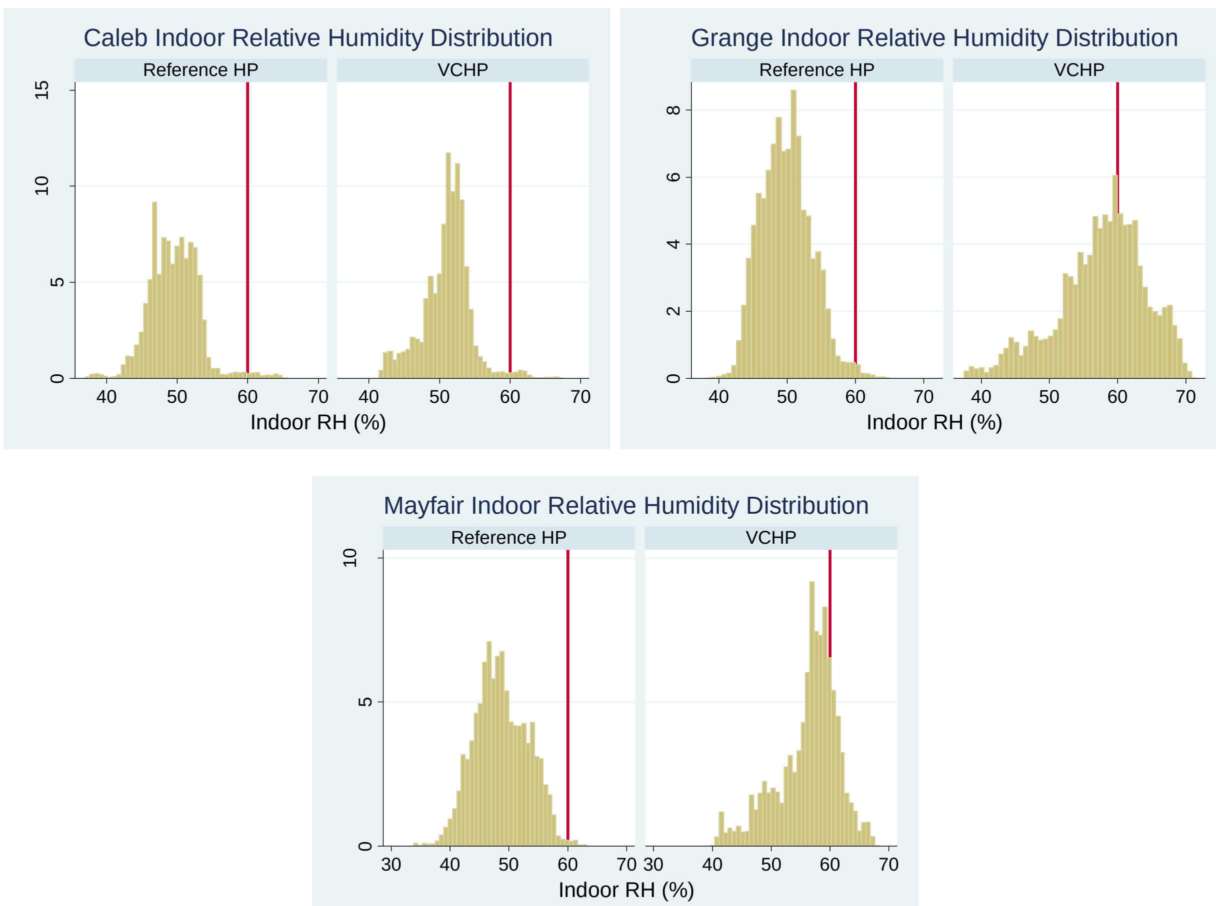


FIGURE 22. INDOOR RELATIVE HUMIDITY DISTRIBUTION ON LAST DAY OF CYCLE

Differences in dehumidification performance affect system energy use. VCHP energy use is reduced by not providing dehumidification, while reference system energy use is increased to provide extra dehumidification to remove the moisture that accumulated in the house while the VCHP was active. These trends are apparent in Figure 23, which shows the average indoor humidity for each system in each hour of the three-day cycle. At the Grange and Mayfair houses, humidity increases while the VCHP system is active and decreases while the Reference HP is active. At the Caleb house the difference between systems is much smaller. Figure 23 shows relative humidity still increases somewhat in the Caleb house while the VCHP system is running, but the rate of increase is much smaller than in the other two houses.

There may be multiple factors involved in the observed differences in dehumidification performance. A likely significant factor is the relationship between compressor speed and indoor fan speed. The Grange unit operated at a near constant indoor fan speed regardless of compressor speed. The Mayfair unit was locked on high fan speed at all times. Both units ran long compressor cycles at low speeds the majority of the time, regardless of how far the indoor temperature was from the setpoint. This results in indoor airflow that is high relative to cooling capacity delivered to the indoor coil by the compressor, which reduces latent capacity. The potential for dehumidification by the Mayfair unit was further reduced by the constantly operating fan, which causes any water that did condense in the indoor unit to evaporate between compressor cycles. Stockton's hot dry climate needs less latent cooling than for example Houston or Atlanta, but some latent cooling is still needed.

Many VCHP systems can be configured to operate in various control modes, some of which are intended to influence dehumidification performance. The manufacturers do not currently publish detailed performance data specifying the design performance in each mode, so the degree of influence on dehumidification or other operating characteristics is unknown. It is possible that system designers and installing technicians could select more optimal control modes for the application if detailed performance information were available. The various control modes are often implemented as user selectable options through the thermostat or remote control. The reliability of occupant intervention as a humidity control strategy is not within the scope of this project's experimental design, but the operation manuals for the tested equipment were observed to be sufficiently difficult for the research team to interpret and understand that it appears unlikely the average California homeowner would be capable of making appropriate ad hoc controls adjustments in response to environmental conditions.

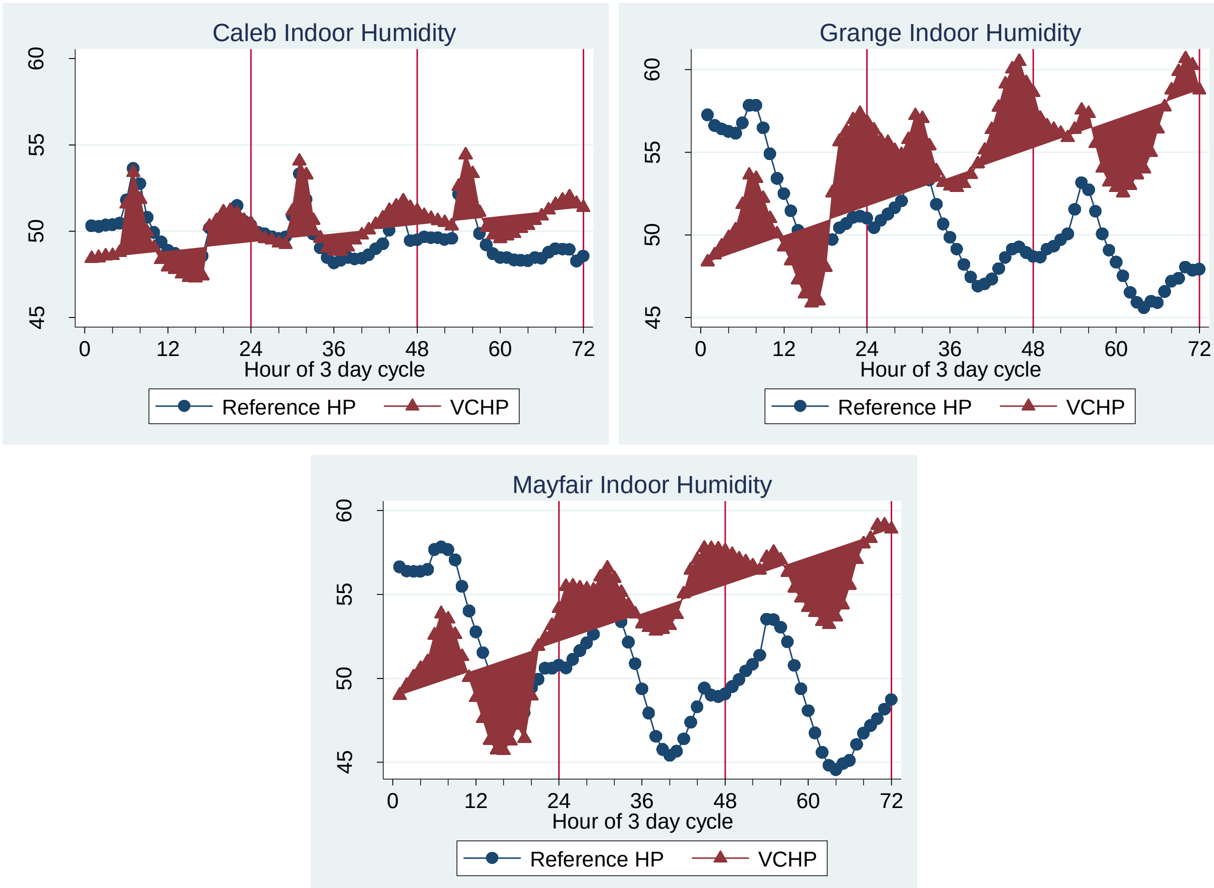


FIGURE 23. AVERAGE HOURLY INDOOR RH

The fundamental performance comparison investigated by the project is of relative AHRI ratings that represent total (sensible + latent) capacity and efficiency. It is therefore necessary to estimate the energy implications of the monitored difference in latent capacity to develop performance-normalized energy use estimates for comparison to the SEER ratings. The estimated energy impacts of monitored differences in latent capacity were developed through the following process:

1) Average latent capacity of each system was characterized by linear regression of the monitored hourly liters of condensate removal against monitored outdoor temperature and outdoor humidity ratio.

2) The difference between reference system and VCHP average latent capacity was calculated for each hour in the monitored data.

3) The manufacturers' published expanded performance tables were used to estimate reference system energy use to provide the difference in latent capacity at the monitored temperatures for each hour.

4) Results were summed into daily energy totals (including the latent capacity adjustments) and projected to the Title 24 weather file for Stockton by linear regression against monitored daily average outdoor temperature and humidity ratio.

5) Annual results were summed, excluding days with no projected air conditioner energy use. The results are listed in Table 20, and adjusted cooling energy results are described in the section below titled Performance Normalized Annual Cooling Energy.

TABLE 20. LATENT CAPACITY DIFFERENCE ESTIMATED ENERGY IMPACT

SITE	ESTIMATED IMPACT OF LATENT CAPACITY DIFFERENCE, ANNUAL KWH	% OF REFERENCE SYSTEM ANNUAL ENERGY USE
Caleb	28	3.4%
Grange	68	12.4%
Mayfair	72	12.0%

COOLING SEASON INDOOR TEMPERATURE CONTROL

ACCA Manual RS (ACCA 2015) guidelines recommend that indoor temperatures be maintained within 3°F of the thermostat setpoint during cooling season, with no more than 6°F room-to-room temperature variation. Ductless systems face an inherent challenge in meeting these criteria due to the lack of conditioned air distribution to each room of the house. The study applied an optimistic test scenario with regard to ductless system thermal comfort. The doors to all rooms were left open at all times. Transfer fans delivering air to rooms not directly served by an indoor head were operated constantly on the days when the ductless systems were active.

Differences in ducted vs. ductless system temperature control performance were observed, particularly at Caleb, the largest house. Table 21 shows the percentage of one-minute data points meeting the ACCA Manual RS criteria for each system. Average temperatures in each room relative to the thermostat setpoint are shown in Figure 24 through Figure 26. These plots show the temperature difference data in two ways: 1) as a function of outdoor temperature, and 2) as a 24-hour time series. Note that in the time-series data it can be seen that the reference systems in each house did not run during the early morning hours due to the absence of a cooling load, while the VCHP systems would sometimes run through the night at low output.

TABLE 21. COOLING TEMPERATURE CONTROL PERFORMANCE RELATIVE TO ACCA MANUAL RS

SITE	SYSTEM	% OF TIME WITH ROOM TEMPERATURES WITHIN 3 °F OF SETPOINT	% OF TIME WITH LESS THAN 6 °F ROOM-TO-ROOM TEMPERATURE DIFFERENCE
Caleb	Reference HP	71%	100%
	VCHP	52%	85%
Grange	Reference HP	94%	100%
	VCHP	90%	100%
Mayfair	Reference HP	75%	100%
	VCHP	97%	100%

The data represented in Table 21 and Figure 24 through Figure 26 were filtered to only include minute data where:

1) The whole house fan did not operate during the hour or during the prior hour. This is to eliminate periods with low indoor temperatures due to whole house fan cooling.
2) Indoor temperature was below the setpoint due to mild conditions.

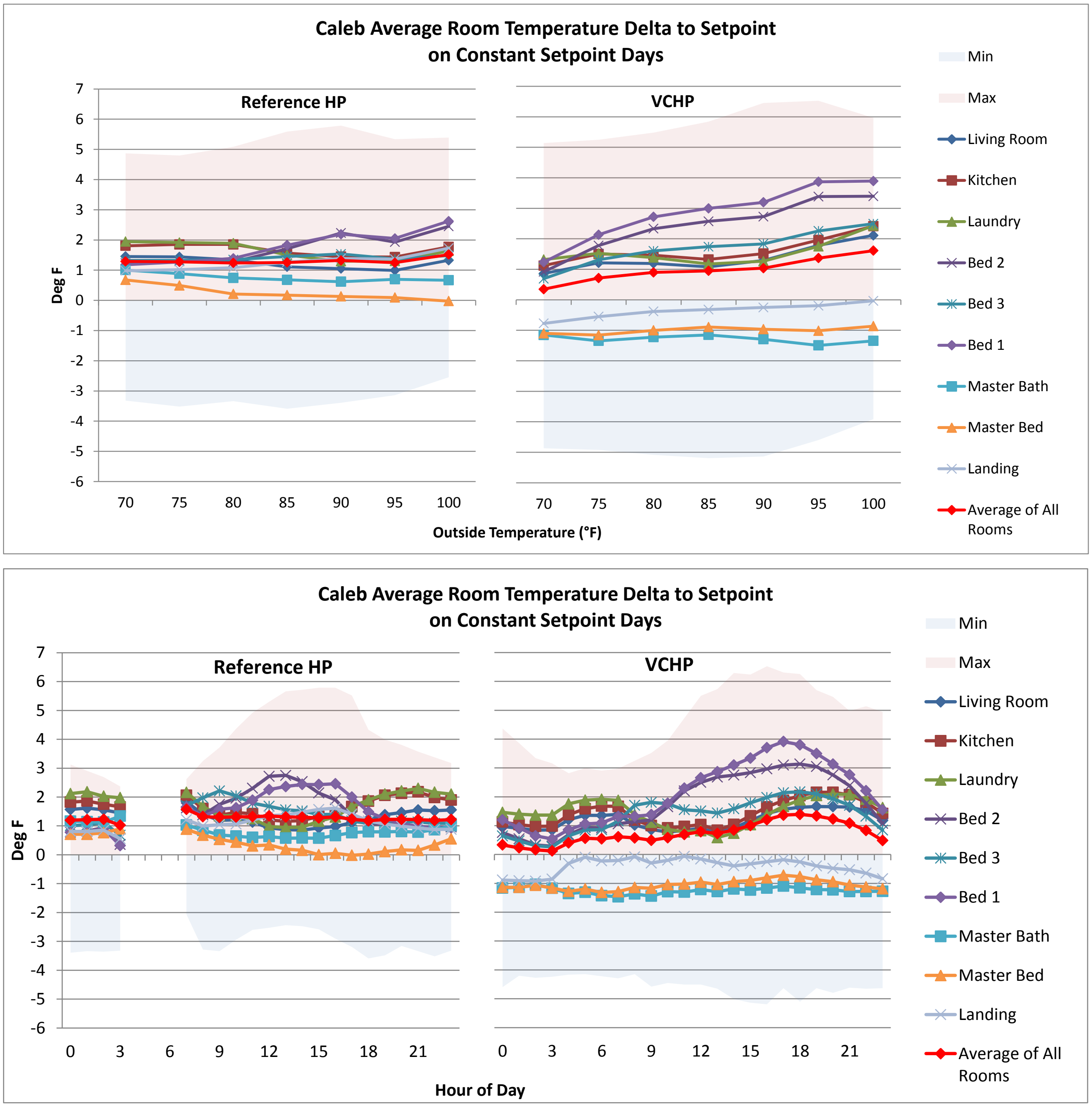
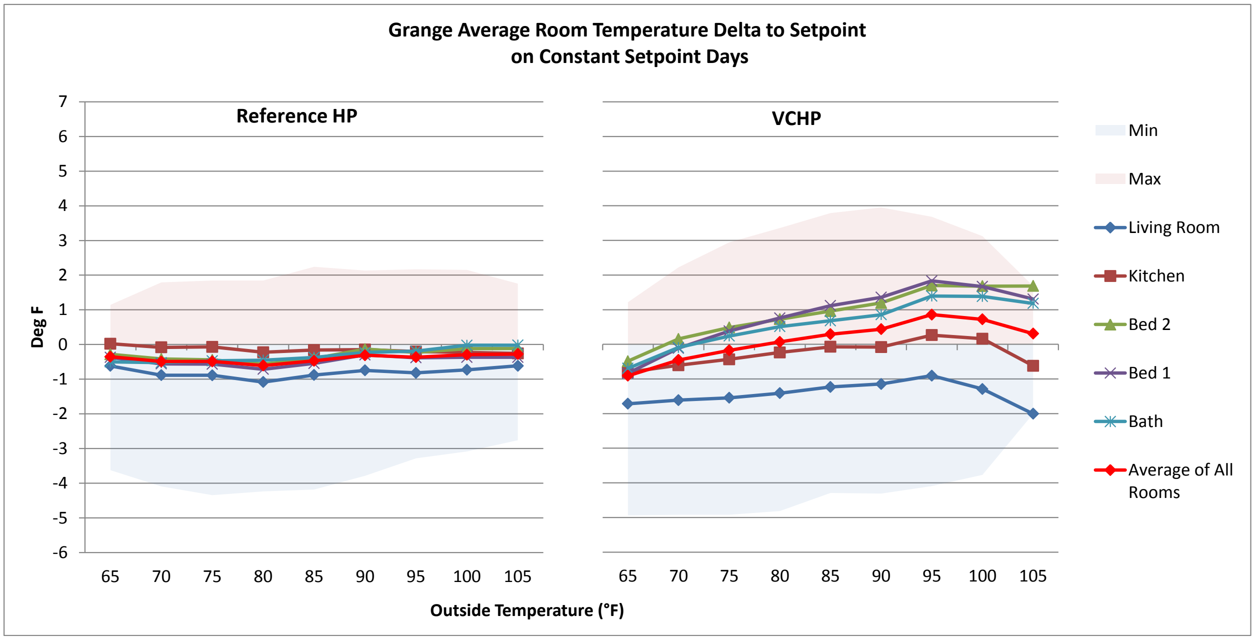


FIGURE 24. CALEB ROOM TEMPERATURES DURING CONSTANT SETPOINT COOLING



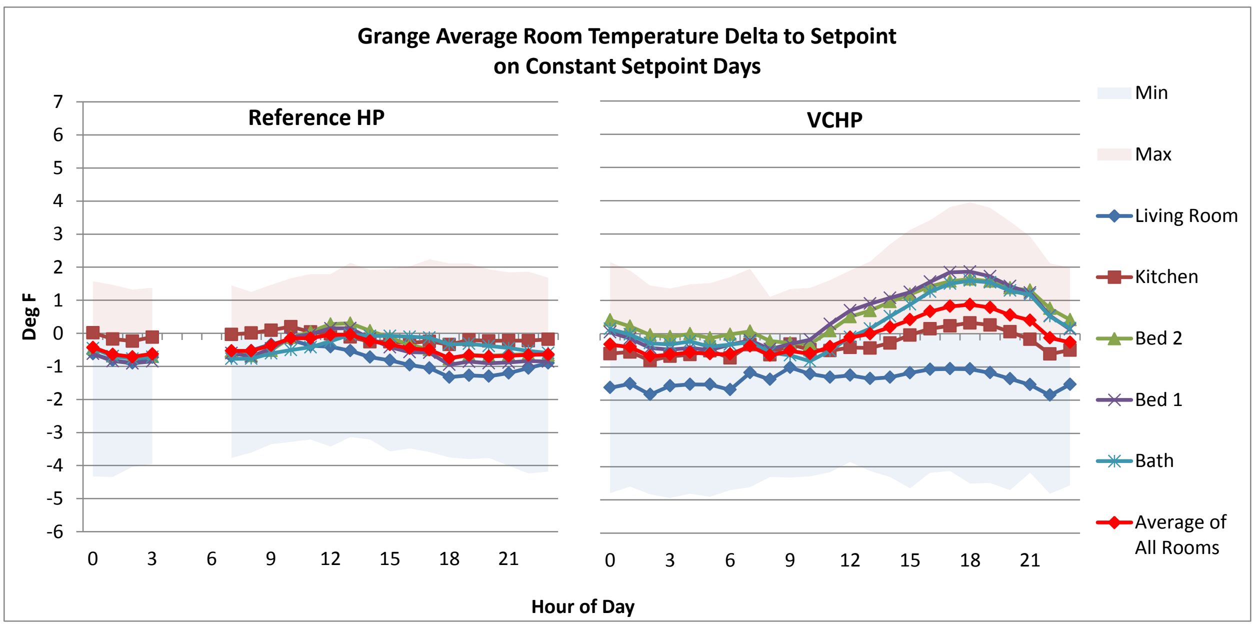


FIGURE 25. GRANGE ROOM TEMPERATURES DURING CONSTANT SETPOINT COOLING

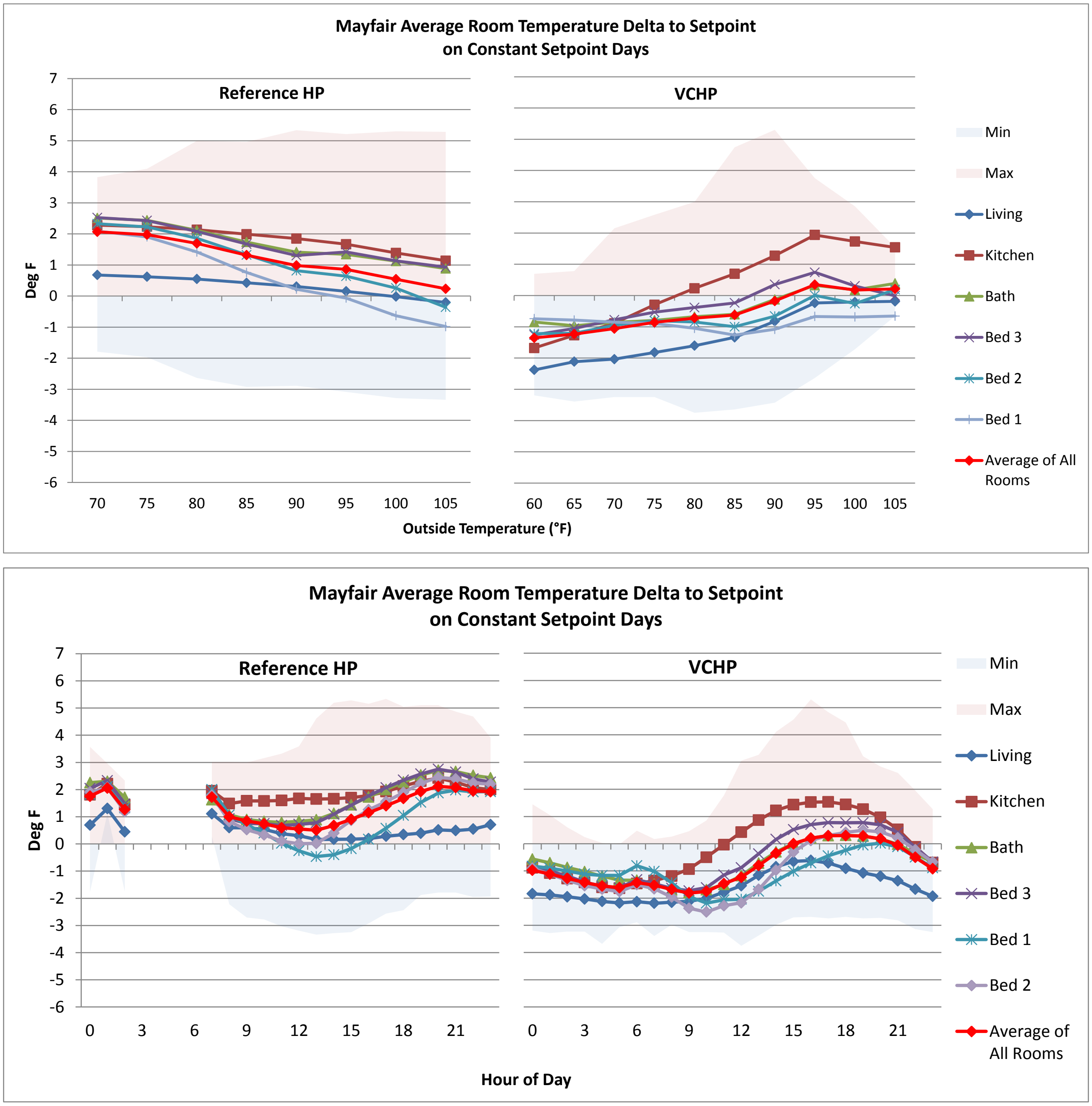


FIGURE 26. MAYFAIR ROOM TEMPERATURES DURING CONSTANT SETPOINT COOLING

The ductless VCHP systems at the Caleb and Grange houses provided less consistent room temperatures than the ducted Reference HP systems. The Grange VCHP unit was able to maintain room-to-room differences within the 6°F Manual RS guidelines, but the difference in room-to-room temperature performance is clearly visible in Figure 25. At both houses, room-to-room temperature differences increased with outdoor temperature, and were largest in the afternoon and evening hours.

The VCHP system at the small Grange house was able to meet 3°F Manual RS guidelines for room-to-setpoint temperature 90% of the time, while the VCHP system at the larger Caleb house experienced rooms more than 3°F from setpoint nearly half of the time. The large Caleb house was also a challenge for the single zone Reference HP system, which met Manual RS guidelines 71% of the time. It is common to find automatic damper zoning implemented to address this comport problem.

The ducted VCHP system at Mayfair performed similarly to the ducted Reference HP system with respect to room-to-room temperature control. The VCHP system maintained average house temperature 1.8 °F lower than the Reference HP system. There are at least three contributing factors to the average temperature difference:

1) The VCHP system operated the indoor fan on high speed all of the time, so air was constantly circulated around the house.
2) The VCHP system controls tended to cool the house to below setpoint at lower outdoor temperatures.
3) The Reference HP system ran shorter cycles during which house temperatures were quickly pulled down, followed by a longer period of temperature drift at warmer temperatures before the living room, where the thermostatic control is located, reached the top of the deadband. The living room was maintained within the 2 °F deadband of setpoint specified for the thermostatic controls, but other rooms were warmer.

As a result of these factors, the Mayfair Reference HP system maintained temperatures within Manual RS guidelines 75% of the time compared to 97% for the ducted VCHP system with constantly operating fan.

The energy impact associated with the average house temperature difference at Mayfair was estimated by performing the linear regression of VCHP daily energy use against daily outdoor temperature, with outdoor temperature offset by +1.8 °F to represent outdoor-indoor temperature differential equivalent to the conditions experience by the Reference HP. The resulting estimate indicates that at average house indoor temperatures equivalent to the Reference HP, the Mayfair VCHP annual cooling energy use would be reduced by 69 kWh (10%).

Average indoor temperatures were matched to within 0.5 °F at the other two houses, and no cooling energy adjustment is applied in those cases.

Performance Normalized Annual Cooling Energy

Annual cooling energy estimates are shown in Table 22. Normalized values reflect the estimated energy impact of latent capacity differences and the energy impact of difference in average house temperature at Mayfair. Given the negative savings for Mayfair, additional analysis is done to assess the impact of the constant indoor fan operation, and an estimate of what performance would have with intermittent fan operation is presented later in this report.

TABLE 22. PERFORMANCE NORMALIZED ANNUAL COOLING ENERGY

Site	System	Annual Cooling Energy, Unadjusted (kWh)	Latent Capacity Normalization (kWh)	Indoor Temperature Normalization (kWh)	Annual Cooling energy, Normalized (kWh)
Caleb	Reference HP	807	-28	-	780
	VCHP	457	-	-	457
Grange	Reference HP	547	-68	-	479
	VCHP	320	-	-	320
Mayfair	Reference HP	600	-72	-	528
	VCHP	707	-	-69	638

Table 23 shows percent cooling energy savings for the VCHP system compared to the reference systems. The expected percent savings are predicted based on the ratio of SEER ratings between the VCHP and reference systems. While SEER is not proven to be an accurate predictor of actual performance, it is the DOE and AHRI certified performance rating for these residential air conditioning systems and appears on the yellow and black label. Uncertainties in basing energy performance estimates on the SEER rating include:

- The SEER test conditions and calculation assumptions are not representative of the California climate.
- The SEER test conditions are not representative of any US climate with regard to humidity. The AHRI D test for cycling performance is conducted at 82 °F outdoor temperature, 80 °F indoor temperature, and less than 22% indoor relative humidity.
- The SEER test methods originated as tests for single speed equipment, and are not proven to produce reliable results for VCHP systems. At present, the SEER test methods "lock" variable-speed equipment at fixed speeds, essentially forcing them to function as single speed systems at each test point. VCHP system controls can be quite complex, are also quite diverse with different manufacturers favoring different control logic, and can significantly affect system performance in a variety of ways. Variable-speed systems operating under their intended control programming may perform better, or worse than indicated by the locked-speed SEER tests.

TABLE 23. VCHP ANNUAL COOLING ENERGY SAVINGS

SITE	SYSTEM	SEER	SEER PREDICTED COOLING ENERGY SAVINGS	MONITORED SAVINGS, UNADJUSTED	PERFORMANCE NORMALIZED SAVINGS**
Caleb	Reference HP	14			
	VCHP	20.9*	33%	43%	41%
Grange	Reference HP	14			
	VCHP	25.5	45%	41%	33%
Mayfair	Reference HP	14			
	VCHP	16	13%	-18%	-21%

*CAPACITY WEIGHTED AVERAGE OF THE TWO VCHP SYSTEMS AT CALEB

** SAVINGS NORMALIZED FOR LOWER LATENT COOLING AT CALEB AND GRANGE AND FOR FAN OPERATION AT MAYFAIR

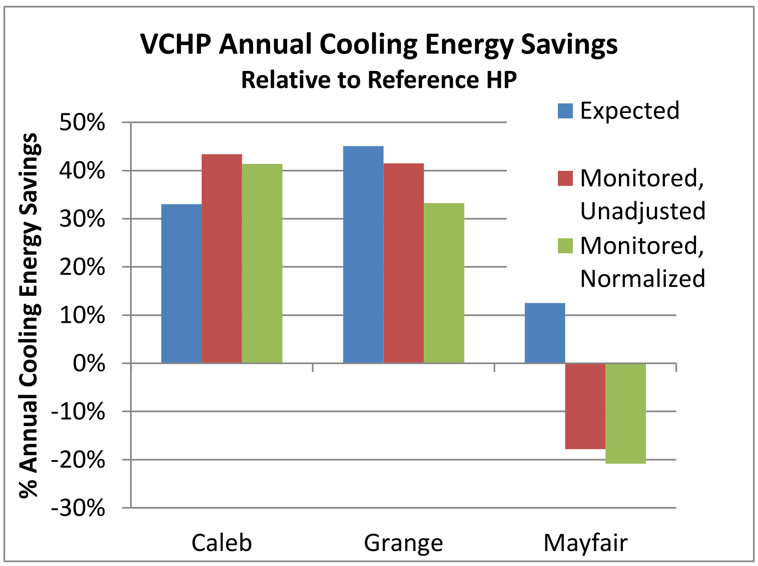


FIGURE 27. VCHP ANNUAL COOLING ENERGY SAVINGS RELATIVE TO THE REFERENCE SYSTEM

AIR DISTRIBUTION IMPACTS ON COOLING ENERGY PERFORMANCE

Mayfair VCHP energy use was significantly impacted by power draw from a constantly operating indoor air handler fan. The fan was adjusted by the manufacturer after initial installation to operate constantly on high speed in response to inability of the VCHP system to meet cooling load on hot days. Eliminating the constant fan power draw of 69W when the compressor is not running would reduce the Mayfair annual energy use by an estimated 166 kWh. On the other hand, intermittent operation would allow room-to-room temperature difference to rise and might adversely affect comfort performance.

Caleb and Grange VCHP energy use is optimistic due to very low energy use by the constantly operating transfer fans. The transfer fans installed in this study are not representative of the products that are currently available in the market for this application. Ducting into each room was located within the conditioned envelope. They are best-in-class exhaust fans, and their performance is described on page 17. The standard transfer fans that are currently commercially available are significantly less efficient. Based on manufacturer specifications, the standard transfer fan unit watt draw is approximately 50 watts each, 10 times the watt draw of the fans used in this study at the Caleb house. It is estimated that the commercially available products would increase transfer fan power from 9 watts to 50 watts at Grange and from 10 watts to 100 watts at Caleb. The corresponding increase in daily energy use (C_{TF}) is 2.16 kWh for Caleb and 0.99 kWh for Grange. This would increase annual energy use by 394 kWh for Caleb and 181 kWh for Grange. This result highlights the fact that it will advantageous for VCHP installations with transfer fans to use much better fans.

Figure 28 shows the estimated impact of using standard commercially available transfer fans at Caleb and Grange, and of allowing the indoor fan on the Mayfair unit to cycle with the compressor rather than operating constantly. In this scenario, the cooling energy savings for the ducted VCHP system at Mayfair approach the expected percentage while the Caleb and Grange energy savings are completely negated by the energy consumption of constantly operating transfer fans. It is worth noting that Mayfair comfort conditions would be impacted by eliminating the constant air handler fan operation.

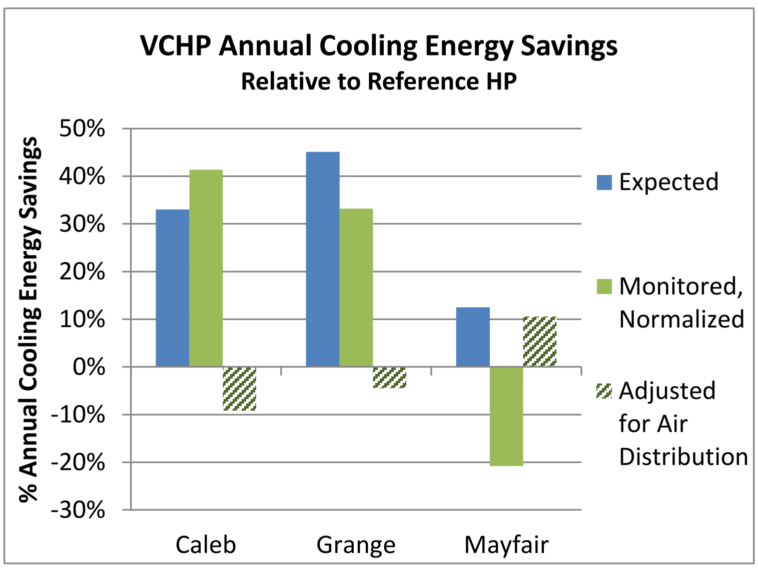


FIGURE 28. VCHP COOLING SAVINGS ADJUSTED FOR AIR DISTRIBUTION ENERGY IMPACTS

PEAK DEMAND

The maximum recorded hourly kWh during peak afternoon hours for each system are tabulated by hour and outdoor temperature bin in Table 24. For the hours shown, the VCHP systems produced demand reductions of 50% on average at the Caleb house, 64% at Grange, and 44% at Mayfair in the 95-100 °F temperature bin. These values do not account for humidity or temperature comfort differences or for the potential for occupant interactions to increase demand in response to uncomfortable conditions.

TABLE 24. MAXIMUM HOURLY COOLING KWH AT CONSTANT SETPOINT

		Reference HP Maximum Hourly kWh			VCHP Maximum Hourly kWh			Demand Reduction (kW)		
	Temp Bin	85-90	90-95	95-100	85-90	90-95	95-100	85-90	90-95	95-100
Site	Hour									
Caleb	14	0.75	0.90	1.23	0.33	0.33	0.56	0.43	0.57	0.66
	15	0.77	0.95	1.26	0.48	0.55	0.65	0.29	0.39	0.61
	16	0.87	1.22	**1.35**	0.52	0.54	**0.69**	0.35	0.68	**0.66**
	17	1.16	1.28	1.22	0.49	0.68	0.62	0.67	0.60	0.60
	18	1.08	1.22	-	0.55	0.62	-	0.52	0.60	-
Grange	14	0.44	0.52	0.72	0.19	0.21	0.23	0.25	0.31	0.49
	15	0.49	0.55	0.76	0.26	0.22	0.34	0.24	0.33	0.41
	16	0.56	0.61	0.78	0.28	0.22	0.34	0.28	0.39	0.44
	17	0.60	0.69	**0.82**	0.23	0.20	**0.20**	0.37	0.49	**0.62**
	18	0.66	0.74	0.80	0.18	0.21	-	0.48	0.53	-
Mayfair	14	0.66	0.93	**1.16**	0.30	0.42	0.49	0.36	0.51	**0.67**
	15	0.63	0.80	1.08	0.36	0.43	0.63	0.27	0.37	0.45
	16	0.62	0.83	1.09	0.41	0.47	**0.64**	0.21	0.36	0.45
	17	0.69	0.87	0.94	0.44	0.44	0.61	0.25	0.43	0.33
	18	0.65	0.79	0.73	0.42	0.45	-	0.23	0.34	-

VCHP system speed and power draw cannot be assumed to ramp linearly with outdoor temperature. Caution should be used in extrapolating demand to higher temperature bins.

SYSTEM OPERATING CHARACTERISTICS

The VCHP systems ran longer compressor cycles than the single-speed Reference HP systems. The Reference HP units ran short cycles that rarely exceeded 15 minutes. This is to be expected since the system was oversized based on standard industry practice. The Grange and Mayfair VCHP units operated continuously for the majority of their run time, often extending to several hours at less than peak capacity. The Caleb VCHP units cycled even on the hottest days. Figure 29 illustrates the difference in cycle times between the reference systems and the VCHP systems, using data from the constant setpoint days.

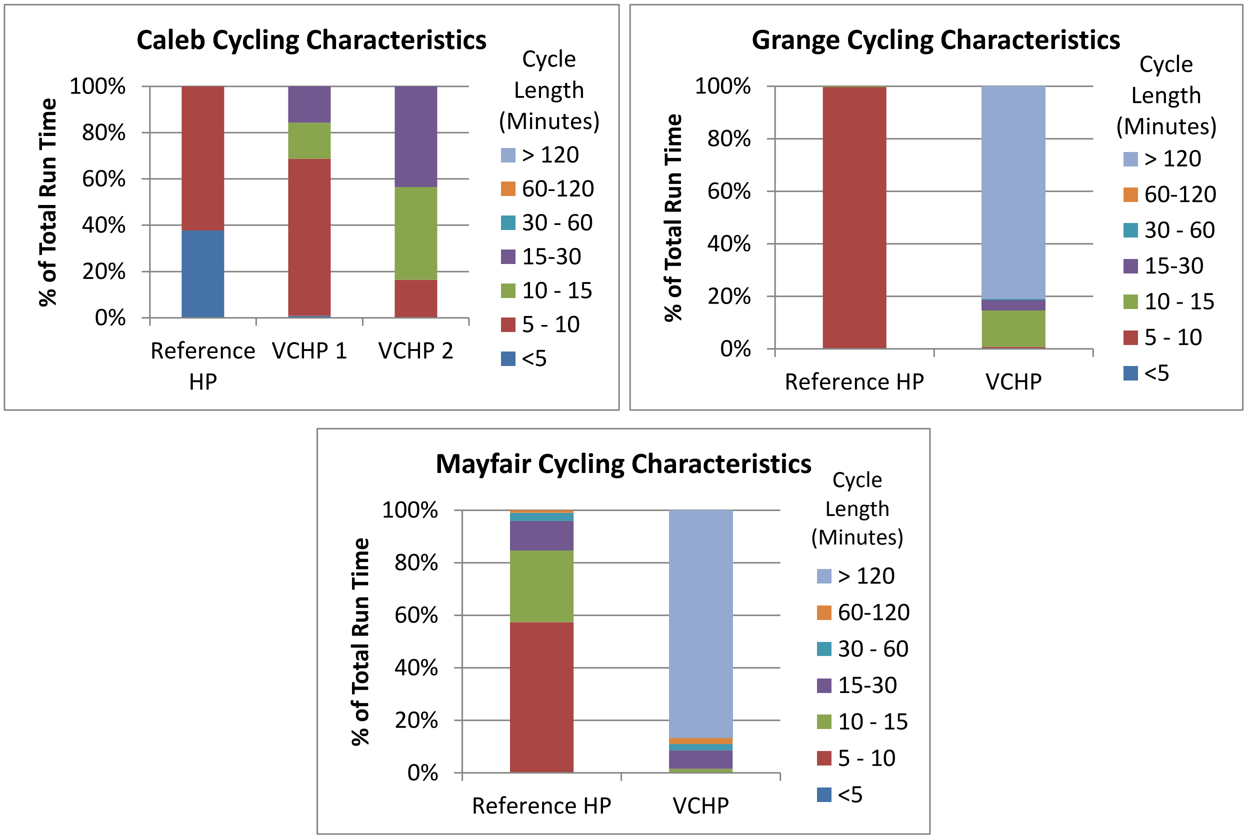


FIGURE 29. COOLING MODE CYCLING CHARACTERISTICS (CONSTANT SETPOINT DAYS??)

COOLING PERFORMANCE WITH THERMOSTAT SETBACK AND RECOVERY

INDOOR TEMPERATURE CONTROL

On the first day of each flip/flop cycle the HVAC systems were disabled and indoor temperatures were uncontrolled until 5PM. At 5PM the systems were turned on, with a 76 °F setpoint. Customers may operate their systems this way to save money. This produced a period of temperature recovery, where the single-speed systems were expected to operate continuously and the variable-speed systems were expected to operate at high speeds to pull the house temperature down to setpoint.

Table 25 shows the percentage of one-minute data points meeting the ACCA Manual RS criteria for each system. Average temperatures in each room relative to the thermostat setpoint are shown in Figure 30 through Figure 32. Appendix D includes additional graphs of measured temperature in each room on a single hot recovery day, with corresponding HVAC unit power draw. The data represented in Table 25 and Figure 30 through Figure 32 were filtered to only include minutes where:

1. The minute occurred after the system is turned on at 5:00PM.

2. The heat pump operated during the hour.

Figure 30 through Figure 32 include only the days with daily high temperature of at least 90 °F, to illustrate performance with significant cooling loads during recovery.

Table 25. Cooling Recovery Temperature Control Relative to Manual RS

	Site	System	% of Time with Room Temperatures within 3 °F of Setpoint	% of Time with Less Than 6 °F Room-to-Room Temperature Difference
All Days	Caleb	Reference HP	62%	99%
		VCHP	33%	69%
	Grange	Reference HP	89%	100%
		VCHP	66%	94%
	Mayfair	Reference HP	47%	100%
		VCHP	74%	100%
Days with Daily High Temperature ≥ 90 °F	Caleb	Reference HP	69%	99%
		VCHP	15%	52%
	Grange	Reference HP	87%	100%
		VCHP	39%	86%
	Mayfair	Reference HP	48%	100%
		VCHP	53%	100%

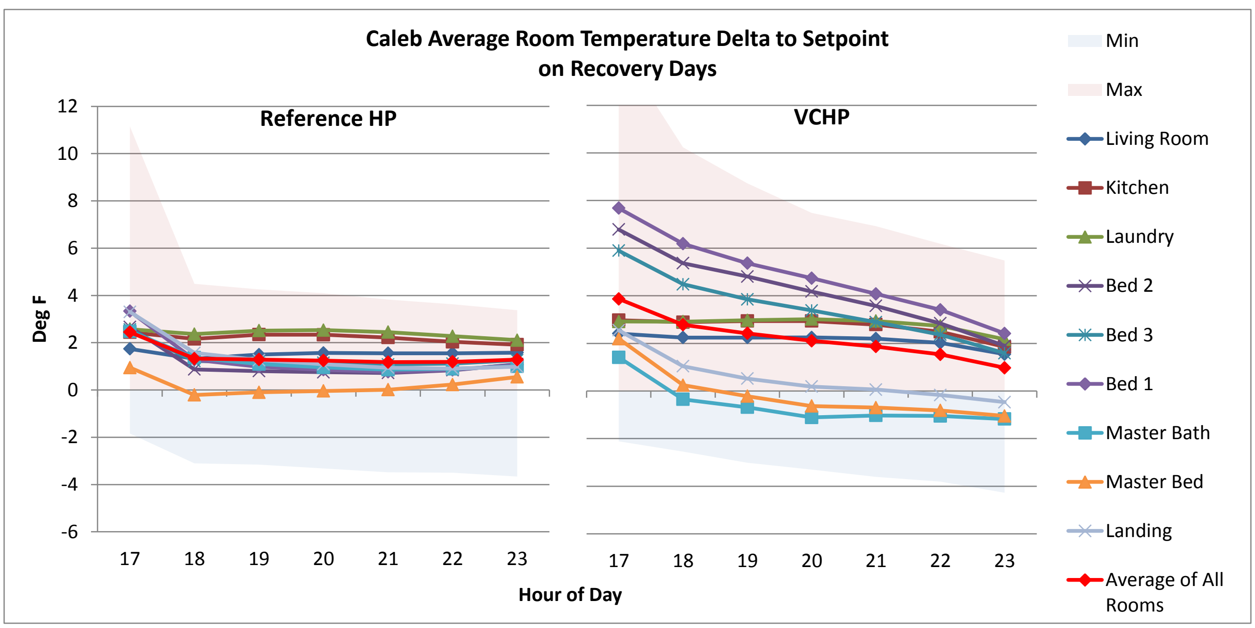


Figure 30. Caleb Room Temperatures during Cooling Recovery

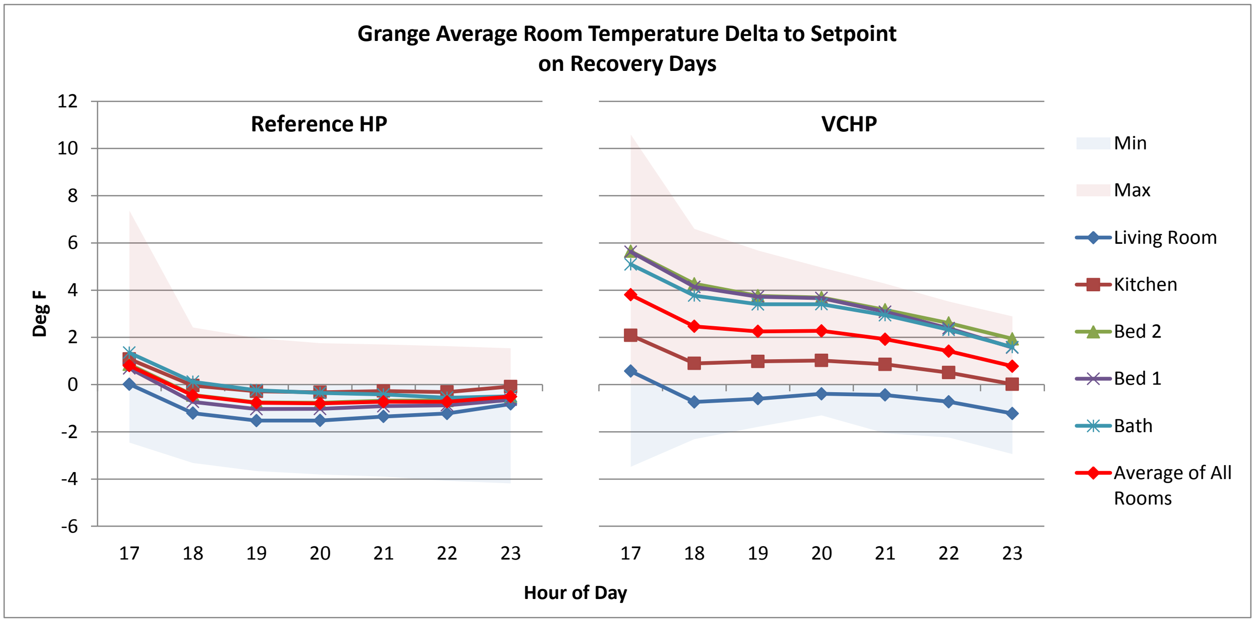


FIGURE 31. GRANGE ROOM TEMPERATURES DURING COOLING RECOVERY

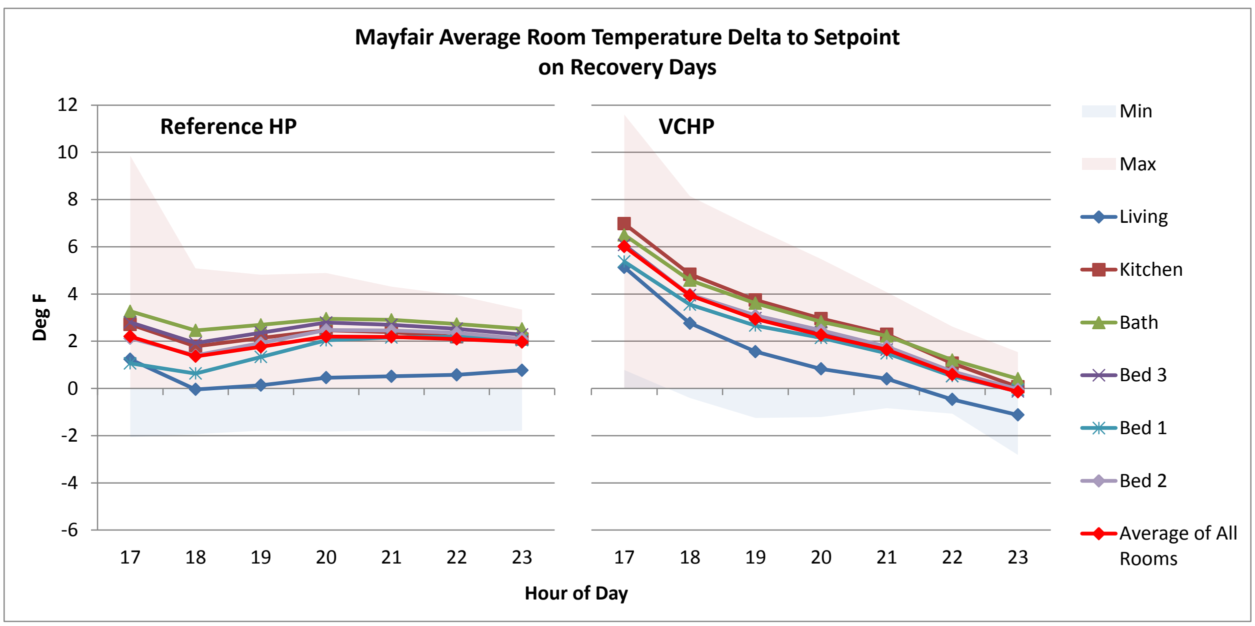


FIGURE 32. MAYFAIR ROOM TEMPERATURES DURING COOLING RECOVERY

The ductless VCHP systems at Caleb and Grange performed substantially worse than the ducted Reference HP systems relative to the Manual RS guidelines.

The Reference HP system at the Mayfair house struggled to keep all rooms within 3°F of setpoint due to the same factors discussed for the constant setpoint days, which were exacerbated by thermal mass of the house during recovery. As on the constant setpoint days, the Mayfair Reference HP system was able to keep the living room (where thermostatic control is located) near setpoint, but other rooms were warmer.

The VCHP systems were not able to pull house temperatures down to setpoint as quickly as the Reference HP systems, particularly on the hottest days (see Appendix D). There were multiple contributing factors, including:

- Even with the doors open and transfer fans running constantly, the rooms that were not directly served by a ductless indoor head experienced long recovery times.
- VCHP control logic caused the units to deliver less than maximum capacity during recovery at two houses. See plots of HVAC unit power in Appendix D.
    - The Caleb VCHP units ramped down to lower speeds and began cycling before setpoint was reached in the rooms with thermostatic control.
    - The Mayfair VCHP unit controls limited maximum capacity operation to one hour, causing the unit to ramp down to lower speeds before setpoint was reached.
- VCHP unit sizing was specified by the manufacturers. The VCHP units at Grange and Mayfair were sized smaller than the Reference HP units, and in the case of Mayfair the nominal capacity of the selected unit was lower than the peak cooling load based on Manual J calculations (see Table 7 and Table 8). The reference system at Grange is somewhat larger than necessary due the fact that the reference systems are not available with cooling capacity less than 18,000 Btu/hr.

COOLING ENERGY USE

House temperature differences during recovery from a thermostat setback were too great for a meaningful energy use comparison to be developed. In addition to affecting cooling loads, warmer house temperatures during VCHP recovery raise the potential for occupants to interact with the thermostat (i.e. lower the setpoint) in ways that increase energy use above the monitored values. This is particularly true for the two houses where VCHP controls caused the units to ramp down from maximum capacity before setpoint was reached.

Energy performance of each system with a constant thermostat setpoint, and with a thermostat setback and 5 PM recovery, are plotted in Figure 33 through Figure 35. Linear regression fits to the data are also shown to illustrate average trends. The following observations can be made regarding energy performance with the thermostat setback and recovery schedule, in comparison to a constant setpoint:

- Daily energy use of the Reference HP is reduced at all three houses
- Daily energy use of the VCHP is:
    - Reduced at Caleb
    - Slightly reduced at Grange
    - Increased at Mayfair. For this VCHP system, prolonged operation at higher and less efficient compressor speeds during Recovery

outweighed the energy saved by not running the system during the day.

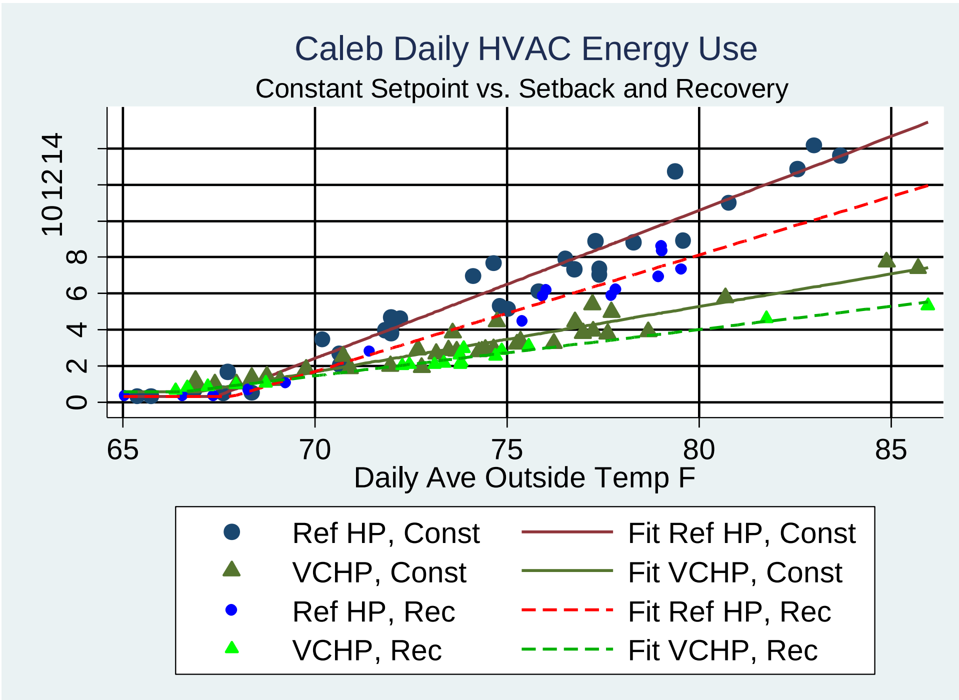


FIGURE 33. CALEB RECOVERY ENERGY PERFORMANCE

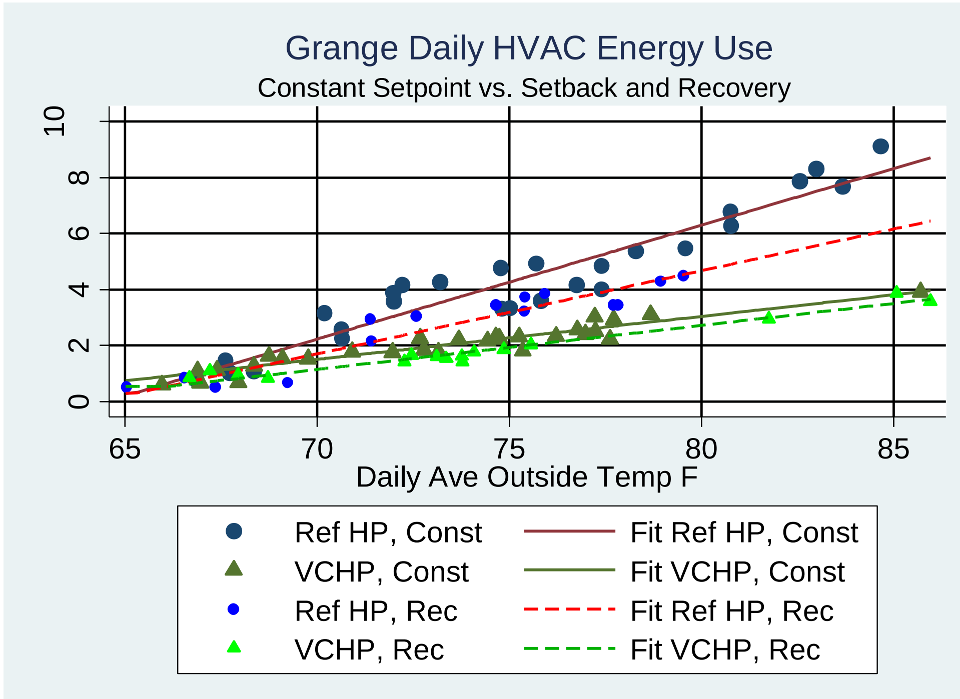


FIGURE 34. GRANGE RECOVERY ENERGY PERFORMANCE

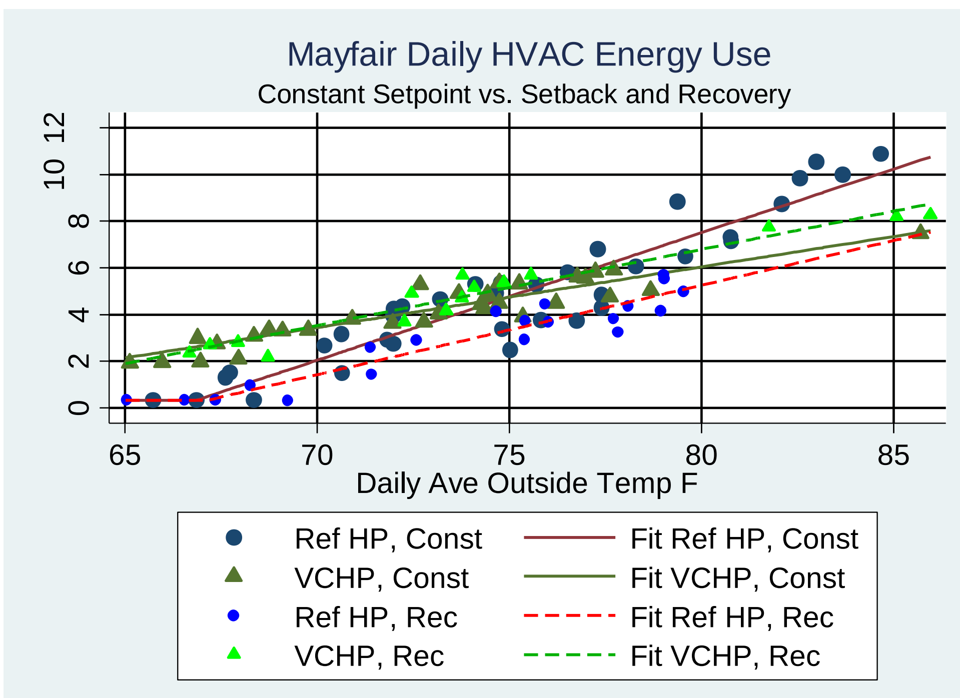


FIGURE 35. MAYFAIR RECOVERY ENERGY PERFORMANCE

The regression coefficients corresponding to the Recovery regressions shown in Figure 33 through Figure 35 are shown in Table 26, presented in the same format as the Constant Setpoint regressions previously discussed. Caution should be used in applying these regressions to annual energy use estimates, as very large comfort differences were observed during recovery. Based on the temperature recovery times observed in this study, it is unlikely that human occupants would choose to operate VCHP systems on the setback and recovery schedule represented by these regressions.

TABLE 26. COOLING ENERGY REGRESSION COEFFICIENTS

SITE	SYSTEM	E_T	C1	R^2	C2	C_{TF}
Caleb	Reference HP	0.643	-43.7	0.94	0.33	
	VCHP	0.256	-17.0	0.96	0.33	0.24
Grange	Reference HP	0.297	-19.4	0.84	0.30	
	VCHP	0.157	-10.4	0.96	0.34	0.21
Mayfair	Reference HP	0.383	-25.7	0.85	0.33	
	VCHP	0.327	-21.3	0.93	1.90	

PEAK DEMAND

The thermostat setback and recovery schedule increases peak demand significantly above the demand with a constant setpoint. Hourly energy use with each schedule is shown in Figure 36. Maximum hourly kWh by hour and temperature bin are tabulated in Table 27.

There is potential for occupant interactions with the VCHP controls to increase peak demand above the values recorded in this study:

- The Caleb VCHP unit ramped down from high speed and began cycling before reaching setpoint. Temperatures in rooms not directly served by an indoor head were well above setpoint. It is likely that occupants would lower the thermostat setpoint to cause the system to produce more cooling. This would cause the VCHP to ramp to a higher speed with higher power draw.
- The Grange VCHP met setpoint in the room served by the indoor head prior to ramping down from high speed, but rooms not directly served took longer to approach setpoint. It is possible that an occupant demanding comfort in an indirectly served room could adjust the thermostat and cause the system to remain at high speed.
- The Mayfair VCHP ramped down from maximum speed prior to reaching setpoint. It is likely that occupants would lower the thermostat setpoint to cause the system to produce more cooling. This would primarily affect the second hour after recovery because the system is already running at maximum speed during the first hour on peak days.

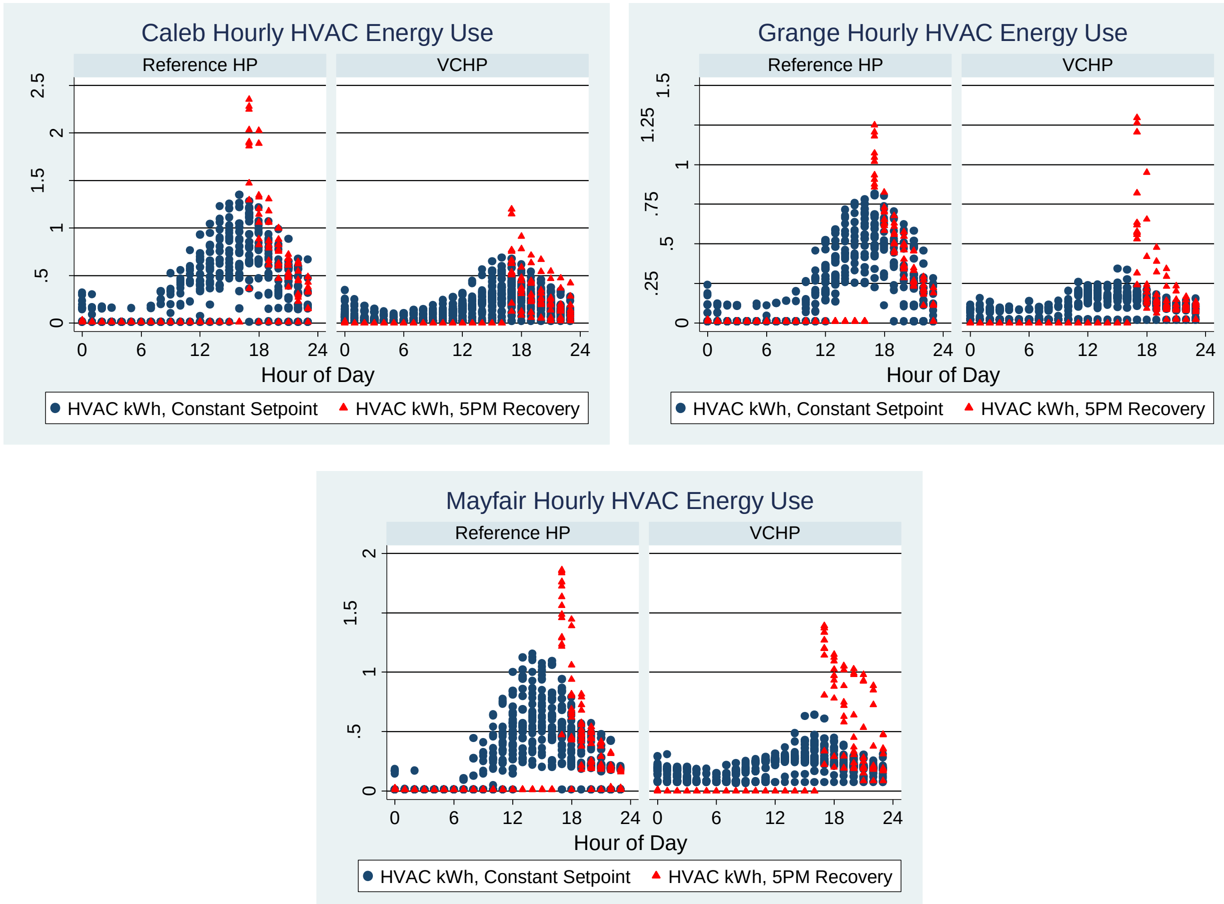


FIGURE 36. HOURLY COOLING ENERGY USE PROFILES

TABLE 27. MAXIMUM HOURLY KWH DURING RECOVERY

		REFERENCE HP MAXIMUM HOURLY KWH			VCHP MAXIMUM HOURLY KWH			DEMAND REDUCTION (KW)		
	TEMP BIN	85-90	90-95	95-100	85-90	90-95	95-100	85-90	90-95	95-100
SITE	HOUR									
Caleb	17	2.25	2.35	-	0.77	0.63	1.20	1.48	1.73	-
	18	1.89	-	-	0.48	0.91	-	1.41	-	-
Grange	17	1.21	1.25	-	0.55	0.62	1.26	0.65	0.63	-
	18	0.83	-	-	0.22	0.66	-	0.61	-	-
Mayfair	17	1.76	1.86	-	1.16	1.27	1.37	0.60	0.59	-
	18	1.39	-	-	1.02	1.12	-	0.36	-	-

VCHP demand can change significantly as the compressor ramps to lower speed/capacity. This can be seen in hour 17 for the Caleb and Grange houses. Maximum recorded hourly kWh in the 95-100 °F bin is double the value for the 90-95°F bin. At Grange, the VCHP maximum hourly kWh (in the 95-100 °F bin) approaches that of the Reference HP (in the 90-95 °F bin) even though the Reference HP is rated half a ton larger cooling capacity, with 17% lower EER and 45% lower SEER ratings than the VCHP unit.

HEATING PERFORMANCE

ANNUAL HEATING ENERGY USE

Annual heating energy use was modeled by linear regression of daily HVAC system energy use against daily average outdoor temperature. Energy use resulting from constant power draws from HVAC system electrical components and constantly operating fans was subtracted from the daily energy use prior to performing the regressions. Total daily HVAC energy use is calculated as the sum of the regression predicted energy use plus energy use resulting from constant power draws. It was assumed that half of the constant power draw is attributed to heating season, and the other half attributed to cooling season.

The Caleb VCHP system experienced temperature control problems, described in more detail in the Indoor Temperature Control section of this report on page 40. Manufacturer representatives adjusted settings and ran diagnostic tests to investigate the control issues through much of the heating season. As a result, the data set available for analysis was limited to 10 days with known reliable indoor temperature control. Data was potentially usable for an additional 10 days that occurred during periods of control excursions but were not impacted by work at the house or settings modifications that affected energy use. The potentially usable days were screened for inclusion in the analysis using the following criteria:

1) Average daily temperature in each of the 3 rooms with VCHP thermostatic controls is no more than 2 °F below setpoint
2) No more than 1% of minutes in the day are more than 3 °F below setpoint in any of the 3 rooms with thermostatic control
3) The temperature in any of the 3 rooms with thermostatic control does not exceed 5 °F above setpoint when the compressor is running

This process identified an additional 5 days with usable Caleb VCHP data. The resulting data set was compared to the Reference HP data set to ensure indoor temperatures were sufficiently similar for a heating energy use comparison to be made. The average daily indoor temperature for the Reference HP and VCHP data sets was found to differ by less than 0.5 °F.

Average house temperatures for the Reference HP and VCHP systems at the other two houses also differed by less than 0.5 °F.

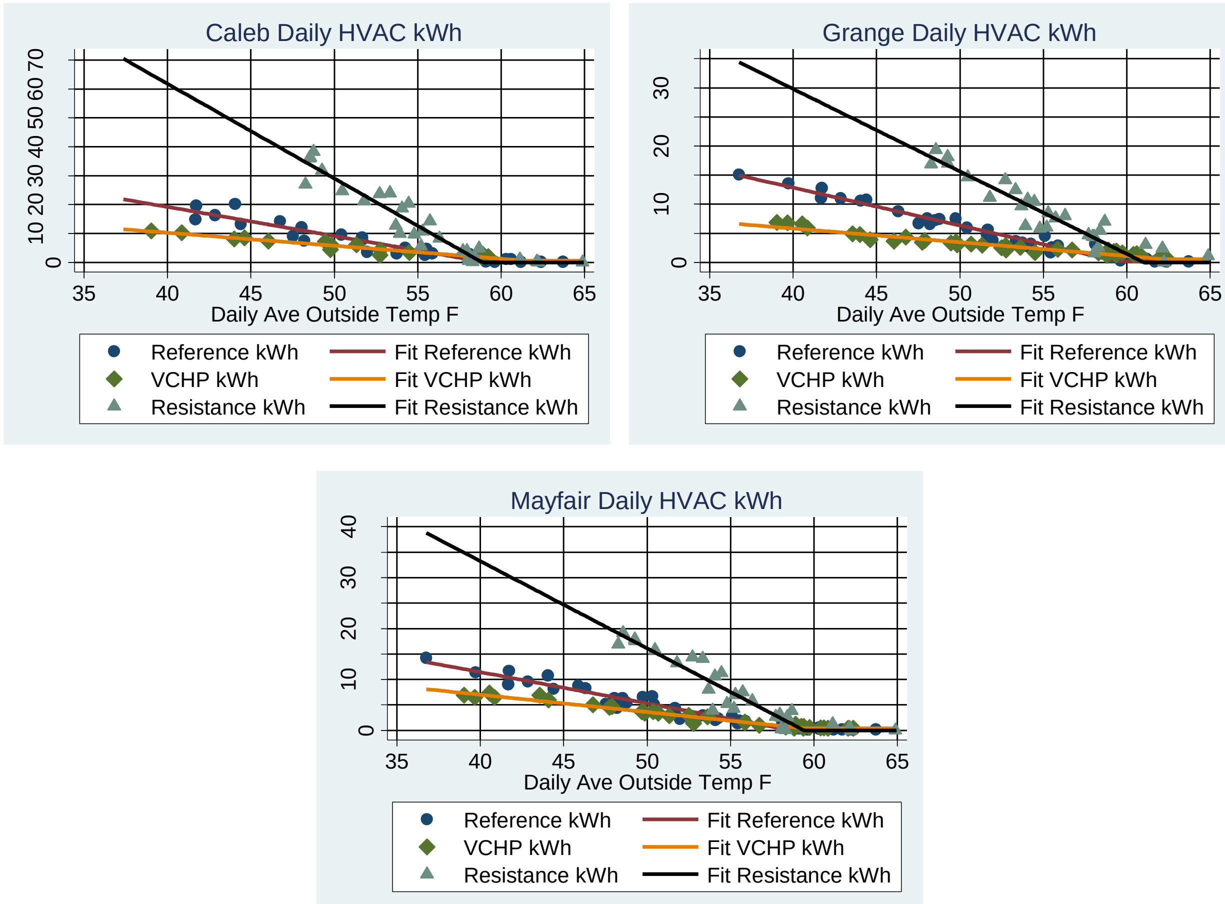


FIGURE 37. HEATING ENERGY USE LINEAR REGRESSIONS

Annual heating energy use was calculated as:

$$kWh_{HEAT} = \sum_{i=1}^{365} \left(Max(0, T_i \times E_T + C1) + \frac{C2 + C_{TF}}{2}\right)$$

Where:

T_i = Daily average outdoor temperature (°F) for day i, for each of 365 days in a year

E_T = Linear regression daily energy use (kWh) slope against daily average outdoor temperature (°F)

C1 = Linear regression constant

C2 = Heat pump daily energy use (kWh) due to constant power draws, half of which is attributed to heating season

C_{TF} = Transfer fan daily energy use (kWh), half of which is attributed to heating season

TABLE 28. HEATING ENERGY USE REGRESSION COEFFICIENTS

SITE	SYSTEM	E_T	C1	R^2	C2	C_{TF}
Caleb	Reference HP	-1.070	63.0	0.91	0.18	-
	VCHP	-0.441	27.2	0.89	0.33	0.24
	Electric Resistance	-3.275	192.8	0.90	0.00	-
Grange	Reference HP	-0.649	38.6	0.96	0.17	-
	VCHP	-0.236	14.7	0.90	0.34	0.21
	Electric Resistance	-1.417	86.5	0.87	0.00	-
Mayfair	Reference HP	-0.613	35.8	0.93	0.17	-
	VCHP	-0.340	20.2	0.95	0.40	-
	Electric Resistance	-1.712	101.7	0.88	0.00	-

The linear regression results were applied to the Title 24 weather file for Stockton to develop annual heating energy use estimates. The results are shown in Table 29. Also shown are the effective efficiencies of the VCHP and Reference HP systems relative to the electric resistance heaters. Electric resistance heat is a useful benchmark by which to compare the systems, but the relative efficiency values shouldn't be viewed as a true seasonal COP because the electric resistance heaters are controlled to maintain extremely constant temperatures throughout the house (+/- 0.5 °F in every room), while the temperatures will vary between rooms in the heat pump cases. Therefore, the heat pumps and the electric resistance heaters are not necessarily providing an identical amount of heat.

The effective efficiencies for the reference systems shown in Table 29 range from 2.5 to 3.2. These efficiencies are slightly better than predicted by their 8.2 HSPF values, which is equivalent to an efficiency of 2.4.

The effective efficiencies calculated for the VCHP systems are quite a bit better than their HSPF ratings. The calculated effective efficiencies range from 4.5 to 5.0, while the efficiency based on their ratings would be from 2.9 to 3.4. HSPF ratings are calculated for DOE climate region IV, which is colder than climate region III where Stockton is located. Stockton's heating design temperature is 30°F, while Kansas City, which is in climate region IV, has a heating design temperature of 6°F.

TABLE 29. ANNUAL HEATING ENERGY USE

SITE	SYSTEM	ANNUAL HEATING ENERGY USE (KWH)	EFFECTIVE EFFICIENCY RELATIVE TO ELECTRIC RESISTANCE HEAT*
Caleb	Reference HP	1662	3.2
	VCHP	1051	5.0
	Electric Resistance	5277	
Grange	Reference HP	1152	2.5
	VCHP	632	4.5
	Electric Resistance	2846	
Mayfair	Reference HP	965	3.0
	VCHP	653	4.5
	Electric Resistance	2926	

* Effective efficiency = electric resistance kWh / heat pump kWh.

TABLE 30. VCHP ANNUAL HEATING ENERGY SAVINGS

SITE	SYSTEM	HSPF	HSPF PREDICTED HEATING ENERGY SAVINGS	MONITORED SAVINGS
Caleb	Reference HP	8.2		
	VCHP	10.5*	22%	37%
Grange	Reference HP	8.2		
	VCHP	11.5	29%	45%
Mayfair	Reference HP	8.2		
	VCHP	10	18%	32%

*Capacity weighted average of the two VCHP systems at Caleb

Annual heating energy savings relative to expectations based on the relative HSPF ratings are shown in Table 30 and Figure 38.

Also shown in Figure 38 are estimated annual heating savings if standard efficiency transfer fans had been used with the ductless VCHP systems at the Caleb and Grange houses. The estimated difference in transfer fan energy use is identical to the cooling season difference. It is estimated that the commercially available products would increase transfer fan daily energy use by 2.16 kWh for Caleb, and by 0.99 kWh for Grange. The manufacturer changed the Mayfair VCHP unit indoor fan setting from Constant to Auto for heating season, eliminating the constant fan power draw that occurred during cooling season. Therefore, no adjustment is necessary for air distribution for the ducted system at Mayfair during the heating season.

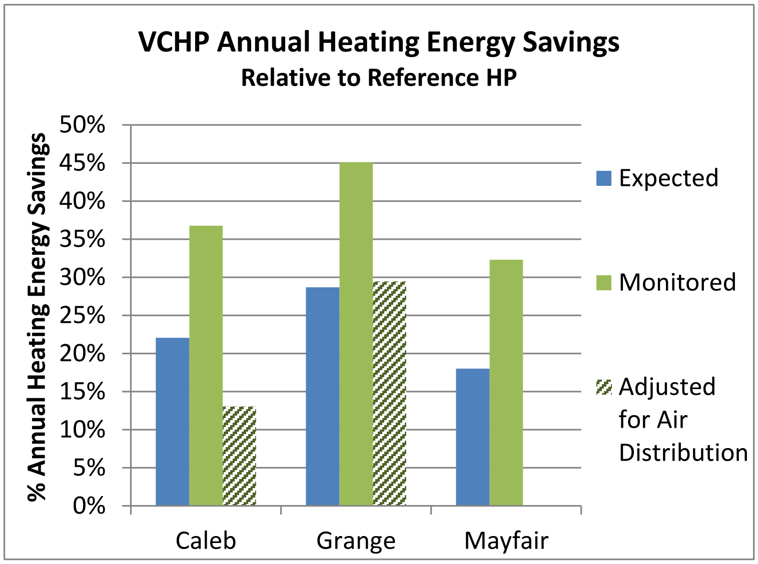


FIGURE 38. VCHP ANNUAL HEATING ENERGY SAVINGS

INDOOR TEMPERATURE CONTROL

ACCA Manual RS guidelines recommend that indoor temperatures be maintained within 2 °F of the thermostat setpoint during the heating season, with no more than 4 °F room-to-room temperature variation.

Differences in ducted vs. ductless system temperature control performance were observed at the Caleb and Grange houses. The Reference HP system also struggled to meet Manual RS guidelines at the two-story Caleb house. Table 31 shows the percentage of one-minute data points meeting the ACCA Manual RS criteria for each system. Average temperatures in each room relative to the thermostat setpoint are shown in Figure 39 through Figure 41. The constant setpoint data represented in Table 31 and Figure 39, 39, and 40 were filtered to include only minute data where:

1) The heat pump operated during the hour. This is to eliminate periods when indoor temperature exceeded the setpoint due to mild conditions.
2) For the Caleb house, only the days that were included in the heating energy use analysis were included. This excludes the days with known temperature control issues, system diagnostic testing, or modified control configurations.

The Caleb VCHP systems experienced temperature control issues through much of the heating season. The systems did not maintain temperatures near setpoint. Temperatures in the rooms served by the three indoor heads were sometimes maintained near setpoint, and sometime fell to as much as 6 °F below setpoint. The systems were mechanically capable of providing the needed heating capacity, but the controls systems caused them to operate at low speeds or cycle instead of ramping up to meet the heating load.

Attempts by the project team to remedy the Caleb temperature control problem by adjusting thermostat setpoints were unsuccessful. Thermostat adjustments produced unpredictable results. Adjustments sometimes produced no change in room temperatures, and other times resulted in overshoot with room temperatures changing by more than double the change in setpoint.

Manufacturer representatives attempted adjustments several times and ran diagnostic tests on the Caleb VCHP system from late January through the end of heating season. The diagnostics indicated that the remote thermostats were the most likely cause of the control problems. The remote thermostats were removed, but it was not possible to confirm that the internal thermostats (located within the air handlers) provided better temperature control after the remedy, due to lack of cold weather in the spring of 2016.

TABLE 31. HEATING TEMPERATURE CONTROL PERFORMANCE RELATIVE TO MANUAL RS

SITE	SYSTEM	% OF TIME WITH ROOM TEMPERATURES WITHIN 2 °F OF SETPOINT	% OF TIME WITH LESS THAN 4 °F ROOM TO ROOM TEMPERATURE DIFFERENCE
Caleb	Reference HP	54%	90%
	VCHP	20%	67%
Grange	Reference HP	78%	99%
	VCHP	32%	93%
Mayfair	Reference HP	96%	100%
	VCHP	95%	100%

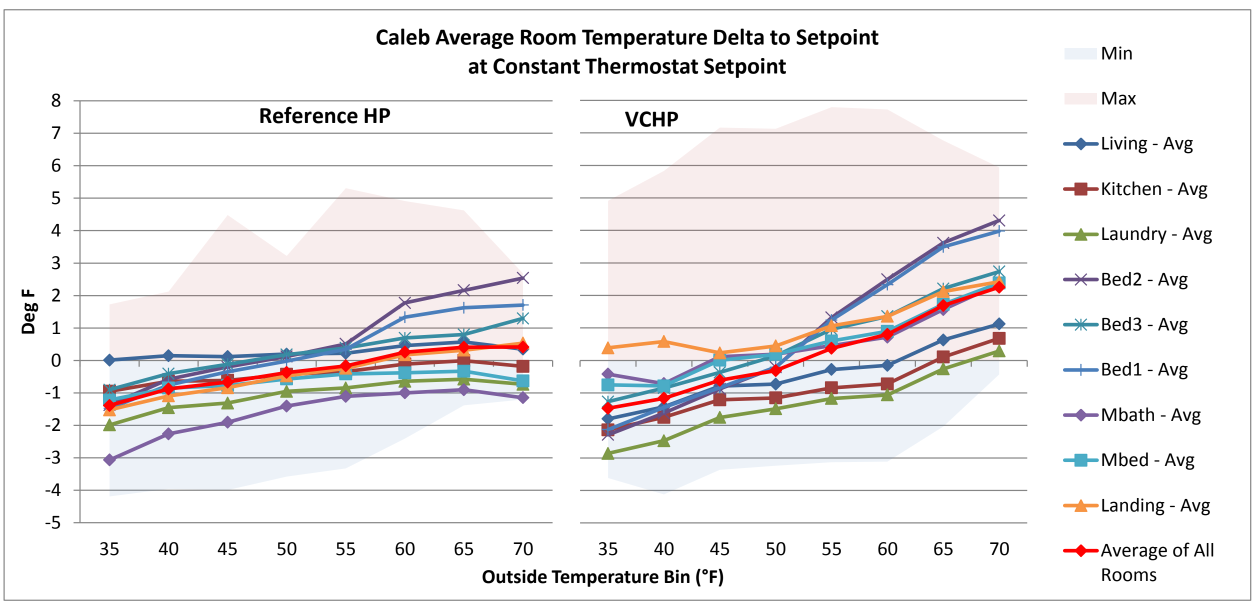


FIGURE 39. CALEB ROOM TEMPERATURES DURING CONSTANT SETPOINT HEATING

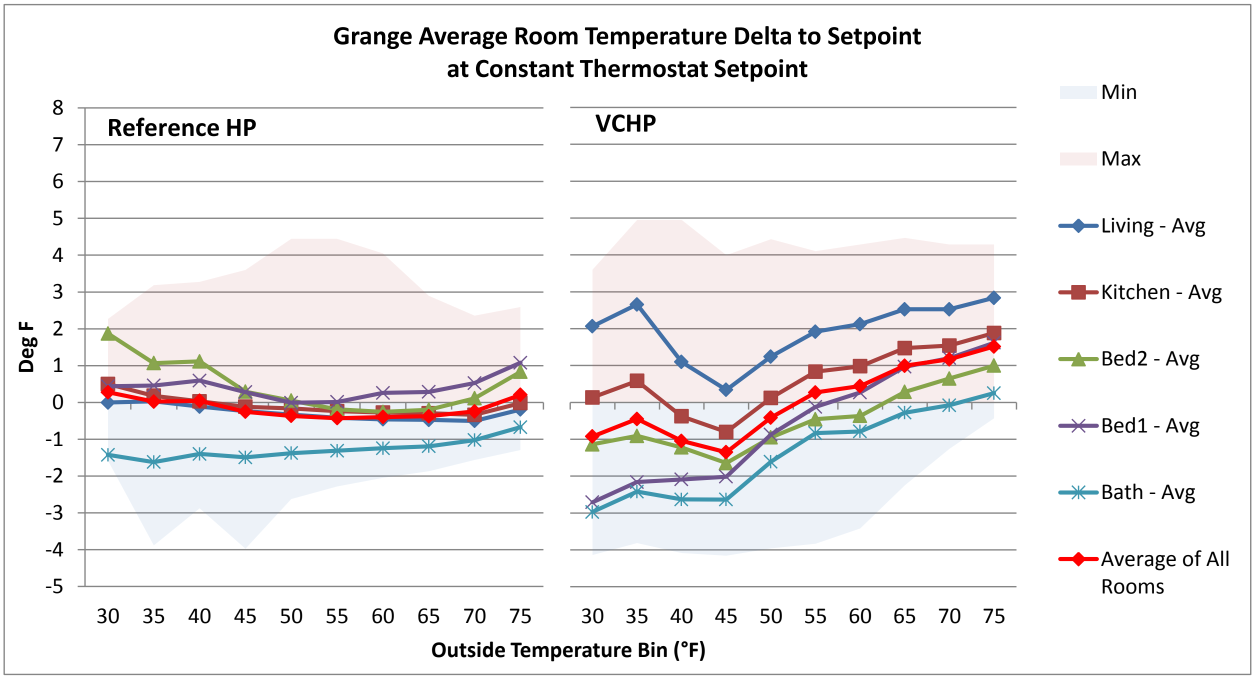


FIGURE 40. GRANGE ROOM TEMPERATURES DURING CONSTANT SETPOINT HEATING

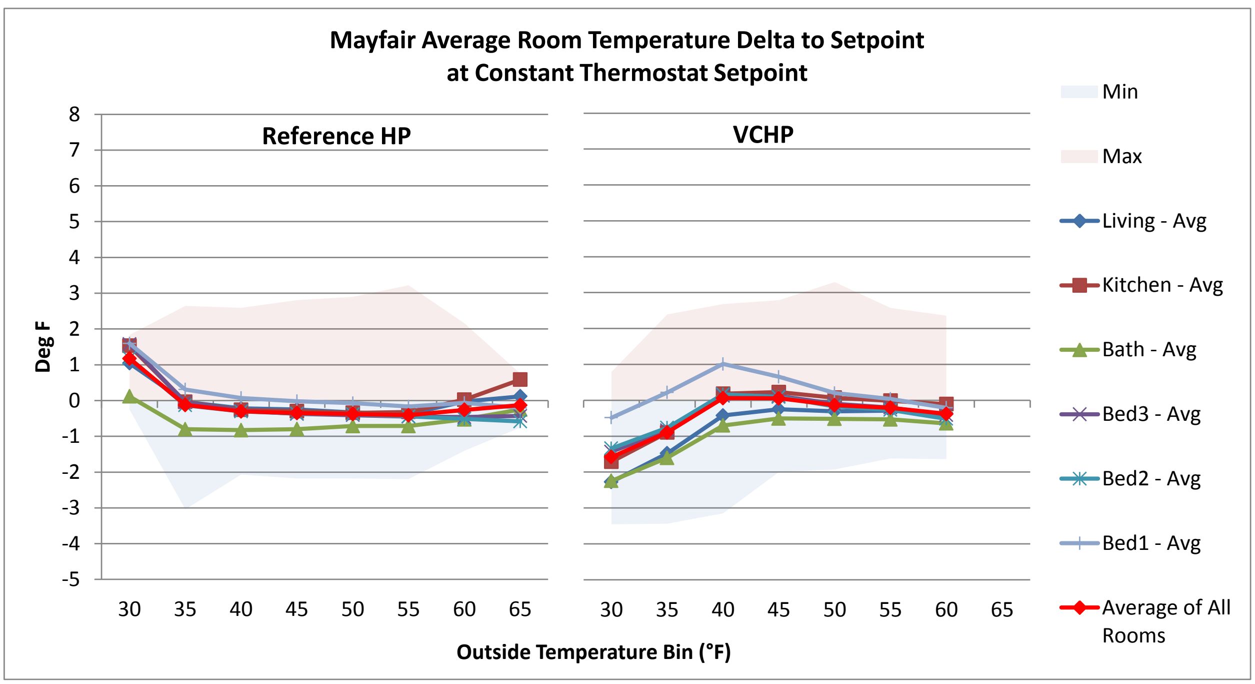


FIGURE 41. MAYFAIR ROOM TEMPERATURES DURING CONSTANT SETPOINT HEATING

Even with the data filtered to remove the days with extremely poor temperature control, the Caleb VCHP system was only able to maintain temperatures within 2 °F of setpoint 20% of the time. The Reference HP system also struggled to maintain room temperatures near setpoint throughout the Caleb house, meeting the Manual RS guidelines about half of the time.

Figure 40 shows a "V" shape in the Grange VCHP room temperature profile. This is related to controls that caused the system to operate at two distinct speeds rather than modulating compressor speed to match the heating load. The system ran at a lower speed at mild outdoor temperatures, and began ramping to a higher speed in the 40 °F temperature bin. This behavior differs from compressor ramping observed in the cooling mode, and is a contributing factor to the Grange VCHP system failing to meet Manual RS guidelines 2/3 of the time.

The Mayfair VCHP system was unable to meet heating load on colder days, and indoor temperatures can be seen declining below the 40°F temperature bin in Figure 41. Defrost cycles that averaged 7 minutes in duration and occurred approximately every 40 minutes on the coldest days were a contributing factor. The manufacturer was notified of the defrost behavior and inability to meet heating load on cold days, but declined to make any adjustments to the system.

System Operating Characteristics

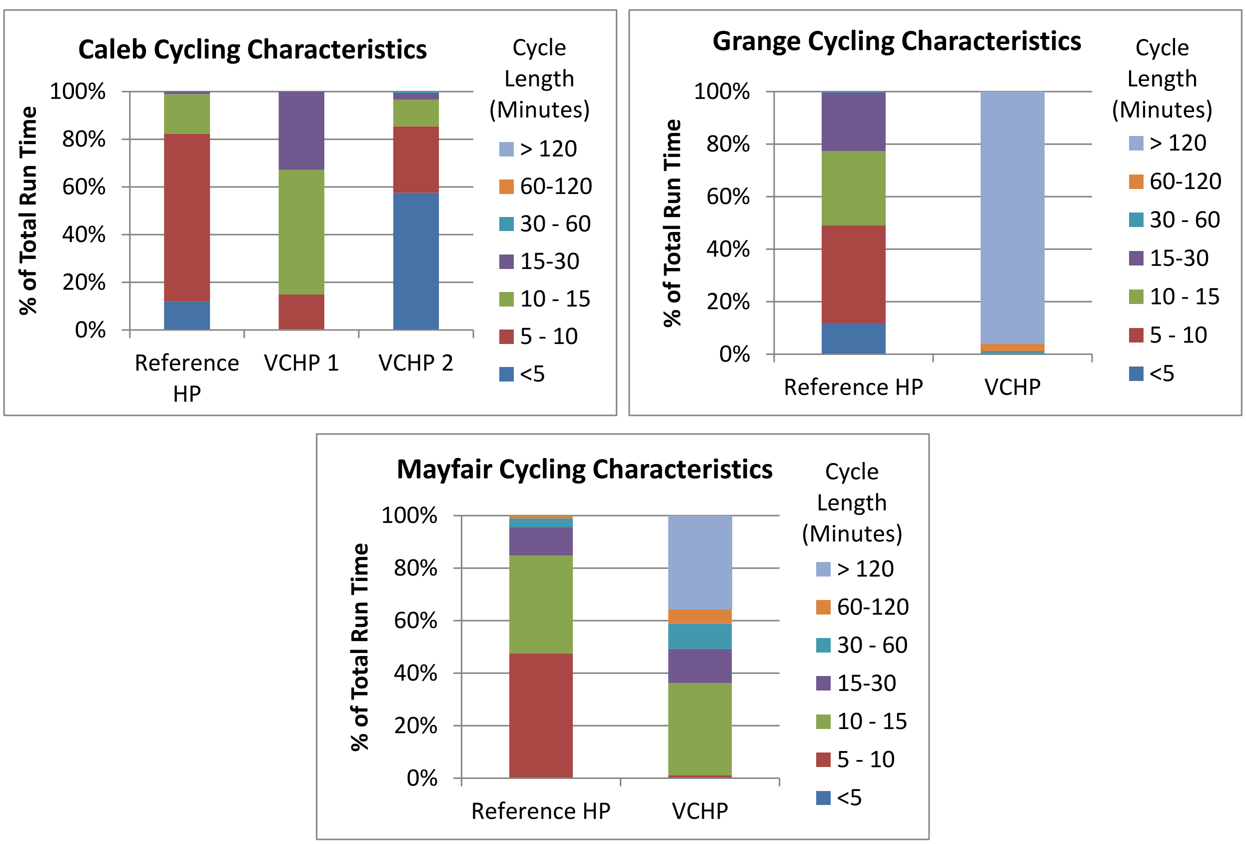


Figure 42. Heating Mode Cycling Characteristics

The Reference HP systems at all three houses ran short cycles that rarely exceeded 15 minutes.

The VCHP systems at Caleb also ran short cycles, particularly the 2nd floor multi-split unit which ran cycles of less than 5 minutes more than 50% of the time. The Grange and Mayfair VCHP units ran longer heating cycles, with the Grange unit operating continuously the majority of the time.

Defrost

The Reference HP systems did not enter defrost mode because system capacity was high enough in each case that none of the systems ran continuously for a period long enough to trigger standard defrost modes.

The VCHP systems ran defrost cycles on colder days. Average measured defrost characteristics are shown in Table 32.

Table 32. VCHP Defrost Characteristics

	Caleb*		Grange		Mayfair	
Average Daily Outside Temp. Bin °F	Average Minutes of Defrost/Day	Average # of Defrost Cycles/Day	Average Minutes of Defrost/Day	Average # of Defrost Cycles/Day	Average Minutes of Defrost/Day	Average # of Defrost Cycles/Day
35-40	8.0	3.0	12.5	2.5	49.0	7.5
40-45	0	0	6.2	1.2	21.5	2.5
45-50	0	0	0	0	0	0
50-55	0	0	0	0	1.0	0.3
55-60	0	0	0	0	0	0

* The amount of defrost at Caleb may be understated due to cycling behavior that made defrost difficult to identify in the measured data.

The Caleb 2nd floor VCHP system ran many very short compressor cycles and ramped the indoor head fans in ways that made it impossible to conclusively distinguish between heating and defrost on cycles shorter than two minutes. The above figures for Caleb include only cycles that were at least two minutes in length. There may be additional defrost mode cycles that were shorter than two minutes. Visual review of the data suggests that some of the short cycles may have been related to defrost. The first floor VCHP unit at Caleb did not enter defrost mode.

The greatest amount of defrost mode run time was observed on the Mayfair VCHP unit. As previously discussed, this unit entered defrost mode approximately every 40 minutes during periods of low outdoor temperature. After defrost the setpoint temperature was not met.

EVALUATIONS

The VCHP systems tested in this study produced mixed results with regard to both energy and comfort performance.

COOLING PERFORMANCE

Monitored VCHP system cooling energy performance ranged from better than expected based on relative SEER ratings at the Caleb house to substantially worse than expected at the Mayfair house. Energy performance is significantly influenced by air distribution equipment and configuration:

- Continuously operating room-to-room air transfer fans were installed with the ductless VCHP systems at the Caleb and Grange houses. The fans installed in this study were customized high efficiency bathroom exhaust fans and are not representative of standard commercially available transfer products. The estimated energy consumption of standard commercially available air transfer fans would increase the annual cooling energy use of the high efficiency ductless VCHP units at the Caleb and Grange houses to equal to or greater than that of the code minimum efficiency ducted Reference HP systems.
- The Mayfair ducted VCHP system was configured to run the indoor fan constantly on high speed. This constant fan operation was a significant contributor to the worse than expected energy performance of this system. If the fan had cycled with the compressor, annual cooling energy is projected to be near expectations based on relative SEER ratings, but indoor temperatures and RH would have been impacted.

HEATING PERFORMANCE

Monitored VCHP system heating energy performance was better than expected based on relative HSPF ratings at all three houses. These results are also influenced by supplemental air distribution systems used with the ductless VCHP systems. If standard commercially available air transfer fans had been installed, annual heating energy use is projected to be higher than predicted by HSPF ratings at the Caleb house, and near expectations at the Grange house.

PEAK ELECTRIC DEMAND IMPACT

The VCHP systems provided significant summer peak demand reductions ranging from 44% to 64% when the systems were operated at a constant thermostat setpoint. Demand reductions with a thermostat setback and recovery schedule are less certain due to room-to-room temperature differences and VCHP systems failing to meet setpoint before ramping to lower speeds. This performance would likely lead to occupant interventions that would increase demand above the values recorded in this study. For the one VCHP system that reached setpoint before ramping to lower speeds (Grange), there was little or no peak demand reduction during recovery.

IMPACT OF SETBACK CONTROLS

Thermostat setback and recovery schedules are not certain to save energy with VCHP systems. VCHP system efficiencies are generally lower at the highest compressor speeds, and high speed operation during recovery can outweigh the energy benefits of turning the air conditioner off or to a higher temperature setpoint during daytime hours.

The Mayfair VCHP system used more energy on setback and recovery days than on days with a constant thermostat setpoint. Controls programming from the manufacturer limited compressor operation at maximum speed to about one hour, but the system continued to run at the next highest speed for up to 4 more hours before reaching the thermostat setpoint. In comparison the reference cooling system would typically reach setpoint within one hour on hot days.

The ductless VCHP system at Caleb reached setpoint within about two hours on hot days in the room with the indoor unit (see Appendix D). Measured data show that the unit did not operate constantly at full capacity during this cool-down period. Rooms cooled indirectly via transfer fans took significantly longer to cool down.

The ductless VCHP system at Grange succeeded in reaching setpoint within about 45 minutes on a hot day, but indirectly-cooled rooms took many hours to reach within 3°F of the setpoint.

COMFORT PERFORMANCE

Comfort issues were observed with regard to both temperature and humidity control.

- At two houses (Grange and Mayfair), the VCHP systems provided inadequate latent cooling to maintain indoor humidity below 60%. It is possible that control configurations could be adjusted to increase the latent capacity provided by these units, but delivering higher total capacity would increase energy use above the monitored values.
- Despite an optimistic experimental design with regard to air distribution to rooms not directly served by a ductless VCHP indoor head (doors open at all times, constantly operating low power air transfer fan), temperature comfort issues were observed.
    - The ductless VCHP systems at Caleb failed to meet ACCA Manual RS guidelines for room-setpoint and room-to-room temperature variation the majority of the time.
    - The Grange ductless VCHP system performed well relative to Manual RS in cooling season, but heating season temperature differences exceeded Manual RS guidelines the majority of the time.
    - At both Caleb and Grange, which are equipped with ductless VCHP systems, rooms not directly served by an indoor head experienced long recovery times following a thermostat setback. Recovery times were particularly long at the Caleb house, where the VCHP units ramped to lower speeds and began cycling before setpoint was reached.

CONTROLS

VCHP system controls are complex, often not well documented, often not fully accessible or understood by installers, and sometimes problematic.

- The Caleb VCHP systems failed to maintain temperatures near setpoint in the heating season. Diagnosing a potential cause of the problem required multiple rounds of controls adjustments and testing by a representative of the manufacturer. The diagnostic testing extended over two months, and the diagnosis couldn't be conclusively confirmed before the end of heating season.
- Early in the 2015 cooling monitoring, the Mayfair VCHP system failed to meet cooling loads on hot days because the control configuration prevented the system from ramping to higher speeds. The manufacturer addressed the problem by setting the indoor fan to run on maximum speed constantly. The system was then able to meet sensible cooling loads, but failed to meet latent loads and suffered a substantial energy penalty from the constantly running fan.
- The Grange and Mayfair VCHP systems provided inadequate dehumidification to maintain indoor relative humidity below 60%. At the conclusion of this study, the manufacturers indicated that control configurations could be adjusted to increase the latent capacity provided by these units.

The experimental design was optimistic with regard to control configurations. The manufacturers were allowed to specify the VCHP controls settings they believed would produce the best results in the monitored houses. It is unlikely that the typical HVAC contractor installing these systems is more knowledgeable than, or would select more optimal controls configurations than the equipment manufacturer. It would also be unrealistic to expect that the typical VCHP system installation in California will be monitored, and controls settings adjusted as needed based on the monitored data. The observed inability of VCHP systems to perform as needed without intervention to alter the controls configuration is reason for concern.

SYSTEM SIZING

VCHP system sizing is not fully understood, not well informed by the available performance information, influenced by controls logic and configuration, and potentially problematic. The research team provided the manufacturers with the full room-by-room load calculations in Appendix A. The VCHP manufacturers then specified system sizing for each house. Based on the results of this study, a representative of the manufacturer of the Mayfair VCHP system believes the system was undersized, despite having been provided with load calculation results. In the investigation of this concern, the team reviewed the data and found that the controls were driving the system at less than maximum capacity even as the temperature setpoint was not being met. As noted above in the discussion of setback controls, other VCHP systems also appeared to reduce output before setpoints were achieved. The control algorithms that govern system speed are defined in the proprietary firmware and are not user accessible or adjustable. Detailed performance information indicating system capabilities in the various control modes would improve the ability of system designers to select appropriate VCHP systems for the application. The performance information needs to reflect not only hardware capabilities, but also the influence of control algorithms in the firmware.

INSTALLER IMPACT

The VCHP systems evaluated in this study performed significantly better than those evaluated in the preceding year. The difference in results suggests that local contractors do not have adequate training and expertise.

- The 2015-16 units were specified by the manufacturers. The 2014-15 units were specified by local contractors who were authorized dealers of the brand installed.
- The 2015-16 units were installed by contractors selected by the manufacturers, with controls settings specified by the manufacturers. The 2014-15 units were installed and configured by local contractors who were authorized dealers of the brand installed. In one case, a unit in the 2014-15 study was found to have been installed with low refrigerant charge.

PERFORMANCE VERIFICATION METHOD OF TEST

Proven and publicly accessible methods of test to verify proper VCHP system installation and operation do not currently exist and are needed. The California Energy Commission has found that AC and HP systems need to be inspected and verified to be properly installed and working at rated efficiency levels. The CEC expects to implement verification protocols for VCHP systems. The units in this study were installed under manufacturer supervision and are therefore believed to be installed and operating as intended. These installations are not representative of those performed by the general population of HVAC contractors. The units in the 2014-15 study were installed by local contractors without direct supervision by the manufacturer, and one of the three systems was found to be significantly undercharged at the end of the study. For the reference systems, the CEC requires verification of charge, airflow, and indoor fan watts/cfm. For VCHP systems, the only current requirement is that the refrigerant charging be witnessed by a special energy efficiency inspector (a HERS rater). A key measure of forced air system performance is the heating or cooling output as determined by the airflow through the system and the difference in return air and supply temperatures. Airflow and representative supply air temperature measurements are both problematic for ductless VCHP systems.

RECOMMENDATIONS

Additional research is needed to develop a better understanding of comfort and energy performance of VCHP systems in California homes. Areas of need include:

- Further study is needed of the energy impacts associated with room-to-room air distribution. Of particular importance is the energy use of constantly operating fans.
  - Standard room-to-room air transfer fans have 5 to 10 times the watt draw of the units installed in this study. Additional evaluation of VCHP system energy use with standard transfer fans is needed to determine

energy impacts that may be expected in a standard ductless VCHP system installation.

- Short-ducted VCHP systems are potentially a better air distribution option but are also capable of contributing significant fan energy use to the VCHP system, particularly if configured to operate the fan constantly as was the case at the Mayfair house during cooling season. Additional study is needed to evaluate the energy performance of ducted VCHP systems in comparison to ductless units with air transfer fans.

- Further study of VCHP comfort issues is needed. In particular:
  - Evaluation of performance with interior doors closed. The optimistic test scenario applied in this study is not representative of real world use where bedroom doors are likely to be closed at times.
  - Evaluation of ductless systems with no transfer fans. Since transfer fan energy use is a concern, it would be useful to evaluate the ability of ductless VCHP systems to provide comfort without supplemental air distribution fans.
  - Evaluation of ducted VCHP systems in other houses. The Mayfair ducted VCHP unit performed well with respect to comfort on days with a constant thermostat setpoint. It would be useful to evaluate ducted installations in the other houses to compare differences in ducted vs. ductless system performance.
  - Assessment of controls modification options beyond thermostat adjustments. This will be most productive if OEMs choose to engage the research team in solving performance problems.
  - Assessment of field accessible controls that allow the installer to set up the system for the application. Of particular importance is humidity control and recovery from setback.
- Further study of efficiency rating test methods is needed. Energy performance of the systems evaluated in this study was not aligned with the standard efficiency ratings for heating and cooling. The test methods currently used to develop the SEER and HSPF ratings lock VCHP units at fixed compressor speeds, causing them to operate in ways that are not representative of field operation. Results are then applied to calculations that assume system behavior that does not align with actual controls operation. Since variable-speed components and control programs can vary substantially from system to system, test methods that simulate a range of real-world conditions and allow VCHP systems to function as designed should be developed. Lab testing of the same or similar systems operating under their own controls is needed so that field and lab results can be compared.
- Development of Title 24 Alternative Compliance Method (ACM) simulation protocol for VCHP systems including eligibility requirements that address required features.
- Development of best practices and field verified performance protocols.
- Development of generic control scenarios suitable for California climates which are set by installers with default settings which allow acceptable energy and comfort performance.
- Design recommendations for manufacturers

    - Design systems so that air handlers and ducts fit in 12-inch hallway ceiling soffits.
    - Produce ½, ¾, 1 and 1.5 ton units.
    - Include a fault detection device that is difficult or impossible for occupants to ignore.
- Installation kit recommendations for manufacturers. Sell ducted mini-split systems with complete "installation kits" that include:
    - Comprehensive instructions to ensure proper installation
    - Guidance on creating an air barrier and fire stopping for the ceiling soffit
    - Oversized return air plenum that the air handler is mounted inside
    - Supply plenum with the correct number and size of duct openings for that unit
    - Oversized return air filter grille
    - Double-deflection supply grilles with very low static pressure loss
    - Appropriately sized straight supply boots for high sidewall air delivery in each room
    - Fixed moisture removal rates for precise humidity control
    - Precise home temperature control
    - Simple occupant operating instructions
    - Sales literature/training for builders' sales staff and real estate agents
- Installer training
    - PG&E should provide basic training through the WE&T program on general VCHP installation practices, including topics like adjusting refrigerant charge for lineset length, making sure the flare fittings don't leak, and setting the indoor fan to auto.
    - Manufacturers should provide better training than they currently do, and programs installing VCHP systems should require proof that installers (the technician, not only the contractor) have been through the manufacturer training. These systems are complex, and there are differences between manufacturers. Therefore, training on specific equipment is important.

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APPENDIX A – MANUAL J LOAD CALCULATIONS

GRANGE LOAD CALCULATIONS

Davis Energy Group

Load Short Form
Entire House
Wrightsoft Corp

Job:
Date: March 15, 2015
By:

131 Hartwell Ave, Lexington, MA 02421 Phone: 800-225-8697 Fax: 781-861-2058 Web: www.wrightsoft.com

Project Information

For: Grange Retrofit, 3622 Grange Ave
3622 Grange Ave, Stockton, CA

Design Information

	Htg	Clg
Outside db (°F)	33	98
Inside db (°F)	70	75
Design TD (°F)	37	23
Daily range	-	H
Inside humidity (%)	30	50
Moisture difference (gr/lb)	11	-3

Infiltration

Method	Blower door
Shielding / stories	3 (partial) / 2
Pressure / AVF	50 Pa / 642 cfm

HEATING EQUIPMENT

Make	Generic	
Trade		
Model	SEER 14.0, HSPF 8.1	
AHRI ref		
Efficiency	8.2 HSPF	
Heating input		
Heating output	14898	Btuh @ 47°F
Temperature rise	27	°F
Actual air flow	***499***	cfm
Air flow factor	0.039	cfm/Btuh
Static pressure	0	in H2O
Space thermostat		

COOLING EQUIPMENT

Make	Generic	
Trade		
Cond	SEER 14.0, HSPF 8.1	
Coil		
AHRI ref		
Efficiency	12.2 EER, 14 SEER	
Sensible cooling	10480	Btuh
Latent cooling	4492	Btuh
Total cooling	14972	Btuh
Actual air flow	499	cfm
Air flow factor	0.054	cfm/Btuh
Static pressure	0.40	in H2O
Load sensible heat ratio	0.93	

ROOM NAME	Area (ft²)	Htg load (Btuh)	Clg load (Btuh)	Htg AVF (cfm)	Clg AVF (cfm)
KITCHEN	138	2611	2747	***102***	148
BATH	52	1459	696	***57***	37
HALL	81	0	0	***0***	0
GREAT ROOM	251	2891	2745	***113***	148
BEDROOM 2	202	3065	1585	***120***	85
BEDROOM 1	153	2750	1512	***107***	81
Entire House d	878	12775	9285	***499***	499
Other equip loads		0	0		
Equip. @ 1.03 RSM			9554		
Latent cooling			698		
TOTALS	878	12775	10253	***499***	499

Bold/italic values have been manually overridden

Calculations approved by ACCA to meet all requirements of Manual J 8th Ed.

wrightsoft Right-Suite® Universal 2015 15.0.13 RSU00533
...Wrightsuite\Grange\GRANGE-CA-Retrofit_DEG_F.rup Calc = MJ8 Front Door faces: SW

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Page 1

Davis Energy Group

Loads for Multiple Orientations

Entire House

Wrightsoft Corp

Job:
Date: March 15, 2015
By:

131 Hartwell Ave, Lexington, MA 02421 Phone: 800-225-8697 Fax: 781-861-2058 Web: www.wrightsoft.com

Project Information

For: Grange Retrofit, 3622 Grange Ave
3622 Grange Ave, Stockton, CA

Design Conditions

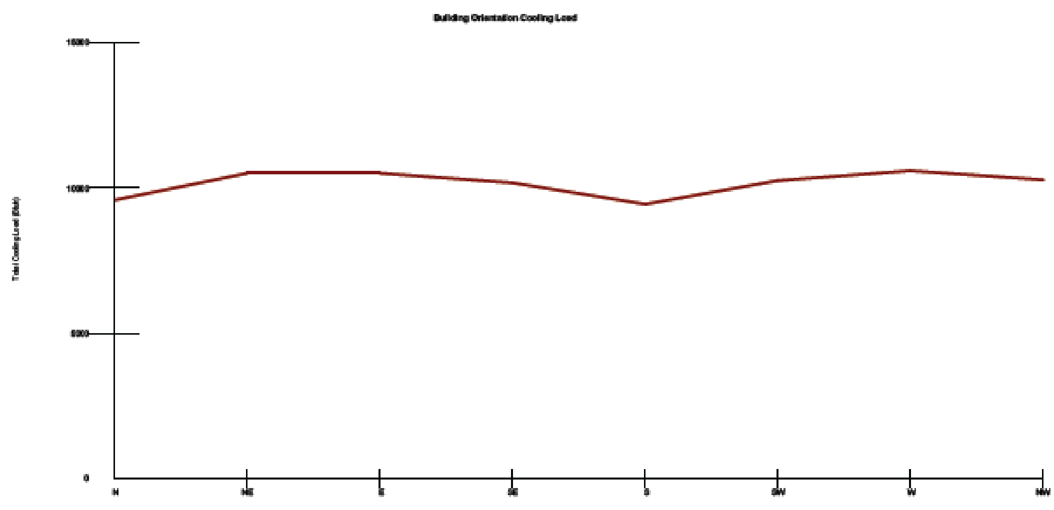
Location:
Stockton Metropolitan AP, CA, US
Elevation: 26 ft
Latitude: 38°N

Outdoor:	**Heating**	**Cooling**
Dry bulb (°F)	33	98
Daily range (°F)	-	32 (H)
Wet bulb (°F)	-	69
Wind speed (mph)	15.0	7.5

Indoor:	**Heating**	**Cooling**
Indoor temperature (°F)	70	75
Design TD (°F)	37	23
Relative humidity (%)	30	50
Moisture difference (gr/lb)	10.9	-3.0

Infiltration:

Front Door	North	Northeast	East	Southeast	South	Southwest	West	Northwest
Sensible Load (Btuh)	8891	9804	9804	9474	8751	9554	9894	9588
Latent Load (Btuh)	698	698	698	698	698	698	698	698
Total Load (Btuh)	9589	10502	10502	10172	9450	10253	10593	10287
Heating AVF (cfm)	499	499	499	499	499	499	499	499
Cooling AVF (cfm)	499	499	499	499	499	499	499	499



Current Orientation: Front Door faces Southwest
Highest Cooling Load: Front Door faces West

Calculations approved by ACCA to meet all requirements of Manual J 8th Ed.

Davis Energy Group

Building Analysis
Entire House
Wrightsoft Corp

Job:
Date: March 15, 2015
By:

131 Hartwell Ave, Lexington, MA 02421 Phone: 800-225-8697 Fax: 781-861-2058 Web: www.wrightsoft.com

Project Information

For: Grange Retrofit, 3622 Grange Ave
3622 Grange Ave, Stockton, CA

Design Conditions

Location:
Stockton Metropolitan AP, CA, US
Elevation: 26 ft
Latitude: 38°N

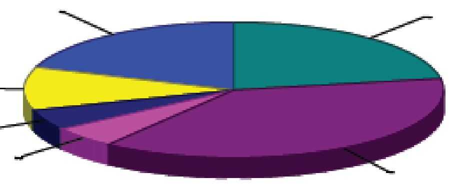
Outdoor:	**Heating**	**Cooling**
Dry bulb (°F)	33	98
Daily range (°F)	-	32 (H)
Wet bulb (°F)	-	69
Wind speed (mph)	15.0	7.5

Indoor:	**Heating**	**Cooling**
Indoor temperature (°F)	70	75
Design TD (°F)	37	23
Relative humidity (%)	30	50
Moisture difference (gr/lb)	10.9	-3.0

Infiltration:
Method: Blower door
Shielding / stories: 3 (partial) / 2
Pressure / AVF: 50 Pa / 642 cfm

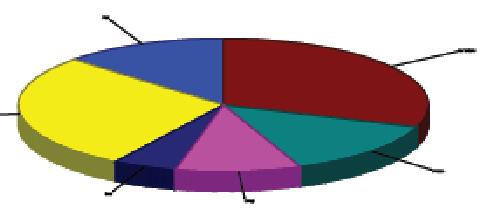
Heating

Component	Btuh/ft²	Btuh	% of load
Walls	2.7	2493	19.5
Glazing	11.2	1323	10.4
Doors	14.5	611	4.8
Ceilings	0.8	659	5.2
Floors	5.5	4842	37.9
Infiltration	3.3	2848	22.3
Ducts		0	0
Piping		0	0
Humidification		0	0
Ventilation		0	0
Adjustments		0	
Total		**12775**	**100.0**



Cooling

Component	Btuh/ft²	Btuh	% of load
Walls	1.3	1206	13.0
Glazing	22.1	2617	28.2
Doors	11.2	468	5.0
Ceilings	1.0	920	9.9
Floors	0	0	0
Infiltration	1.4	1254	13.5
Ducts		0	0
Ventilation		0	0
Internal gains		2820	30.4
Blower		0	0
Adjustments		0	
Total		**9285**	**100.0**



Latent Cooling Load = 698 Btuh
Overall U-value = 0.094 Btuh/ft²-°F

Data entries checked.

Davis Energy Group

Component Constructions
Entire House
Wrightsoft Corp

Job:
Date: March 15, 2015
By:

131 Hartwell Ave, Lexington, MA 02421 Phone: 800-225-8697 Fax: 781-861-2058 Web: www.wrightsoft.com

Project Information

For: Grange Retrofit, 3622 Grange Ave
3622 Grange Ave, Stockton, CA

Design Conditions

Location:
Stockton Metropolitan AP, CA, US
Elevation: 26 ft
Latitude: 38°N

Outdoor:	**Heating**	**Cooling**
Dry bulb (°F)	33	98
Daily range (°F)	-	32 (H)
Wet bulb (°F)	-	69
Wind speed (mph)	15.0	7.5

Indoor:	**Heating**	**Cooling**
Indoor temperature (°F)	70	75
Design TD (°F)	37	23
Relative humidity (%)	30	50
Moisture difference (gr/lb)	10.9	-3.0

Infiltration:
Method: Blower door
Shielding / stories: 3 (partial) / 2
Pressure / AVF: 50 Pa / 642 cfm

Construction descriptions	Or	Area ft²	U-value Btuh/ft²-°F	Insul R ft²-°F/Btuh	Htg HTM Btuh/ft²	Loss Btuh	Clg HTM Btuh/ft²	Gain Btuh
Walls								
12B-5sw: Frm wall, wd ext, 1/2" wood shth, r-11 cav ins, 1/2" gypsum board int fnsh, r-5 ext bd ins, 2"x4" wood frm, 16" o.c. stud	ne	244	0.068	16.0	2.54	618	1.33	323
	se	186	0.068	16.0	2.54	472	1.33	247
	sw	262	0.068	16.0	2.54	665	1.33	348
	nw	44	0.068	16.0	2.54	112	1.33	58
	all	736	0.068	16.0	2.54	1867	1.33	976
Partitions								
Frm wall, stucco ext, r-13 cav ins, 1/2" gypsum board int fnsh, 2"x4" wood frm, 16" o.c. stud: Frm wall, stucco ext, r-13 cav ins, 1/2" gypsum board int fnsh, 2"x4" wood frm, 16" o.c. stud		179	0.094	13.0	3.50	626	1.28	230
Windows								
1 glazing, clr glz, mtl no brk frm mat, 1/8" thk: 1 glazing, clr glz, mtl no brk frm mat, 1/8" thk; NFRC rated (SHGC=0.25); 50% outdoor insect screen; 6.67 ft head ht	ne	52	0.300	0	11.2	584	20.3	1061
	se	24	0.300	0	11.2	269	23.6	566
	sw	42	0.300	0	11.2	470	23.6	990
	all	118	0.300	0	11.2	1323	22.1	2617
Doors								
11D0: Door, wd sc type	sw	21	0.390	0	14.5	305	11.2	234
	n	21	0.390	0	14.5	305	11.2	234
	all	42	0.390	0	14.5	611	11.2	468
Ceilings								
16B-50ad: Attic ceiling, asphalt shingles roof mat, r-50 ceil ins, 1/2" gypsum board int fnsh		453	0.020	50.0	0.75	338	1.04	472
		425	0.020	50.0	0.75	320	1.05	448
	all	878	0.020	50.0	0.75	659	1.05	920
Floors								
22A-tpm: Bg floor, heavy dry or light damp soil, on grade depth		110	1.180	0	44.0	4842	0	0

Davis Energy Group

Project Summary
Entire House
Wrightsoft Corp

Job:
Date: March 15, 2015
By:

131 Hartwell Ave, Lexington, MA 02421 Phone: 800-225-8697 Fax: 781-861-2058 Web: www.wrightsoft.com

Project Information

For: Grange Retrofit, 3622 Grange Ave
3622 Grange Ave, Stockton, CA

Notes: Several assumptions had to be made in order to complete this model, due to incomplete data. Please reference the accompanying list of assumptions for details.

Design Information

Weather: Stockton Metropolitan AP, CA, US

Winter Design Conditions

Outside db	33	°F
Inside db	70	°F
Design TD	37	°F

Summer Design Conditions

Outside db	98	°F
Inside db	75	°F
Design TD	23	°F
Daily range	H	
Relative humidity	50	%
Moisture difference	-3	gr/lb

Heating Summary

Structure	12775	Btuh
Ducts	0	Btuh
Central vent (0 cfm)	0	Btuh
Humidification	0	Btuh
Piping	0	Btuh
Equipment load	12775	Btuh

Infiltration

Method	Blower door
Shielding / stories	3 (partial) / 2
Pressure / AVF	50 Pa / 642 cfm

	Heating	Cooling
Area (ft²)	878	878
Volume (ft³)	6941	6941
Air changes/hour	0.53	0.33
Equiv. AVF (cfm)	69	50

Sensible Cooling Equipment Load Sizing

Structure	9285	Btuh
Ducts	0	Btuh
Central vent (0 cfm)	0	Btuh
Blower	0	Btuh
Use manufacturer's data	n	
Rate/swing multiplier	1.03	
Equipment sensible load	9554	Btuh

Latent Cooling Equipment Load Sizing

Structure	698	Btuh
Ducts	0	Btuh
Central vent (0 cfm)	0	Btuh
Equipment latent load	698	Btuh
Equipment total load	10253	Btuh
Req. total capacity at 0.70 SHR	1.1	ton

Heating Equipment Summary

Make	Generic
Trade	
Model	SEER 14.0, HSPF 8.1
AHRI ref	

Efficiency	8.2 HSPF	
Heating input		
Heating output	14898	Btuh @ 47°F
Temperature rise	27	°F
Actual air flow	***499***	cfm
Air flow factor	0.039	cfm/Btuh
Static pressure	0	in H2O
Space thermostat		

Cooling Equipment Summary

Make	Generic
Trade	
Cond	SEER 14.0, HSPF 8.1
Coil	
AHRI ref	

Efficiency	12.2 EER, 14 SEER	
Sensible cooling	10480	Btuh
Latent cooling	4492	Btuh
Total cooling	14972	Btuh
Actual air flow	499	cfm
Air flow factor	0.054	cfm/Btuh
Static pressure	0.40	in H2O
Load sensible heat ratio	0.93	

Bold/italic values have been manually overridden

Calculations approved by ACCA to meet all requirements of Manual J 8th Ed.

Davis Energy Group

AED Assessment

Entire House

Wrightsoft Corp

Job:
Date: March 15, 2015
By:

131 Hartwell Ave, Lexington, MA 02421 Phone: 800-225-8697 Fax: 781-861-2058 Web: www.wrightsoft.com

Project Information

For: Grange Retrofit, 3622 Grange Ave
3622 Grange Ave, Stockton, CA

Design Conditions

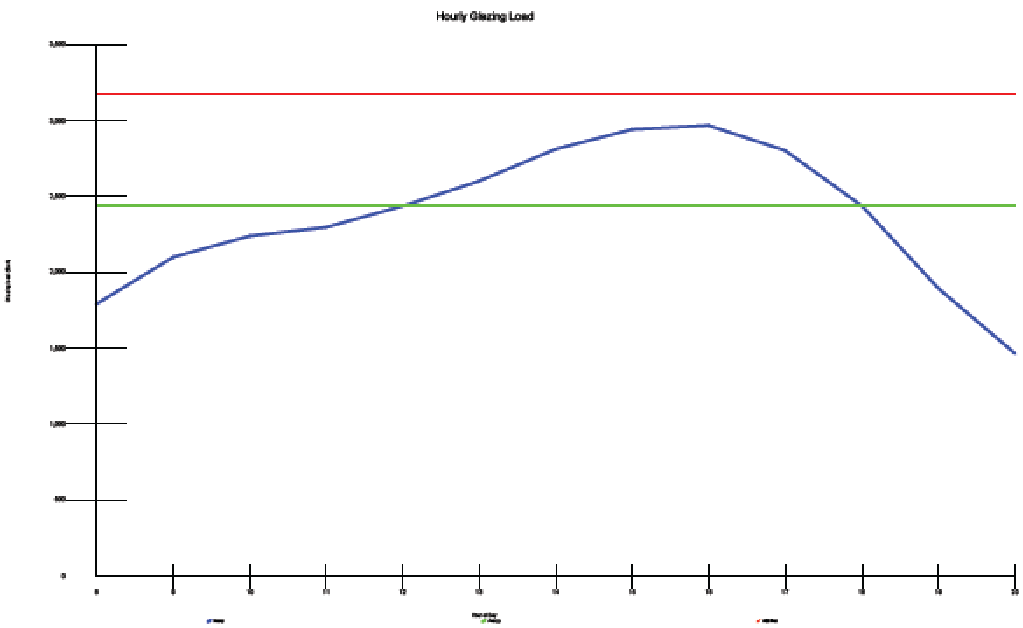
Location:
Stockton Metropolitan AP, CA, US
Elevation: 26 ft
Latitude: 38°N

Outdoor:	**Heating**	**Cooling**
Dry bulb (°F)	33	98
Daily range (°F)	-	32 (H)
Wet bulb (°F)	-	69
Wind speed (mph)	15.0	7.5

Indoor:	**Heating**	**Cooling**
Indoor temperature (°F)	70	75
Design TD (°F)	37	23
Relative humidity (%)	30	50
Moisture difference (gr/lb)	10.9	-3.0

Infiltration:

Test for Adequate Exposure Diversity



Maximum hourly glazing load exceeds average by 21.4%.

House has adequate exposure diversity (AED), based on AED limit of 30%.

AED excursion: 0 Btuh

Davis Energy Group

Right-J® Worksheet
Entire House
Wrightsoft Corp

Job:
Date: March 15, 2015
By:

131 Hartwell Ave, Lexington, MA 02421 Phone: 800-225-8697 Fax: 781-861-2058 Web: www.wrightsoft.com

		Entire House	KITCHEN
1	Room name	Entire House	KITCHEN
2	Exposed wall	110.0 ft	17.8 ft
3	Room height	7.9 ft d	8.0 ft heat/cool
4	Room dimensions		16.3 x 8.5 ft
5	Room area	877.8 ft²	138.1 ft²

	Ty	Construction number	U-value (Btuh/ft²-°F)	Or	HTM (Btuh/ft²) Heat	HTM (Btuh/ft²) Cool	Entire House Area (ft²) or perimeter (ft) Gross	Entire House Area or perimeter N/P/S	Entire House Load (Btuh) Heat	Entire House Load (Btuh) Cool	Kitchen Area (ft²) or perimeter (ft) Gross	Kitchen Area or perimeter N/P/S	Kitchen Load (Btuh) Heat	Kitchen Load (Btuh) Cool
6	W	12B-5sw	0.068	ne	2.54	1.33	296	244	618	323	0	0	0	0
.	G	1 glazing, clr glz,	0.300	ne	11.19	20.33	52	0	584	1061	0	0	0	0
.	W	12B-5sw	0.068	se	2.54	1.33	210	186	472	247	12	12	30	16
.	G	1 glazing, clr glz,	0.300	se	11.19	23.57	24	0	269	566	0	0	0	0
11	W	12B-5sw	0.068	sw	2.54	1.33	325	262	665	348	130	109	276	145
	G	1 glazing, clr glz,	0.300	sw	11.19	23.57	42	0	470	990	21	0	235	495
	D	11D0	0.390	sw	14.55	11.15	21	21	305	234	0	0	0	0
	W	12B-5sw	0.068	nw	2.54	1.33	44	44	112	58	0	0	0	0
	P	Frm wall, stucco ext	0.094	-	3.50	1.28	200	179	626	230	102	81	283	104
	D	11D0	0.390	n	14.55	11.15	21	21	305	234	21	21	305	234
	C	16B-50ad	0.020	-	0.75	1.04	453	453	338	472	0	0	0	0
	C	DftCeil	0.020	-	0.75	1.05	425	425	320	448	138	138	104	146
	F	22A-tpm	1.180	-	44.01	0.00	878	110	4842	0	138	18	781	0
6	c) AED excursion									0				105
	Envelope loss/gain								9927	5211			2016	1245
12	a) Infiltration								2848	1254			462	203
	b) Room ventilation								0	0			0	0
13	Internal gains:		Occupants @		230		4			920	1			230
			Appliances/other							1900				1000
	Subtotal (lines 6 to 13)								12775	9285			2478	2678
	Less external load								0	0			0	0
	Less transfer								0	0			0	0
	Redistribution								0	0			133	69
14	Subtotal								12775	9285			2611	2747
15	Duct loads						0%	0%	0	0	-0%	0%	0	0
	Total room load								12775	9285			2611	2747
	Air required (cfm)								499	499			102	148

Calculations approved by ACCA to meet all requirements of Manual J 8th Ed.

Right-J® Worksheet
Entire House
Wrightsoft Corp

Job:
Date: March 15, 2015
By:

131 Hartwell Ave, Lexington, MA 02421 Phone: 800-225-8697 Fax: 781-861-2058 Web: www.wrightsoft.com

							BATH				HALL			
1	Room name						BATH				HALL			
2	Exposed wall						12.8 ft				4.8 ft			
3	Room height						8.0 ft		heat/cool		7.0 ft		heat/cool	
4	Room dimensions						1.0 x 52.3 ft				1.0 x 81.2 ft			
5	Room area						52.3 ft²				81.2 ft²			
	Ty	Construction number	U-value (Btuh/ft²-°F)	Or	HTM (Btuh/ft²)		Area (ft²) or perimeter (ft)		Load (Btuh)		Area (ft²) or perimeter (ft)		Load (Btuh)	
					Heat	Cool	Gross	N/P/S	Heat	Cool	Gross	N/P/S	Heat	Cool
6	W	12B-5sw	0.068	ne	2.54	1.33	0	0	0	0	0	0	0	0
.	G	1 glazing, clr glz,	0.300	ne	11.19	20.33	0	0	0	0	0	0	0	0
.	W	12B-5sw	0.068	se	2.54	1.33	0	0	0	0	0	0	0	0
.	G	1 glazing, clr glz,	0.300	se	11.19	23.57	0	0	0	0	0	0	0	0
11	W	12B-5sw	0.068	sw	2.54	1.33	58	49	124	65	33	12	31	16
	G	1 glazing, clr glz,	0.300	sw	11.19	23.57	9	0	101	212	0	0	0	0
	D	11D0	0.390	sw	14.55	11.15	0	0	0	0	21	21	305	234
	W	12B-5sw	0.068	nw	2.54	1.33	44	44	112	58	0	0	0	0
	P	Frm wall, stucco ext	0.094	-	3.50	1.28	0	0	0	0	0	0	0	0
	D	11D0	0.390	n	14.55	11.15	0	0	0	0	0	0	0	0
	C	16B-50ad	0.020	-	0.75	1.04	0	0	0	0	0	0	0	0
	C	DftCeil	0.020	-	0.75	1.05	52	52	39	55	81	81	61	86
	F	22A-tpm	1.180	-	44.01	0.00	52	13	561	0	81	5	209	0
6	c) AED excursion									60				-10
	Envelope loss/gain								937	451			607	326
12	a) Infiltration b) Room ventilation								332 0	146 0			108 0	48 0
13	Internal gains:		Occupants @ Appliances/other		230		0			0 0	0			0 0
	Subtotal (lines 6 to 13)								1269	597			715	373
   14 15	Less external load Less transfer Redistribution Subtotal Duct loads						-0%	0%	0 0 189 1459 0	0 0 99 696 0	-0%	0%	0 0 -715 0 0	0 0 -373 0 0
	Total room load Air required (cfm)								1459 57	696 37			0 0	0 0

Calculations approved by ACCA to meet all requirements of Manual J 8th Ed.

Right-J® Worksheet
Entire House
Wrightsoft Corp

Job:
Date: March 15, 2015
By:

131 Hartwell Ave, Lexington, MA 02421 Phone: 800-225-8697 Fax: 781-861-2058 Web: www.wrightsoft.com

		GREAT ROOM	BEDROOM 2
1	Room name	GREAT ROOM	BEDROOM 2
2	Exposed wall	20.5 ft	28.8 ft
3	Room height	8.0 ft heat/cool	8.0 ft heat/cool
4	Room dimensions	20.5 x 12.3 ft	16.5 x 12.3 ft
5	Room area	251.1 ft²	202.1 ft²

	Ty	Construction number	U-value (Btuh/ft²-°F)	Or	HTM (Btuh/ft²) Heat	HTM (Btuh/ft²) Cool	GREAT ROOM Area (ft²) or perimeter (ft) Gross	GREAT ROOM Area (ft²) or perimeter (ft) N/P/S	GREAT ROOM Load (Btuh) Heat	GREAT ROOM Load (Btuh) Cool	BEDROOM 2 Area (ft²) or perimeter (ft) Gross	BEDROOM 2 Area (ft²) or perimeter (ft) N/P/S	BEDROOM 2 Load (Btuh) Heat	BEDROOM 2 Load (Btuh) Cool
6	W	12B-5sw	0.068	ne	2.54	1.33	164	124	314	164	132	120	304	159
.	G	1 glazing, clr glz,	0.300	ne	11.19	20.33	40	0	450	817	12	0	134	244
.	W	12B-5sw	0.068	se	2.54	1.33	0	0	0	0	98	86	218	114
.	G	1 glazing, clr glz,	0.300	se	11.19	23.57	0	0	0	0	12	0	134	283
11	W	12B-5sw	0.068	sw	2.54	1.33	0	0	0	0	0	0	0	0
	G	1 glazing, clr glz,	0.300	sw	11.19	23.57	0	0	0	0	0	0	0	0
	D	11D0	0.390	sw	14.55	11.15	0	0	0	0	0	0	0	0
	W	12B-5sw	0.068	nw	2.54	1.33	0	0	0	0	0	0	0	0
	P	Frm wall, stucco ext	0.094	-	3.50	1.28	98	98	343	126	0	0	0	0
	D	11D0	0.390	n	14.55	11.15	0	0	0	0	0	0	0	0
	C	16B-50ad	0.020	-	0.75	1.04	251	251	187	262	202	202	151	211
	C	DftCeil	0.020	-	0.75	1.05	0	0	0	0	0	0	0	0
	F	22A-tpm	1.180	-	44.01	0.00	251	21	902	0	202	29	1265	0
6		c) AED excursion								-73				-42
		Envelope loss/gain							2196	1296			2207	969
12		a) Infiltration b) Room ventilation							534 0	235 0			748 0	329 0
13		Internal gains:	Occupants @ Appliances/other		230		1			230 900	1			230 0
		Subtotal (lines 6 to 13)							2730	2661			2956	1528
   14 15		Less external load Less transfer Redistribution Subtotal Duct loads					-0%	0%	0 0 161 2891 0	0 0 84 2745 0	-0%	0%	0 0 109 3065 0	0 0 57 1585 0
		Total room load Air required (cfm)							2891 113	2745 148			3065 120	1585 85

Calculations approved by ACCA to meet all requirements of Manual J 8th Ed.

wrightsoft Right-Suite® Universal 2015 15.0.13 RSU00533
...Wrightsuite\Grange\GRANGE-CA-Retrofit_DEG_F.rup Calc = MJ8 Front Door faces: SW

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Right-J® Worksheet
Entire House
Wrightsoft Corp

Job:
Date: March 15, 2015
By:

131 Hartwell Ave, Lexington, MA 02421 Phone: 800-225-8697 Fax: 781-861-2058 Web: www.wrightsoft.com

1	Room name	BEDROOM 1
2	Exposed wall	25.5 ft
3	Room height	8.0 ft heat/cool
4	Room dimensions	1.0 x 152.9 ft
5	Room area	152.9 ft²

	Ty	Construction number	U-value (Btuh/ft²-°F)	Or	HTM (Btuh/ft²) Heat	HTM (Btuh/ft²) Cool	Area (ft²) or perimeter (ft) Gross	Area (ft²) or perimeter (ft) N/P/S	Load (Btuh) Heat	Load (Btuh) Cool	Area or perimeter Gross	Area or perimeter N/P/S	Load Heat	Load Cool
6	W	12B-5sw	0.068	ne	2.54	1.33	0	0	0	0				
.	G	1 glazing, clr glz,	0.300	ne	11.19	20.33	0	0	0	0				
.	W	12B-5sw	0.068	se	2.54	1.33	100	88	223	117				
.	G	1 glazing, clr glz,	0.300	se	11.19	23.57	12	0	134	283				
11	W	12B-5sw	0.068	sw	2.54	1.33	104	92	233	122				
	G	1 glazing, clr glz,	0.300	sw	11.19	23.57	12	0	134	283				
	D	11D0	0.390	sw	14.55	11.15	0	0	0	0				
	W	12B-5sw	0.068	nw	2.54	1.33	0	0	0	0				
	P	Frm wall, stucco ext	0.094	-	3.50	1.28	0	0	0	0				
	D	11D0	0.390	n	14.55	11.15	0	0	0	0				
	C	16B-50ad	0.020	-	0.75	1.04	0	0	0	0				
	C	DftCeil	0.020	-	0.75	1.05	153	153	115	161				
	F	22A-tpm	1.180	-	44.01	0.00	153	26	1122	0				

			Gross	N/P/S	Heat	Cool
6	c) AED excursion					-40
	Envelope loss/gain				1963	926
12	a) Infiltration				664	292
	b) Room ventilation				0	0
13	Internal gains:	Occupants @ 230	1			230
		Appliances/other				0
	Subtotal (lines 6 to 13)				2627	1448
	Less external load				0	0
	Less transfer				0	0
	Redistribution				123	64
14	Subtotal				2750	1512
15	Duct loads		-0%	0%	0	0
	Total room load				2750	1512
	Air required (cfm)				107	81

Calculations approved by ACCA to meet all requirements of Manual J 8th Ed.

Mayfair Load Calculations

Davis Energy Group

Load Short Form
Entire House
Wrightsoft Corp

Job:
Date: Feb 23, 2015
By:

131 Hartwell Ave, Lexington, MA 02421 Phone: 800-225-8697 Fax: 781-861-2058 Web: www.wrightsoft.com

Project Information

For: Mayfair - Retrofit, K Hovnaninan Homes
16 West Mayfair Ave, Stockton, CA

Design Information

	Htg	Clg
Outside db (°F)	33	98
Inside db (°F)	70	75
Design TD (°F)	37	23
Daily range	-	H
Inside humidity (%)	30	50
Moisture difference (gr/lb)	11	-3

Infiltration

Method	Blower door
Shielding / stories	3 (partial) / 2
Pressure / AVF	50 Pa / 981 cfm

HEATING EQUIPMENT

Make	Generic
Trade	
Model	SEER 14.0, HSPF 8.1
AHRI ref	
Efficiency	8.2 HSPF
Heating input	
Heating output	25761 Btuh @ 47°F
Temperature rise	27 °F
Actual air flow	863 cfm
Air flow factor	0.055 cfm/Btuh
Static pressure	0.40 in H2O
Space thermostat	

COOLING EQUIPMENT

Make	Generic
Trade	
Cond	SEER 14.0, HSPF 8.1
Coil	
AHRI ref	
Efficiency	12.2 EER, 14 SEER
Sensible cooling	18123 Btuh
Latent cooling	7767 Btuh
Total cooling	25890 Btuh
Actual air flow	863 cfm
Air flow factor	0.057 cfm/Btuh
Static pressure	0.40 in H2O
Load sensible heat ratio	0.96

ROOM NAME	Area (ft²)	Htg load (Btuh)	Clg load (Btuh)	Htg AVF (cfm)	Clg AVF (cfm)
KITCHEN	146	2124	3008	118	172
BATH	54	681	528	38	30
BEDROOM 3	141	2736	2101	152	120
BEDROOM 2	167	2579	2156	143	123
BEDROOM 1	142	1773	1581	98	90
GREAT ROOM	437	5690	5708	315	327
Entire House d	1087	15583	15083	863	863
Other equip loads		0	0		
Equip. @ 1.03 RSM			15521		
Latent cooling			654		
TOTALS	1087	15583	16175	863	863

Calculations approved by ACCA to meet all requirements of Manual J 8th Ed.

wrightsoft Right-Suite® Universal 2015 15.0.13 RSU00533
...Mayfair\RSU Models\Mayfair -Retrofit_DEG_F.rup Calc = MJ8 Front Door faces: NE
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Davis Energy Group

Loads for Multiple Orientations

Entire House

Wrightsoft Corp

Job:
Date: Feb 23, 2015
By:

131 Hartwell Ave, Lexington, MA 02421 Phone: 800-225-8697 Fax: 781-861-2058 Web: www.wrightsoft.com

Project Information

For: Mayfair - Retrofit, K Hovnaninan Homes
16 West Mayfair Ave, Stockton, CA

Design Conditions

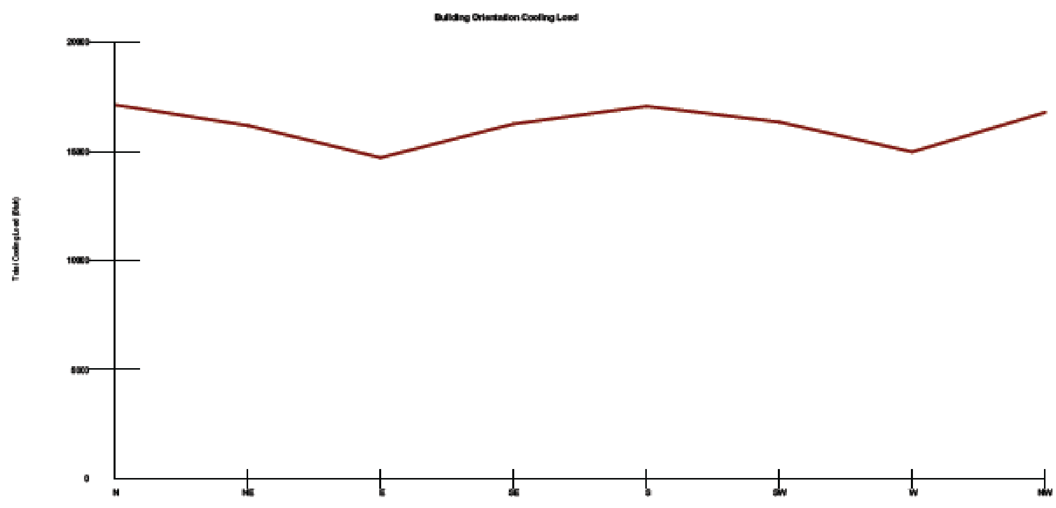
Location:
Stockton Metropolitan AP, CA, US
Elevation: 26 ft
Latitude: 38°N

Outdoor:	**Heating**	**Cooling**
Dry bulb (°F)	33	98
Daily range (°F)	-	32 (H)
Wet bulb (°F)	-	69
Wind speed (mph)	15.0	7.5

Indoor:	**Heating**	**Cooling**
Indoor temperature (°F)	70	75
Design TD (°F)	37	23
Relative humidity (%)	30	50
Moisture difference (gr/lb)	10.9	-3.0

Infiltration:

Front Door	North	Northeast	East	Southeast	South	Southwest	West	Northwest
Sensible Load (Btuh)	16479	15521	14056	15601	16411	15690	14315	16126
Latent Load (Btuh)	654	654	654	654	654	654	654	654
Total Load (Btuh)	17134	16175	14710	16255	17065	16345	14970	16781
Heating AVF (cfm)	863	863	863	863	863	863	863	863
Cooling AVF (cfm)	863	863	863	863	863	863	863	863



Current Orientation: Front Door faces Northeast
Highest Cooling Load: Front Door faces North

Calculations approved by ACCA to meet all requirements of Manual J 8th Ed.

Davis Energy Group

Building Analysis
Entire House
Wrightsoft Corp

Job:
Date: Feb 23, 2015
By:

131 Hartwell Ave, Lexington, MA 02421 Phone: 800-225-8697 Fax: 781-861-2058 Web: www.wrightsoft.com

Project Information

For: Mayfair - Retrofit, K Hovnaninan Homes
16 West Mayfair Ave, Stockton, CA

Design Conditions

Location:
Stockton Metropolitan AP, CA, US
Elevation: 26 ft
Latitude: 38°N

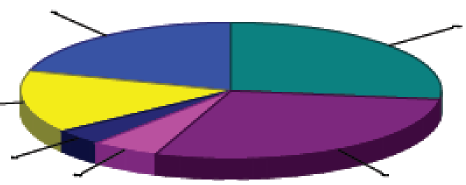
Outdoor:	**Heating**	**Cooling**
Dry bulb (°F)	33	98
Daily range (°F)	-	32 (H)
Wet bulb (°F)	-	69
Wind speed (mph)	15.0	7.5

Indoor:	**Heating**	**Cooling**
Indoor temperature (°F)	70	75
Design TD (°F)	37	23
Relative humidity (%)	30	50
Moisture difference (gr/lb)	10.9	-3.0

Infiltration:
Method: Blower door
Shielding / stories: 3 (partial) / 2
Pressure / AVF: 50 Pa / 981 cfm

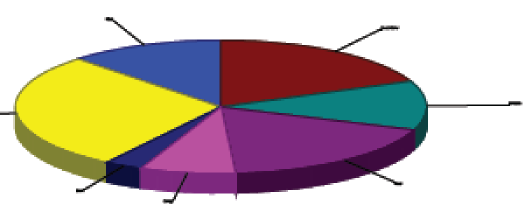
Heating

Component	Btuh/ft²	Btuh	% of load
Walls	3.4	3150	20.2
Glazing	11.9	2333	15.0
Doors	14.5	586	3.8
Ceilings	0.7	811	5.2
Floors	4.1	4491	28.8
Infiltration	4.2	4213	27.0
Ducts		0	0
Piping		0	0
Humidification		0	0
Ventilation		0	0
Adjustments		0	
Total		**15583**	**100.0**



Cooling

Component	Btuh/ft²	Btuh	% of load
Walls	2.0	1842	12.2
Glazing	21.9	4289	28.4
Doors	11.2	449	3.0
Ceilings	1.0	1132	7.5
Floors	2.5	2757	18.3
Infiltration	1.8	1794	11.9
Ducts		0	0
Ventilation		0	0
Internal gains		2820	18.7
Blower		0	0
Adjustments		0	
Total		**15083**	**100.0**



Latent Cooling Load = 654 Btuh
Overall U-value = 0.151 Btuh/ft²-°F

Data entries checked.

Davis Energy Group

Component Constructions
Entire House
Wrightsoft Corp

Job:
Date: Feb 23, 2015
By:

131 Hartwell Ave, Lexington, MA 02421 Phone: 800-225-8697 Fax: 781-861-2058 Web: www.wrightsoft.com

Project Information

For: Mayfair - Retrofit, K Hovnaninan Homes
16 West Mayfair Ave, Stockton, CA

Design Conditions

Location:
Stockton Metropolitan AP, CA, US
Elevation: 26 ft
Latitude: 38°N

Outdoor:	**Heating**	**Cooling**
Dry bulb (°F)	33	98
Daily range (°F)	-	32 (H)
Wet bulb (°F)	-	69
Wind speed (mph)	15.0	7.5

Indoor:	**Heating**	**Cooling**
Indoor temperature (°F)	70	75
Design TD (°F)	37	23
Relative humidity (%)	30	50
Moisture difference (gr/lb)	10.9	-3.0

Infiltration:
Method: Blower door
Shielding / stories: 3 (partial) / 2
Pressure / AVF: 50 Pa / 981 cfm

Construction descriptions	Or	Area ft²	U-value Btuh/ft²-°F	Insul R ft²-°F/Btuh	Htg HTM Btuh/ft²	Loss Btuh	Clg HTM Btuh/ft²	Gain Btuh
Walls								
12C-0sw: Frm wall, wd ext, 1/2" wood shth, r-13 cav ins, 1/2" gypsum board int fnsh, 2"x4" wood frm, 16" o.c. stud	ne	204	0.091	13.0	3.39	692	2.15	438
	se	265	0.091	13.0	3.39	898	2.15	568
	sw	52	0.091	13.0	3.39	177	2.15	112
	nw	240	0.091	13.0	3.39	814	2.15	515
	all	760	0.091	13.0	3.39	2581	2.15	1633
Partitions								
Frm wall, stucco ext, 1/2" wood shth, r-13 cav ins, 1/2" gypsum board int fnsh, 2"x4" wood frm, 16" o.c. stud: Frm wall, stucco ext, 1/2" wood shth, r-13 cav ins, 1/2" gypsum board int fnsh, 2"x4" wood frm, 16" o.c. stud		176	0.087	13.0	3.24	570	1.19	209
Windows								
1 glazing, clr glz, mtl /w brk frm mat, 1/8" thk: 1 glazing, clr glz, mtl /w brk frm mat, 1/8" thk; NFRC rated (SHGC=0.25); 50% outdoor insect screen; 6.67 ft head ht	ne	24	0.320	0	11.9	286	20.7	498
	se	72	0.320	0	11.9	864	24.0	1736
	nw	99	0.320	0	11.9	1182	20.7	2055
	all	195	0.320	0	11.9	2333	21.9	4289
Doors								
11D0: Door, wd sc type	se	21	0.390	0	14.5	305	11.2	234
	nw	19	0.390	0	14.5	280	11.2	215
	all	40	0.390	0	14.5	586	11.2	449
Ceilings								
16B-50ad: Attic ceiling, asphalt shingles roof mat, r-5 roof ins, r-50 ceil ins, 1/2" gypsum board int fnsh		1087	0.020	50.0	0.75	811	1.04	1132
Floors								
19A-0cscp: Flr floor, frm flr, 8" thkns, carpet flr fnsh, tight crwl ovr		1087	0.295	0	4.13	4491	2.54	2757

Davis Energy Group

Project Summary
Entire House
Wrightsoft Corp

Job:
Date: Feb 23, 2015
By:

131 Hartwell Ave, Lexington, MA 02421 Phone: 800-225-8697 Fax: 781-861-2058 Web: www.wrightsoft.com

Project Information

For: Mayfair - Retrofit, K Hovnaninan Homes
16 West Mayfair Ave, Stockton, CA

Notes: Several assumptions had to be made in order to complete this model, due to incomplete data. Please reference the accompanying list of assumptions for details.

Design Information

Weather: Stockton Metropolitan AP, CA, US

Winter Design Conditions

Outside db	33	°F
Inside db	70	°F
Design TD	37	°F

Summer Design Conditions

Outside db	98	°F
Inside db	75	°F
Design TD	23	°F
Daily range	H	
Relative humidity	50	%
Moisture difference	-3	gr/lb

Heating Summary

Structure	15583	Btuh
Ducts	0	Btuh
Central vent (0 cfm)	0	Btuh
Humidification	0	Btuh
Piping	0	Btuh
Equipment load	15583	Btuh

Infiltration

Method	Blower door
Shielding / stories	3 (partial) / 2
Pressure / AVF	50 Pa / 981 cfm

	Heating	Cooling
Area (ft²)	1087	1087
Volume (ft³)	8692	8692
Air changes/hour	0.65	0.40
Equiv. AVF (cfm)	103	71

Sensible Cooling Equipment Load Sizing

Structure	15083	Btuh
Ducts	0	Btuh
Central vent (0 cfm)	0	Btuh
Blower	0	Btuh
Use manufacturer's data	n	
Rate/swing multiplier	1.03	
Equipment sensible load	15521	Btuh

Latent Cooling Equipment Load Sizing

Structure	654	Btuh
Ducts	0	Btuh
Central vent (0 cfm)	0	Btuh
Equipment latent load	654	Btuh
Equipment total load	16175	Btuh
Req. total capacity at 0.70 SHR	1.8	ton

Heating Equipment Summary

Make	Generic
Trade	
Model	SEER 14.0, HSPF 8.1
AHRI ref	

Efficiency	8.2 HSPF	
Heating input		
Heating output	25761	Btuh @ 47°F
Temperature rise	27	°F
Actual air flow	863	cfm
Air flow factor	0.055	cfm/Btuh
Static pressure	0.40	in H2O
Space thermostat		

Cooling Equipment Summary

Make	Generic
Trade	
Cond	SEER 14.0, HSPF 8.1
Coil	
AHRI ref	

Efficiency	12.2 EER, 14 SEER	
Sensible cooling	18123	Btuh
Latent cooling	7767	Btuh
Total cooling	25890	Btuh
Actual air flow	863	cfm
Air flow factor	0.057	cfm/Btuh
Static pressure	0.40	in H2O
Load sensible heat ratio	0.96	

Calculations approved by ACCA to meet all requirements of Manual J 8th Ed.

DAVIS ENERGY GROUP

AED Assessment
Entire House
Wrightsoft Corp

Job:
Date: Feb 23, 2015
By:

131 Hartwell Ave, Lexington, MA 02421 Phone: 800-225-8697 Fax: 781-861-2058 Web: www.wrightsoft.com

Project Information

For: Mayfair - Retrofit, K Hovnaninan Homes
16 West Mayfair Ave, Stockton, CA

Design Conditions

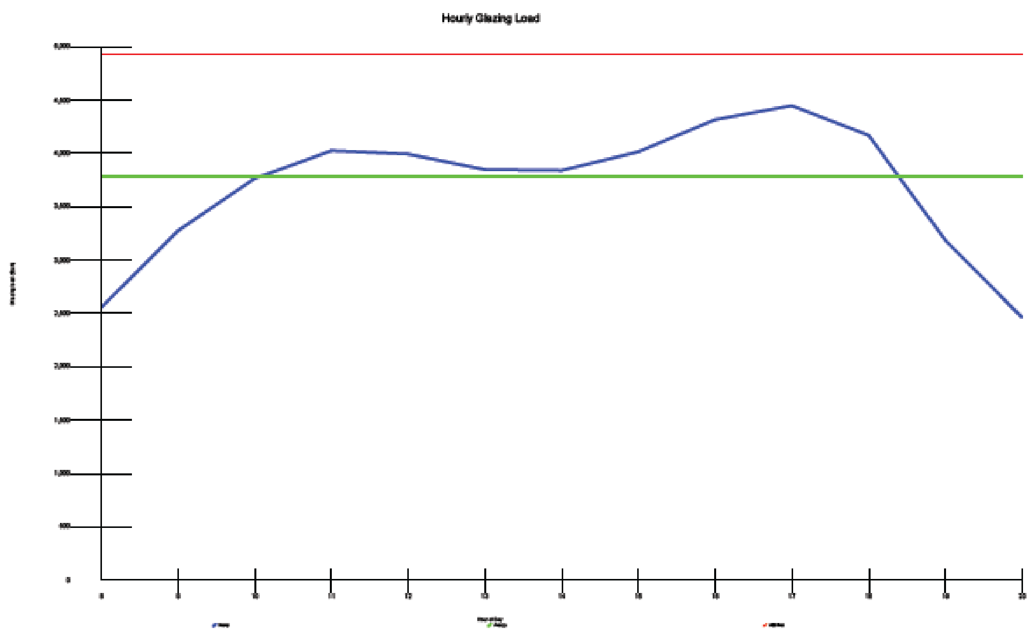
Location:
Stockton Metropolitan AP, CA, US
Elevation: 26 ft
Latitude: 38°N

Outdoor:	**Heating**	**Cooling**
Dry bulb (°F)	33	98
Daily range (°F)	-	32 (H)
Wet bulb (°F)	-	69
Wind speed (mph)	15.0	7.5

Indoor:	**Heating**	**Cooling**
Indoor temperature (°F)	70	75
Design TD (°F)	37	23
Relative humidity (%)	30	50
Moisture difference (gr/lb)	10.9	-3.0

Infiltration:

Test for Adequate Exposure Diversity



Maximum hourly glazing load exceeds average by 17.4%.

House has adequate exposure diversity (AED), based on AED limit of 30%.

AED excursion: 0 Btuh

Davis Energy Group

Right-J® Worksheet
Entire House
Wrightsoft Corp

Job:
Date: Feb 23, 2015
By:

131 Hartwell Ave, Lexington, MA 02421 Phone: 800-225-8697 Fax: 781-861-2058 Web: www.wrightsoft.com

		Entire House	KITCHEN
1	Room name	Entire House	KITCHEN
2	Exposed wall	124.5 ft	16.3 ft
3	Room height	8.0 ft d	8.0 ft heat/cool
4	Room dimensions		16.3 x 9.0 ft
5	Room area	1086.5 ft²	146.3 ft²

	Ty	Construction number	U-value (Btuh/ft²-°F)	Or	HTM (Btuh/ft²) Heat	HTM (Btuh/ft²) Cool	Entire House Area (ft²) or perimeter (ft) Gross	Entire House Area (ft²) or perimeter (ft) N/P/S	Entire House Load (Btuh) Heat	Entire House Load (Btuh) Cool	Kitchen Area (ft²) or perimeter (ft) Gross	Kitchen Area (ft²) or perimeter (ft) N/P/S	Kitchen Load (Btuh) Heat	Kitchen Load (Btuh) Cool
6	W	12C-0sw	0.091	ne	3.39	2.15	228	204	692	438	0	0	0	0
.	G	1 glazing, clr glz,	0.320	ne	11.94	20.74	24	0	286	498	0	0	0	0
.	W	12C-0sw	0.091	se	3.39	2.15	358	265	898	568	0	0	0	0
.	G	1 glazing, clr glz,	0.320	se	11.94	23.99	72	0	864	1736	0	0	0	0
11	D	11D0	0.390	se	14.55	11.15	21	21	305	234	0	0	0	0
	W	12C-0sw	0.091	sw	3.39	2.15	52	52	177	112	0	0	0	0
	W	12C-0sw	0.091	nw	3.39	2.15	358	240	814	515	130	87	294	186
	G	1 glazing, clr glz,	0.320	nw	11.94	20.74	99	0	1182	2055	24	0	286	498
	D	11D0	0.390	nw	14.55	11.15	19	19	280	215	19	19	280	215
	P	Frm wall, stucco ext	0.087	-	3.24	1.19	176	176	570	209	0	0	0	0
	C	16B-50ad	0.020	-	0.75	1.04	1087	1087	811	1132	146	146	109	152
	F	19A-0cscp	0.295	-	4.13	2.54	1087	1087	4491	2757	146	146	605	371
6		c) AED excursion								0				121
		Envelope loss/gain							11370	10469			1575	1544
12		a) Infiltration							4213	1794			550	234
		b) Room ventilation							0	0			0	0
13		Internal gains:	Occupants @		230		4			920	1			230
			Appliances/other							1900				1000
		Subtotal (lines 6 to 13)							15583	15083			2124	3008
		Less external load							0	0			0	0
		Less transfer							0	0			0	0
		Redistribution							0	0			0	0
14		Subtotal							15583	15083			2124	3008
15		Duct loads					0%	0%	0	0	-0%	0%	0	0
		Total room load							15583	15083			2124	3008
		Air required (cfm)							863	863			118	172

Calculations approved by ACCA to meet all requirements of Manual J 8th Ed.

wrightsoft Right-Suite® Universal 2015 15.0.13 RSU00533
...Mayfair\RSU Models\Mayfair -Retrofit_DEG_F.rup Calc = MJ8 Front Door faces: NE

2015-Mar-24 16:51:30
Page 1

Davis Energy Group

Right-J® Worksheet
Entire House
Wrightsoft Corp

Job:
Date: Feb 23, 2015
By:

131 Hartwell Ave, Lexington, MA 02421 Phone: 800-225-8697 Fax: 781-861-2058 Web: www.wrightsoft.com

							BATH				BEDROOM 3			
1	Room name						BATH				BEDROOM 3			
2	Exposed wall						6.0 ft				30.3 ft			
3	Room height						8.0 ft		heat/cool		8.0 ft		heat/cool	
4	Room dimensions						6.0 x 9.0 ft				1.0 x 140.6 ft			
5	Room area						54.0 ft²				140.6 ft²			
	Ty	Construction number	U-value (Btuh/ft²-°F)	Or	HTM (Btuh/ft²)		Area (ft²) or perimeter (ft)		Load (Btuh)		Area (ft²) or perimeter (ft)		Load (Btuh)	
					Heat	Cool	Gross	N/P/S	Heat	Cool	Gross	N/P/S	Heat	Cool
6	W	12C-0sw	0.091	ne	3.39	2.15	0	0	0	0	140	128	434	275
.	G	1 glazing, clr glz,	0.320	ne	11.94	20.74	0	0	0	0	12	0	143	249
.	W	12C-0sw	0.091	se	3.39	2.15	0	0	0	0	0	0	0	0
.	G	1 glazing, clr glz,	0.320	se	11.94	23.99	0	0	0	0	0	0	0	0
11	D	11D0	0.390	se	14.55	11.15	0	0	0	0	0	0	0	0
	W	12C-0sw	0.091	sw	3.39	2.15	0	0	0	0	20	20	68	43
	W	12C-0sw	0.091	nw	3.39	2.15	48	42	143	90	82	70	238	150
	G	1 glazing, clr glz,	0.320	nw	11.94	20.74	6	0	72	124	12	0	143	249
	D	11D0	0.390	nw	14.55	11.15	0	0	0	0	0	0	0	0
	P	Frm wall, stucco ext	0.087	-	3.24	1.19	0	0	0	0	0	0	0	0
	C	16B-50ad	0.020	-	0.75	1.04	54	54	40	56	141	141	105	147
	F	19A-0cscp	0.295	-	4.13	2.54	54	54	223	137	141	141	581	357
6	c) AED excursion									34				-34
	Envelope loss/gain								478	442			1713	1435
12	a) Infiltration								203	86			1024	436
	b) Room ventilation								0	0			0	0
13	Internal gains:		Occupants @	230			0			0	1			230
			Appliances/other							0				0
	Subtotal (lines 6 to 13)								681	528			2736	2101
	Less external load								0	0			0	0
	Less transfer								0	0			0	0
	Redistribution								0	0			0	0
14	Subtotal								681	528			2736	2101
15	Duct loads						-0%	0%	0	0	-0%	0%	0	0
	Total room load								681	528			2736	2101
	Air required (cfm)								38	30			152	120

Calculations approved by ACCA to meet all requirements of Manual J 8th Ed.

Davis Energy Group

Right-J® Worksheet
Entire House
Wrightsoft Corp

Job:
Date: Feb 23, 2015
By:

131 Hartwell Ave, Lexington, MA 02421 Phone: 800-225-8697 Fax: 781-861-2058 Web: www.wrightsoft.com

							BEDROOM 2				BEDROOM 1			
1	Room name						BEDROOM 2				BEDROOM 1			
2	Exposed wall						25.0 ft				15.5 ft			
3	Room height						8.0 ft		heat/cool		8.0 ft		heat/cool	
4	Room dimensions						1.0 x 167.1 ft				1.0 x 141.5 ft			
5	Room area						167.1 ft²				141.5 ft²			
	Ty	Construction number	U-value (Btuh/ft²-°F)	Or	HTM (Btuh/ft²)		Area (ft²) or perimeter (ft)		Load (Btuh)		Area (ft²) or perimeter (ft)		Load (Btuh)	
					Heat	Cool	Gross	N/P/S	Heat	Cool	Gross	N/P/S	Heat	Cool
6	W	12C-0sw	0.091	ne	3.39	2.15	88	76	258	163	0	0	0	0
.	└G	1 glazing, clr glz,	0.320	ne	11.94	20.74	12	0	143	249	0	0	0	0
.	W	12C-0sw	0.091	se	3.39	2.15	112	96	326	206	92	76	258	163
.	├G	1 glazing, clr glz,	0.320	se	11.94	23.99	16	0	191	384	16	0	191	384
11	└D	11D0	0.390	se	14.55	11.15	0	0	0	0	0	0	0	0
	W	12C-0sw	0.091	sw	3.39	2.15	0	0	0	0	32	32	109	69
	W	12C-0sw	0.091	nw	3.39	2.15	0	0	0	0	0	0	0	0
	├G	1 glazing, clr glz,	0.320	nw	11.94	20.74	0	0	0	0	0	0	0	0
	└D	11D0	0.390	nw	14.55	11.15	0	0	0	0	0	0	0	0
	P	Frm wall, stucco ext	0.087	-	3.24	1.19	0	0	0	0	0	0	0	0
	C	16B-50ad	0.020	-	0.75	1.04	167	167	125	174	142	142	106	147
	F	19A-0cscp	0.295	-	4.13	2.54	167	167	691	424	142	142	585	359
6	c) AED excursion									-35				6
	Envelope loss/gain								1734	1565			1248	1128
12	a) Infiltration								846	360			524	223
	b) Room ventilation								0	0			0	0
13	Internal gains:	Occupants @	230				1			230	1			230
		Appliances/other								0				0
	Subtotal (lines 6 to 13)								2579	2156			1773	1581
	Less external load								0	0			0	0
	Less transfer								0	0			0	0
	Redistribution								0	0			0	0
14	Subtotal								2579	2156			1773	1581
15	Duct loads						-0%	0%	0	0	-0%	0%	0	0
	Total room load								2579	2156			1773	1581
	Air required (cfm)								143	123			98	90

Calculations approved by ACCA to meet all requirements of Manual J 8th Ed.

Davis Energy Group

Right-J® Worksheet
Entire House
Wrightsoft Corp

Job:
Date: Feb 23, 2015
By:

131 Hartwell Ave, Lexington, MA 02421 Phone: 800-225-8697 Fax: 781-861-2058 Web: www.wrightsoft.com

1	Room name	GREAT ROOM	
2	Exposed wall	31.5 ft	
3	Room height	8.0 ft heat/cool	
4	Room dimensions	1.0 x 437.0 ft	
5	Room area	437.0 ft²	

	Ty	Construction number	U-value (Btuh/ft²-°F)	Or	HTM (Btuh/ft²) Heat	HTM (Btuh/ft²) Cool	Area (ft²) or perimeter (ft) Gross	Area (ft²) or perimeter (ft) N/P/S	Load (Btuh) Heat	Load (Btuh) Cool	Area or perimeter Gross	Area or perimeter N/P/S	Load Heat	Load Cool
6	W	12C-0sw	0.091	ne	3.39	2.15	0	0	0	0				
.	G	1 glazing, clr glz,	0.320	ne	11.94	20.74	0	0	0	0				
.	W	12C-0sw	0.091	se	3.39	2.15	154	93	314	199				
.	G	1 glazing, clr glz,	0.320	se	11.94	23.99	40	0	482	968				
11	D	11D0	0.390	se	14.55	11.15	21	21	305	234				
	W	12C-0sw	0.091	sw	3.39	2.15	0	0	0	0				
	W	12C-0sw	0.091	nw	3.39	2.15	98	41	139	88				
	G	1 glazing, clr glz,	0.320	nw	11.94	20.74	57	0	681	1184				
	D	11D0	0.390	nw	14.55	11.15	0	0	0	0				
	P	Frm wall, stucco ext	0.087	-	3.24	1.19	176	176	570	209				
	C	16B-50ad	0.020	-	0.75	1.04	437	437	326	455				
	F	19A-0cscp	0.295	-	4.13	2.54	437	437	1806	1109				
6	c) AED excursion									-92				
	Envelope loss/gain								4624	4354				
12	a) Infiltration								1066	454				
	b) Room ventilation								0	0				
13	Internal gains:	Occupants @	230				0			0				
		Appliances/other								900				
	Subtotal (lines 6 to 13)								5690	5708				
	Less external load								0	0				
	Less transfer								0	0				
	Redistribution								0	0				
14	Subtotal								5690	5708				
15	Duct loads						-0%	0%	0	0				
	Total room load								5690	5708				
	Air required (cfm)								315	327				

Calculations approved by ACCA to meet all requirements of Manual J 8th Ed.

CALEB LOAD CALCULATIONS

Load Short Form
Entire House
Wrightsoft Corp

Davis Energy Group

Job:
Date: March 15, 2015
By:

131 Hartwell Ave, Lexington, MA 02421 Phone: 800-225-8697 Fax: 781-861-2058 Web: www.wrightsoft.com

Project Information

For: Caleb- Retrofit
1770 Caleb Circle, Stockton, CA

Design Information

	Htg	Clg
Outside db (°F)	33	98
Inside db (°F)	70	75
Design TD (°F)	37	23
Daily range	-	H
Inside humidity (%)	30	50
Moisture difference (gr/lb)	11	-3

Infiltration	
Method	Blower door
Shielding / stories	3 (partial) / 2
Pressure / AVF	50 Pa / 1615 cfm

HEATING EQUIPMENT

Make	Generic	
Trade		
Model	SEER 14.0, HSPF 8.1	
AHRI ref		
Efficiency	8.2 HSPF	
Heating input		
Heating output	35540	Btuh @ 47°F
Temperature rise	27	°F
Actual air flow	***1191***	cfm
Air flow factor	0.047	cfm/Btuh
Static pressure	0	in H2O
Space thermostat		

COOLING EQUIPMENT

Make	Generic	
Trade		
Cond	SEER 14.0, HSPF 8.1	
Coil		
AHRI ref		
Efficiency	12.2 EER, 14 SEER	
Sensible cooling	25003	Btuh
Latent cooling	10715	Btuh
Total cooling	35718	Btuh
Actual air flow	1191	cfm
Air flow factor	0.059	cfm/Btuh
Static pressure	0.40	in H2O
Load sensible heat ratio	0.96	

ROOM NAME	Area (ft²)	Htg load (Btuh)	Clg load (Btuh)	Htg AVF (cfm)	Clg AVF (cfm)
BED 1	157	1716	1617	***81***	95
BED 2	160	1846	1467	***88***	86
MASTER BED	253	2357	2290	***112***	135
GREAT ROOM	656	10059	6312	***478***	372
BATH	35	1239	369	***59***	22
LAUNDRY	56	590	744	***28***	44
KITCHEN	199	3117	2912	***148***	172
ROOM 11	67	0	0	***0***	0
BED 3	140	1081	1830	***51***	108
BONUS	264	1449	1493	***69***	88
MASTER BATH	124	1629	1187	***77***	70
BATH 2	61	0	0	***0***	0

Bold/italic values have been manually overridden

Calculations approved by ACCA to meet all requirements of Manual J 8th Ed.

wrightsoft Right-Suite® Universal 2015 15.0.13 RSU00533
...ping\Wrightsuite\Caleb\Caleb-Retrofit_DEG_F.rup Calc = MJ8 Front Door faces: S

2015-Mar-24 14:19:56
Page 1

Entire House	d	2171	25084	20221	***1191***	1191
Other equip loads			0	0		
Equip. @ 1.03 RSM				20807		
Latent cooling				770		
TOTALS		2171	25084	21577	***1191***	1191

Bold/italic values have been manually overridden

Calculations approved by ACCA to meet all requirements of Manual J 8th Ed.

Loads for Multiple Orientations

Entire House

Wrightsoft Corp

Job:
Date: March 15, 2015
By:

131 Hartwell Ave, Lexington, MA 02421 Phone: 800-225-8697 Fax: 781-861-2058 Web: www.wrightsoft.com

Project Information

For: Caleb- Retrofit
1770 Caleb Circle, Stockton, CA

Design Conditions

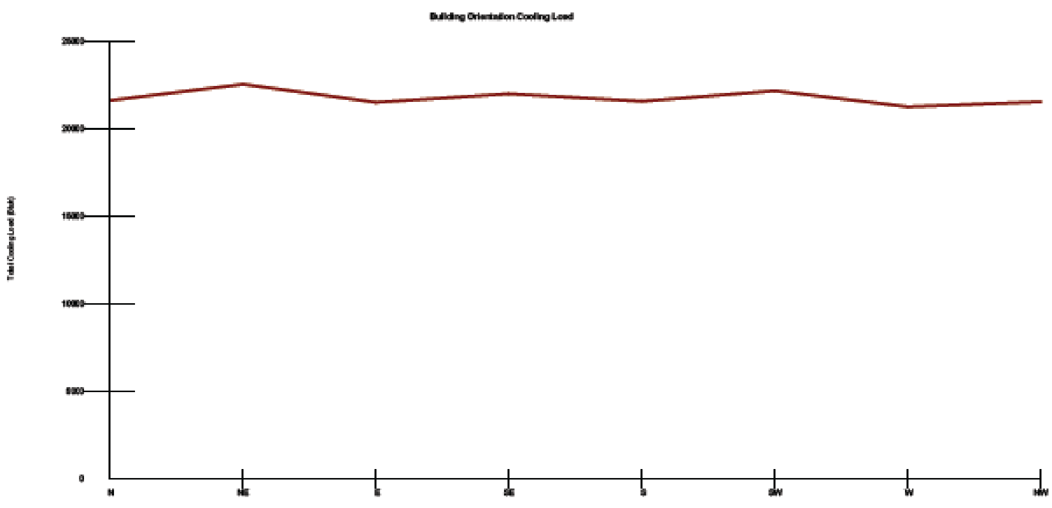
Location:
Stockton Metropolitan AP, CA, US
Elevation: 26 ft
Latitude: 38°N

Outdoor:	**Heating**	**Cooling**
Dry bulb (°F)	33	98
Daily range (°F)	-	32 (H)
Wet bulb (°F)	-	69
Wind speed (mph)	15.0	7.5

Indoor:	**Heating**	**Cooling**
Indoor temperature (°F)	70	75
Design TD (°F)	37	23
Relative humidity (%)	30	50
Moisture difference (gr/lb)	10.9	-3.0

Infiltration:

Front Door	North	Northeast	East	Southeast	South	Southwest	West	Northwest
Sensible Load (Btuh)	20866	21785	20749	21238	20807	21407	20500	20787
Latent Load (Btuh)	770	770	770	770	770	770	770	770
Total Load (Btuh)	21636	22555	21519	22008	21577	22176	21270	21556
Heating AVF (cfm)	1191	1191	1191	1191	1191	1191	1191	1191
Cooling AVF (cfm)	1191	1191	1191	1191	1191	1191	1191	1191



Current Orientation: Front Door faces South
Highest Cooling Load: Front Door faces Northeast

Calculations approved by ACCA to meet all requirements of Manual J 8th Ed.

Davis Energy Group

Building Analysis
Entire House
Wrightsoft Corp

Job:
Date: March 15, 2015
By:

131 Hartwell Ave, Lexington, MA 02421 Phone: 800-225-8697 Fax: 781-861-2058 Web: www.wrightsoft.com

Project Information

For: Caleb- Retrofit
1770 Caleb Circle, Stockton, CA

Design Conditions

Location:
Stockton Metropolitan AP, CA, US
Elevation: 26 ft
Latitude: 38°N

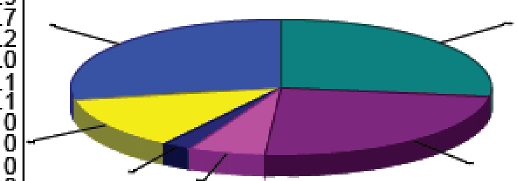
Outdoor:	**Heating**	**Cooling**
Dry bulb (°F)	33	98
Daily range (°F)	-	32 (H)
Wet bulb (°F)	-	69
Wind speed (mph)	15.0	7.5

Indoor:	**Heating**	**Cooling**
Indoor temperature (°F)	70	75
Design TD (°F)	37	23
Relative humidity (%)	30	50
Moisture difference (gr/lb)	10.9	-3.0

Infiltration:
Method: Blower door
Shielding / stories: 3 (partial) / 2
Pressure / AVF: 50 Pa / 1615 cfm

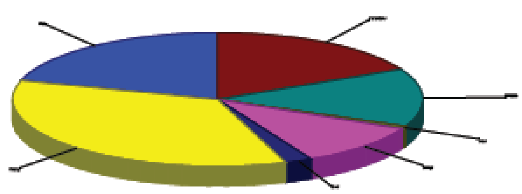
Heating

Component	Btuh/ft²	Btuh	% of load
Walls	3.2	6991	27.9
Glazing	11.2	3186	12.7
Doors	14.5	560	2.2
Ceilings	1.2	1493	6.0
Floors	4.9	6049	24.1
Infiltration	2.7	6804	27.1
Ducts		0	0
Piping		0	0
Humidification		0	0
Ventilation		0	0
Adjustments		0	
Total		**25084**	**100.0**



Cooling

Component	Btuh/ft²	Btuh	% of load
Walls	1.9	4128	20.4
Glazing	24.8	7071	35.0
Doors	11.2	429	2.1
Ceilings	1.7	2085	10.3
Floors	0.1	122	0.6
Infiltration	1.1	2836	14.0
Ducts		0	0
Ventilation		0	0
Internal gains		3550	17.6
Blower		0	0
Adjustments		0	
Total		**20221**	**100.0**



Latent Cooling Load = 770 Btuh
Overall U-value = 0.099 Btuh/ft²-°F

Data entries checked.

Davis Energy Group

Component Constructions
Entire House
Wrightsoft Corp

Job:
Date: March 15, 2015
By:

131 Hartwell Ave, Lexington, MA 02421 Phone: 800-225-8697 Fax: 781-861-2058 Web: www.wrightsoft.com

Project Information

For: Caleb- Retrofit
1770 Caleb Circle, Stockton, CA

Design Conditions

Location:
Stockton Metropolitan AP, CA, US
Elevation: 26 ft
Latitude: 38°N

Outdoor:

	Heating	Cooling
Dry bulb (°F)	33	98
Daily range (°F)	-	32 (H)
Wet bulb (°F)	-	69
Wind speed (mph)	15.0	7.5

Indoor:

	Heating	Cooling
Indoor temperature (°F)	70	75
Design TD (°F)	37	23
Relative humidity (%)	30	50
Moisture difference (gr/lb)	10.9	-3.0

Infiltration:

Method	Blower door
Shielding / stories	3 (partial) / 2
Pressure / AVF	50 Pa / 1615 cfm

Construction descriptions	Or	Area ft²	U-value Btuh/ft²-°F	Insul R ft²-°F/Btuh	Htg HTM Btuh/ft²	Loss Btuh	Clg HTM Btuh/ft²	Gain Btuh
Walls								
12C-0sw: Frm wall, wd ext, 1/2" wood shth, r-13 cav ins, 1/2" gypsum board int fnsh, 2"x4" wood frm, 16" o.c. stud	n	51	0.091	13.0	3.39	171	2.15	108
	ne	13	0.091	13.0	3.39	42	2.15	27
	e	108	0.091	13.0	3.39	365	2.15	231
	s	80	0.091	13.0	3.39	272	2.15	172
	w	184	0.091	13.0	3.39	625	2.15	395
	all	435	0.091	13.0	3.39	1475	2.15	933
12D-0sw: Frm wall, wd ext, 1/2" wood shth, r-17 cav ins, 1/2" gypsum board int fnsh, 2"x4" wood frm, 16" o.c. stud	n	256	0.086	15.0	3.21	821	1.86	476
	e	630	0.086	15.0	3.21	2019	1.86	1169
	se	32	0.086	15.0	3.21	102	1.86	59
	s	259	0.086	15.0	3.21	829	1.86	480
	sw	28	0.086	15.0	3.21	91	1.86	53
	w	476	0.086	15.0	3.21	1527	1.86	884
	nw	40	0.086	15.0	3.21	127	1.86	73
	all	1720	0.086	15.0	3.21	5517	1.86	3195
Partitions								
(none)								
Windows								
2 glazing, clr outr, air gas, mtl /w brk frm mat, clr innr, 1/4" gap, 1/4" thk; 2 glazing, clr outr, air gas, mtl /w brk frm mat, clr innr, 1/4" gap, 1/4" thk; NFRC rated (SHGC=0.35); 50% outdoor insect screen; 6.67 ft head ht	n	12	0.300	0	11.2	134	12.4	149
	n	36	0.300	0	11.2	403	12.4	446
	e	24	0.300	0	11.2	269	36.0	865
	sw	39	0.300	0	11.2	435	30.5	1186
	w	16	0.300	0	11.2	179	36.0	577
	w	13	0.300	0	11.2	145	36.0	466
	all	140	0.300	0	11.2	1564	26.4	3688
2 glazing, clr outr, air gas, mtl /w brk frm mat, clr innr, 1/4" gap, 1/4" thk; 2 glazing, clr outr, air gas, mtl /w brk frm mat, clr innr, 1/4" gap, 1/4" thk; NFRC rated (SHGC=0.35); 50% blinds closed, dark; 50% outdoor insect screen; 6.67 ft head ht	n	48	0.300	0	11.2	537	10.8	518
	e	33	0.300	0	11.2	369	31.6	1044
	s	24	0.300	0	11.2	269	16.0	383
	w	40	0.300	0	11.2	448	31.6	1265
	all	145	0.300	0	11.2	1623	22.1	3210

Doors								
11D0: Door, wd sc type	s	18	0.390	0	14.5	255	11.2	195
	nw	21	0.390	0	14.5	305	11.2	234
	all	39	0.390	0	14.5	560	11.2	429
Ceilings								
16B-30ad: Attic ceiling, asphalt shingles roof mat, r-30 ceil ins, 1/2" gypsum board int fnsh		1226	0.032	30.0	1.19	1463	1.67	2044
16B-7ad: Attic ceiling, asphalt shingles roof mat, r-7 ceil ins, 1/2" gypsum board int fnsh		7	0.112	7.0	4.18	30	5.84	41
Floors								
20P-30c: Flr floor, frm flr, 6" thkns, carpet flr fnsh, r-30 cav ins, amb ovr		287	0.035	30.0	1.31	375	0.42	122
22A-tpm: Bg floor, heavy dry or light damp soil, on grade depth		129	1.180	0	44.0	5674	0	0

Davis Energy Group

Project Summary
Entire House
Wrightsoft Corp

Job:
Date: March 15, 2015
By:

131 Hartwell Ave, Lexington, MA 02421 Phone: 800-225-8697 Fax: 781-861-2058 Web: www.wrightsoft.com

Project Information

For: Caleb- Retrofit
1770 Caleb Circle, Stockton, CA

Notes: Several assumptions had to be made in order to complete this model, due to incomplete data. Please reference the accompanying list of assumptions for details.

Design Information

Weather: Stockton Metropolitan AP, CA, US

Winter Design Conditions

Outside db	33	°F
Inside db	70	°F
Design TD	37	°F

Summer Design Conditions

Outside db	98	°F
Inside db	75	°F
Design TD	23	°F
Daily range	H	
Relative humidity	50	%
Moisture difference	-3	gr/lb

Heating Summary

Structure	25084	Btuh
Ducts	0	Btuh
Central vent (0 cfm)	0	Btuh
Humidification	0	Btuh
Piping	0	Btuh
Equipment load	25084	Btuh

Infiltration

Method	Blower door
Shielding / stories	3 (partial) / 2
Pressure / AVF	50 Pa / 1615 cfm

	Heating	Cooling
Area (ft²)	2171	2171
Volume (ft³)	19263	19263
Air changes/hour	0.48	0.30
Equiv. AVF (cfm)	166	113

Sensible Cooling Equipment Load Sizing

Structure	20221	Btuh
Ducts	0	Btuh
Central vent (0 cfm)	0	Btuh
Blower	0	Btuh
Use manufacturer's data	n	
Rate/swing multiplier	1.03	
Equipment sensible load	20807	Btuh

Latent Cooling Equipment Load Sizing

Structure	770	Btuh
Ducts	0	Btuh
Central vent (0 cfm)	0	Btuh
Equipment latent load	770	Btuh
Equipment total load	21577	Btuh
Req. total capacity at 0.70 SHR	2.5	ton

Heating Equipment Summary

Make	Generic
Trade	
Model	SEER 14.0, HSPF 8.1
AHRI ref	

Efficiency	8.2 HSPF	
Heating input		
Heating output	35540	Btuh @ 47°F
Temperature rise	27	°F
Actual air flow	***1191***	cfm
Air flow factor	0.047	cfm/Btuh
Static pressure	0	in H2O
Space thermostat		

Cooling Equipment Summary

Make	Generic
Trade	
Cond	SEER 14.0, HSPF 8.1
Coil	
AHRI ref	

Efficiency	12.2 EER, 14 SEER	
Sensible cooling	25003	Btuh
Latent cooling	10715	Btuh
Total cooling	35718	Btuh
Actual air flow	1191	cfm
Air flow factor	0.059	cfm/Btuh
Static pressure	0.40	in H2O
Load sensible heat ratio	0.96	

Bold/italic values have been manually overridden

Calculations approved by ACCA to meet all requirements of Manual J 8th Ed.

Davis Energy Group

AED Assessment

Entire House

Wrightsoft Corp

Job:
Date: March 15, 2015
By:

131 Hartwell Ave, Lexington, MA 02421 Phone: 800-225-8697 Fax: 781-861-2058 Web: www.wrightsoft.com

Project Information

For: Caleb- Retrofit
1770 Caleb Circle, Stockton, CA

Design Conditions

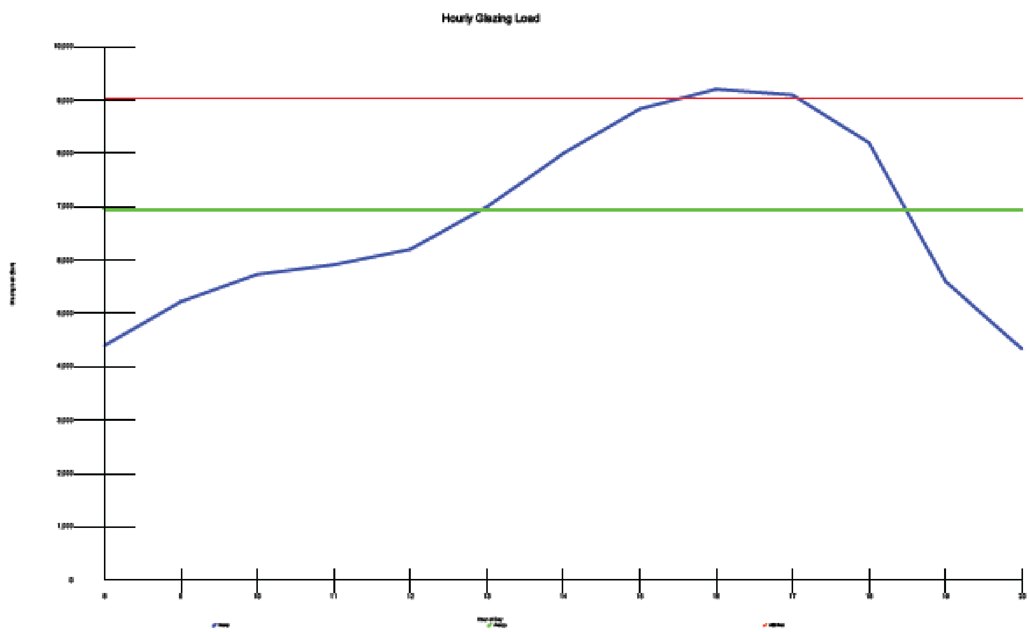
Location:
Stockton Metropolitan AP, CA, US
Elevation: 26 ft
Latitude: 38°N

Outdoor:	**Heating**	**Cooling**
Dry bulb (°F)	33	98
Daily range (°F)	-	32 (H)
Wet bulb (°F)	-	69
Wind speed (mph)	15.0	7.5

Indoor:	**Heating**	**Cooling**
Indoor temperature (°F)	70	75
Design TD (°F)	37	23
Relative humidity (%)	30	50
Moisture difference (gr/lb)	10.9	-3.0

Infiltration:

Test for Adequate Exposure Diversity



Maximum hourly glazing load exceeds average by 32.5%.

House does not have adequate exposure diversity (AED), based on AED limit of 30%.

AED excursion: 173 Btuh (PFG - 1.3*AFG)

Right-J® Worksheet
Entire House
Wrightsoft Corp

Job:
Date: March 15, 2015
By:

131 Hartwell Ave, Lexington, MA 02421 Phone: 800-225-8697 Fax: 781-861-2058 Web: www.wrightsoft.com

		Entire House	BED 1
1	Room name	Entire House	BED 1
2	Exposed wall	277.4 ft	26.0 ft
3	Room height	8.9 ft d	8.0 ft heat/cool
4	Room dimensions		1.0 x 156.8 ft
5	Room area	2171.4 ft²	156.8 ft²

	Ty	Construction number	U-value (Btuh/ft²-°F)	Or	HTM (Btuh/ft²) Heat	HTM (Btuh/ft²) Cool	Entire House Area (ft²) or perimeter (ft) Gross	Entire House Area (ft²) or perimeter (ft) N/P/S	Entire House Load (Btuh) Heat	Entire House Load (Btuh) Cool	BED 1 Area (ft²) or perimeter (ft) Gross	BED 1 Area (ft²) or perimeter (ft) N/P/S	BED 1 Load (Btuh) Heat	BED 1 Load (Btuh) Cool
6	W	12C-0sw	0.091	n	3.39	2.15	63	51	171	108	0	0	0	0
.	G	2 glazing, clr outr,	0.300	n	11.19	12.39	12	0	134	149	0	0	0	0
.	W	12D-0sw	0.086	n	3.21	1.86	340	256	821	476	92	68	218	126
.	G	2 glazing, clr outr,	0.300	n	11.19	12.39	36	0	403	446	0	0	0	0
11	G	2 glazing, clr outr,	0.300	n	11.19	10.79	48	0	537	518	24	0	269	259
	W	12C-0sw	0.091	ne	3.39	2.15	13	13	42	27	0	0	0	0
	W	12C-0sw	0.091	e	3.39	2.15	108	108	365	231	0	0	0	0
	W	12D-0sw	0.086	e	3.21	1.86	687	630	2019	1169	116	104	333	193
	G	2 glazing, clr outr,	0.300	e	11.19	36.05	24	0	269	865	0	0	0	0
	G	2 glazing, clr outr,	0.300	e	11.19	31.63	33	0	369	1044	12	0	138	390
	W	12D-0sw	0.086	se	3.21	1.86	32	32	102	59	0	0	0	0
	W	12C-0sw	0.091	s	3.39	2.15	98	80	272	172	0	0	0	0
	D	11D0	0.390	s	14.55	11.15	18	18	255	195	0	0	0	0
	W	12D-0sw	0.086	s	3.21	1.86	283	259	829	480	0	0	0	0
	G	2 glazing, clr outr,	0.300	s	11.19	15.97	24	0	269	383	0	0	0	0
	W	12D-0sw	0.086	sw	3.21	1.86	67	28	91	53	0	0	0	0
	G	2 glazing, clr outr,	0.300	sw	11.19	30.53	39	0	435	1186	0	0	0	0
	W	12C-0sw	0.091	w	3.39	2.15	200	184	625	395	0	0	0	0
	G	2 glazing, clr outr,	0.300	w	11.19	36.05	16	0	179	577	0	0	0	0
	W	12D-0sw	0.086	w	3.21	1.86	529	476	1527	884	0	0	0	0
	G	2 glazing, clr outr,	0.300	w	11.19	36.05	13	0	145	466	0	0	0	0
	G	2 glazing, clr outr,	0.300	w	11.19	31.63	40	0	448	1265	0	0	0	0
	W	12D-0sw	0.086	nw	3.21	1.86	61	40	127	73	0	0	0	0
	D	11D0	0.390	nw	14.55	11.15	21	21	305	234	0	0	0	0
	C	16B-30ad	0.032	-	1.19	1.67	1226	1226	1463	2044	157	157	187	261
	C	16B-7ad	0.112	-	4.18	5.84	7	7	30	41	0	0	0	0
	F	20P-30c	0.035	-	1.31	0.42	287	287	375	122	0	0	0	0
	F	22A-tpm	1.180	-	44.01	0.00	946	129	5674	0	0	0	0	0
6	c) AED excursion									173				-80
	Envelope loss/gain								18280	13834			1144	1149
12	a) Infiltration b) Room ventilation								6804 0	2836 0			571 0	238 0
13	Internal gains:		Occupants @ Appliances/other		230		5			1150 2400	1			230 0
	Subtotal (lines 6 to 13)								25084	20221			1716	1617
   14 15	Less external load Less transfer Redistribution Subtotal Duct loads						0%	0%	0 0 0 25084 0	0 0 0 20221 0	-0%	0%	0 0 0 1716 0	0 0 0 1617 0
	Total room load Air required (cfm)								25084 1191	20221 1191			1716 81	1617 95

Calculations approved by ACCA to meet all requirements of Manual J 8th Ed.

wrightsoft Right-Suite® Universal 2015 15.0.13 RSU00533
...ping\Wrightsuite\Caleb\Caleb-Retrofit_DEG_F.rup Calc = MJ8 Front Door faces: S

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Davis Energy Group

Right-J® Worksheet
Entire House
Wrightsoft Corp

Job:
Date: March 15, 2015
By:

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							LAUNDRY				KITCHEN			
1	Room name						LAUNDRY				KITCHEN			
2	Exposed wall						3.8 ft				27.5 ft			
3	Room height						10.0 ft		heat/cool		10.0 ft		heat/cool	
4	Room dimensions						1.0 x 55.9 ft				1.0 x 199.0 ft			
5	Room area						55.9 ft²				199.0 ft²			
	Ty	Construction number	U-value (Btuh/ft²-°F)	Or	HTM (Btuh/ft²) Heat	HTM Cool	Area (ft²) or perimeter (ft) Gross	N/P/S	Load (Btuh) Heat	Load Cool	Area (ft²) or perimeter (ft) Gross	N/P/S	Load (Btuh) Heat	Load Cool
6	W	12C-0sw	0.091	n	3.39	2.15	0	0	0	0	63	51	171	108
.	G	2 glazing, clr outr,	0.300	n	11.19	12.39	0	0	0	0	12	0	134	149
.	W	12D-0sw	0.086	n	3.21	1.86	0	0	0	0	0	0	0	0
.	G	2 glazing, clr outr,	0.300	n	11.19	12.39	0	0	0	0	0	0	0	0
11	G	2 glazing, clr outr,	0.300	n	11.19	10.79	0	0	0	0	0	0	0	0
	W	12C-0sw	0.091	ne	3.39	2.15	0	0	0	0	13	13	42	27
	W	12C-0sw	0.091	e	3.39	2.15	0	0	0	0	0	0	0	0
	W	12D-0sw	0.086	e	3.21	1.86	0	0	0	0	0	0	0	0
	G	2 glazing, clr outr,	0.300	e	11.19	36.05	0	0	0	0	0	0	0	0
	G	2 glazing, clr outr,	0.300	e	11.19	31.63	0	0	0	0	0	0	0	0
	W	12D-0sw	0.086	se	3.21	1.86	0	0	0	0	0	0	0	0
	W	12C-0sw	0.091	s	3.39	2.15	38	20	68	43	0	0	0	0
	D	11D0	0.390	s	14.55	11.15	18	18	255	195	0	0	0	0
	W	12D-0sw	0.086	s	3.21	1.86	0	0	0	0	0	0	0	0
	G	2 glazing, clr outr,	0.300	s	11.19	15.97	0	0	0	0	0	0	0	0
	W	12D-0sw	0.086	sw	3.21	1.86	0	0	0	0	0	0	0	0
	G	2 glazing, clr outr,	0.300	sw	11.19	30.53	0	0	0	0	0	0	0	0
	W	12C-0sw	0.091	w	3.39	2.15	0	0	0	0	200	184	625	395
	G	2 glazing, clr outr,	0.300	w	11.19	36.05	0	0	0	0	16	0	179	577
	W	12D-0sw	0.086	w	3.21	1.86	0	0	0	0	0	0	0	0
	G	2 glazing, clr outr,	0.300	w	11.19	36.05	0	0	0	0	0	0	0	0
	G	2 glazing, clr outr,	0.300	w	11.19	31.63	0	0	0	0	0	0	0	0
	W	12D-0sw	0.086	nw	3.21	1.86	0	0	0	0	0	0	0	0
	D	11D0	0.390	nw	14.55	11.15	0	0	0	0	0	0	0	0
	C	16B-30ad	0.032	-	1.19	1.67	0	0	0	0	0	0	0	0
	C	16B-7ad	0.112	-	4.18	5.84	0	0	0	0	0	0	0	0
	F	20P-30c	0.035	-	1.31	0.42	0	0	0	0	0	0	0	0
	F	22A-tpm	1.180	-	44.01	0.00	56	4	165	0	199	28	1210	0
6	c) AED excursion									-37				112
	Envelope loss/gain								488	201			2362	1367
12	a) Infiltration								103	43			755	315
	b) Room ventilation								0	0			0	0
13	Internal gains:		Occupants @ 230				0			0	1			230
			Appliances/other							500				1000
	Subtotal (lines 6 to 13)								590	744			3117	2912
	Less external load								0	0			0	0
	Less transfer								0	0			0	0
	Redistribution								0	0			0	0
14	Subtotal								590	744			3117	2912
15	Duct loads						-0%	0%	0	0	-0%	0%	0	0
	Total room load								590	744			3117	2912
	Air required (cfm)								28	44			148	172

Calculations approved by ACCA to meet all requirements of Manual J 8th Ed.

Davis Energy Group

Right-J® Worksheet
Entire House
Wrightsoft Corp

Job:
Date: March 15, 2015
By:

131 Hartwell Ave, Lexington, MA 02421 Phone: 800-225-8697 Fax: 781-861-2058 Web: www.wrightsoft.com

		ROOM 11	BED 3
1	Room name	ROOM 11	BED 3
2	Exposed wall	6.3 ft	12.8 ft
3	Room height	8.0 ft heat/cool	8.0 ft heat/cool
4	Room dimensions	6.3 x 10.8 ft	12.8 x 11.0 ft
5	Room area	67.2 ft²	140.3 ft²

	Ty	Construction number	U-value (Btuh/ft²-°F)	Or	HTM (Btuh/ft²) Heat	HTM (Btuh/ft²) Cool	ROOM 11 Area (ft²) or perimeter (ft) Gross	ROOM 11 Area N/P/S	ROOM 11 Load (Btuh) Heat	ROOM 11 Load (Btuh) Cool	BED 3 Area (ft²) or perimeter (ft) Gross	BED 3 Area N/P/S	BED 3 Load (Btuh) Heat	BED 3 Load (Btuh) Cool
6	W	12C-0sw	0.091	n	3.39	2.15	0	0	0	0	0	0	0	0
.	└G	2 glazing, clr outr,	0.300	n	11.19	12.39	0	0	0	0	0	0	0	0
.	W	12D-0sw	0.086	n	3.21	1.86	0	0	0	0	0	0	0	0
.	├G	2 glazing, clr outr,	0.300	n	11.19	12.39	0	0	0	0	0	0	0	0
11	└G	2 glazing, clr outr,	0.300	n	11.19	10.79	0	0	0	0	0	0	0	0
	W	12C-0sw	0.091	ne	3.39	2.15	0	0	0	0	0	0	0	0
	W	12C-0sw	0.091	e	3.39	2.15	50	50	170	107	0	0	0	0
	W	12D-0sw	0.086	e	3.21	1.86	0	0	0	0	0	0	0	0
	├G	2 glazing, clr outr,	0.300	e	11.19	36.05	0	0	0	0	0	0	0	0
	└G	2 glazing, clr outr,	0.300	e	11.19	31.63	0	0	0	0	0	0	0	0
	W	12D-0sw	0.086	se	3.21	1.86	0	0	0	0	0	0	0	0
	W	12C-0sw	0.091	s	3.39	2.15	0	0	0	0	0	0	0	0
	└D	11D0	0.390	s	14.55	11.15	0	0	0	0	0	0	0	0
	W	12D-0sw	0.086	s	3.21	1.86	0	0	0	0	0	0	0	0
	└G	2 glazing, clr outr,	0.300	s	11.19	15.97	0	0	0	0	0	0	0	0
	W	12D-0sw	0.086	sw	3.21	1.86	0	0	0	0	0	0	0	0
	└G	2 glazing, clr outr,	0.300	sw	11.19	30.53	0	0	0	0	0	0	0	0
	W	12C-0sw	0.091	w	3.39	2.15	0	0	0	0	0	0	0	0
	└G	2 glazing, clr outr,	0.300	w	11.19	36.05	0	0	0	0	0	0	0	0
	W	12D-0sw	0.086	w	3.21	1.86	0	0	0	0	102	82	263	152
	├G	2 glazing, clr outr,	0.300	w	11.19	36.05	0	0	0	0	0	0	0	0
	└G	2 glazing, clr outr,	0.300	w	11.19	31.63	0	0	0	0	20	0	224	633
	W	12D-0sw	0.086	nw	3.21	1.86	0	0	0	0	0	0	0	0
	└D	11D0	0.390	nw	14.55	11.15	0	0	0	0	0	0	0	0
	C	16B-30ad	0.032	-	1.19	1.67	67	67	80	112	140	140	167	234
	C	16B-7ad	0.112	-	4.18	5.84	0	0	0	0	0	0	0	0
	F	20P-30c	0.035	-	1.31	0.42	0	0	0	0	0	0	0	0
	F	22A-tpm	1.180	-	44.01	0.00	0	0	0	0	0	0	0	0
6	c) AED excursion									-13				301
	Envelope loss/gain								250	206			654	1319
12	a) Infiltration								137	57			280	117
	b) Room ventilation								0	0			0	0
13	Internal gains:	Occupants @	230				0			0	1			230
		Appliances/other								0				0
	Subtotal (lines 6 to 13)								387	264			934	1686
	Less external load								0	0			0	0
	Less transfer								0	0			0	0
	Redistribution								-387	-264			146	163
14	Subtotal								0	0			1081	1830
15	Duct loads						-0%	0%	0	0	-0%	0%	0	0
	Total room load								0	0			1081	1830
	Air required (cfm)								0	0			51	108

Calculations approved by ACCA to meet all requirements of Manual J 8th Ed.

Right-J® Worksheet
Entire House
Wrightsoft Corp

Job:
Date: March 15, 2015
By:

131 Hartwell Ave, Lexington, MA 02421 Phone: 800-225-8697 Fax: 781-861-2058 Web: www.wrightsoft.com

		BONUS	MASTER BATH
1	Room name	BONUS	MASTER BATH
2	Exposed wall	17.0 ft	22.3 ft
3	Room height	8.0 ft heat/cool	8.0 ft heat/cool
4	Room dimensions	1.0 x 264.2 ft	11.5 x 10.8 ft
5	Room area	264.2 ft²	123.6 ft²

	Ty	Construction number	U-value (Btuh/ft²-°F)	Or	HTM (Btuh/ft²) Heat	HTM (Btuh/ft²) Cool	BONUS Area (ft²) or perimeter (ft) Gross	BONUS N/P/S	BONUS Load (Btuh) Heat	BONUS Load (Btuh) Cool	MASTER BATH Area (ft²) or perimeter (ft) Gross	MASTER BATH N/P/S	MASTER BATH Load (Btuh) Heat	MASTER BATH Load (Btuh) Cool
6	W	12C-0sw	0.091	n	3.39	2.15	0	0	0	0	0	0	0	0
.	G	2 glazing, clr outr,	0.300	n	11.19	12.39	0	0	0	0	0	0	0	0
.	W	12D-0sw	0.086	n	3.21	1.86	0	0	0	0	0	0	0	0
.	G	2 glazing, clr outr,	0.300	n	11.19	12.39	0	0	0	0	0	0	0	0
11	G	2 glazing, clr outr,	0.300	n	11.19	10.79	0	0	0	0	0	0	0	0
	W	12C-0sw	0.091	ne	3.39	2.15	0	0	0	0	0	0	0	0
	W	12C-0sw	0.091	e	3.39	2.15	0	0	0	0	0	0	0	0
	W	12D-0sw	0.086	e	3.21	1.86	136	123	396	229	92	84	269	156
	G	2 glazing, clr outr,	0.300	e	11.19	36.05	0	0	0	0	0	0	0	0
	G	2 glazing, clr outr,	0.300	e	11.19	31.63	13	0	142	401	8	0	90	253
	W	12D-0sw	0.086	se	3.21	1.86	0	0	0	0	0	0	0	0
	W	12C-0sw	0.091	s	3.39	2.15	0	0	0	0	0	0	0	0
	D	11D0	0.390	s	14.55	11.15	0	0	0	0	0	0	0	0
	W	12D-0sw	0.086	s	3.21	1.86	0	0	0	0	86	78	250	145
	G	2 glazing, clr outr,	0.300	s	11.19	15.97	0	0	0	0	8	0	90	128
	W	12D-0sw	0.086	sw	3.21	1.86	0	0	0	0	0	0	0	0
	G	2 glazing, clr outr,	0.300	sw	11.19	30.53	0	0	0	0	0	0	0	0
	W	12C-0sw	0.091	w	3.39	2.15	0	0	0	0	0	0	0	0
	G	2 glazing, clr outr,	0.300	w	11.19	36.05	0	0	0	0	0	0	0	0
	W	12D-0sw	0.086	w	3.21	1.86	0	0	0	0	0	0	0	0
	G	2 glazing, clr outr,	0.300	w	11.19	36.05	0	0	0	0	0	0	0	0
	G	2 glazing, clr outr,	0.300	w	11.19	31.63	0	0	0	0	0	0	0	0
	W	12D-0sw	0.086	nw	3.21	1.86	0	0	0	0	0	0	0	0
	D	11D0	0.390	nw	14.55	11.15	0	0	0	0	0	0	0	0
	C	16B-30ad	0.032	-	1.19	1.67	264	264	315	441	124	124	148	206
	C	16B-7ad	0.112	-	4.18	5.84	0	0	0	0	0	0	0	0
	F	20P-30c	0.035	-	1.31	0.42	0	0	0	0	110	110	144	47
	F	22A-tpm	1.180	-	44.01	0.00	0	0	0	0	0	0	0	0
6	c) AED excursion									83				-54
	Envelope loss/gain								853	1153			990	881
12	a) Infiltration								373	156			489	204
	b) Room ventilation								0	0			0	0
13	Internal gains:		Occupants @	230			0			0	0			0
			Appliances/other							0				0
	Subtotal (lines 6 to 13)								1226	1309			1479	1085
	Less external load								0	0			0	0
	Less transfer								0	0			0	0
	Redistribution								223	184			150	102
14	Subtotal								1449	1493			1629	1187
15	Duct loads						-0%	0%	0	0	-0%	0%	0	0
	Total room load								1449	1493			1629	1187
	Air required (cfm)								69	88			77	70

Calculations approved by ACCA to meet all requirements of Manual J 8th Ed.

Right-J® Worksheet
Entire House
Wrightsoft Corp

Job:
Date: March 15, 2015
By:

131 Hartwell Ave, Lexington, MA 02421 Phone: 800-225-8697 Fax: 781-861-2058 Web: www.wrightsoft.com

1	Room name				BATH 2									
2	Exposed wall				5.5 ft									
3	Room height				8.0 ft heat/cool									
4	Room dimensions				5.5 x 11.0 ft									
5	Room area				60.5 ft²									
	Ty	Construction number	U-value (Btuh/ft²-°F)	Or	HTM (Btuh/ft²)		Area (ft²) or perimeter (ft)		Load (Btuh)		Area or perimeter		Load	
					Heat	Cool	Gross	N/P/S	Heat	Cool	Gross	N/P/S	Heat	Cool
6	W	12C-0sw	0.091	n	3.39	2.15	0	0	0	0				
.	└G	2 glazing, clr outr,	0.300	n	11.19	12.39	0	0	0	0				
.	W	12D-0sw	0.086	n	3.21	1.86	0	0	0	0				
.	├G	2 glazing, clr outr,	0.300	n	11.19	12.39	0	0	0	0				
11	└G	2 glazing, clr outr,	0.300	n	11.19	10.79	0	0	0	0				
	W	12C-0sw	0.091	ne	3.39	2.15	0	0	0	0				
	W	12C-0sw	0.091	e	3.39	2.15	0	0	0	0				
	W	12D-0sw	0.086	e	3.21	1.86	0	0	0	0				
	├G	2 glazing, clr outr,	0.300	e	11.19	36.05	0	0	0	0				
	└G	2 glazing, clr outr,	0.300	e	11.19	31.63	0	0	0	0				
	W	12D-0sw	0.086	se	3.21	1.86	0	0	0	0				
	W	12C-0sw	0.091	s	3.39	2.15	0	0	0	0				
	└D	11D0	0.390	s	14.55	11.15	0	0	0	0				
	W	12D-0sw	0.086	s	3.21	1.86	0	0	0	0				
	└G	2 glazing, clr outr,	0.300	s	11.19	15.97	0	0	0	0				
	W	12D-0sw	0.086	sw	3.21	1.86	0	0	0	0				
	└G	2 glazing, clr outr,	0.300	sw	11.19	30.53	0	0	0	0				
	W	12C-0sw	0.091	w	3.39	2.15	0	0	0	0				
	└G	2 glazing, clr outr,	0.300	w	11.19	36.05	0	0	0	0				
	W	12D-0sw	0.086	w	3.21	1.86	44	40	128	74				
	├G	2 glazing, clr outr,	0.300	w	11.19	36.05	0	0	0	0				
	└G	2 glazing, clr outr,	0.300	w	11.19	31.63	4	0	45	127				
	W	12D-0sw	0.086	nw	3.21	1.86	0	0	0	0				
	└D	11D0	0.390	nw	14.55	11.15	0	0	0	0				
	C	16B-30ad	0.032	-	1.19	1.67	61	61	72	101				
	C	16B-7ad	0.112	-	4.18	5.84	0	0	0	0				
	F	20P-30c	0.035	-	1.31	0.42	0	0	0	0				
	F	22A-tpm	1.180	-	44.01	0.00	0	0	0	0				
6	c) AED excursion									56				
	Envelope loss/gain								245	358				
12	a) Infiltration								121	50				
	b) Room ventilation								0	0				
13	Internal gains:		Occupants @		230		0			0				
			Appliances/other							0				
	Subtotal (lines 6 to 13)								366	408				
	Less external load								0	0				
	Less transfer								0	0				
	Redistribution								-366	-408				
14	Subtotal								0	0				
15	Duct loads						-0%	0%	0	0				
	Total room load								0	0				
	Air required (cfm)								0	0				

Calculations approved by ACCA to meet all requirements of Manual J 8th Ed.

Appendix B – Reference System Commissioning Reports

Grange Reference System Commissioning Report

Base Case Air Source Heat Pump Installation - at Grange

Site:	[redacted]
Commissioning Date	15-May-15
Installers	Mike MacFarland
	Brian Tyrrell

<u>Installed Equipment</u>

Outdoor Unit Make	[redacted]	
Outdoor Unit Model#	[redacted]	
Indoor Unit Make	[redacted]	
Indoor Unit Model#	[redacted]	
Refrigerant type	410A	
Quantity of refr in system	7 lbs 13.0 oz	lbs, oz

Comments:

1. The condensing unit came from the factory and had been used in testing.
2. The condensing unit was received with the service valves open (which alowed air and moisture into the
3. A new filter/dryer was installed at the indoor unit.

<u>Final Airflow Measurements</u>

Total airflow	608	cfm	Measured using:	True Flow
Indoor fan Watt draw	170	Watts	Measured using:	Extech 380940
Watt/cfm	0.28	W/cfm		
Cooling mode static pressure	0.41	" w.c.	Measured using:	DG-700

<u>Register Airflows</u>

Measured using: Flow Blaster

	Manual-J	Target	Final	Final air balance for even room temperatures	
			5/15/2015	6/30/2015	Deviation
Kitchen	155	209	182	187	89%
Hall	39	0			
Bath	0	0			
Great Room	155	209	174	166	79%
Bedroom 2	90	135	131	163	121%
Bedroom 1	86	131	119	168	128%
Total	525	684	606	684	

Comments:

1. The system had to be re-balanced to provide evan cooling room-to-room.

HP Operation Verification

Measurements taken after 10 minutes of cooling operation

Take all temperature and power readings within 60 seconds of each other

Outdoor temperature	89	Measured using:	Fluke 52-2
Supply air temperature	58.3	Measured using:	Fluke 52-2
Return air temperature	77.1	Measured using:	Fluke 52-2
Outdoor unit power	1,280	Measured using:	Extech 380940
Indoor unit power	170	Measured using:	Extech 380940
Subcooling	5.5	Measured using:	JB Digital Gauge Set
Superheat	5	Measured using:	JB Digital Gauge Set

Comments:

"By signing, I certify the above readings and attest that the installed unit has been properly installed and is operating as intended:"

Commissioning Agent 1	Mike MacFarland
Commissioning Agent 2	Rick Chitwood

Measurement Equipment Accuracy:	
Electronic Charging Scales, Accu-charge II	0.5% of reading +/- least significant digit
Air Flow Measurement, Energy Conservatory TrueFlow	+/- 7% when used with the DG-700 manometer
Watt Meter, Extech 380940	+/- 1.5% + 3 dgts (10 W resolution)
Manometer, Energy Conservatory DG-700	+/- 1% of reading or 2 times the resolution, whichever is greater
Capture Hood, Energy Conservatory FlowBlaster	+/- 5% of indicated flow or +/- 2 CFM
Digital Thermometer, Fluke 52-2	+/- 0.05% +0.3C
Digital Refrigeration Gauge Set, JB DM2-3	+/- 0.5% pressure, +/- 0.9F temperature

Mayfair Reference System Commissioning Report

Base Case Air Source Heat Pump Installation - at Mayfair

Site:	[redacted]
Commissioning Date	5/13/2015
Installers	Mike MacFarland
	Brian Tyrrell

Installed Equipment		
Outdoor Unit Make	[redacted]	
Outdoor Unit Model#	[redacted]	
Indoor Unit Make	[redacted]	
Indoor Unit Model#	[redacted]	
Refrigerant type	410A	
Quantity of refr in system	8 lbs 13.0 oz	lbs, oz

Comments:

1. The condensing unit came from the factory and had been used in testing.
2. The condensing unit was received with the service valves open (which alowed air and moisture into the
3. A new filter/dryer was installed at the indoor unit.

Final Airflow Measurements				
Total airflow	827	cfm	Measured using:	True Flow
Indoor fan Watt draw	240	Watts	Measured using:	Extech 380940
Watt/cfm	0.29	W/cfm		
Cooling mode static pressure	0.483	" w.c.	Measured using:	DG-700

Register Airflows

Measured using: Flow Blaster

	Manual-J	Target	Final 5/19/2015	Final air balance for even room temperatures 7/10/2015	Deviation
Kitchen	140	166	128	136	82%
Bath	24	0			
Bedroom 3	97	123	92	159	129%
Bedroom 2	100	127	145	150	118%
Bedroom 1	73	94	112	115	122%
Dining Room	0	160	173	129	81%
Great Room	266	160	182	135	84%
Total	700	830	832	824	

Comments:

1. The system had to be re-balanced on 7/10/2015 to provide evan cooling room-to-room.

HP Operation Verification	Measurements taken after 10 minutes of cooling operation Take all temperature and power readings within 60 seconds of each other		
Outdoor temperature	95	Measured using:	Fluke 52-2
Supply air temperature	57.5	Measured using:	Fluke 52-2
Return air temperature	73.7	Measured using:	Fluke 52-2
Outdoor unit power	1,580	Measured using:	Extech 380940
Indoor unit power	240	Measured using:	Extech 380940
Subcooling	7.3	Measured using:	JB Digital Gauge Set
Superheat	6	Measured using:	JB Digital Gauge Set

Comments: 1. Testing done on a 69F day. Condenser air flow restricted to simulate a 95F day.

"By signing, I certify the above readings and attest that the installed unit has been properly installed and is operating as intended:"

Commissioning Agent 1	Mike MacFarland
Commissioning Agent 2	Rick Chitwood

Measurement Equipment Accuracy:	
Electronic Charging Scales, Accu-charge II	0.5% of reading +/- least significant digit
Air Flow Measurement, Energy Conservatory TrueFlow	+/- 7% when used with the DG-700 manometer
Watt Meter, Extech 380940	+/- 1.5% + 3 dgts (10 W resolution)
Manometer, Energy Conservatory DG-700	+/- 1% of reading or 2 times the resolution, whichever is greater
Capture Hood, Energy Conservatory FlowBlaster	+/- 5% of indicated flow or +/- 2 CFM
Digital Thermometer, Fluke 52-2	+/- 0.05% +0.3C
Digital Refrigeration Gauge Set, JB DM2-3	+/- 0.5% pressure, +/- 0.9F temperature

Caleb Reference System Commissioning Report

Base Case Air Source Heat Pump Installation - at Caleb

Site:	Caleb
Commissioning Date	5/19/2015
Installers	Mike MacFarland
	Brian Tyrrell

<u>Installed Equipment</u>

Outdoor Unit Make		
Outdoor Unit Model#		
Indoor Unit Make		
Indoor Unit Model#		
Refrigerant type	410A	
Quantity of refr in system	9 lbs 5.75 oz	lbs, oz

Comments:

1. The condensing unit came from the factory and had been used in testing.
2. The condensing unit was received with the service valves open (which alowed air and moisture into th
3. A new filter/dryer was installed at the indoor unit.

<u>Final Airflow Measurements</u>

Total airflow	1,057	cfm	Measured using:	True Flow
Indoor fan Watt draw	410	Watts	Measured using:	Extech 380940
Watt/cfm	0.39	W/cfm		
Cooling mode static pressur	0.48	" w.c.	Measured using:	DG-700

<u>Register Airflows</u>

Measured using: Flow Blaster

	Manual-J	Target	Final 5/19/2015	Final air balance for even room temperatures 7/1/2015	Deviation
Bedroom 1	95	105	162	191	182%
Bedroom 2	86	97	157	184	190%
Bedroom 3	108	116	105	119	103%
Master Bedroom	135	204	498	388	190%
Master Bath	70	0	0	0	
Bonus	88	0	0	0	
Great Room	372	334	95	86	26%
Kitchen	172	214	70	61	29%
Powder Room	22	0	0	0	
Laundry	44	0	0	0	
Total	1,192	1,070	1,087	1,029	

Comments:

1. The Manual-J calculation assumed 10 supply grilles but there are only 6 installed.
2. The system had to be re-balanced on 7/1/2015 to provide evan cooling room-to-room.

HP Operation Verification

Measurements taken after 10 minutes of cooling operation
Take all temperature and power readings within 60 seconds of each other

Outdoor temperature	76	Measured using:	Fluke 52-2
Supply air temperature	62.6	Measured using:	Fluke 52-2
Return air temperature	79	Measured using:	Fluke 52-2
Outdoor unit power	2,070	Measured using:	Extech 380940
Indoor unit power	410	Measured using:	Extech 380940
Subcooling	6.5	Measured using:	JB Digital Gauge Set
Superheat	3.6	Measured using:	JB Digital Gauge Set

Comments:

"By signing, I certify the above readings and attest that the installed unit has been properly installed and is operating as intended:"

Commissioning Agent 1	Mike MacFarland
Commissioning Agent 2	Rick Chitwood

Measurement Equipment Accuracy:	
Electronic Charging Scales, Accu-charge II	0.5% of reading +/- least significant digit
Air Flow Measurement, Energy Conservatory TrueFlow	+/- 7% when used with the DG-700 manometer
Watt Meter, Extech 380940	+/- 1.5% + 3 dgts (10 W resolution)
Manometer, Energy Conservatory DG-700	+/- 1% of reading or 2 times the resolution, whichever is greater
Capture Hood, Energy Conservatory FlowBlaster	+/- 5% of indicated flow or +/- 2 CFM
Digital Thermometer, Fluke 52-2	+/- 0.05% +0.3C
Digital Refrigeration Gauge Set, JB DM2-3	+/- 0.5% pressure, +/- 0.9F temperature

Appendix C – VCHSP System Inspection Reports

Grange VCHP System Inspection Report

AHRI Mini-split Committee Proposed Installation Inspection Checklist

INSTALLATION DATA

Site Address: [redacted] Grange Avenue

Stockton

State: CA **Zip/Postal Code:** 95204 **Country:** USA

Installing Contractor: Energy Docs **Telephone:** 530-945-7401

System Reference: [redacted] **AHRI Certified Reference No.:** [redacted]

Rated Capacity (Cooling/Heating): 11,000 / 12,000

Location: Back Patio **Rated SEER/HSPF:** SEER 25.5 / HSPF 12.0

Equipment Purchased from: [redacted]

COMMENTS AND POINTS FOR ATTENTION

This site has an air transfer fan to move air from the living room, where the mini-split head is located, to the two bedrooms. A Panasonic bathroom exhaust fan, FV-11-15VK1, was installed and programmed to deliver 75 CFM to each of the two bedrooms, using only 9 Watts total (the low Watt draw is due to exceptional installation quality; oversized, well supported, and straight - ducting). The fan is operated 24 hours a day when the mini-split is cooling or heating the home.

HERS Inspector's Name: Allen Amaro, CC2005672

HERS Inspector's Signature:

Date: 10/27/2015

SYSTEM				
NO.	**SYSTEM AND INSTALLATION STATUS**			**REMARKS**
1	Installation Location	Outdoor Unit	☐ Rooftop XX Other Location (Back Patio)	
2	Installation Parameters within Manufacturer's Clearances	Outdoor Unit Indoor Units	XX Acceptable ☐ Not Acceptable XX Acceptable ☐ Not Acceptable	
3	Total System Piping[1]		Outdoor to Indoors: 17 Ft.	
4	Furthest Piping Length (Multi-splits only)		Outdoor to Indoor: N/A Ft.	
5	Height Difference (Multi-splits only)		Outdoor to Indoor: +6 Ft. Indoor to Indoor: N/A Ft.	
6	Standard of Pipe-work[2]		XX Acceptable ☐ Not Acceptable	
7	Standard of Pipe Insulation[2]		XX Acceptable ☐ Not Acceptable	
8	Liquid Line Insulated (if required)		XX Yes ☐ No	
9	Control Method		XX Wired ☐ Wireless	
10	Remote Controller Operation		XX Acceptable ☐ Not Acceptable	

OUTDOOR UNIT			Location	Back Patio		
NO.	**OUTDOOR UNIT OPERATION STATUS**					**REMARKS**
11	Outdoor Unit Details	Model No: [redacted]		Serial No: [redacted]		
12	Power Source (Voltage)	L1 - N 121 V	L2 - N 122 V	L3 - N N/A V	Gnd – N 0 V	
13	Vibration / Noise[2]	Compressor Fan	XX Acceptable ☐ Not Acceptable XX Acceptable ☐ Not Acceptable			
14	Additional Refrigerant Charge (if applicable)			None Oz.		
15	Outdoor Unit Refrigerant Charge from Factory			40.6 Oz.		
16	Maximum Line Length (without adding refrigerant charge)			41 feet		

Refrigerant Charge Calculation:

No lineset length adjustment required

Factory Charge 2 Lbs. 8.6 Oz.
Recovered 2 Lbs. 7.5 Oz.
Installed 2 Lbs. 8.5 Oz. (scale reads in half ounce increments)

REMARKS:

Outdoor Temperature 71 °F

DUCTLESS INDOOR UNIT # : 1		Distance/Elevation from Outdoor Unit: 17'/ +6'				
Location	Living Room					REMARKS
Model No.	[redacted]	Serial No.:	[redacted]			
Voltage	Line Voltage	242 V				
Inlet Temperature	Cooling:	73 DB°F	Heating:	79 DB°F		
Outlet Temperature	Cooling:	48 DB°F	Heating:	99 DB°F		

MAYFAIR VCHP SYSTEM INSPECTION REPORT

AHRI Mini-split Committee Proposed Installation Inspection Checklist

INSTALLATION DATA

Site Address: [redacted]West Mayfair
Stockton

State: CA **Zip/Postal Code:** 95207 **Country:** USA

Installing Contractor: Queirolo's Heating & Air Conditioning **Telephone:** 209-464-9658

System Reference: [redacted] **AHRI Certified Reference No.:** [redacted]

Rated Capacity (Cooling/Heating): 11,500 / 13,600

Location: Back Yard **Rated SEER/HSPF:** SEER 16.00 / HSPF 10.0

Equipment Purchased from: Provided by [redacted]

COMMENTS AND POINTS FOR ATTENTION

This is a ducted mini-split with the air handler and ducts located in a sealed, and exhaust ventilated, crawlspace.

The California Energy Code requires additional acceptance testing. CF-3R forms with test results are attached.

HERS Inspector's Name: Allen Amaro, CC2005672

HERS Inspector's Signature:

Date: 11/3/2015

SYSTEM				
NO.	**SYSTEM AND INSTALLATION STATUS**			**REMARKS**
1	Installation Location	Outdoor Unit	☐ Rooftop XX Other Location (Back Wall)	
2	Installation Parameters within Manufacturer's Clearances	Outdoor Unit Indoor Units	XX Acceptable ☐ Not Acceptable XX Acceptable ☐ Not Acceptable	
3	Total System Piping[1]		Outdoor to Indoors: 22.2 Ft.	
4	Furthest Piping Length (Multi-splits only)		Outdoor to Indoor: N/A Ft.	
5	Height Difference (Multi-splits only)		Outdoor to Indoor: -2.0 Ft. Indoor to Indoor: N/A Ft.	
6	Standard of Pipe-work[2]		XX Acceptable ☐ Not Acceptable	
7	Standard of Pipe Insulation[2]		XX Acceptable ☐ Not Acceptable	
8	Liquid Line Insulated (if required)		XX Yes ☐ No	
9	Control Method		☐ Wired XX Wireless	
10	Remote Controller Operation		XX Acceptable ☐ Not Acceptable	

OUTDOOR UNIT			Location	Wall mount on back wall of house	
NO.	**OUTDOOR UNIT OPERATION STATUS**				**REMARKS**
11	Outdoor Unit Details	Model No: [redacted]		Serial No: [redacted]	
12	Power Source (Voltage)	L1 - N 120 V	L2 - N 120 V	L3 - N N/A V Gnd – N 0 V	
13	Vibration / Noise[2]	Compressor Fan	XX Acceptable ☐ Not Acceptable XX Acceptable ☐ Not Acceptable		
14	Additional Refrigerant Charge (if applicable)			None Oz.	
15	Outdoor Unit Refrigerant Charge from Factory			41.0 Oz.	
16	Maximum Line Length (without adding refrigerant charge)			25 feet	

Refrigerant Charge Calculation:

No lineset length adjustment required

Factory Charge	2 Lbs. 9.0 Oz.
Recovered	2 Lbs. 2.5 Oz. (no purge function on the recovery pump)
Installed	2 Lbs. 9.0 Oz.

REMARKS:

Outdoor Temperature 64 °F

DUCTED INDOOR UNIT[3] # : 1		Airflow (cfm) : 421		Distance/Elevation from Outdoor Unit: 22.2 / -2		
Location	Crawlspace					REMARKS
Model No.	[redacted]	Serial No.:		[redacted]		
Voltage	Line Voltage	241 V				
Inlet Temperature[4]	Cooling:	74 DB°F	Heating:	69 DB°F		
Outlet Temperature[4]	Cooling:	50 DB°F	Heating:	95 DB°F		

Caleb First Floor VCHP System Inspection Report

AHRI Mini-split Committee Proposed Installation Inspection Checklist

INSTALLATION DATA

Site Address: [redacted]aleb Circle
Stockton

State: CA **Zip/Postal Code:** 95210 **Country:** USA

Installing Contractor: Energy Docs **Telephone:** 530-945-7401

System Reference: [redacted] **AHRI Certified Reference No.:** [redacted]

Rated Capacity (Cooling/Heating): 12,000 / 14,400

Location: Side Yard **Rated SEER/HSPF:** SEER 23.0 / HSPF 12.5

Equipment Purchased from: [redacted]

COMMENTS AND POINTS FOR ATTENTION

HERS Inspector's Name: Allen Amaro, CC2005672

HERS Inspector's Signature:

Date: 11/12/2015

SYSTEM				
NO.	SYSTEM AND INSTALLATION STATUS			REMARKS
1	Installation Location	Outdoor Unit	☐ Rooftop XX Other Location (Side Yard)	
2	Installation Parameters within Manufacturer's Clearances	Outdoor Unit Indoor Units	XX Acceptable ☐ Not Acceptable XX Acceptable ☐ Not Acceptable	
3	Total System Piping[1]		Outdoor to Indoors: 30 Ft.	
4	Furthest Piping Length (Multi-splits only)		Outdoor to Indoor: N/A Ft.	
5	Height Difference (Multi-splits only)		Outdoor to Indoor: +6 Ft. Indoor to Indoor: N/A Ft.	
6	Standard of Pipe-work[2]		XX Acceptable ☐ Not Acceptable	
7	Standard of Pipe Insulation[2]		XX Acceptable ☐ Not Acceptable	
8	Liquid Line Insulated (if required)		XX Yes ☐ No	
9	Control Method		XX Wired ☐ Wireless	
10	Remote Controller Operation		XX Acceptable ☐ Not Acceptable	

OUTDOOR UNIT			Location	Side Yard		
NO.	OUTDOOR UNIT OPERATION STATUS					REMARKS
11	Outdoor Unit Details	Model No: [redacted]		Serial No: [redacted]		
12	Power Source (Voltage)	L1 - N 123 V	L2 - N 123 V	L3 - N N/A V	Gnd – N 0 V	
13	Vibration / Noise[2]	Compressor Fan	XX Acceptable ☐ Not Acceptable XX Acceptable ☐ Not Acceptable			
14	Additional Refrigerant Charge (if applicable)			None Oz.		
15	Outdoor Unit Refrigerant Charge from Factory			42.4 Oz.		
16	Maximum Line Length (without adding refrigerant charge)			98.4 feet		

Refrigerant Charge Calculation:
No lineset length adjustment required

Factory Charge	2.65 Lbs.
Recovered	2.50 Lbs.
Installed	2.65 Lbs.

Outdoor Temperature 63 °F

DUCTLESS INDOOR UNIT # : 1		Distance/Elevation from Outdoor Unit: 30'/ +6'			
Location	Dining Room				REMARKS
Model No.	[redacted]	Serial No.: [redacted]			
Voltage	Line Voltage 247 V				
Inlet Temperature	Cooling:	64.9 DB°F	Heating:	73.0 DB°F	
Outlet Temperature	Cooling:	48.5 DB°F	Heating:	103.4 DB°F	

CALEB SECOND FLOOR VCHP SYSTEM INSPECTION REPORT

AHRI Mini-split Committee Proposed Installation Inspection Checklist

INSTALLATION DATA

Site Address: [redacted] Caleb Circle
Stockton

State: CA **Zip/Postal Code:** 95210 **Country:** USA

Installing Contractor: Energy Docs **Telephone:** 530-945-7401

System Reference: [redacted] **AHRI Certified Reference No.:** [redacted]

Rated Capacity (Cooling/Heating): 18,000 / 22,000

Location: Side Yard **Rated SEER/HSPF:** SEER 19.5 / HSPF 9.2

Equipment Purchased from: [redacted]

COMMENTS AND POINTS FOR ATTENTION

This site has two air transfer fans to move air from the second floor bonus room/landing area, where one of the multi-split heads is located, to the three second floor bedrooms. A Panasonic bathroom exhaust fan, FV-11-15VK1, was installed and programmed to deliver 75 CFM to two of the bedrooms (bedroom 2 and bedroom 3). A second Panasonic bathroom exhaust fan, FV-05-11VK1, was installed and programmed to deliver 75 CFM to the southwest bedroom (bedroom 1). The total watt draw for the two air transfer fans is 10 Watts (the low Watt draw is due to exceptional installation quality; oversized, well supported, and straight - ducting). The fan is operated 24 hours a day when the m-splits are cooling or heating the home.

HERS Inspector's Name: Allen Amaro, CC2005672

HERS Inspector's Signature:

Date: 11/12/2015

SYSTEM				
NO.	**SYSTEM AND INSTALLATION STATUS**			**REMARKS**
1	Installation Location	Outdoor Unit	☐ Rooftop XX Other Location (Side Yard)	
2	Installation Parameters within Manufacturer's Clearances	Outdoor Unit Indoor Units	XX Acceptable ☐ Not Acceptable XX Acceptable ☐ Not Acceptable	
3	Total System Piping[1]		Outdoor to Indoors: 113.5 Ft.	
4	Furthest Piping Length (Multi-splits only)		Outdoor to Indoor: 68.0 Ft.	
5	Height Difference (Multi-splits only)		Outdoor to Indoor: +17.5 Ft. Indoor to Indoor: 1.0 Ft.	
6	Standard of Pipe-work[2]		XX Acceptable ☐ Not Acceptable	
7	Standard of Pipe Insulation[2]		XX Acceptable ☐ Not Acceptable	
8	Liquid Line Insulated (if required)		XX Yes ☐ No	
9	Control Method		XX Wired ☐ Wireless	
10	Remote Controller Operation		XX Acceptable ☐ Not Acceptable	

OUTDOOR UNIT		Location	Side Yard			
NO.	**OUTDOOR UNIT OPERATION STATUS**					**REMARKS**
11	Outdoor Unit Details	Model No: [redacted]		Serial No: [redacted]		
12	Power Source (Voltage)	L1 - N 123 V	L2 - N 123 V	L3 - N N/A V	Gnd – N 0 V	
13	Vibration / Noise[2]	Compressor Fan	XX Acceptable ☐ Not Acceptable XX Acceptable ☐ Not Acceptable			
14	Additional Refrigerant Charge (if applicable)			3.3 Oz.		
15	Outdoor Unit Refrigerant Charge from Factory			91.7 Oz.		
16	Maximum Line Length (without adding refrigerant charge)			98.4 feet		

Refrigerant Charge Calculation:

68 feet + 45.5 feet = 113.5 feet (total line set length) 113.5 feet – 98.4 feet = 15.1 feet (extra length)
15.1 feet x 0.22 Oz./Ft = 3.3 Oz. (additional refrigerant charge, 3.3 Oz. = 0.21 Lbs.)

Factory Charge 5.73 Lbs. + 0.21 Lbs. = 5.94
Recovered 5.41 Lbs.
Installed 5.94 Lbs.

Outdoor Temperature 63 °F

DUCTLESS INDOOR UNIT # : 1		Distance/Elevation from Outdoor Unit: 45.5'/ +16.5'			
Location	Second Floor Bonus Room/Landing				REMARKS
Model No.	[redacted]	Serial No.:	[redacted]		
Voltage	Line Voltage 247 V				
Inlet Temperature	Cooling:	65.9 DB°F	Heating:	77.2 DB°F	
Outlet Temperature	Cooling:	48.9 DB°F	Heating:	110.9 DB°F	

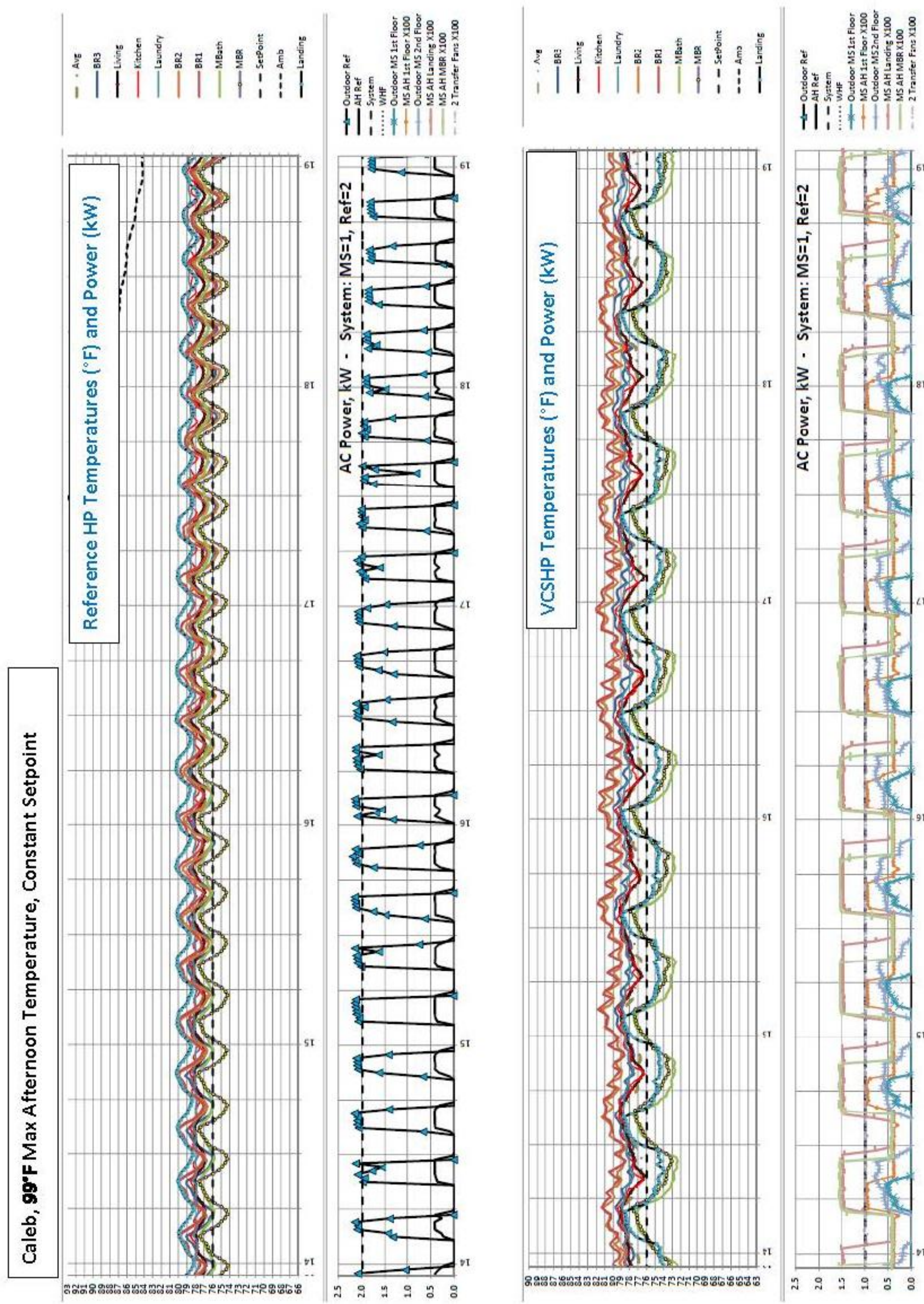
DUCTLESS INDOOR UNIT # : 2		Distance/Elevation from Outdoor Unit: 68.0' / +17.5'			
Location	Second Floor Master Bedroom				REMARKS
Model No.	[redacted]	Serial No.:	[redacted]		
Voltage	Line Voltage 247 V				
Inlet Temperature	Cooling:	66.3 DB°F	Heating:	71.8 DB°F	
Outlet Temperature	Cooling:	48.1 DB°F	Heating:	107.1 DB°F	

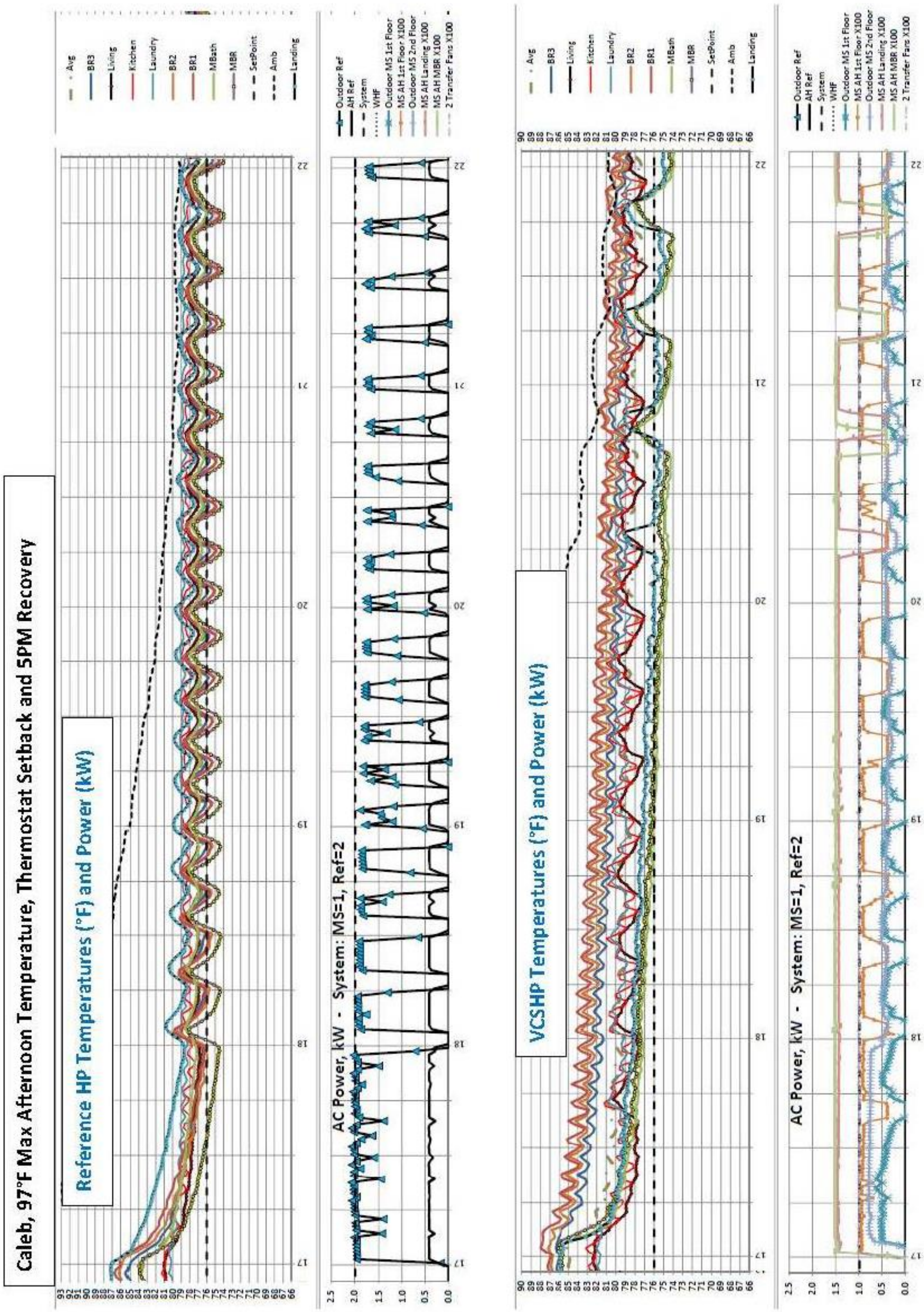
APPENDIX D – TIME-SERIES CHARTS

- Caleb – 99°F Max Afternoon Temperature, Constant Thermostat Setpoint
- Caleb – 97°F Max Afternoon Temperature, Thermostat Setback and 5pm Recovery
- Grange – 99°F Max Afternoon Temperature, Constant Thermostat Setpoint
- Grange – 97°F Max Afternoon Temperature, Thermostat Setback and 5pm Recovery
- Mayfair – 99°F Max Afternoon Temperature, Constant Thermostat Setpoint
- Mayfair – 97°F Max Afternoon Temperature, Thermostat Setback and 5pm Recovery

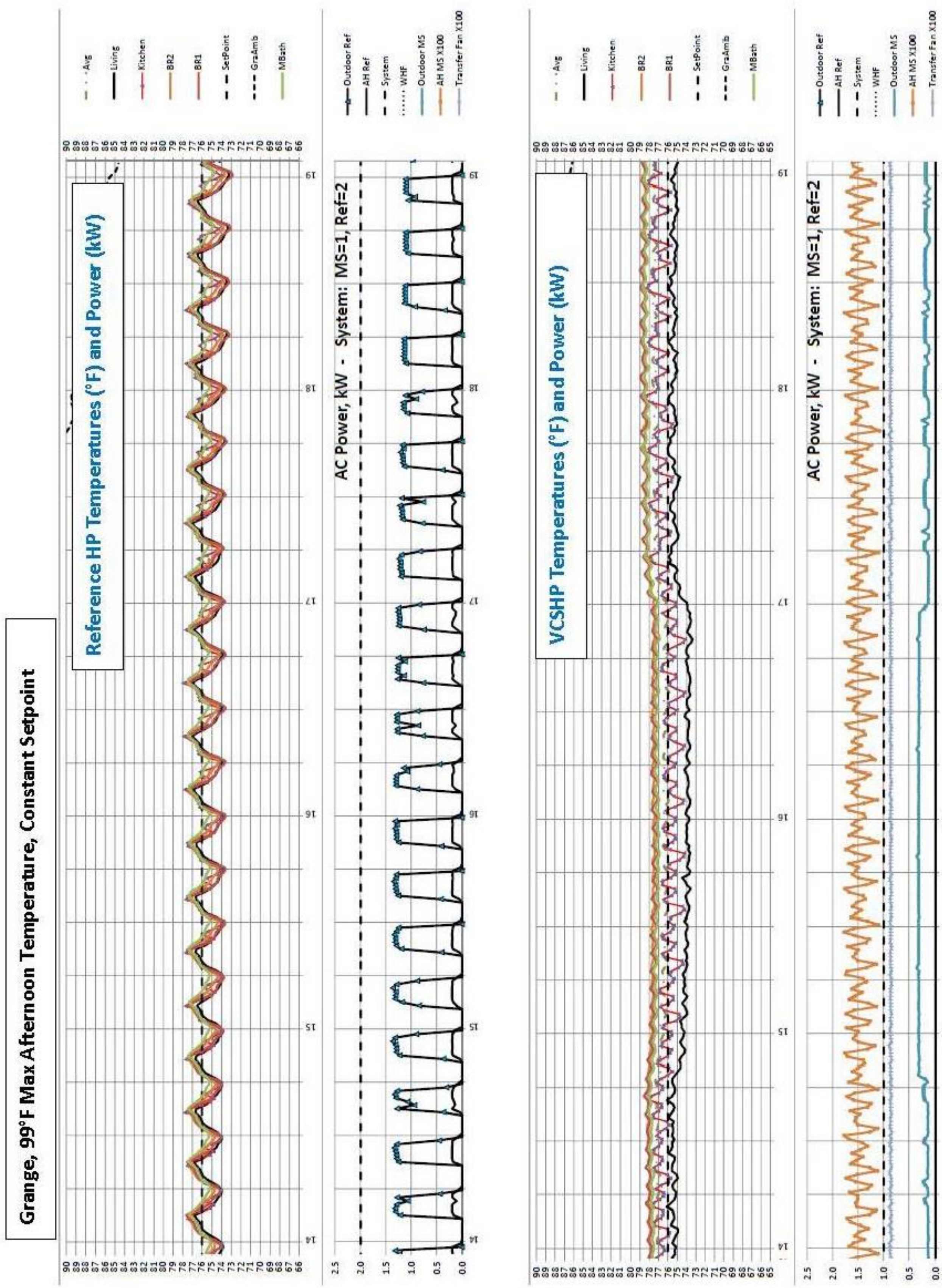
Each of the following charts includes a snapshot of measured data for one afternoon. Each chart includes four parts

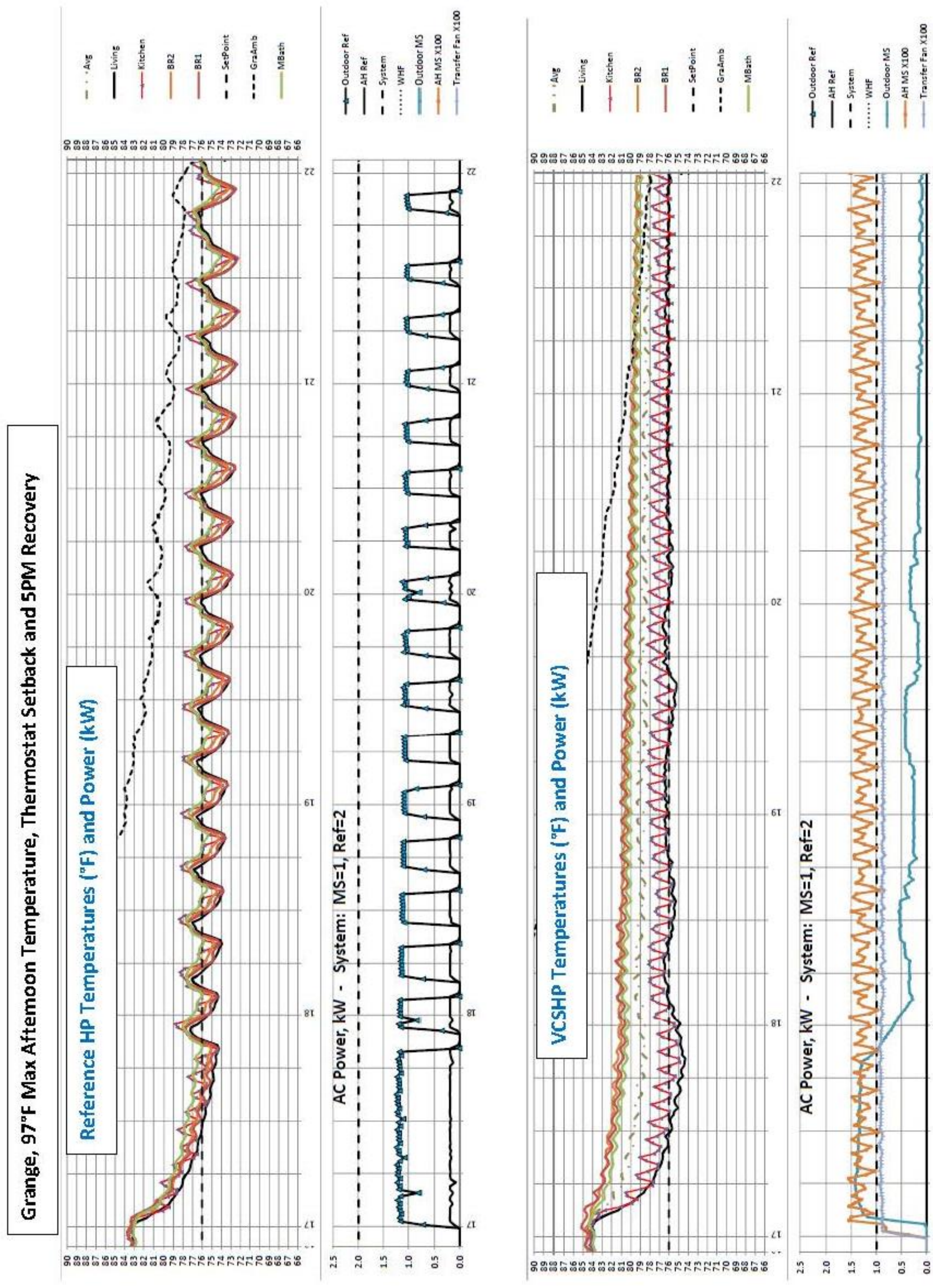
1. Reference system – indoor temperatures in each room
2. Reference system – power for outdoor and indoor units
3. VCHP system – indoor temperatures for each room
4. VCHP system – power for outdoor and indoor units

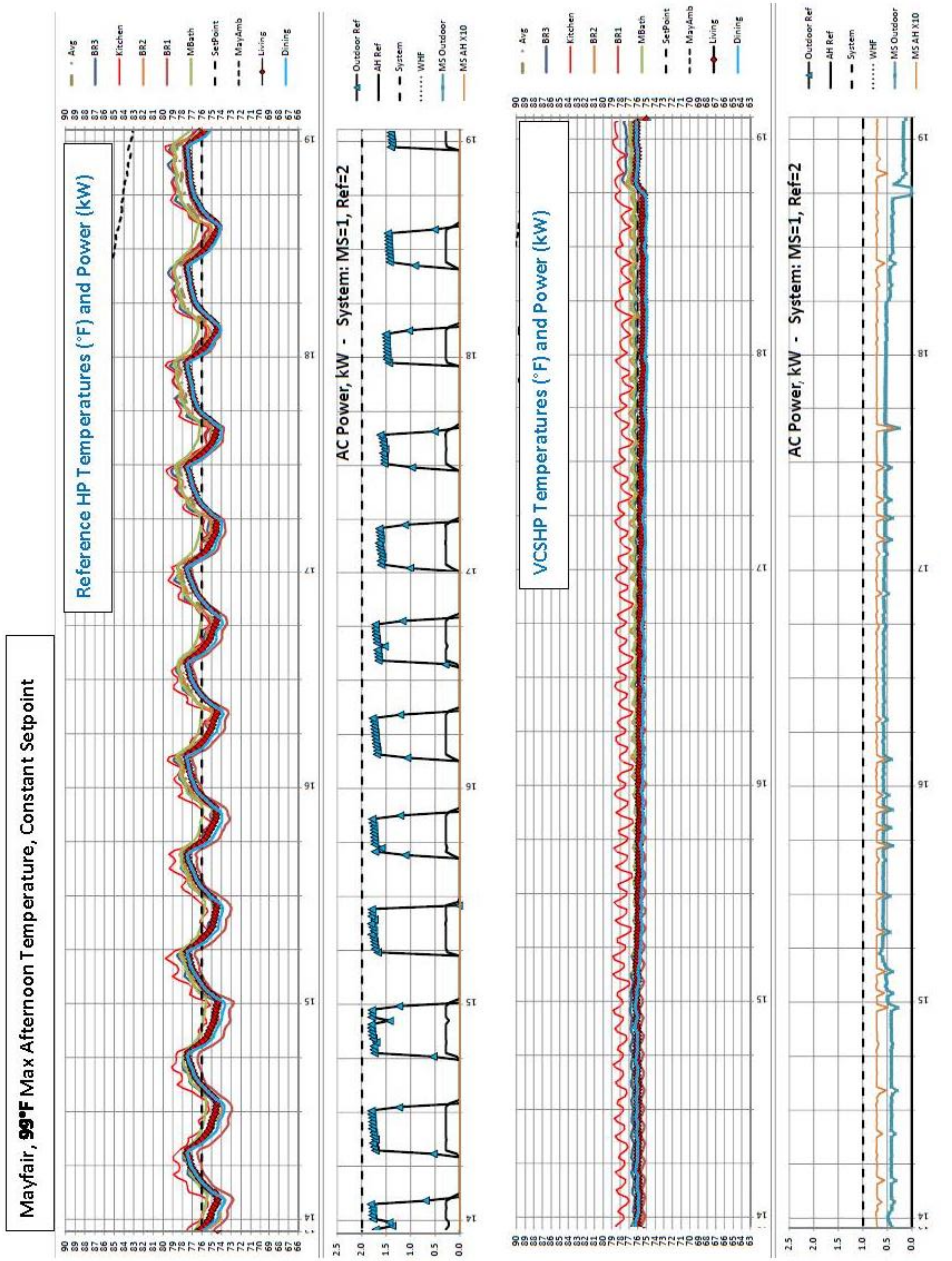

Caleb, 99°F Max Afternoon Temperature, Constant Setpoint
Reference HP Temperatures (°F) and Power (kW)
AC Power, kW - System: MS=1, Ref=2
VCSHP Temperatures (°F) and Power (kW)
AC Power, kW - System: MS=1, Ref=2
Avg
BR3
Living
Kitchen
Laundry
BR2
BR1
MBath
MBR
SetPoint
Amb
Landing
Outdoor Ref
AH Ref
System
WHF
Outdoor MS 1st Floor
MS AH 1st Floor X100
Outdoor MS 2nd Floor
MS AH Landing X100
MS AH MBR X100
2 Transfer Fans X100

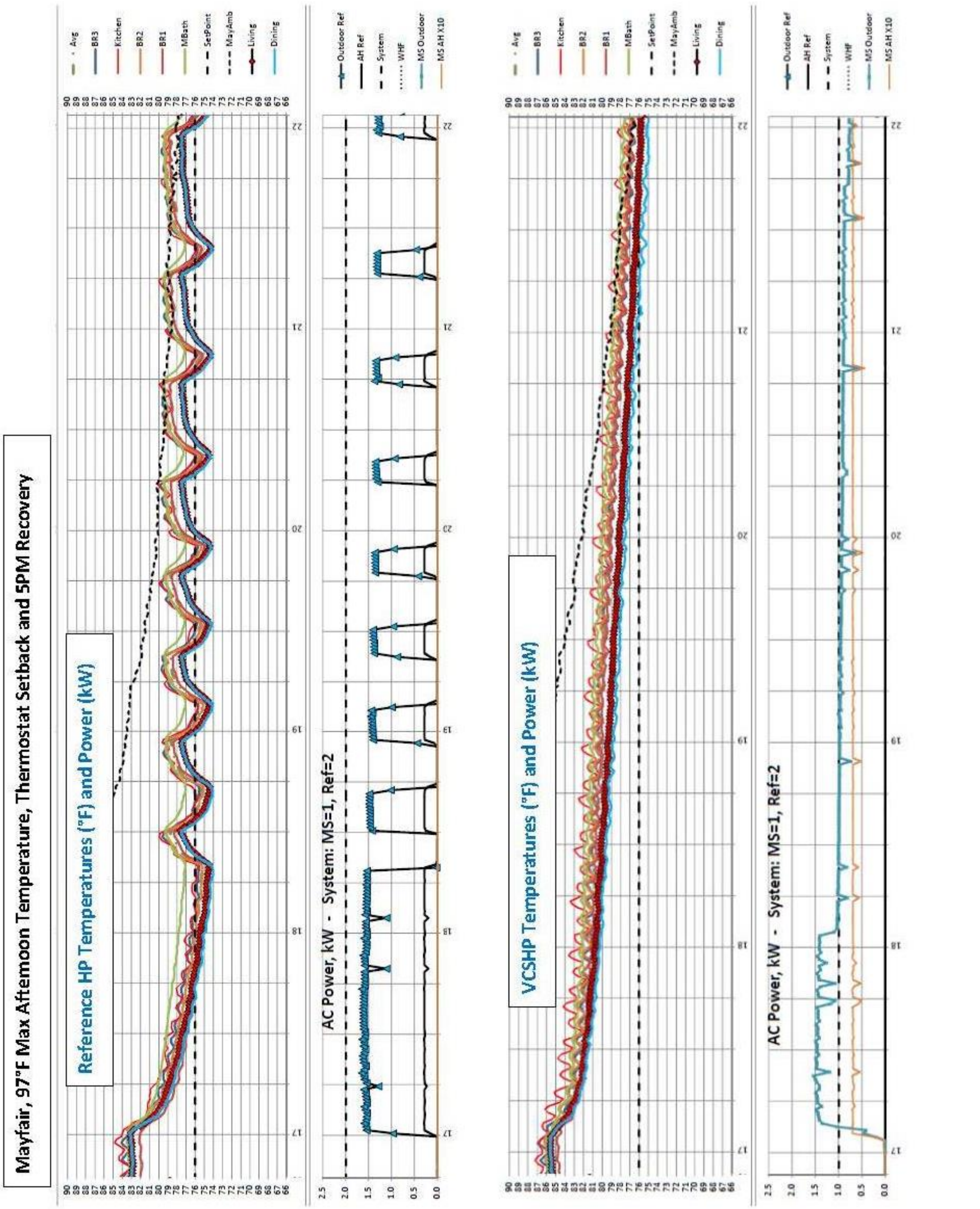


Caleb, 97°F Max Afternoon Temperature, Thermostat Setback and 5PM Recovery
Reference HP Temperatures (°F) and Power (kW)
Avg
BR3
Living
Kitchen
Laundry
BR2
BR1
MBath
MBR
SetPoint
Amb
Landing
AC Power, kW - System: MS=1, Ref=2
Outdoor Ref
AH Ref
System
WHF
Outdoor MS 1st Floor
MS AH 1st Floor X100
Outdoor MS 2nd Floor
MS AH Landing X100
MS AH MBR X100
2 Transfer Fans X100
VCSHP Temperatures (°F) and Power (kW)
AC Power, kW - System: MS=1, Ref=2


Grange, 99°F Max Afternoon Temperature, Constant Setpoint
Reference HP Temperatures (°F) and Power (kW)
AC Power, kW - System: MS=1, Ref=2
VCSHP Temperatures (°F) and Power (kW)
AC Power, kW - System: MS=1, Ref=2
Avg
Living
Kitchen
BR2
BR1
SetPoint
GrzAmb
MBath
Outdoor Ref
AH Ref
System
WHF
Outdoor MS
AH MS X100
Transfer Fan X100


Grange, 97°F Max Afternoon Temperature, Thermostat Setback and 5PM Recovery
Reference HP Temperatures (°F) and Power (kW)
Avg
Living
Kitchen
BR2
BR1
SetPoint
GraAmb
MBath
AC Power, kW - System: MS=1, Ref=2
Outdoor Ref
AH Ref
System
WHF
Outdoor MS
AH MS X100
Transfer Fan X100
VCSHP Temperatures (°F) and Power (kW)
AC Power, kW - System: MS=1, Ref=2


Mayfair, 99°F Max Afternoon Temperature, Constant Setpoint
Reference HP Temperatures (°F) and Power (kW)
Avg
BR3
Kitchen
BR2
BR1
MBath
SetPoint
MayAmb
Living
Dining
AC Power, kW - System: MS=1, Ref=2
Outdoor Ref
AH Ref
System
WHF
MS Outdoor
MS AH X10
VCSHP Temperatures (°F) and Power (kW)
AC Power, kW - System: MS=1, Ref=2



Mayfair, 97°F Max Afternoon Temperature, Thermostat Setback and 5PM Recovery
Reference HP Temperatures (°F) and Power (kW)
AC Power, kW - System: MS=1, Ref=2
VCSHP Temperatures (°F) and Power (kW)
AC Power, kW - System: MS=1, Ref=2
Avg
BR3
Kitchen
BR2
BR1
MBath
SetPoint
MayAmb
Living
Dining
Outdoor Ref
AH Ref
System
WHF
MS Outdoor
MS AH X10

APPENDIX E –INPUT POWER VS. OUTDOOR TEMPERATURE

The following plots show input power vs. outdoor temperature for the heat pump systems in heating and cooling modes. The plotted values are one minute data points during times when the compressor was operating. For the VCHP systems, this includes times when the system is running at low speeds during ramping at the beginning or end of cycles. Total heat pump system input power is plotted. Transfer fan power is not included.

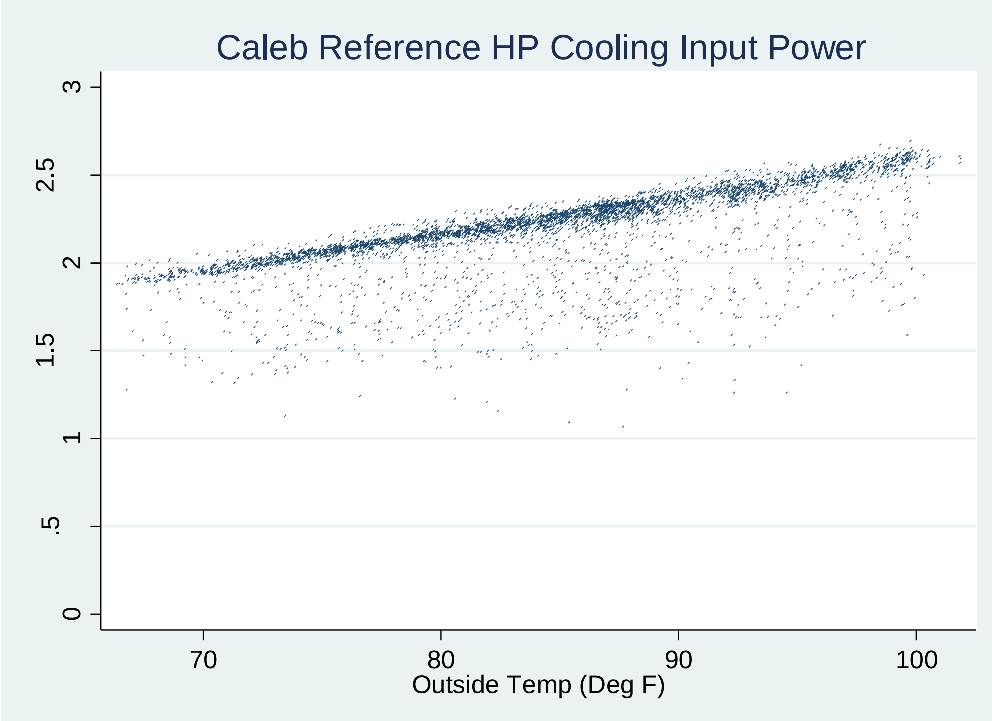


FIGURE 43. CALEB REFERENCE HEAT PUMP IN COOLING MODE

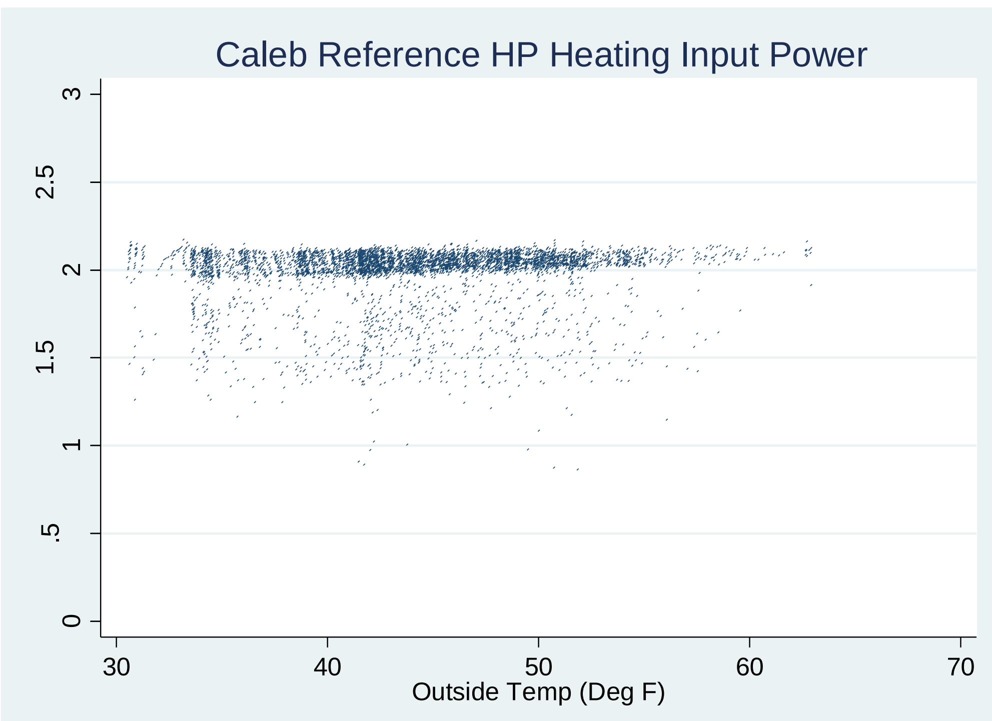


FIGURE 44. CALEB REFERENCE HEAT PUMP IN HEATING MODE

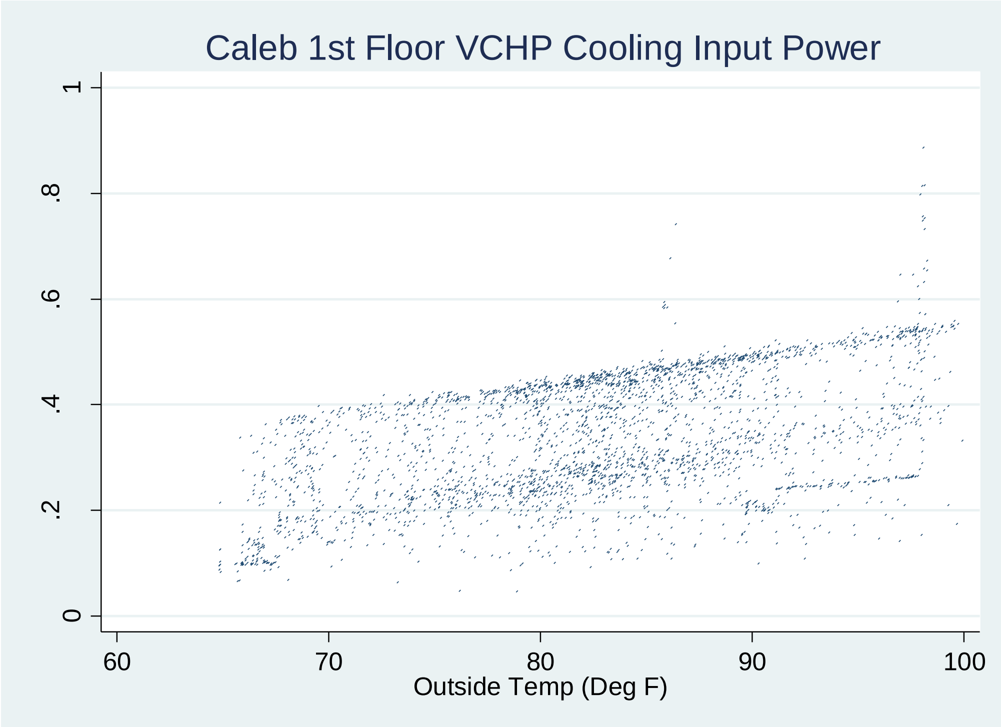


FIGURE 45. CALEB 1ST FLOOR VCHP SYSTEM IN COOLING MODE

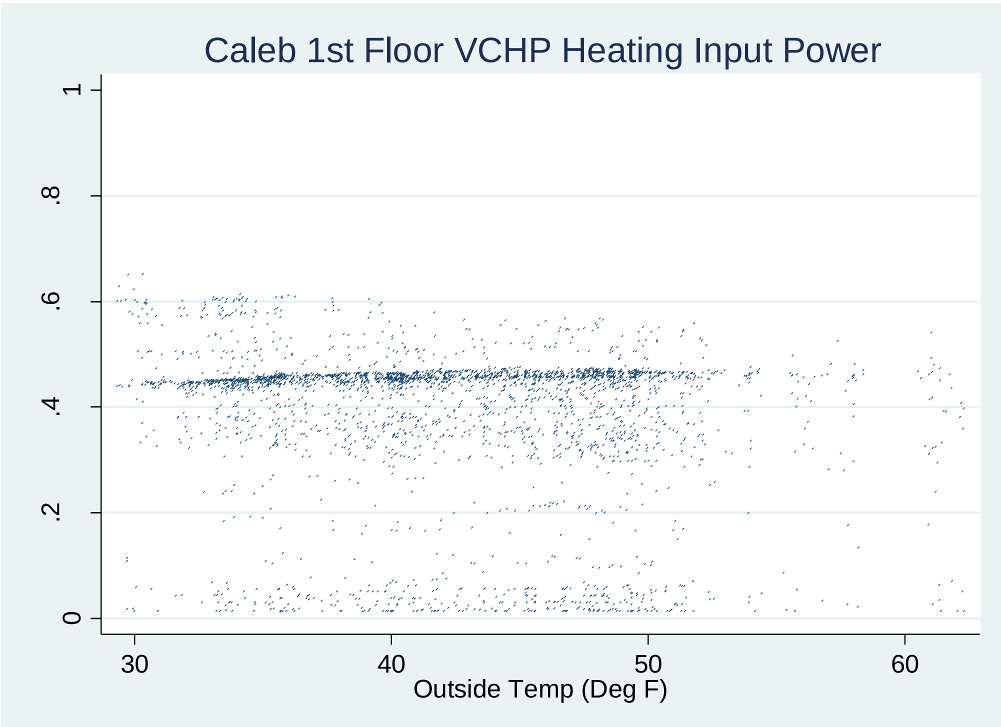


FIGURE 46. CALEB 1ST FLOOR VCHP IN HEATING MODE

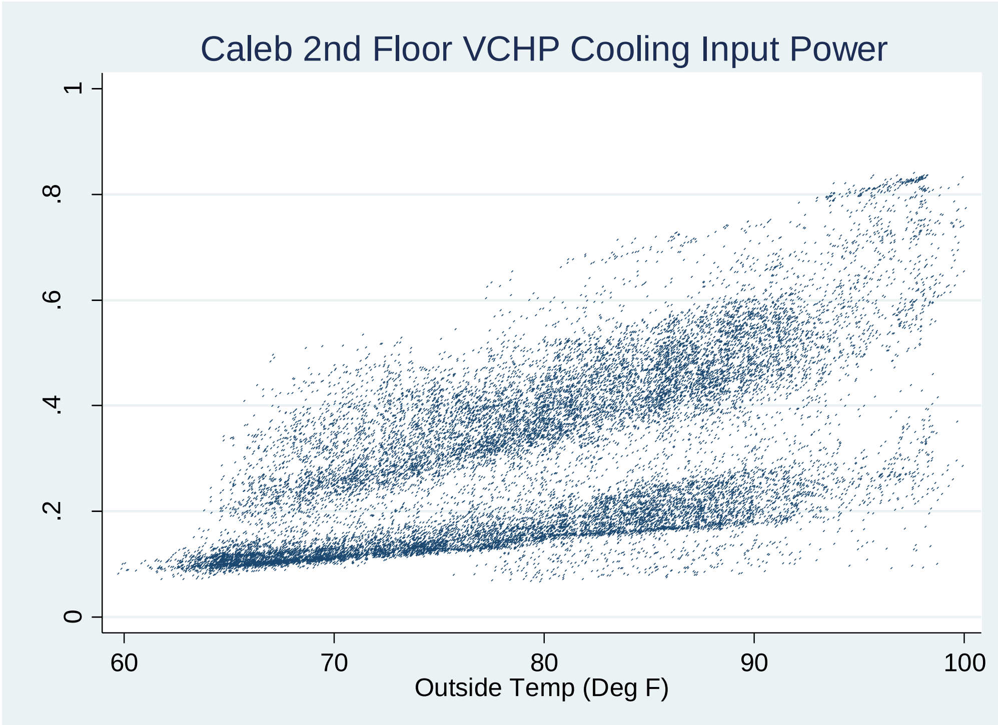


FIGURE 47. CALEB 2ND FLOOR VCHP SYSTEM IN COOLING MODE

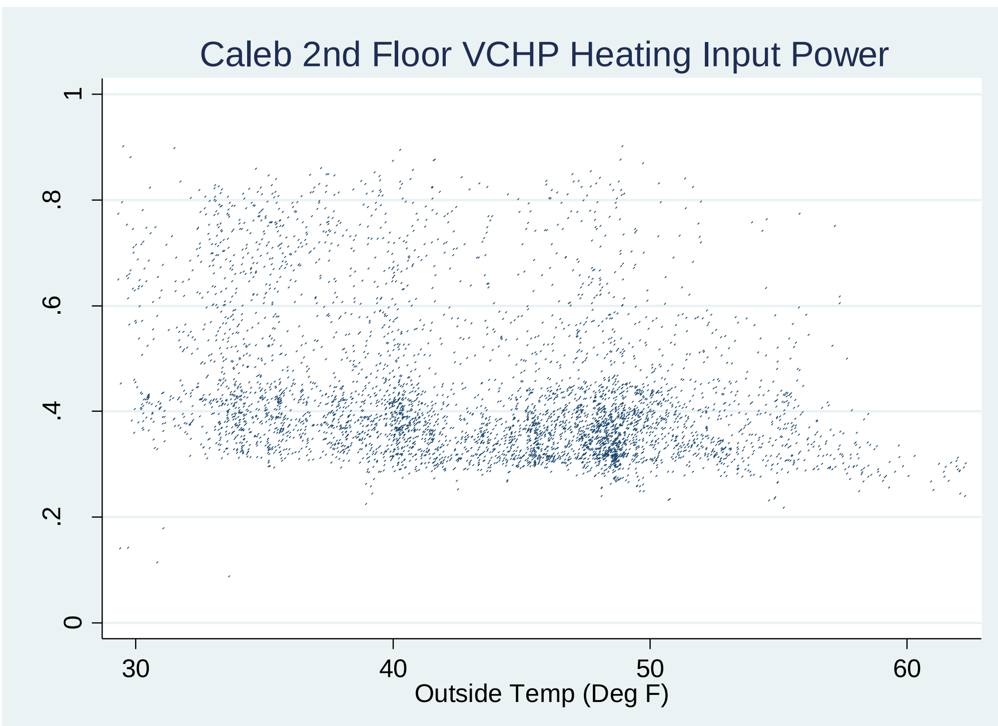


FIGURE 48. CALEB 2ND FLOOR VCHP IN HEATING MODE

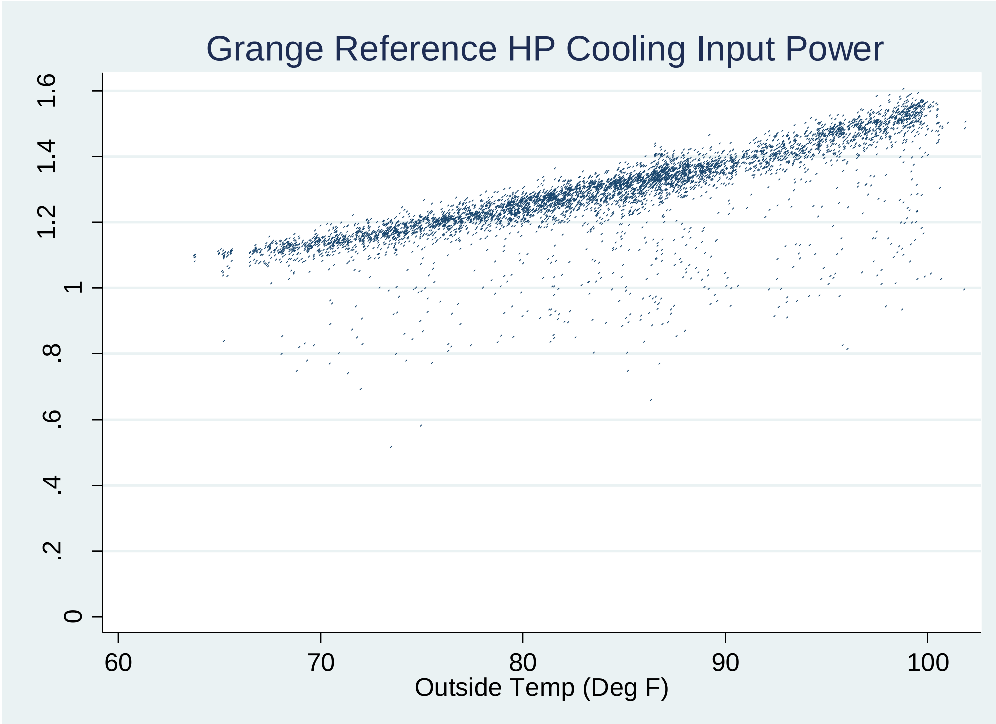


FIGURE 49. GRANGE REFERENCE HEAT PUMP IN COOLING MODE

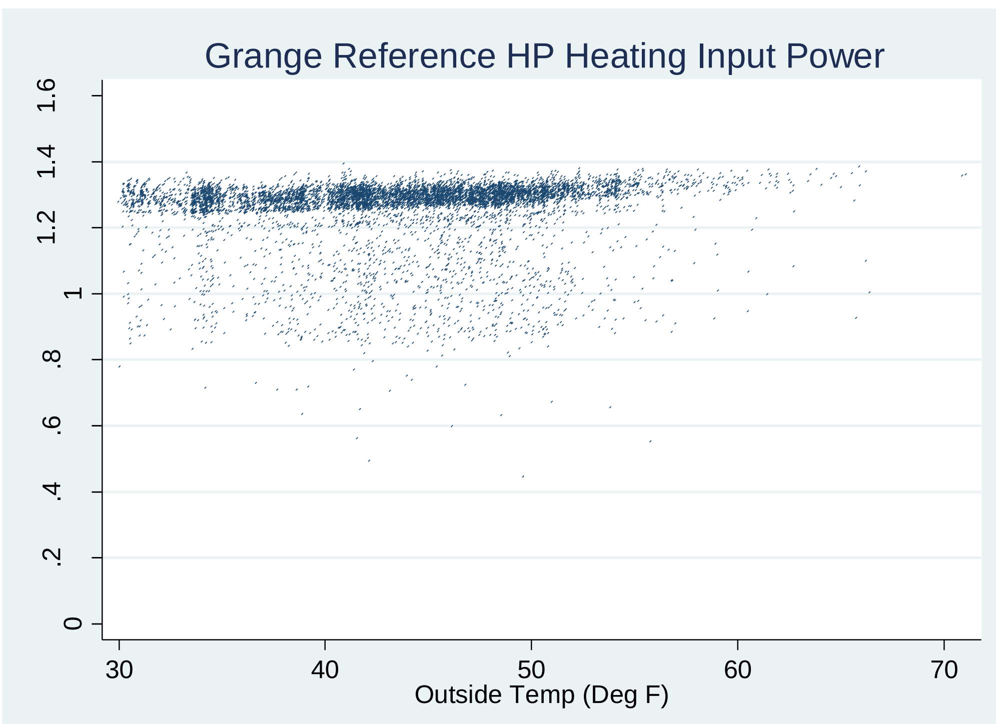


FIGURE 50. GRANGE REFERENCE HEAT PUMP IN HEATING MODE

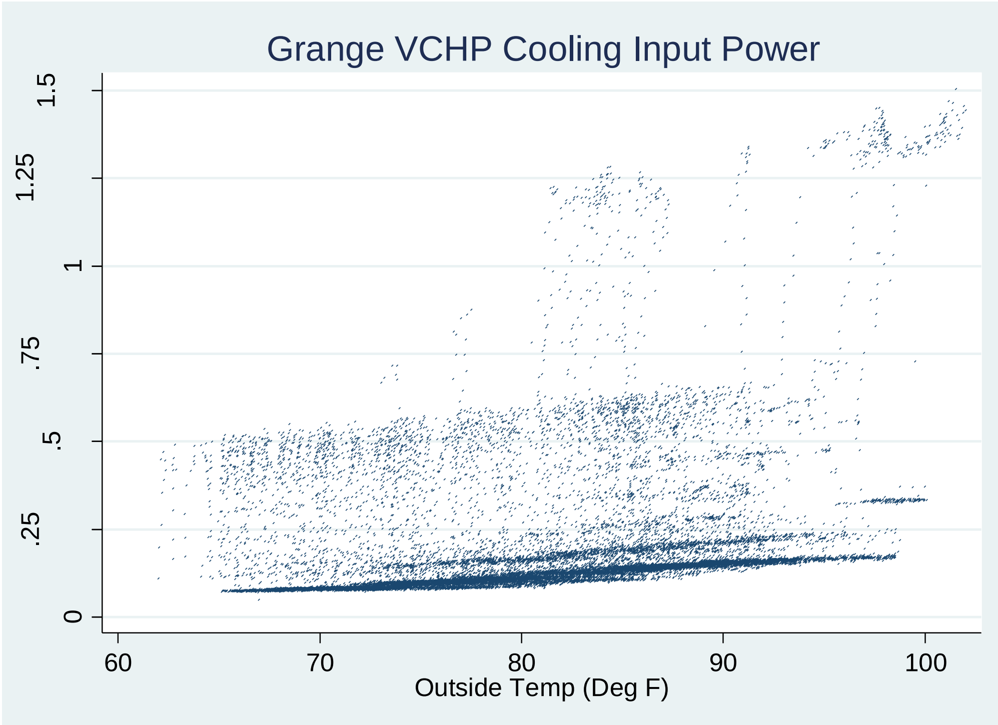


FIGURE 51. GRANGE VCHP IN COOLING MODE

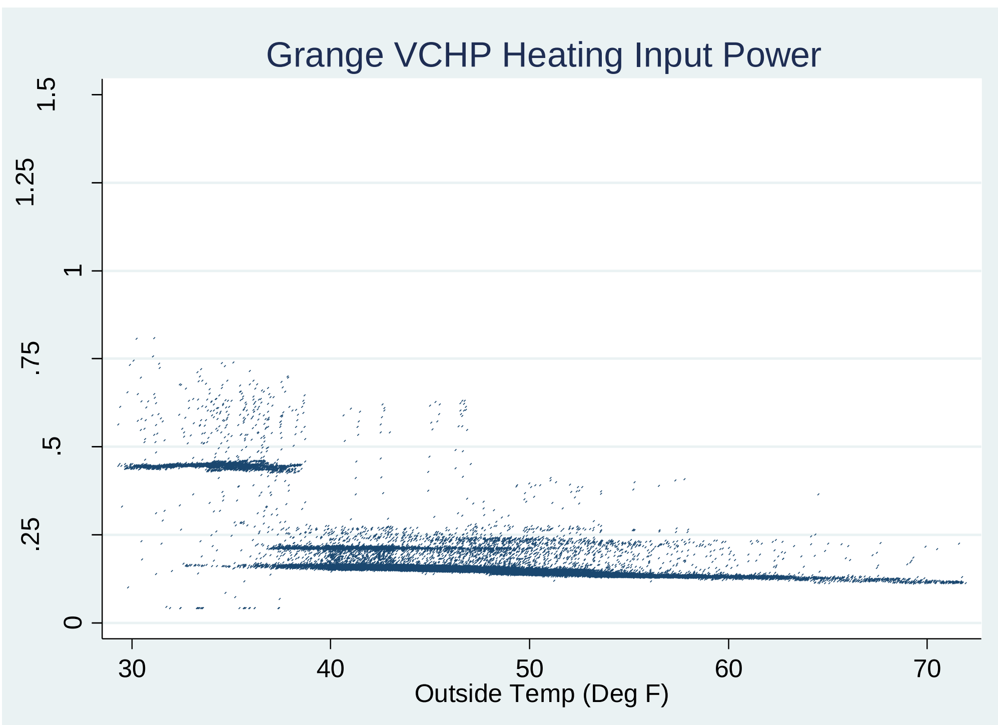


FIGURE 52. GRANGE VCHP IN HEATING MODE

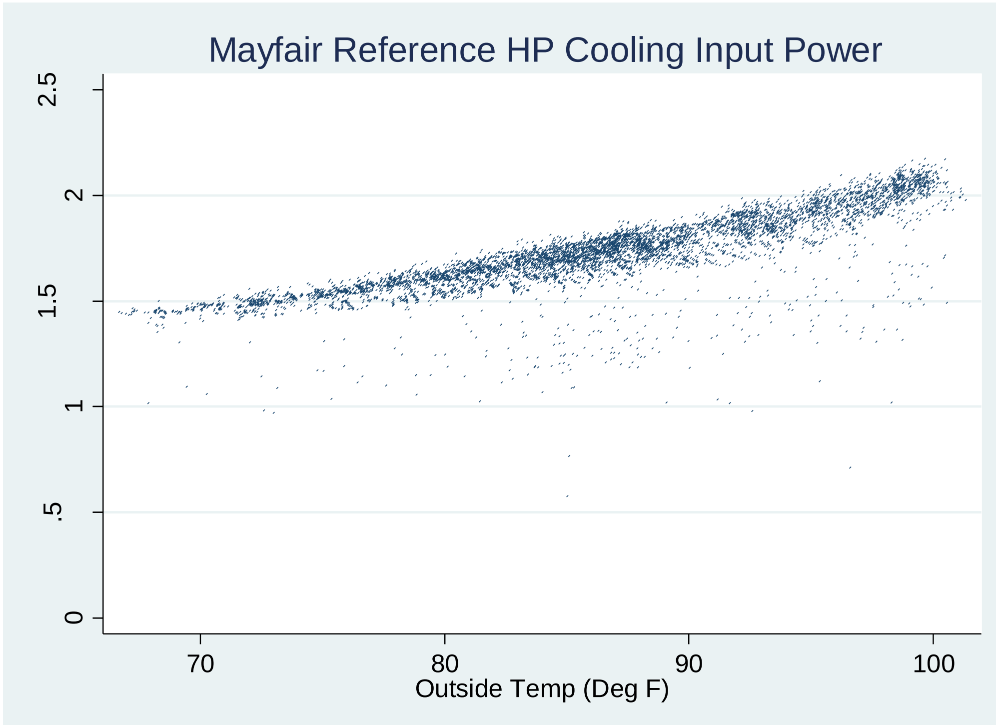


FIGURE 53. MAYFAIR REFERENCE HEAT PUMP IN COOLING MODE

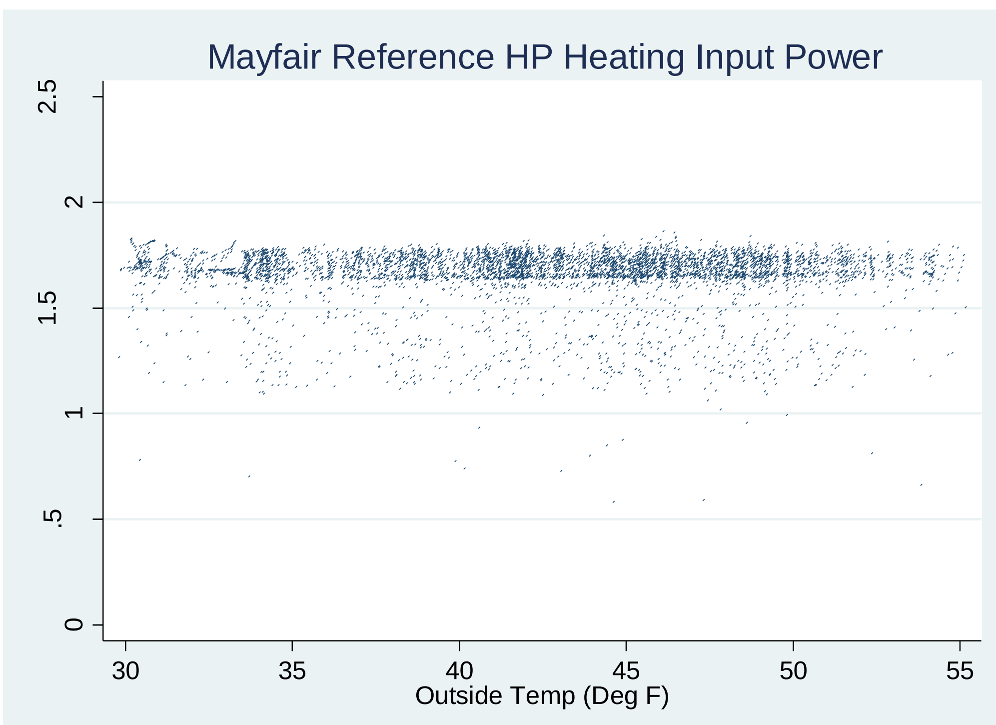


FIGURE 54. MAYFAIR REFERENCE HEAT PUMP IN HEATING MODE

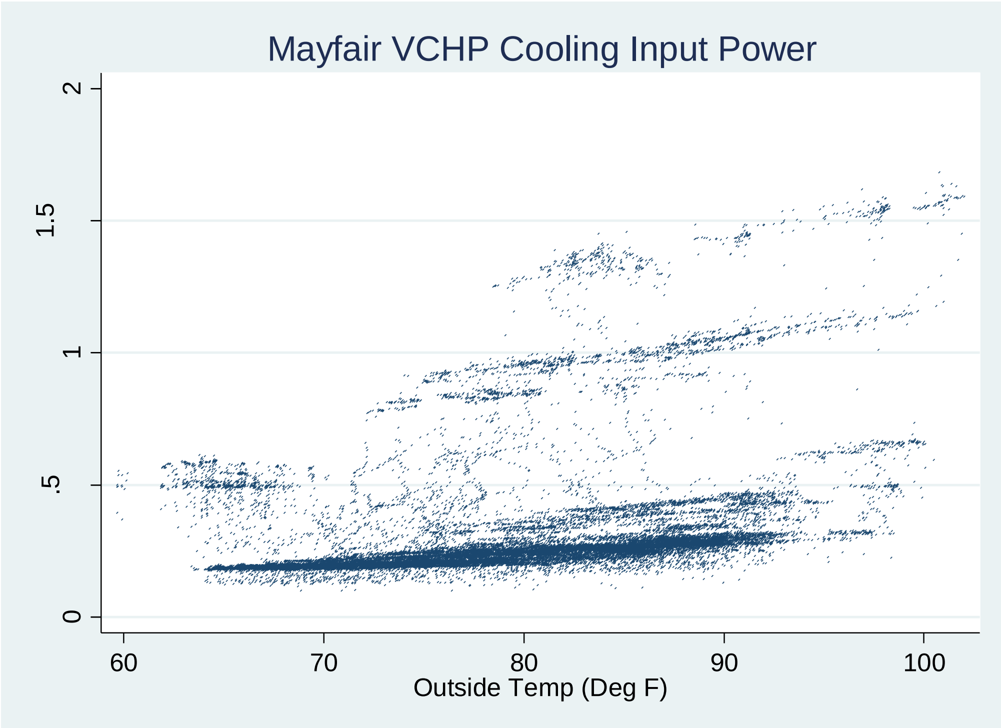


FIGURE 55. MAYFAIR VCHP IN COOLING MODE

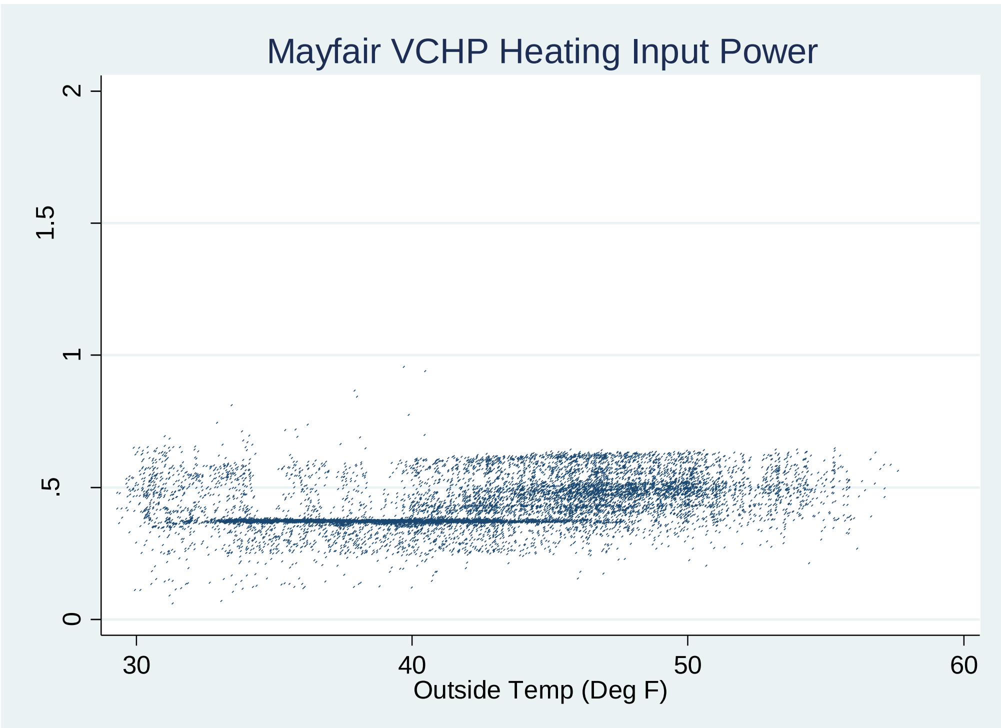


FIGURE 56. MAYFAIR VCHP IN HEATING MODE