Pacific Northwest
NATIONAL LABORATORY

PNNL-ACT-10092

Energy Saving Quantification of Ductless Heat Pumps (DHP) in Existing Homes

June 2020

Yan Chen
Karthikeya Devaprasad
Zhihong Pang
Cheryn E Metzger (Project Manager)

U.S. DEPARTMENT OF ENERGY

Prepared for the U.S. Department of Energy
under Contract DE-AC05-76RL01830

DISCLAIMER

PACIFIC NORTHWEST NATIONAL LABORATORY
operated by
BATTELLE
for the
UNITED STATES DEPARTMENT OF ENERGY
under Contract DE-AC05-76RL01830

Printed in the United States of America

Available to DOE and DOE contractors from the
Office of Scientific and Technical Information,
P.O. Box 62, Oak Ridge, TN 37831-0062;
ph: (865) 576-8401
fax: (865) 576-5728
email: reports@adonis.osti.gov

Available to the public from the National Technical Information Service
5301 Shawnee Rd., Alexandria, VA 22312
ph: (800) 553-NTIS (6847)
email: orders@ntis.gov <https://www.ntis.gov/about>
Online ordering: http://www.ntis.gov

PNNL-ACT-10092

Energy Saving Quantification of Ductless Heat Pumps (DHP) in Existing Homes

Preliminary Results

June 2020

Yan Chen
Karthikeya Devaprasad
Zhihong Pang
Cheryn E Metzger (Project Manager)

Prepared for
the U.S. Department of Energy
under Contract DE-AC05-76RL01830

Pacific Northwest National Laboratory
Richland, Washington 99354

Abstract

In residential retrofit applications, ductless mini-split heat pumps (DHP) are often reported to have high-energy savings potential, depending on the system they are supplementing or replacing. However, recently, there have been a number of utility studies and analyses indicating these energy savings are not being achieved when the existing system is left in place for backup heating or air conditioning. The Pacific Northwest National Laboratory conducted a three-phase project to help determine which control strategies would have the most energy savings impact in various climate zones around the United States. The first phase developed the standalone simulation model for the PNNL Lab Homes and investigated the energy-saving potential from different control strategies and HVAC system configurations. The second phase focused on conducting experiments in the PNNL Lab Homes, which tested the most promising solutions that were modeled in the first phase. The third phase used the field data to calibrate the simulation model and then extrapolated the results to different climate locations and different building sizes. This report focuses on the third phase of the study, including five major parts: model calibration, parametric model setup, results, a sensitivity analysis of air leakage rate, and conclusions.

Acknowledgments

The authors would like to thank Silicon Valley Power, the American Public Power Association, the Northwest Energy Efficiency Alliance, the Bonneville Power Administration and the New York State Research and Development Authority for their support for this project and important topic. The authors would also like to thank Travis Ashley and Jaime Kolln for assistance with the field data interpretation, as well as Sam Rosenburg and Jordan Dentz for their thorough review of this report.

Acronyms and Abbreviations

AC	Air Conditioner
CZ	Climate Zone
DHP	Ductless Heat Pump
eFAF	Electric Forced Air Furnace
ER	Electric Resistance
IECC	International Energy Conservation Code
SEER	seasonal Energy Efficiency Ratio
BPA	Bonneville Power Administration
HSPF	Heating Season Performance Factor
NEEA	Northwest Energy Efficiency Alliance

Contents

Abstract ii
Acknowledgments iii
Acronyms and Abbreviations iv
Contents v
1.0 Introduction 1
1.1 Background 1
1.2 Scope and Objective 2
2.0 Model Calibration 3
2.1 Lab Homes Model Assumptions 3
2.2 Two Types of HVAC System Configurations 5
2.3 Calibration Process and Criteria 6
2.4 Results of Model Calibration 8
3.0 Parametric Model Setup 13
3.1 Modeling Assumptions 13
3.2 Variation 1 - HVAC System Control Cases 13
3.3 Variation 2 - Climate Zones 17
3.4 Variation 3 - Prototype Buildings Size 18
3.5 Summary of all the cases 20
4.0 Results 21
4.1 National result 21
4.2 New York result 37
4.3 California result 40
5.0 Sensitivity Analysis of Air Leakage Rate 56
6.0 Conclusions 58
7.0 References 59

Figures

Figure 1. Lab Home floor plan and thermal zoning in the EnergyPlus model. 3
Figure 2. HVAC system configuration diagram for Central System with DHP 5
Figure 3. HVAC system configuration diagram for Zoned equipment with DHP 5
Figure 4. Flowchart indicating the process for model calibration 7
Figure 5. Comparison of measured and simulated power consumption for heating baseline – central system only 9
Figure 6. Comparison of measured and simulated power consumption for central heating baseline (sensor in master bedrooms) 9
Figure 7. Comparison of measured and simulated power consumption for baseline model with central system in cooling mode and DHP disabled. 10
Figure 8. Comparison of measured and simulated power consumption for DHP only heating baseline. 10
Figure 9. Comparison of measured and simulated power consumption for zonal heating baseline (doors open) 11
Figure 10. Comparison of measured and simulated power consumption for zonal heating baseline (doors closed) 11
Figure 11. Comparison of measured and simulated power consumption for Zonal cooling baseline (doors open) 12
Figure 12. Comparison of measured and simulated power consumption for zonal cooling baseline (doors closed) 12

Tables

Table 1. Building characteristics....4
Table 2. HVAC system specification for EnergyPlus model....4
Table 3. Results of model calibration process....8
Table 4. Zoned Home +DHP Model (Heating Focus)....14
Table 5. Zoned Home +DHP Model (Cooling Focus)....15
Table 6. Electric Forced Air Furnace/Central AC + DHP Model....16
Table 7. Climate Zones Used for the Parametric Study (New York and National)....17
Table 8. Climate Zones Used for the Parametric Study (California climate zone map)....18
Table 9. Two sizes of prototype building model....19
Table 10. Prototype Characteristics....20
Table 11. Energy Use and Savings in National for CZ1Moist (DHP with Zonal Heating and Cooling)....21
Table 12. Energy Use and Savings in National for CZ1Moist (DHP with Central System)....21
Table 13. Energy Use and Savings in National for CZ1Moist (Tropical) (DHP with Zonal Heating and Cooling)....22
Table 14. Energy Use and Savings in National for CZ1Moist (Tropical) (DHP with Central System)....22
Table 15. Energy Use and Savings in National for CZ2Dry (DHP with Zonal Heating and Cooling)....23
Table 16. Energy Use and Savings in National for CZ2Dry (DHP with Central System)....23
Table 17. Energy Use and Savings in National for CZ2Moist (DHP with Zonal Heating and Cooling)....24
Table 18. Energy Use and Savings in National for CZ2Moist (DHP with Central System)....24
Table 19. Energy Use and Savings in National for CZ3Dry (DHP with Zonal Heating and Cooling)....25
Table 20. Energy Use and Savings in National for CZ3Dry (DHP with Central System)....25
Table 21. Energy Use and Savings in National for CZ3Marine (DHP with Zonal Heating and Cooling)....26
Table 22. Energy Use and Savings in National for CZ3Marine (DHP with Central System)....26
Table 23. Energy Use and Savings in National for CZ3Moist (DHP with Zonal Heating and Cooling)....27
Table 24. Energy Use and Savings in National for CZ3Moist (DHP with Central System)....27
Table 25. Energy Use and Savings in National for CZ4Dry (DHP with Zonal Heating and Cooling)....28

Table 26. Energy Use and Savings in National for CZ4Dry (DHP with Central System) 28
Table 27. Energy Use and Savings in National for CZ4Marine (DHP with Zonal Heating and Cooling) 29
Table 28. Energy Use and Savings in National for CZ4Marine (DHP with Central System) 29
Table 29. Energy Use and Savings in National for CZ4Moist (DHP with Zonal Heating and Cooling) 30
Table 30. Energy Use and Savings in National for CZ4Moist (DHP with Central System) 30
Table 31. Energy Use and Savings in National for CZ5Dry (DHP with Zonal Heating and Cooling) 31
Table 32. Energy Use and Savings in National for CZ5Dry (DHP with Central System) 31
Table 33. Energy Use and Savings in National for CZ5Moist (DHP with Zonal Heating and Cooling) 32
Table 34. Energy Use and Savings in National for CZ5Moist (DHP with Central System) 32
Table 35. Energy Use and Savings in National for CZ6Dry (DHP with Zonal Heating and Cooling) 33
Table 36. Energy Use and Savings in National for CZ6Dry (DHP with Central System) 33
Table 37. Energy Use and Savings in National for CZ6Moist (DHP with Zonal Heating and Cooling) 34
Table 38. Energy Use and Savings in National for CZ6Moist (DHP with Central System) 34
Table 39. Energy Use and Savings in National for CZ7 (DHP with Zonal Heating and Cooling) 35
Table 40. Energy Use and Savings in National for CZ7 (DHP with Central System) 35
Table 41. Energy Use and Savings in National for CZ8 (DHP with Zonal Heating and Cooling) 36
Table 42. Energy Use and Savings in National for CZ8 (DHP with Central System) 36
Table 43. Energy Use and Savings in New York for CZ4Moist (DHP with Zonal Heating and Cooling) 37
Table 44. Energy Use and Savings in New York for CZ4Moist (DHP with Central System) 37
Table 45. Energy Use and Savings in New York for CZ5Moist (DHP with Zonal Heating and Cooling) 38
Table 46. Energy Use and Savings in New York for CZ5Moist (DHP with Central System) 38
Table 47. Energy Use and Savings in New York for CZ6Moist (DHP with Zonal Heating and Cooling) 39
Table 48. Energy Use and Savings in New York for CZ6Moist (DHP with Central System) 39

Table 49. Energy Use and Savings in California for CA1 (DHP with Zonal Heating and Cooling) 40
Table 50. Energy Use and Savings in California for CA1 (DHP with Central System) 40
Table 51. Energy Use and Savings in California for CA2 (DHP with Zonal Heating and Cooling) 41
Table 52. Energy Use and Savings in California for CA2 (DHP with Central System) 41
Table 53. Energy Use and Savings in California for CA3 (DHP with Zonal Heating and Cooling) 42
Table 54. Energy Use and Savings in California for CA3 (DHP with Central System) 42
Table 55. Energy Use and Savings in California for CA4 (DHP with Zonal Heating and Cooling) 43
Table 56. Energy Use and Savings in California for CA4 (DHP with Central System) 43
Table 57. Energy Use and Savings in California for CA5 (DHP with Zonal Heating and Cooling) 44
Table 58. Energy Use and Savings in California for CA5 (DHP with Central System) 44
Table 59. Energy Use and Savings in California for CA6 (DHP with Zonal Heating and Cooling) 45
Table 60. Energy Use and Savings in California for CA6 (DHP with Central System) 45
Table 61. Energy Use and Savings in California for CA7 (DHP with Zonal Heating and Cooling) 46
Table 62. Energy Use and Savings in California for CA7 (DHP with Central System) 46
Table 63. Energy Use and Savings in California for CA8 (DHP with Zonal Heating and Cooling) 47
Table 64. Energy Use and Savings in California for CA8 (DHP with Central System) 47
Table 65. Energy Use and Savings in California for CA9 (DHP with Zonal Heating and Cooling) 48
Table 66. Energy Use and Savings in California for CA9 (DHP with Central System) 48
Table 67. Energy Use and Savings in California for CA10 (DHP with Zonal Heating and Cooling) 49
Table 68. Energy Use and Savings in California for CA10 (DHP with Central System) 49
Table 69. Energy Use and Savings in California for CA11 (DHP with Zonal Heating and Cooling) 50
Table 70. Energy Use and Savings in California for CA11 (DHP with Central System) 50
Table 71. Energy Use and Savings in California for CA12 (DHP with Zonal Heating and Cooling) 51
Table 72. Energy Use and Savings in California for CA12 (DHP with Central System) 51
Table 73. Energy Use and Savings in California for CA13 (DHP with Zonal Heating and Cooling) 52
Table 74. Energy Use and Savings in California for CA13 (DHP with Central System) 52

Table 75. Energy Use and Savings in California for CA14 (DHP with Zonal Heating and Cooling) 53
Table 76. Energy Use and Savings in California for CA14 (DHP with Central System) 53
Table 77. Energy Use and Savings in California for CA15 (DHP with Zonal Heating and Cooling) 54
Table 78. Energy Use and Savings in California for CA15 (DHP with Central System) 54
Table 79. Energy Use and Savings in California for CA16 (DHP with Zonal Heating and Cooling) 55
Table 80. Energy Use and Savings in California for CA16 (DHP with Central System) 55
Table 81. Energy Use and Savings in CZ5B (DHP with Central system) 56
Table 82. Energy Use and Savings in CZ5B (DHP with Zonal Heating and Cooling) 57

1.0 Introduction

1.1 Background

The ductless mini-split heat pump (DHP) is considered as a viable alternative to central systems (Dentz et al., 2014; Logsdon et al., 2016; Roth et al., 2006). Compared with the typical central system and other HVAC systems, a DHP has several advantages. First, it does not require any ductwork; thus, in retrofit applications, no ducts have to be added to spaces that did not have them before (Metzger et al., 2018). For this reason, DHP is particularly suited to retrofits in historic buildings. Second, the compact size of the DHP's indoor unit allows a broader range of applications, especially when space is limited.

The most significant advantage of the DHP is that it can save a considerable amount of energy (Metzger et al., 2018). Several attributes contribute to its excellent energy-efficiency. First, a DHP system typically uses an inverter-driven compressor, which can achieve very high efficiency. Many of the DHPs currently on the market have seasonal energy efficiency ratios (SEERs) of 20 or above, while most central heat pump systems are rated at the minimum Federal standard of SEER 13 (Winkler, 2011a). A survey by NEEA and the Bonneville Power Administration (BPA) (Bonneville Power Administration, 2016) suggested that about 80% of the sold DHPs had a heating season performance factor (HSPF) over 9 in the U.S. Northwest region in 2014, while only 20% of the sold central systems reached this efficiency. Unlike central systems, DHP can be easily zoned by installing multiple indoor units, which can be independently controlled. In this way, only those spaces that are actively used need to be heated and cooled and any energy waste and occupant discomfort due to overheating and overcooling can be minimized (Winkler, 2011a). Lastly, because DHP systems are ductless, energy losses through duct leakage and conduction to unconditioned spaces are eliminated.

The DHP market is increasing dramatically in the US in recent years. A survey by the Northwest Energy Efficiency Alliance found that 90% of interviewees were satisfied with their DHP system (NEEA, 2009). Additionally, more than three-quarters of the DHP owners who purchased in 2015 have recommended this product to others (Conzemius et al., 2016).

Several recent studies investigated the energy savings from DHP system. For example, Metzger et al. (2018) used an energy simulation to compare the energy use of homes with four different space conditioning systems: electric baseboards and window air-conditioning for cooling, a central air source heat pump, a ductless mini-split, and a ducted mini-split. In a mix of six prototype buildings and three climate zones in the Northwest, the ductless mini-split was always the most efficient option. In this study, ductless mini-splits saved 37 to 64% annually compared to the electric baseboard/window air-conditioner baseline.

Logsdon and Larson (2016) conducted an observational study on the Stack House Apartments in Seattle, WA. The building contained both apartments with and without DHP systems. Based on the utility billing data, they found that the DHP system can save about 350 kWh of electricity for each apartment per year, compared to the non-DHP system, which used about 3,000 kWh per apartment per year. Although this case study did not use a fair comparison method due to the limitations of the candidate building, the DHP's potential for saving space heating energy was confirmed.

Dentz et al. (2014) used an energy simulation to explore the retrofit opportunity of the DHP system for low- to mid-rise multifamily buildings. The simulation results suggested that the DHP system was cost-effective for building retrofits, especially for buildings in regions with high-cost heating fuels, such as liquefied petroleum gas (LPG), fuel oil, and electricity.

To evaluate the ability of the DHP system to maintain an acceptable thermal comfort for residential occupants, the Fraunhofer Centre for Sustainable Energy Systems conducted several field tests from October 2011 to June 2012 in Austin, TX (Roth et al., 2013). The temperature and relative humidity were measured in two households before and after the DHPs were installed in a replacement of the existing central system. ASHRAE Standard 55 was used to guide these analyses (ASHRAE, 2013). The results indicated that the DHP system can satisfy the occupants in the bedroom and the living room very well but had a high portion of unmet hours for occupant thermal comfort in the bathrooms. This was primarily because the occupants did not run the dehumidification mode during the actual operation of the DHP system.

Other related research includes the development of a field monitoring protocol for DHPs (Christensen et al., 2011), long-term monitoring of DHP systems in the North-eastern U.S. (Ueno et al., 2015), an energy savings performance evaluation of DHP systems in the U.S. Northwest region using sub-metering data (Geraghty et al., 2009), and a laboratory test for a Fujitsu DHP (Winkler, 2011b) unit.

Those studies mostly focus on the evaluation of the DHP system performance via simulations, lab testing, and on-site experiments. However, none of these projects address the interaction between the DHP and an existing space conditioning system like zonal electric baseboards and window AC, or a central system. Considering that the DHP system is recommended in multiple studies for building retrofit projects, it would be helpful to investigate this interaction between the newly installed DHP and the existing HVAC system. A better understanding of the interaction pattern of the DHP system with the existing HVAC system will help practitioners rate its energy saving performance and guide its applications in a real retrofit project.

1.2 Scope and Objective

The study aims to quantify the energy-saving potential of ductless heat pump systems when they are installed in existing homes that have existing HVAC equipment. Two types of existing HVAC system configurations were explored: 1) a DHP installed in the main living room with a zonal electric system using electric baseboards and window AC units in the bedrooms, and 2) a DHP installed in the main living room with a central HVAC system conditioning the whole house.

The overall scope of this project had three phases. The first phase developed the standalone simulation model for the PNNL Lab Homes and investigated the energy-saving potential from different control strategies and HVAC system configurations. Part of those results were presented in a conference paper (Pang et al. 2019). The second phase focused on conducting experiments in the PNNL Lab Homes, which tested the most promising solutions that were modeled in the first phase. The results from the lab testing were summarized in a report (Ashley et al. 2019). The third phase used the field data to calibrate the simulation model and then extrapolated the results to different climate locations and different building sizes. This report focuses on the third phase of the study, including five major parts: model calibration, parametric model setup, results, a sensitivity analysis of air leakage rate, and conclusions.

2.0 Model Calibration

2.1 Lab Homes Model Assumptions

The side-by-side Lab Homes at PNNL allow energy-saving and grid-responsive technologies to be tested precisely in a controlled environment. Due to this side-by-side orientation, the homes experience the same weather and solar conditions. Each Lab Home is equipped with a central heat pump, a central electric forced air furnace, and electric heaters in each bedroom. For this experiment, DHPs were installed in the living room of both homes, and window air conditioners were also added to each bedroom for the zonal cooling experiments. The floor plan of the Lab Homes, as well as the zones used in the model calibration, are shown in Figure 1.

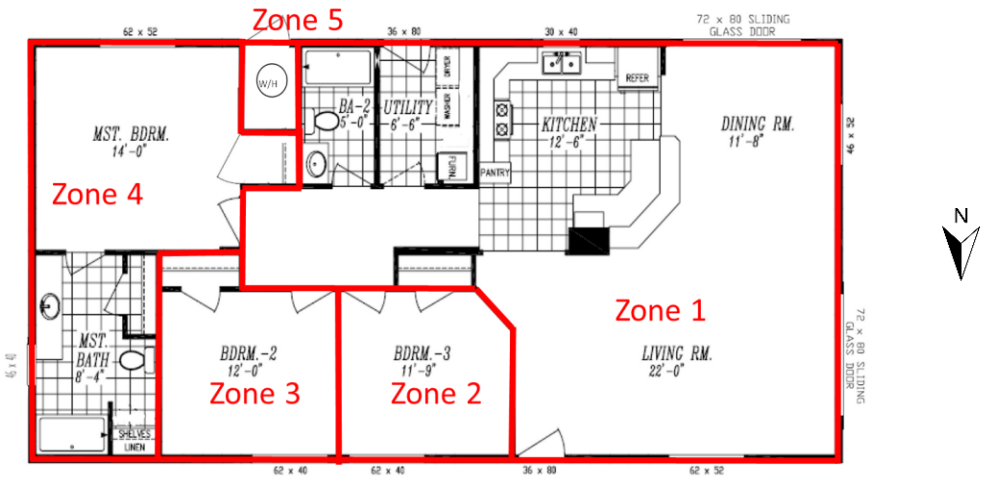

Figure 1. Lab Home floor plan and thermal zoning in the EnergyPlus model.

The following modeling assumptions were used for the duration of this calibration exercise:

- Real weather conditions (i.e., outdoor air dry-bulb temperatures and horizontal solar radiation) collected under the experimental period were used for the simulation.
- Other weather parameters, such as outdoor air wet bulb temperature and wind speeds, and solar radiations were also obtained from the LabHome weather station data.
- Air leakage input based on recent air infiltration testing results.
- All models were created using EnergyPlus v8.9.[1]

[1] EnergyPlus is a whole building energy simulation program developed with support from DOE: https://energyplus.net/.

Table 1. Building characteristics

Item	Description
Building	PNNL Lab Home
Vintage	Existing residential building
Location	Richland, WA, USA
Window fraction	South: 30%, east: 30%, north: 30% west: 30%, average total: 30%
Thermo-characteristics	External wall: 0.535 W/m^2.K Window: 3.127 W/m^2.K
Lighting load	6 W/m^2
Plug load	60 W/m^2

Table 2. HVAC system specification for EnergyPlus model

Equipment	Parameter	Actual Equipment in Lab Home	EnergyPlus calibration model	For National Result Extrapolation
DHP	Model	MUZ-FH18NA	NA	NA
	Cooling capacity	5041 W	5041 W	Autosize
	Heating capacity	5950 W	5840 W	Autosize
	Fan efficiency	0.7	0.7	0.7
	Max air flow rate	0.351 m^3/s	0.351 m^3/s	Autosize
	Rated HSPF	12	12	12
	Rated SEER	22	22	22
	Cooling stage	3	1	1
	Heating stage	3	1	1
Central System	Cooling capacity	8792W	8750 W	Autosize
	Heating capacity	8784W	Autosize	Autosize
	COP	3.81	3.81	3.81
Window AC	Capacity	1465 W	1465 W	Autosize
	Max air flow rate	0.0611 m^3/s	0.0611 m^3/s	Autosize
	Rated SEER	13	13	13
	Cooling stage	2	1	1
Heating baseboard	Capacity	Autosize	Autosize	Autosize
	Heating efficiency	0.97	1	1
Transfer Fan	Air flow rate	200cfm (0.0944 m^3/s)	200cfm (0.0944 m^3/s)	200cfm (0.0944 m^3/s)

Based on the various experimental scenarios formulated and performed in the Lab Homes, EnergyPlus models were created for each of the scenarios. The geometry for the structure was designed exactly as per the Lab Home design, with five thermal zones (Living Room and common areas, Master Bedroom, Guest Bedroom-1, Guest Bedroom-2, Water Heater closet). The HVAC equipment in the model was created according to the rated conditions of the equipment in the Lab Homes.

2.2 Two Types of HVAC System Configurations

There were two main configurations: System-1 and System-2.

- **Central System** (shown in Figure 2) consisted of the DHP in the living room, and a Central electric furnace with fan for heating and a single-speed DX coil for cooling, conditioning all the zones except the water heater closet (Zone 5 in Figure 1).

- **Zonal System** (shown in Figure 3) consisted of the DHP in the living room, and zonal equipment consisting of electric baseboards for heating and window ACs for cooling in each of the bedrooms. The Water Heater closet (Zone 5 in Figure 1) was not conditioned.

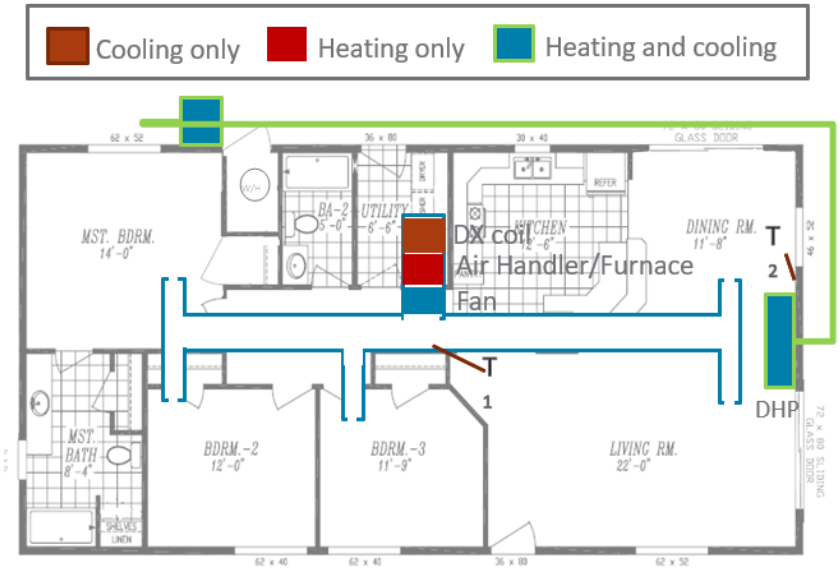

Figure 2. HVAC system configuration diagram for Central System with DHP

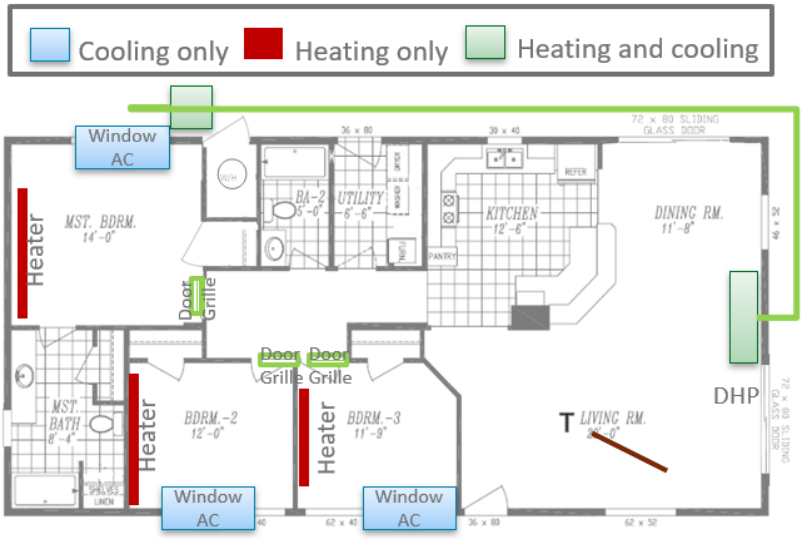

Figure 3. HVAC system configuration diagram for Zoned equipment with DHP

2.3 Calibration Process and Criteria

The data from the experimental home was used for the model calibration. For the calibration, Section 5.3 – Whole Building Calibrated Simulation Approach in ASHRAE Guideline 14 for Measurement of Energy, Water and Demand Savings (ASHRAE 2014) was referenced. According to the guideline, the calculation would require two error metrics to quantify the accuracy of the model: CV-RMSE and NMBE.

CV-RMSE (Co-efficient of Variation of the Root-Mean-Square-Error) is calculated by dividing RMSE by the average energy use. NMBE (Normalized Mean Bias Error) is calculated by dividing the average error by the average energy use.

$$\mathrm{CV}(RMSE) = \frac{\sqrt{\frac{\sum(y_i - \hat{y}_i)^2}{n-p}}}{\bar{y}} \quad (1)$$

$$\mathrm{NMBE} = \frac{\sum_{\mathrm{i=1}}^{\mathrm{n}}(y_i - \hat{y}_i)}{(\mathrm{n} - \mathrm{p}) \times \bar{y}} \quad (2)$$

For calibrated simulations, the CV(RMSE) and NMBE are determined with p = 1.

The calibration process consisted of the following steps:

1. Ensure that the internal loads matched those used during the experiment.
2. The EnergyPlus simulation was run and the results were studied to find the error with respect to the measured values using CV-RMSE and NMBE.
3. The variable parameters like zone-cross-mixing and zone-infiltration were varied.
4. The error metrics were re-calculated.
5. Steps 3 and 4 were repeated until the error metrics were within the required limits.

The calibration process is summarized in a flow chart (Figure 4).

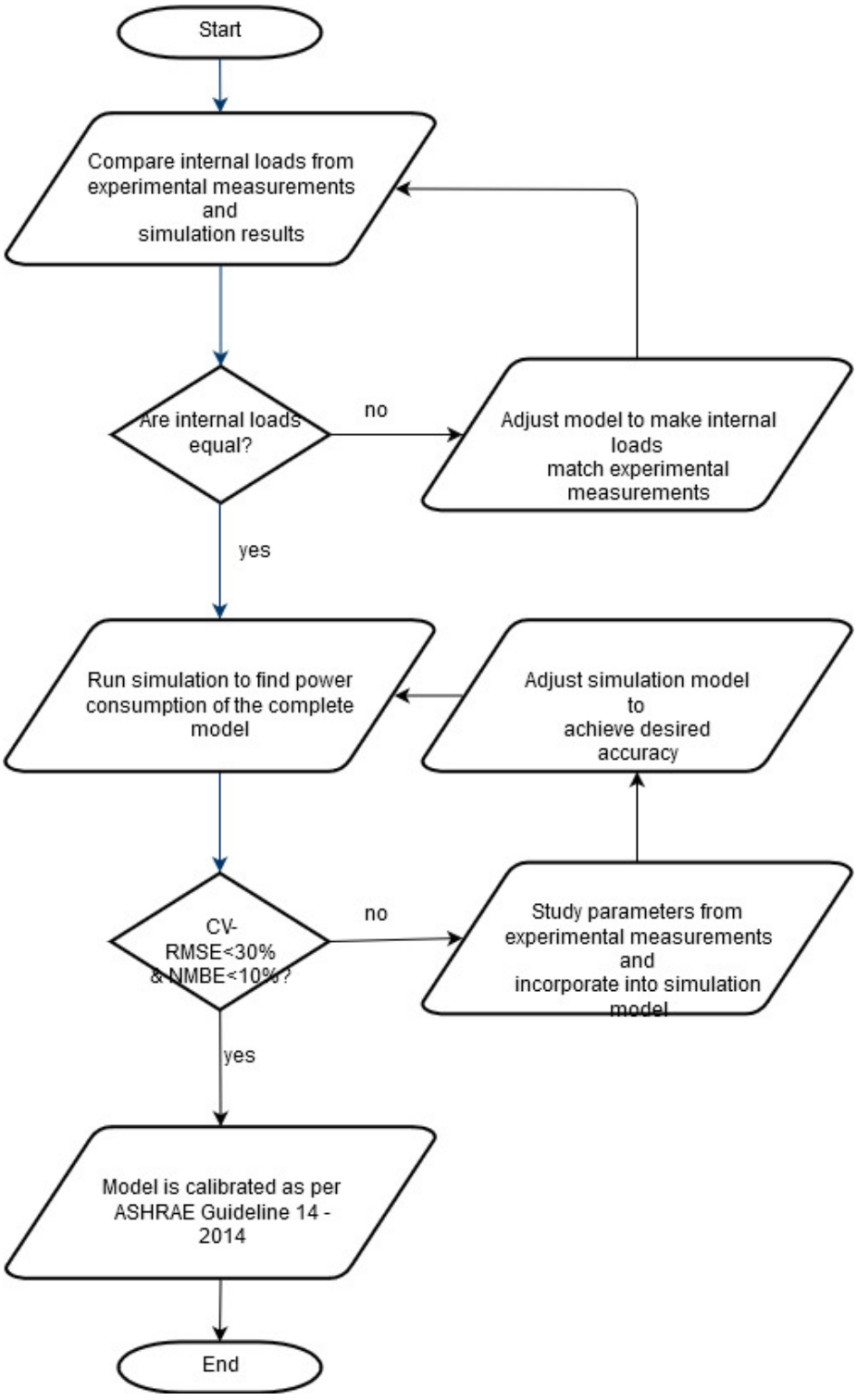

Figure 4. Flowchart indicating the process for model calibration

2.4 Results of Model Calibration

The results of the model calibration process are summarized in Table 3, and timeseries energy usage are plot for each day from Figure 5 to Figure 12. Based on the calibration result, the model has shown a good match with the field measurement for all the baseline cases. Although high values of CV-RMSE were observed for a few instances, the graphical result, in general, has shown a good match with the hourly energy usage pattern. It was always challenging to get an exact match between the energy modeling result and field measurement. Several reasons are found during the calibration effort: 1) The room air temperature in the actual building (e.g., lab home) is not distributed uniformly. At the same time, the EnergyPlus model is restricted to have a uniform air temperature distribution within a thermal zone. A better solution in the future would be to set multiple temperature sensing points in each experimental thermal zone to obtain the average zone temperature for model calibration. 2) It is very challenging (and likely constantly changing based on various indoor and outdoor conditions) to estimate the air mixing flow rate between each thermal zone for each system configuration. 3) It is also very challenging to run this ASHRAE criteria on an hourly basis (because there are only a few days of data for each scenario). Usually these criteria are used on a daily basis, over the course of a year if possible, which provides more forgiveness in the details. Even with these challenges and although the models did not always meet the ASHRAE criteria, the authors believe the calibration results below indicate that the model has been calibrated as best as possible and has achieved an acceptable level of accuracy to move forward with the model extrapolation.

Table 3. Results of model calibration process

System	Experimental Setup	Experiment Date	CV-RMSE	CV-NMBE	Total HVAC Energy Difference (%)
Central	Heating Baseline – Central System Only (Doors open - both homes set to 72°F, sensor in hall)	01/01/19	30.2	18.4	-17.6
Central	Heating Baseline (Doors open - DHP and central set to 72°F, central sensor in master bedroom)	02/04/19	23.8	11.7	-11.2
Central	Cooling Baseline – Central System Only (Doors open, both homes set to 72°F, sensor in hall)	07/21/19	44.9	12.2	-11.7
DHP Only	DHP Only Heating Baseline (Doors open - both homes set to 71°F, sensor at DHP)	01/20/19	14.5	10.2	-9.7
Zonal	Heating Baseline (Doors open – everything set to 72°F)	03/09/19	39.3	-13.4	12.8
Zonal	Heating Baseline (Doors closed – everything set to 72°F)	03/14/19	47.5	-0.4	0.4
Zonal	Cooling Baseline (Doors open – everything set to 76°F, sensor in hall)	08/10/19	21.8	-1.2	1.2
Zonal	Cooling Baseline (Doors closed – everything set to 76°F, sensor in hall)	08/15/19	49.5	25.6	-24.6

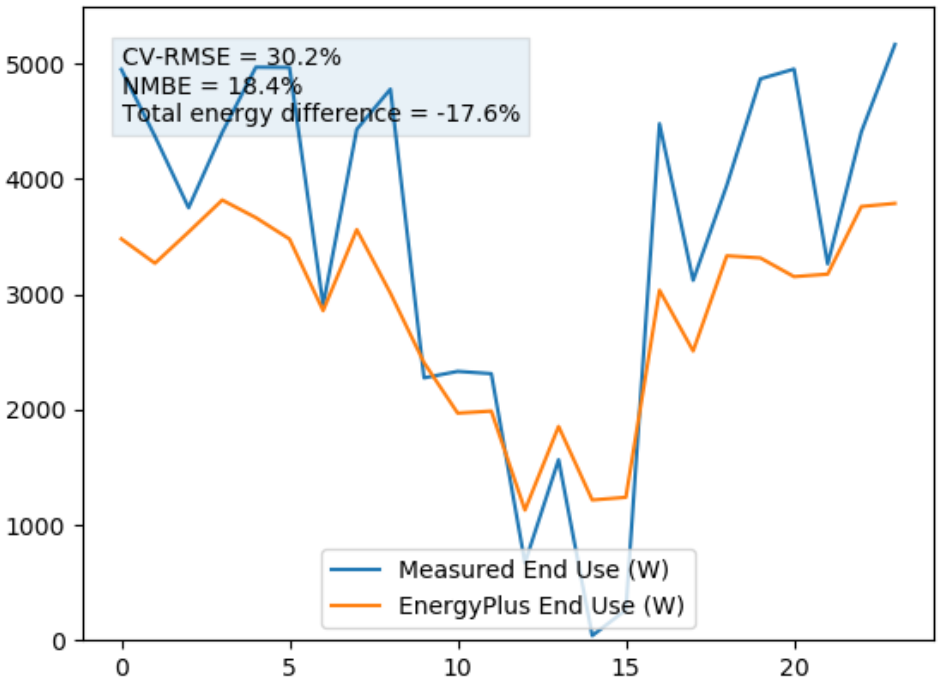

Figure 5. Comparison of measured and simulated power consumption for heating baseline – central system only

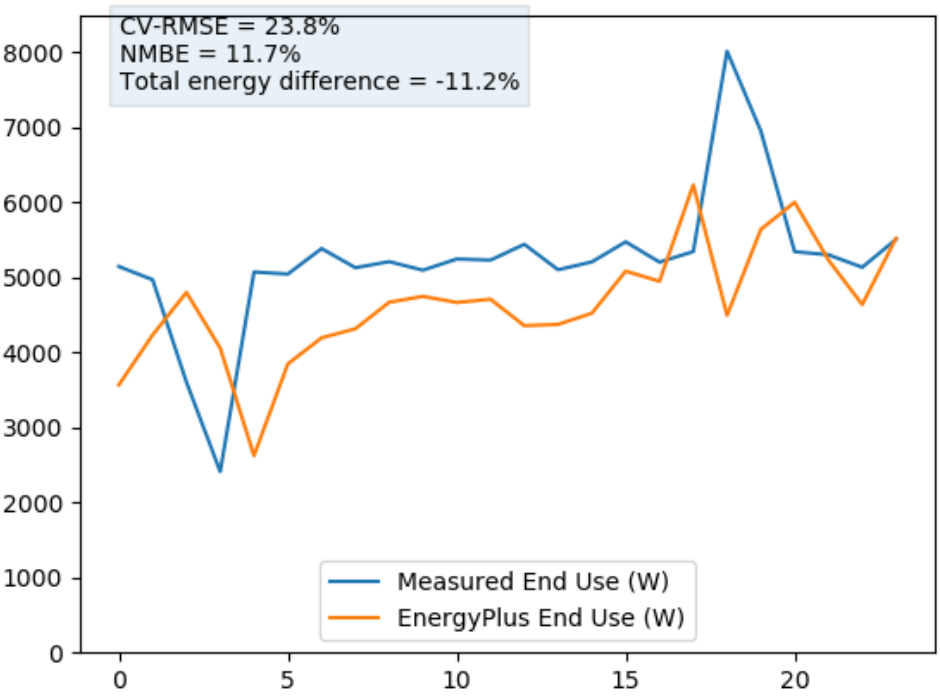

Figure 6. Comparison of measured and simulated power consumption for central heating baseline (sensor in master bedroom)

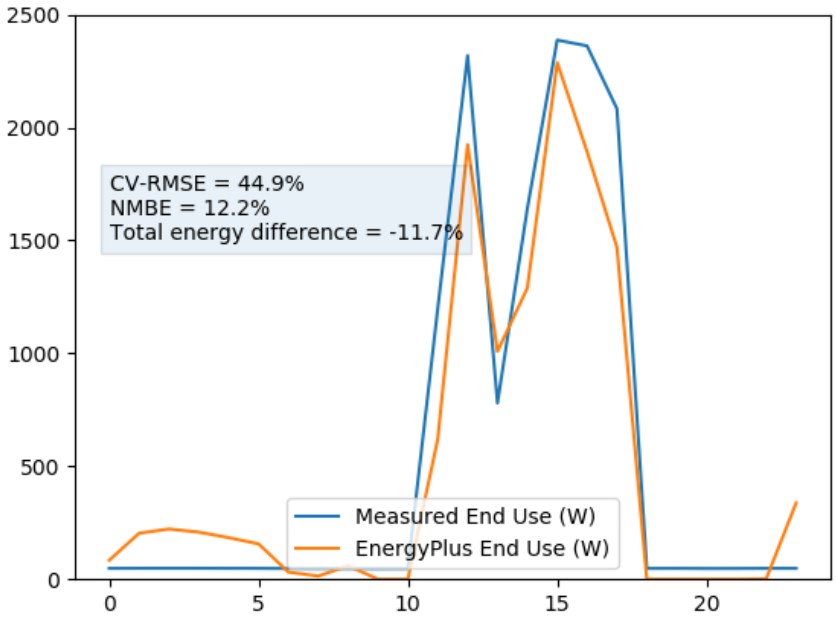

Figure 7. Comparison of measured and simulated power consumption for baseline model with central system in cooling mode (DHP disabled).

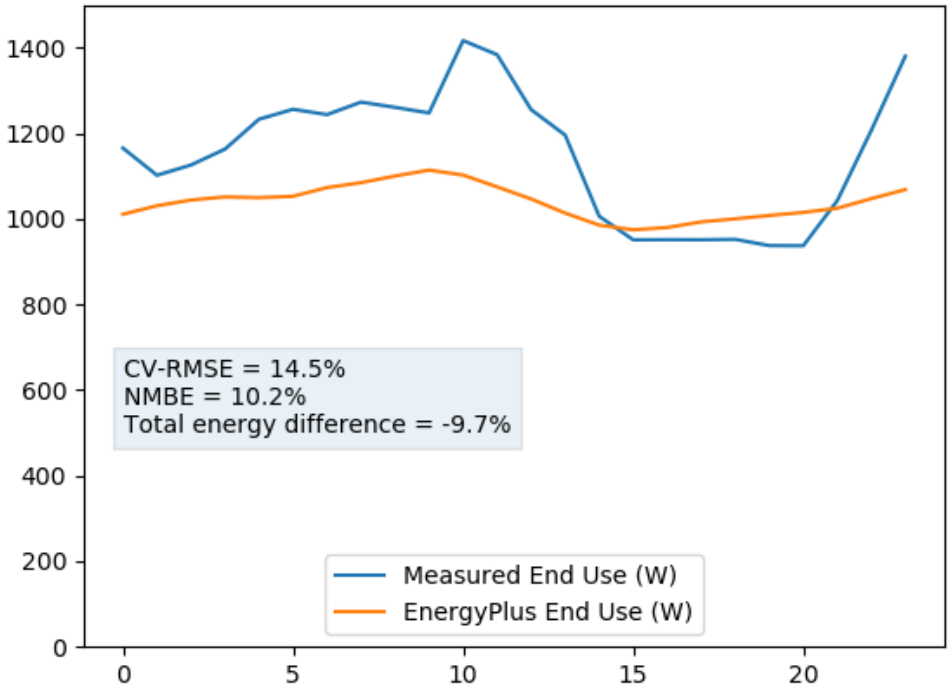

Figure 8. Comparison of measured and simulated power consumption for DHP only heating baseline.

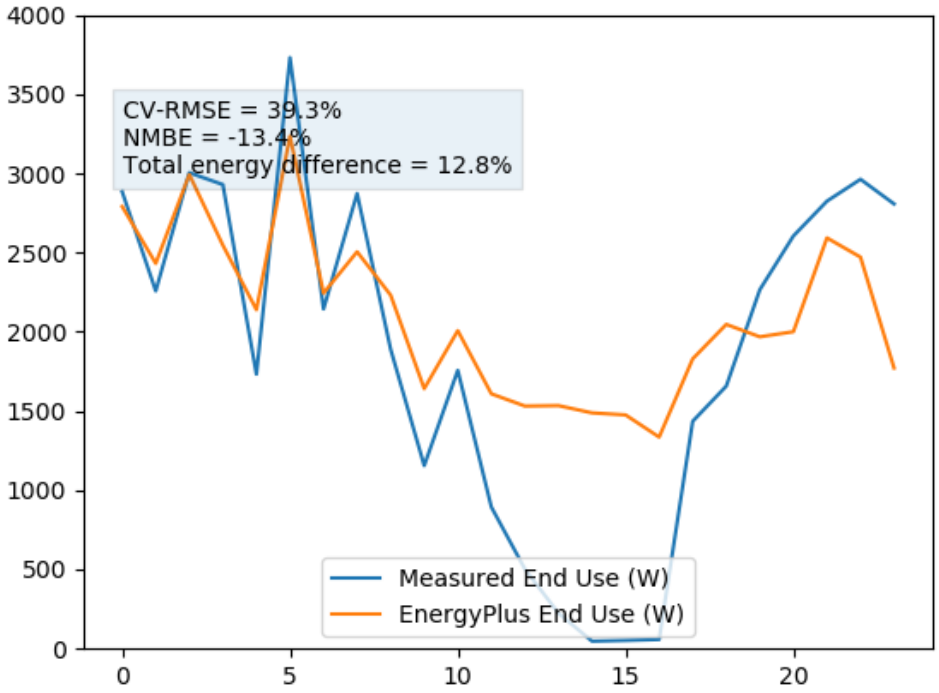

Figure 9. Comparison of measured and simulated power consumption for zonal heating baseline (doors open)

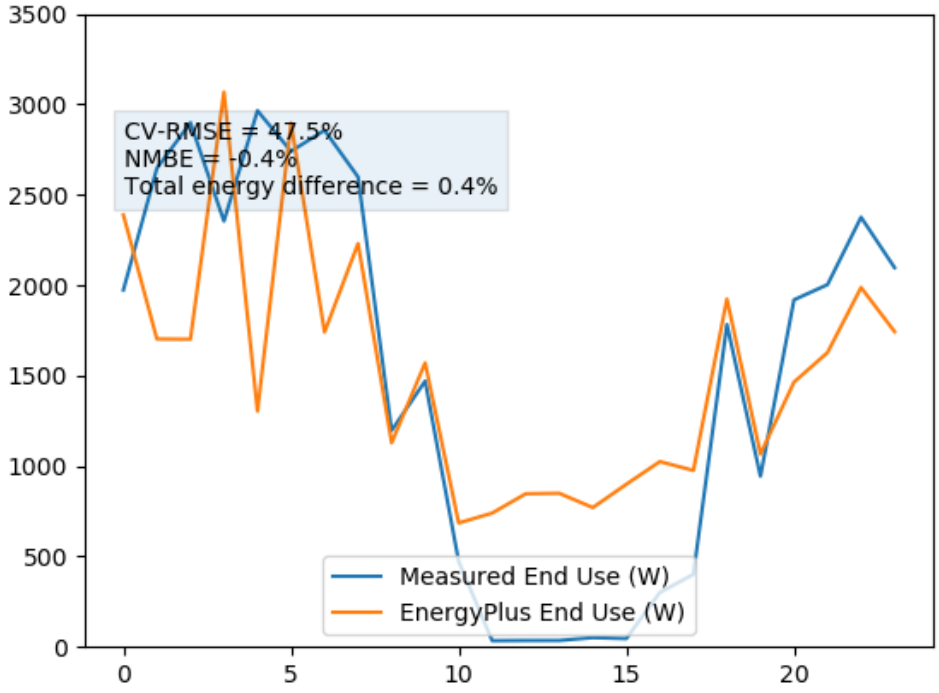

Figure 10. Comparison of measured and simulated power consumption for zonal heating baseline (doors closed)

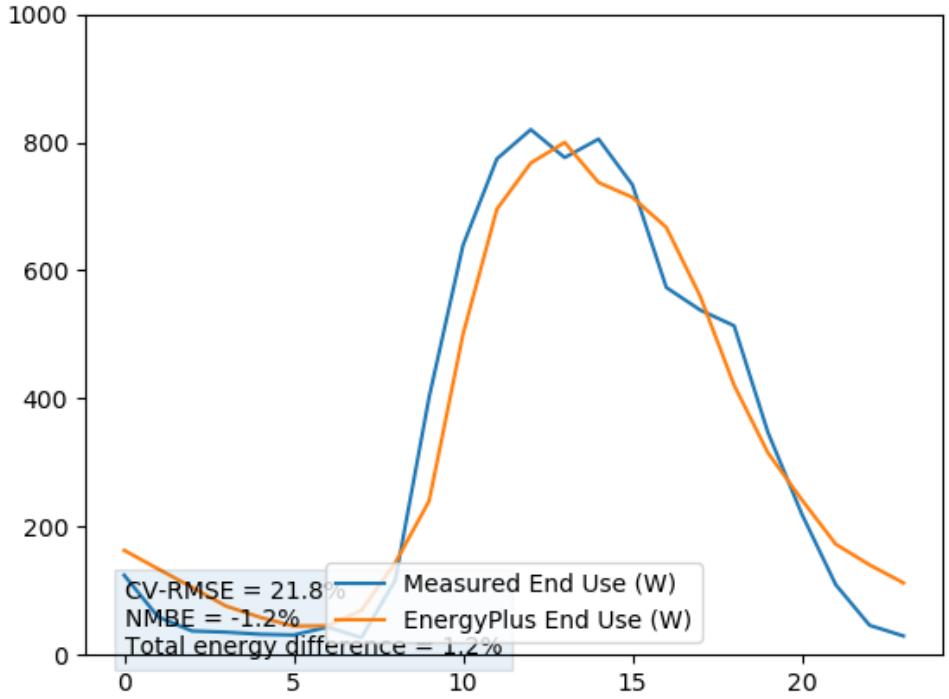

Figure 11. Comparison of measured and simulated power consumption for Zonal cooling baseline (doors open)

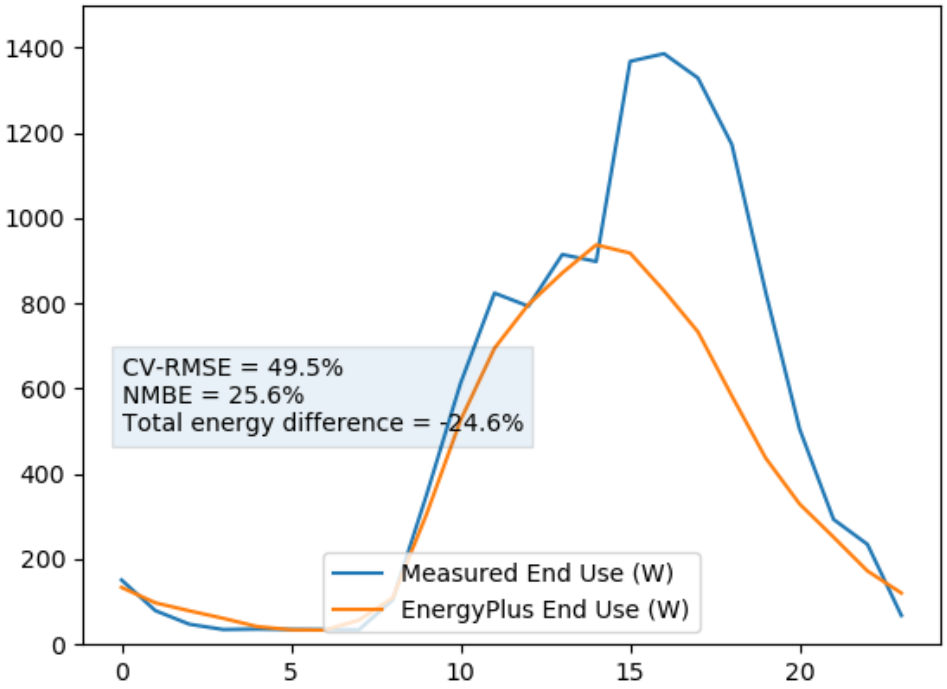

Figure 12. Comparison of measured and simulated power consumption for zonal cooling baseline (doors closed)

3.0 Parametric Model Setup

3.1 Modeling Assumptions

Assumptions made for all of the parametric models were:

- Plug loads and lighting assumptions following the rules used by the simulation-based performance path in the International Energy Conservation Code (IECC) (ICC 2018).
- The cooling set point was 76°F and the heating set point was 71°F. Both were enabled simultaneously, so cooling and heating could presumably be called for in the same day if the indoor temperature moved outside of that band.
- Six time-steps were assumed per hour in the simulation leading to a time step of 10 minutes.
- Central HVAC equipment was set to “Autosize” mode in EnergyPlus so the size of the equipment was determined based on the heating and cooling load calculated from the design condition for each climate zone. With each climate zone, the central HVAC equipment remained the same size regardless of different control scenarios. The DHP was autosized to match the load of zone 1 (which included everything but the bedrooms and the water heater closet). With both systems installed, they more than met the sizing requirements for each prototype home.
- For the central system modeling, 42 cfm of air exchange was assumed to be exchanged between zone 1 and each of the other zones.

3.2 Variation 1 - HVAC System Control Cases

A variety of control scenarios were developed to represent the most typical way of operating the two types of HVAC systems. Those scenarios were discussed among the project advisory committee. For the DHP with zonal backup, four control cases were developed (shown in Table 4 and Table 5); For DHP with central system backup, seven control cases were developed (shown in Table 6)

Some of the scenarios listed below were not conducted as experiments in the lab homes. With the limited amount of time for each season, and the necessity to share the homes with other experiments, only some of the scenarios could be tested.

Table 4. Zoned Home +DHP Model (Heating Focus)

Scenario	Controls Description	How it Was Modeled	How it Was Experimented On
Baseline 1: Dual Use Baseline (Baseboards Disabled in Living Room)	DHP and ER both set to 71°F Living room baseboard decommissioned	Zone 1 load in living room/hall bath met with DHP. Zones 2,3 and 4 load in bedrooms met with baseboards.	Wall heaters turned off in living room. 72°F[1] "set temp" will be specified for DHP and in bedrooms. Experiments ran with doors closed and doors open.
Bedroom Setback	Tell homeowners to turn back baseboards in the bedrooms unless they are using the room. Also, set back from DHP at night.	Bedrooms set at 55°F from 6am to 10pm and 66°F from 10pm to 6am. DHP in living room always set to 71°F.	Due to mild outdoor temperatures, indoor temperatures bumped up. Bedrooms set at 60°F from 6am to 10pm and 80°F from 10pm to 6am. DHP in living room always set to 85°F[2].
Power Transfer Fans	Power transfer fans between living room and bedrooms. Zonal always turned off, unless temp dips lower than 66F at night.	Model will include a small fan between the living room and each bedroom zone with ~200 cfm[3] from 10pm to 6am. DHP in living room always set to 71°F.	Due to mild outdoor weather, DHP set to 85°F at all times. Power transfer fans actually installed in Lab Homes. Power transfer fans controlled with Wi-Fi outlets to be on from 10pm to 6am. Doors closed.
Complex Schedule	Controls based on Time of Day. Smartly/automatically follow the occupant around the house.	Living Room DHP: set to 71°F from 6am to10pm and to 66°F from 10pm to 6am. Bedroom zonal heaters set to 66°F from 9pm to 7am and to 55°F from 7am to 9pm.	Due to mild outdoor weather, DHP set to 85°F from 6am to 10pm, and 80°F from 10pm to 6am. The electric resistance zonal heaters in the bedrooms were set to 60°F from 7am to 9pm and to 80°F from 9pm to 7am.

[1] The controller used at this time during the experiment (Sensibo) had to be run in increments of 2°F, so it was chosen that 72°F would be used instead of the planned 71°F.
[2] After an issue with the Sensibo was discovered, the team found a way to use the app from Mitsubishi which allowed any set point to be chosen.
[3] Air flow rate of transfer fan chosen by the advisory committee

Table 5. Zoned Home +DHP Model (Cooling Focus)

Scenario	Controls Description	How it Was Modeled	How it Was Experimented On
Baseline 1: Dual Use Baseline (No window AC units in Living Room)	DHP and window ACs in bedrooms both set to 76°F. No living room window AC.	Zone 1 load in living room/hall bath met with DHP. Zones 2,3 and 4 load in bedrooms met with window AC.	Set point 76°F for DHP and window ACs in bedrooms. Experiments ran with doors closed and doors open.
Bedroom Setback	Tell homeowners to turn off the window AC in the bedrooms unless they are using the room.	76°F cooling set point for DHP at all times. Window ACs off during the day and set to 81°F from 9pm to 7am.	Same as model.
Power Transfer Fans	Power transfer fans between living room and bedrooms. Window AC always turned off unless temp rises higher than 81°F from 9pm to 7am.	Model will include a small fan between the living room and each bedroom zone with ~200 cfm from 10pm to 6am. DHP in living room always set to 76°F. Window AC always turned off unless temp rises higher than 81°F from 9pm to 7am.	Same as model. Doors closed.
Complex Schedule	Controls based on Time of Day. Smartly/automatically follow the occupant around the house.	Living Room DHP set to 76°F from 6am to 10pm and to 81°F from 10pm to 6am. Bedroom window ACs were off from 7am to 9pm and set to 81°F from 9pm to 7am.	Due to mild outdoor temperatures, DHP set to 65 °F cooling from 6am to 10pm, and 70 °F from 10pm to 6am. The window AC units were off from 7am to 9pm and set to 65°F[1] from 9pm to 7am.

[1] Temperature for experiment accidently set too low.

Table 6. Electric Forced Air Furnace/Central AC + DHP Model

Scenario	Description	How it Was Modeled	How it Was Experimented On
Baseline 1: Dual Use Baseline (sensor in hall)	eFAF (hall thermostat) set to 71/76 and DHP (DHP return) set to 71/76.	Can't be modeled exactly. In lieu of exact model, this is done: both thermostats in zone 1. DHP is primary, eFAF kicks on if not reaching set point.[1]	Both thermostats in zone 1. Both set to 72/76. This baseline was not actually used in the experiment due to unpredictable air-flow and temperature behavior as a result of multiple systems acting at the same time.
Baseline 2: Central System Only	eFAF (hall thermostat) set to 71/76, DHP is disabled.	Multi-zone model. Only the central duct system is enabled.	The central system was set to 72/76 for heating and cooling respectively. No DHP was used in this case. Thermostat located in hallway.
eFAF Fan Only	Run central system as a circulator continuously.	Multi-zone model. Doors closed. DHP 71 heating set point, 76 cooling set point. Doors shut with air flowing back under doors. Follow up after experiments: different duct tightness and ECM motor.	Same as model. Ducts are not that tight in the Lab Homes, so results will likely not show much, if any savings.
Baseline 3: Dual Use Baseline (sensor in master bedroom)	eFAF (master bedroom thermostat) set to 71/76 and DHP (DHP return) set to 71/76.	DHP responding to living room thermostat and eFAF responding to bedroom thermostat.	Same as model.
eFAF Offset	eFAF set back to 67/80 and DHP set to 71/76 all the time.	eFAF (master bedroom thermostat) set to 67/80 and DHP (DHP return) set to 71/76.	Different** Set eFAF back 4 degrees all the time. Thermostats both in zone 1.
Stages	Stage 1: DHP only. Stage 2: Single element backup heat. Stage 3: eFAF on and	Stage 1: DHP Only. Stage 3: eFAF on full power	Not experimented on.

[1] This is forcing the model to what we hope would happen in real life, but does not without the proper controls to force the systems to act this way. The other baselines were developed as a way to try to capture that real life air flow behavior that experiments show.

	set 3 degrees lower than DHP.	when it comes on. No stage 2 modeled.	
Complex Schedule	Controls based on time of day. Smartly/automatically follow the occupant around the house. Bedrooms controlled by central thermostat with sensor in the master bedroom. DHP controlled the same as zonal complex schedule,	Central complex schedule same as zonal complex schedule. Bedrooms controlled by central thermostat with sensor in the master bedroom. DHP controlled the same as zonal complex schedule,	Same as model. Doors open.

3.3 Variation 2 - Climate Zones

The analysis of climate zones follows the typical residential code analysis. Thirty-five locations were chosen to help represent a reasonable distribution of potential energy savings in California, New York, and other states across the United States. Table 7 shows the typical meteorological year-3 locations used in IECC and DOE Building America climate zones associated with the national and New York state climate city locations. Table 8 Shows the climate city location in California based on California-specified climate zone classification.

Table 7. Climate Zones Used for the Parametric Study (New York and National)

National /New York	Climate City	IECC Climate Zone	Moisture Regime	Humidity Designation	Tropical Designation
national analysis	Miami, FL	1	Moist	Warm-Humid	Not Tropical
	Honolulu, HI	1	Moist	Warm-Humid	Tropical
	Houston, TX	2	Moist	Warm-Humid	Not Tropical
	Phoenix, AZ	2	Dry	Not Warm-Humid	Not Tropical
	Memphis, TN	3	Moist	Warm-Humid	Not Tropical
	El Paso, TX	3	Dry	Not Warm-Humid	Not Tropical
	San Francisco, CA	3	Marine	Not Warm-Humid	Not Tropical
	Baltimore, MD	4	Moist	Not Warm-Humid	Not Tropical
	Albuquerque, NM	4	Dry	Not Warm-Humid	Not Tropical
	Salem, OR	4	Marine	Not Warm-Humid	Not Tropical
	Chicago, IL	5	Moist	Not Warm-Humid	Not Tropical
	Boise, ID	5	Dry	Not Warm-Humid	Not Tropical
	Burlington, VT	6	Moist	Not Warm-Humid	Not Tropical
	Helena, MT	6	Dry	Not Warm-Humid	Not Tropical
	Duluth, MN	7	-	Not Warm-Humid	Not Tropical

	Fairbanks, AK	8	-	Not Warm-Humid	Not Tropical
New York state analysis	New York, NY	4	Moist	Not Warm-Humid	Not Tropical
	Albany, NY	5	Moist	Not Warm-Humid	Not Tropical
	Binghamton, NY	6	Moist	Not Warm-Humid	Not Tropical

Table 8. Climate Zones Used for the Parametric Study (California climate zone map)

Climate Zone and Climate City
CZ 1: Arcata
CZ 2: Santa Rosa
CZ 3: Oakland
CZ 4: San Jose-Reid
CZ 5: Santa Maria
CZ 6: Torrance
CZ 7: San Diego-Lindbergh
CZ 8: Fullerton
CZ 9: Burbank-Glendale
CZ10: Riverside
CZ11: Red Bluff
CZ12: Sacramento
CZ13: Fresno
CZ14: Palmdale (used Lancaster)
CZ15: Palm Spring-Intl
CZ16: Blue Canyon

3.4 Variation 3 - Prototype Buildings Size

A parametric analysis was used to provide a variety of use cases that might be helpful for utilities with multiple residential building system types in their building stocks. Table 9 shows the building total square footage, HVAC system configuration and control scenarios for each of the prototypes.

Table 9. Two sizes of prototype building model

	Size A			Size B		
Zone Name	Area [m2]	Area [ft2]	Conditioned (Y/N)	Area [m2]	Area [ft2]	Conditioned (Y/N)
ZONE1	80	862	Yes	120	1288	Yes
ZONE2	13	139	Yes	13	139	Yes
ZONE3	14	155	Yes	14	155	Yes
ZONE4	29	316	Yes	69	742	Yes
ZONE5	2	22	No	2	22	No
Total	139	1493		218	2346	

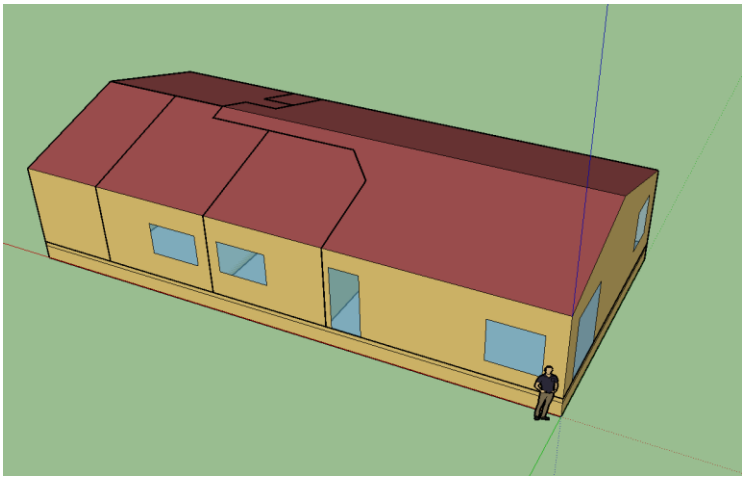

Figure 5. View of EnergyPlus model in Sketchup (Size A: 1493 ft^2)

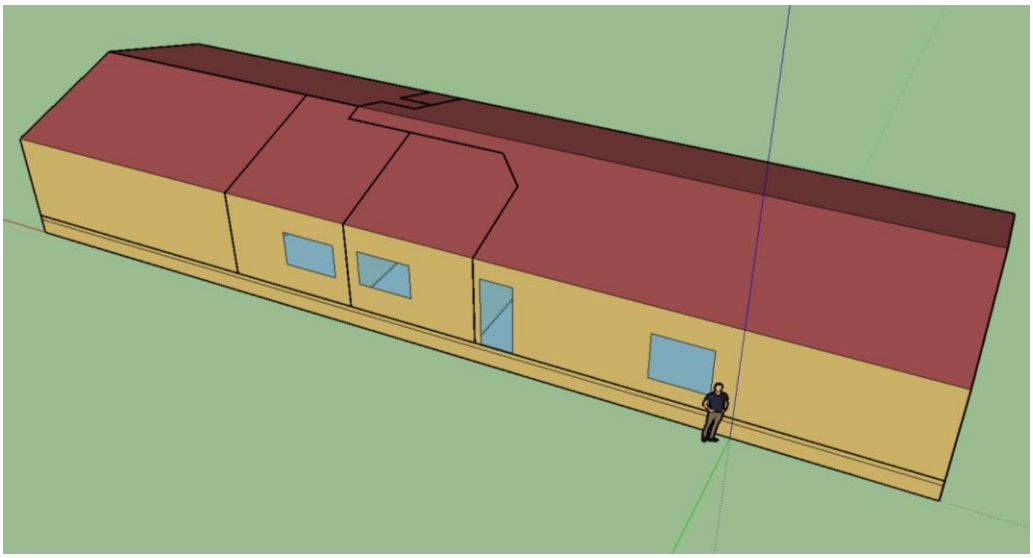

Figure 6. View of EnergyPlus model in Sketchup (Size B: 2346 ft^2)

3.5 Summary of all the cases

The variables described in this chapter provide details for the parametric analysis conducted in this study. This diversity allows utilities and other researchers to pick and choose which modeling results apply to their housing stock and extrapolate potential savings estimates accordingly. Results from these parametric simulations are presented in Chapter 4.

Table 10. Prototype Characteristics

	Building area	HVAC system type	Control Case
Prototype #1	1493 ft^2	DHP with Zonal Heating and Cooling	Baseline 1(Dual Use Baseline)
			Bedroom Setback vs B1
			Power Transfer Fans vs B1
			Complex Schedule vs B1
		DHP with Central Heating and Cooling	Baseline1(Dual Use Baseline, both thermostats in zone 1, set to the same set point)
			Baseline 2(Central Only)
			Fan Only vs B2 (Central Only)
			Baseline 3 (DHP sensor in living room, Central system sensor in master bedroom, can be set to different set points)
			eFAF Offset vs B3
			Stages vs B3
			Complex Schedule vs B3
Prototype #2	2346 ft^2	DHP with Zonal Heating and Cooling	Baseline 1(Dual Use Baseline)
			Bedroom Setback vs B1
			Power Transfer Fans vs B1
			Complex Schedule vs B1
		DHP with Central Heating and Cooling	Baseline 1(Dual Use Baseline, both thermostats in zone 1, set to the same set point)
			Baseline 2(Central Only)
			Fan Only vs B2
			Baseline 3 (DHP sensor in living room, Central system sensor in master bedroom, can be set to different set points)
			EFAF Offset vs B3
			Stages vs B3
			Complex Schedule vs B3

4.0 Results

Results represent year-round savings and are presented according to climate zone, which gives utilities a quick way to find results that are the most applicable to their jurisdictions. This section includes the national result, New York result and California result.

Although it would be ideal to compare the results from these models to the results from the lab homes tests, the results are actually not comparable because the lab homes results were just a few days for each test, and the modeling results represent a combination of heating and cooling tests for the entire year.

4.1 National results

Table 11. Energy Use and Savings in National for CZ1Moist (DHP with Zonal Heating and Cooling)

Control Scenarios	Heating (kwh)	Cooling (kWh)	Fans (kWh)	Interior Equipment (kWh)	Interior Lighting (kWh)	Total End Uses (kWh)	Total Energy saving %	HVAC Energy Usage (kWh)	HVAC Energy Saving %
Building Size A: 1493 ft2									
Baseline 1	8	6994	222	13600	128	20953		7225	
Bedroom Setback	3	5497	231	13600	128	19458	-7%	5731	-21%
Power Transfer Fan	0	5561	258	14914	128	20861	0%	5819	-19%
Complex Schedule	0	5339	222	13600	128	19289	-8%	5561	-23%
Building Size B: 2346 ft2									
Baseline 1	22	10047	306	21503	200	32078		10375	
Bedroom Setback	6	7683	317	21503	200	29708	-7%	8006	-23%
Power Transfer Fan	3	7594	350	22817	200	30964	-3%	7947	-23%
Complex Schedule	3	7444	306	21503	200	29456	-8%	7753	-25%

Table 12. Energy Use and Savings in National for CZ1Moist (DHP with Central System)

Control Scenarios	Heating (kwh)	Cooling (kWh)	Fans (kWh)	Interior Equipment (kWh)	Interior Lighting (kWh)	Total End Uses (kWh)	Total Energy Saving %	HVAC Energy Usage (kWh)	HVAC Energy Saving %
Building Size A: 1493 ft2									
Baseline 1	3	6692	947	13600	128	21369		7642	
Baseline 2 (Central Only)	11	6881	925	13600	128	21544	1%	7817	2%
Fan Only vs B2 (Central Only)	0	5706	2906	13600	128	22342	4%	8611	10%
Baseline 3	22	7444	964	13600	128	22156		8431	
EFAF Offset vs B3	6	6628	778	13600	128	21139	-5%	7411	-12%
Stages vs B3	6	6936	864	13600	128	21533	-3%	7806	-7%

Complex Schedule vs B3	22	5542	431	13600	128	19719	-11%	5994	-29%
Building Size B: 2346 ft2									
Baseline 1	8	9367	1253	21503	200	32331		10628	
Baseline 2 (Central Only)	36	9786	1200	21503	200	32728	1%	11022	4%
Fan Only vs B2 (Central Only)	0	7675	3811	21503	200	33189	1%	11486	4%
Baseline 3	67	10611	1189	21503	200	33569		11867	
EFAF Offset vs B3	11	9517	961	21503	200	32192	-4%	10489	-12%
Stages vs B3	14	9892	1058	21503	200	32667	-3%	10964	-8%
Complex Schedule vs B3	25	7736	575	21503	200	30039	-11%	8336	-30%

Table 13. Energy Use and Savings in National for CZ1Moist (Tropical) (DHP with Zonal Heating and Cooling)

Control Scenarios	Heating (kwh)	Cooling (kWh)	Fans (kWh)	Interior Equipment (kWh)	Interior Lighting (kWh)	Total End Uses (kWh)	Total Energy saving %	HVAC Energy Usage (kWh)	HVAC Energy Saving %
Building Size A: 1493 ft2									
Baseline 1	0	7069	211	13600	128	21008		7281	
Bedroom Setback	0	5431	222	13600	128	19378	-8%	5653	-22%
Power Transfer Fan	0	5575	250	14914	128	20867	-1%	5825	-20%
Complex Schedule	0	5269	214	13600	128	19208	-9%	5483	-25%
Building Size B: 2346 ft2									
Baseline 1	0	10103	292	21503	200	32097		10394	
Bedroom Setback	0	7547	303	21503	200	29553	-8%	7850	-24%
Power Transfer Fan	0	7558	339	22817	200	30914	-4%	7897	-24%
Complex Schedule	0	7325	292	21503	200	29319	-9%	7617	-27%

Table 14. Energy Use and Savings in National for CZ1Moist (Tropical) (DHP with Central System)

Control Scenarios	Heating (kwh)	Cooling (kWh)	Fans (kWh)	Interior Equipment (kWh)	Interior Lighting (kWh)	Total End Uses (kWh)	Total Energy Saving %	HVAC Energy Usage (kWh)	HVAC Energy Saving %
Building Size A: 1493 ft2									
Baseline 1	0	6617	944	13600	128	21289		7561	
Baseline 2 (Central Only)	0	6794	922	13600	128	21444	1%	7717	2%
Fan Only vs B2 (Central Only)	0	5775	2844	13600	128	22350	4%	8619	12%
Baseline 3	0	7656	992	13600	128	22375		8647	
EFAF Offset vs B3	0	6708	817	13600	128	21253	-5%	7525	-13%
Stages vs B3	0	7092	900	13600	128	21717	-3%	7992	-8%
Complex Schedule vs B3	6	5478	428	13600	128	19639	-12%	5911	-32%
Building Size B: 2346 ft2									

Baseline 1	0	9272	1247	21503	200	32222		10519	
Baseline 2 (Central Only)	0	9747	1192	21503	200	32642	1%	10939	4%
Fan Only vs B2 (Central Only)	0	7742	3719	21503	200	33164	2%	11461	5%
Baseline 3	0	10731	1203	21503	200	33636		11933	
EFAF Offset vs B3	0	9600	992	21503	200	32297	-4%	10592	-11%
Stages vs B3	0	9961	1086	21503	200	32750	-3%	11047	-7%
Complex Schedule vs B3	6	7617	567	21503	200	29892	-11%	8189	-31%

Table 15. Energy Use and Savings in National for CZ2Dry (DHP with Zonal Heating and Cooling)

Control Scenarios	Heating (kwh)	Cooling (kWh)	Fans (kWh)	Interior Equipment (kWh)	Interior Lighting (kWh)	Total End Uses (kWh)	Total Energy saving %	HVAC Energy Usage (kWh)	HVAC Energy Saving %
Building Size A: 1493 ft2									
Baseline 1	158	7278	289	13600	128	21453		7725	
Bedroom Setback	53	5969	297	13600	128	20047	-7%	6319	-18%
Power Transfer Fan	22	6161	322	14914	128	21547	0%	6506	-16%
Complex Schedule	14	5775	289	13600	128	19806	-8%	6078	-21%
Building Size B: 2346 ft2									
Baseline 1	319	9900	403	21503	200	32325		10622	
Bedroom Setback	106	8003	414	21503	200	30228	-6%	8522	-20%
Power Transfer Fan	53	8103	442	22817	200	31617	-2%	8597	-19%
Complex Schedule	33	7739	403	21503	200	29881	-8%	8175	-23%

Table 16. Energy Use and Savings in National for CZ2Dry (DHP with Central System)

Control Scenarios	Heating (kwh)	Cooling (kWh)	Fans (kWh)	Interior Equipment (kWh)	Interior Lighting (kWh)	Total End Uses (kWh)	Total Energy Saving %	HVAC Energy Usage (kWh)	HVAC Energy Saving %
Building Size A: 1493 ft2									
Baseline 1	61	7636	1228	13600	128	22650		8925	
Baseline 2 (Central Only)	175	7736	1219	13600	128	22858	1%	9131	2%
Fan Only vs B2 (Central Only)	6	6433	3706	13600	128	23875	4%	10144	11%
Baseline 3	211	8147	1278	13600	128	23364		9636	
EFAF Offset vs B3	75	7481	939	13600	128	22222	-5%	8494	-12%
Stages vs B3	81	7747	1064	13600	128	22619	-3%	8892	-8%
Complex Schedule vs B3	92	6131	483	13600	128	20433	-13%	6706	-30%
Building Size B: 2346 ft2									
Baseline 1	119	10339	1675	21503	200	33836		12133	
Baseline 2 (Central Only)	408	10556	1672	21503	200	34339	1%	12636	4%
Fan Only vs B2 (Central Only)	17	8492	5008	21503	200	35219	3%	13517	7%

Baseline 3	575	11064	1700	21503	200	35044		13339	
EFAF Offset vs B3	136	10128	1228	21503	200	33197	-5%	11492	-14%
Stages vs B3	186	10517	1394	21503	200	33800	-4%	12097	-9%
Complex Schedule vs B3	139	8256	683	21503	200	30781	-12%	9078	-32%

Table 17. Energy Use and Savings in National for CZ2Moist (DHP with Zonal Heating and Cooling)

Control Scenarios	Heating (kwh)	Cooling (kWh)	Fans (kWh)	Interior Equipment (kWh)	Interior Lighting (kWh)	Total End Uses (kWh)	Total Energy saving %	HVAC Energy Usage (kWh)	HVAC Energy Saving %
Building Size A: 1493 ft2									
Baseline 1	522	5744	225	13600	128	20219		6492	
Bedroom Setback	222	4525	233	13600	128	18708	-7%	4981	-23%
Power Transfer Fan	139	4536	256	14914	128	19972	-1%	4931	-24%
Complex Schedule	83	4383	225	13600	128	18422	-9%	4692	-28%
Building Size B: 2346 ft2									
Baseline 1	961	8064	311	21503	200	31042		9336	
Bedroom Setback	422	6167	319	21503	200	28614	-8%	6908	-26%
Power Transfer Fan	292	6081	347	22817	200	29736	-4%	6719	-28%
Complex Schedule	192	5992	311	21503	200	28194	-9%	6494	-30%

Table 18. Energy Use and Savings in National for CZ2Moist (DHP with Central System)

Control Scenarios	Heating (kwh)	Cooling (kWh)	Fans (kWh)	Interior Equipment (kWh)	Interior Lighting (kWh)	Total End Uses (kWh)	Total Energy Saving %	HVAC Energy Usage (kWh)	HVAC Energy Saving %
Building Size A: 1493 ft2									
Baseline 1	228	5561	961	13600	128	20475		6750	
Baseline 2 (Central Only)	511	5664	953	13600	128	20856	2%	7128	6%
Fan Only vs B2 (Central Only)	83	4706	3086	13600	128	21603	4%	7875	10%
Baseline 3	669	6017	997	13600	128	21408		7683	
EFAF Offset vs B3	258	5356	681	13600	128	20019	-6%	6294	-18%
Stages vs B3	350	5608	803	13600	128	20489	-4%	6761	-12%
Complex Schedule vs B3	178	4481	375	13600	128	18764	-12%	5033	-34%
Building Size B: 2346 ft2									
Baseline 1	386	7686	1300	21503	200	31075		9372	
Baseline 2 (Central Only)	1086	7925	1283	21503	200	32000	3%	10294	10%
Fan Only vs B2 (Central Only)	175	6292	4075	21503	200	32244	1%	10542	2%
Baseline 3	1531	8486	1303	21503	200	33022		11319	
EFAF Offset vs B3	522	7528	886	21503	200	30639	-7%	8936	-21%
Stages vs B3	783	7894	1039	21503	200	31419	-5%	9717	-14%

Complex Schedule vs B3	369	6150	522	21503	200	28744	-13%	7042	-38%

Table 19. Energy Use and Savings in National for CZ3Dry (DHP with Zonal Heating and Cooling)

Control Scenarios	Heating (kwh)	Cooling (kWh)	Fans (kWh)	Interior Equipment (kWh)	Interior Lighting (kWh)	Total End Uses (kWh)	Total Energy saving %	HVAC Energy Usage (kWh)	HVAC Energy Saving %
Building Size A: 1493 ft2									
Baseline 1	875	5375	269	13600	128	20247		6519	
Bedroom Setback	364	4181	278	13600	128	18553	-8%	4822	-26%
Power Transfer Fan	197	4344	297	14914	128	19881	-2%	4839	-26%
Complex Schedule	122	4056	269	13600	128	18175	-10%	4447	-32%
Building Size B: 2346 ft2									
Baseline 1	1603	7128	372	21503	200	30806		9103	
Bedroom Setback	669	5481	378	21503	200	28233	-8%	6528	-28%
Power Transfer Fan	453	5542	403	22817	200	29414	-5%	6397	-30%
Complex Schedule	283	5294	367	21503	200	27647	-10%	5944	-35%

Table 20. Energy Use and Savings in National for CZ3Dry (DHP with Central System)

Control Scenarios	Heating (kwh)	Cooling (kWh)	Fans (kWh)	Interior Equipment (kWh)	Interior Lighting (kWh)	Total End Uses (kWh)	Total Energy Saving %	HVAC Energy Usage (kWh)	HVAC Energy Saving %
Building Size A: 1493 ft2									
Baseline 1	364	5472	1208	13600	128	20775		7044	
Baseline 2 (Central Only)	744	5514	1203	13600	128	21186	2%	7461	6%
Fan Only vs B2 (Central Only)	125	4681	3669	13600	128	22203	5%	8475	14%
Baseline 3	961	5831	1256	13600	128	21775		8047	
EFAF Offset vs B3	414	5228	758	13600	128	20128	-8%	6400	-20%
Stages vs B3	511	5478	944	13600	128	20658	-5%	6933	-14%
Complex Schedule vs B3	264	4244	394	13600	128	18631	-14%	4903	-39%
Building Size B: 2346 ft2									
Baseline 1	639	7181	1636	21503	200	31158		9456	
Baseline 2 (Central Only)	1506	7308	1625	21503	200	32144	3%	10439	10%
Fan Only vs B2 (Central Only)	258	6011	4850	21503	200	32822	2%	11119	7%
Baseline 3	2208	7728	1675	21503	200	33314		11611	
EFAF Offset vs B3	781	6831	992	21503	200	30308	-9%	8603	-26%
Stages vs B3	1117	7197	1247	21503	200	31267	-6%	9561	-18%
Complex Schedule vs B3	525	5594	572	21503	200	28394	-15%	6692	-42%

Table 21. Energy Use and Savings in National for CZ3Marine (DHP with Zonal Heating and Cooling)

Control Scenarios	Heating (kwh)	Cooling (kWh)	Fans (kWh)	Interior Equipment (kWh)	Interior Lighting (kWh)	Total End Uses (kWh)	Total Energy saving %	HVAC Energy Usage (kWh)	HVAC Energy Saving %
Building Size A: 1493 ft2									
Baseline 1	319	3378	186	13600	128	17611		3883	
Bedroom Setback	81	2431	192	13600	128	16431	-7%	2703	-30%
Power Transfer Fan	33	2500	203	14914	128	17778	1%	2736	-30%
Complex Schedule	14	2353	186	13600	128	16281	-8%	2553	-34%
Building Size B: 2346 ft2									
Baseline 1	689	4211	242	21503	200	26844		5142	
Bedroom Setback	183	2922	244	21503	200	25056	-7%	3350	-35%
Power Transfer Fan	86	2933	258	22817	200	26297	-2%	3278	-36%
Complex Schedule	33	2789	239	21503	200	24767	-8%	3061	-40%

Table 22. Energy Use and Savings in National for CZ3Marine (DHP with Central System)

Control Scenarios	Heating (kwh)	Cooling (kWh)	Fans (kWh)	Interior Equipment (kWh)	Interior Lighting (kWh)	Total End Uses (kWh)	Total Energy Saving %	HVAC Energy Usage (kWh)	HVAC Energy Saving %
Building Size A: 1493 ft2									
Baseline 1	92	3328	731	13600	128	17878		4150	
Baseline 2 (Central Only)	328	3356	731	13600	128	18139	1%	4414	6%
Fan Only vs B2 (Central Only)	14	2692	2811	13600	128	19244	6%	5517	25%
Baseline 3	453	3400	750	13600	128	18331		4603	
EFAF Offset vs B3	122	2911	361	13600	128	17119	-7%	3394	-26%
Stages vs B3	139	3128	456	13600	128	17450	-5%	3722	-19%
Complex Schedule vs B3	94	2400	194	13600	128	16417	-10%	2689	-42%
Building Size B: 2346 ft2									
Baseline 1	189	4103	953	21503	200	26947		5244	
Baseline 2 (Central Only)	797	4203	961	21503	200	27664	3%	5961	14%
Fan Only vs B2 (Central Only)	39	3197	3533	21503	200	28475	3%	6769	14%
Baseline 3	1564	4450	1022	21503	200	28742		7036	
EFAF Offset vs B3	250	3561	408	21503	200	25925	-10%	4219	-40%
Stages vs B3	392	3967	561	21503	200	26625	-7%	4919	-30%
Complex Schedule vs B3	153	2989	242	21503	200	25086	-13%	3383	-52%

Table 23. Energy Use and Savings in National for CZ3Moist (DHP with Zonal Heating and Cooling)

Control Scenarios	Heating (kwh)	Cooling (kWh)	Fans (kWh)	Interior Equipment (kWh)	Interior Lighting (kWh)	Total End Uses (kWh)	Total Energy saving %	HVAC Energy Usage (kWh)	HVAC Energy Saving %
Building Size A: 1493 ft2									
Baseline 1	1628	4975	225	13600	128	20556		6828	
Bedroom Setback	856	3853	231	13600	128	18667	-9%	4939	-28%
Power Transfer Fan	589	3889	250	14914	128	19767	-4%	4728	-31%
Complex Schedule	603	3728	225	13600	128	18283	-11%	4556	-33%
Building Size B: 2346 ft2									
Baseline 1	2925	6833	311	21503	200	31772		10069	
Bedroom Setback	1567	5158	317	21503	200	28747	-10%	7042	-30%
Power Transfer Fan	1189	5094	339	22817	200	29642	-7%	6622	-34%
Complex Schedule	1183	5003	308	21503	200	28197	-11%	6494	-36%

Table 24. Energy Use and Savings in National for CZ3Moist (DHP with Central System)

Control Scenarios	Heating (kwh)	Cooling (kWh)	Fans (kWh)	Interior Equipment (kWh)	Interior Lighting (kWh)	Total End Uses (kWh)	Total Energy Saving %	HVAC Energy Usage (kWh)	HVAC Energy Saving %
Building Size A: 1493 ft2									
Baseline 1	722	4844	1078	13600	128	20375		6644	
Baseline 2 (Central Only)	1664	4931	1075	13600	128	21394	5%	7669	15%
Fan Only vs B2 (Central Only)	408	4061	3117	13600	128	21311	0%	7586	-1%
Baseline 3	2022	5203	1125	13600	128	22078		8350	
EFAF Offset vs B3	992	4600	717	13600	128	20039	-9%	6308	-24%
Stages vs B3	1333	4839	872	13600	128	20772	-6%	7044	-16%
Complex Schedule vs B3	789	3811	400	13600	128	18728	-15%	5000	-40%
Building Size B: 2346 ft2									
Baseline 1	1247	6569	1444	21503	200	30964		9261	
Baseline 2 (Central Only)	3275	6736	1447	21503	200	33164	7%	11458	24%
Fan Only vs B2 (Central Only)	833	5306	4111	21503	200	31953	-4%	10250	-11%
Baseline 3	4242	7192	1492	21503	200	34628		12925	
EFAF Offset vs B3	2067	6294	961	21503	200	31025	-10%	9322	-28%
Stages vs B3	2786	6644	1156	21503	200	32289	-7%	10586	-18%
Complex Schedule vs B3	1606	5144	567	21503	200	29019	-16%	7317	-43%

Table 25. Energy Use and Savings in National for CZ4Dry (DHP with Zonal Heating and Cooling)

Control Scenarios	Heating (kwh)	Cooling (kWh)	Fans (kWh)	Interior Equipment (kWh)	Interior Lighting (kWh)	Total End Uses (kWh)	Total Energy saving %	HVAC Energy Usage (kWh)	HVAC Energy Saving %
Building Size A: 1493 ft2									
Baseline 1	2111	4375	258	13600	128	20472		6744	
Bedroom Setback	1031	3317	267	13600	128	18342	-10%	4614	-32%
Power Transfer Fan	731	3442	281	14914	128	19494	-5%	4453	-34%
Complex Schedule	561	3214	258	13600	128	17761	-13%	4033	-40%
Building Size B: 2346 ft2									
Baseline 1	3706	5689	353	21503	200	31450		9747	
Bedroom Setback	1847	4228	358	21503	200	28136	-11%	6433	-34%
Power Transfer Fan	1414	4261	378	22817	200	29069	-8%	6053	-38%
Complex Schedule	1178	4075	347	21503	200	27303	-13%	5600	-43%

Table 26. Energy Use and Savings in National for CZ4Dry (DHP with Central System)

Control Scenarios	Heating (kwh)	Cooling (kWh)	Fans (kWh)	Interior Equipment (kWh)	Interior Lighting (kWh)	Total End Uses (kWh)	Total Energy Saving %	HVAC Energy Usage (kWh)	HVAC Energy Saving %
Building Size A: 1493 ft2									
Baseline 1	956	4453	1319	13600	128	20453		6728	
Baseline 2 (Central Only)	1783	4478	1314	13600	128	21303	4%	7575	13%
Fan Only vs B2 (Central Only)	517	3764	3672	13600	128	21681	2%	7953	5%
Baseline 3	2297	4803	1369	13600	128	22200		8469	
EFAF Offset vs B3	1111	4208	775	13600	128	19822	-11%	6094	-28%
Stages vs B3	1453	4447	1025	13600	128	20656	-7%	6925	-18%
Complex Schedule vs B3	739	3392	431	13600	128	18289	-18%	4561	-46%
Building Size B: 2346 ft2									
Baseline 1	1586	5694	1783	21503	200	30767		9064	
Baseline 2 (Central Only)	3419	5792	1767	21503	200	32681	6%	10978	21%
Fan Only vs B2 (Central Only)	956	4700	4783	21503	200	32142	-2%	10439	-5%
Baseline 3	4842	6208	1850	21503	200	34603		12900	
EFAF Offset vs B3	2169	5314	1064	21503	200	30253	-13%	8547	-34%
Stages vs B3	2989	5667	1358	21503	200	31717	-8%	10014	-22%
Complex Schedule vs B3	1578	4342	647	21503	200	28272	-18%	6567	-49%

Table 27. Energy Use and Savings in National for CZ4Marine (DHP with Zonal Heating and Cooling)

Control Scenarios	Heating (kwh)	Cooling (kWh)	Fans (kWh)	Interior Equipment (kWh)	Interior Lighting (kWh)	Total End Uses (kWh)	Total Energy saving %	HVAC Energy Usage (kWh)	HVAC Energy Saving %
Building Size A: 1493 ft2									
Baseline 1	2167	3169	214	13600	128	19278		5550	
Bedroom Setback	1008	2353	217	13600	128	17306	-10%	3578	-36%
Power Transfer Fan	639	2367	228	14914	128	18275	-5%	3233	-42%
Complex Schedule	583	2272	211	13600	128	16794	-13%	3067	-45%
Building Size B: 2346 ft2									
Baseline 1	3936	4131	286	21503	200	30056		8353	
Bedroom Setback	1836	2956	289	21503	200	26783	-11%	5081	-39%
Power Transfer Fan	1306	2908	300	22817	200	27533	-8%	4514	-46%
Complex Schedule	1203	2831	278	21503	200	26017	-13%	4311	-48%

Table 28. Energy Use and Savings in National for CZ4Marine (DHP with Central System)

Control Scenarios	Heating (kwh)	Cooling (kWh)	Fans (kWh)	Interior Equipment (kWh)	Interior Lighting (kWh)	Total End Uses (kWh)	Total Energy Saving %	HVAC Energy Usage (kWh)	HVAC Energy Saving %
Building Size A: 1493 ft2									
Baseline 1	917	3114	1114	13600	128	18869		5144	
Baseline 2 (Central Only)	1953	3133	1114	13600	128	19928	6%	6200	21%
Fan Only vs B2 (Central Only)	408	2539	3261	13600	128	19939	0%	6208	0%
Baseline 3	2347	3189	1172	13600	128	20433		6708	
EFAF Offset vs B3	1069	2742	517	13600	128	18056	-12%	4328	-35%
Stages vs B3	1394	2928	747	13600	128	18797	-8%	5069	-24%
Complex Schedule vs B3	772	2300	300	13600	128	17100	-16%	3372	-50%
Building Size B: 2346 ft2									
Baseline 1	1522	3986	1508	21503	200	28722		7017	
Baseline 2 (Central Only)	3942	4053	1536	21503	200	31233	9%	9531	36%
Fan Only vs B2 (Central Only)	819	3144	4150	21503	200	29817	-5%	8114	-15%
Baseline 3	5644	4308	1694	21503	200	33350		11647	
EFAF Offset vs B3	2192	3489	772	21503	200	28156	-16%	6453	-45%
Stages vs B3	3156	3811	1075	21503	200	29747	-11%	8042	-31%
Complex Schedule vs B3	1628	2953	458	21503	200	26742	-20%	5039	-57%

Table 29. Energy Use and Savings in National for CZ4Moist (DHP with Zonal Heating and Cooling)

Control Scenarios	Heating (kwh)	Cooling (kWh)	Fans (kWh)	Interior Equipment (kWh)	Interior Lighting (kWh)	Total End Uses (kWh)	Total Energy saving %	HVAC Energy Usage (kWh)	HVAC Energy Saving %
Building Size A: 1493 ft2									
Baseline 1	2778	3867	217	13600	128	20592		6861	
Bedroom Setback	1522	2933	222	13600	128	18406	-11%	4678	-32%
Power Transfer Fan	1058	2956	236	14914	128	19292	-6%	4250	-38%
Complex Schedule	1139	2833	214	13600	128	17914	-13%	4186	-39%
Building Size B: 2346 ft2									
Baseline 1	5039	5194	294	21503	200	32231		10528	
Bedroom Setback	2806	3833	300	21503	200	28644	-11%	6939	-34%
Power Transfer Fan	2178	3764	319	22817	200	29278	-9%	6261	-41%
Complex Schedule	2264	3703	289	21503	200	27961	-13%	6256	-41%

Table 30. Energy Use and Savings in National for CZ4Moist (DHP with Central System)

Control Scenarios	Heating (kwh)	Cooling (kWh)	Fans (kWh)	Interior Equipment (kWh)	Interior Lighting (kWh)	Total End Uses (kWh)	Total Energy Saving %	HVAC Energy Usage (kWh)	HVAC Energy Saving %
Building Size A: 1493 ft2									
Baseline 1	1253	3753	1125	13600	128	19858		6131	
Baseline 2 (Central Only)	2844	3817	1119	13600	128	21506	8%	7781	27%
Fan Only vs B2 (Central Only)	750	3111	3061	13600	128	20653	-4%	6922	-11%
Baseline 3	3283	3953	1158	13600	128	22119		8394	
EFAF Offset vs B3	1714	3439	692	13600	128	19569	-12%	5844	-30%
Stages vs B3	2300	3644	875	13600	128	20547	-7%	6819	-19%
Complex Schedule vs B3	1392	2847	408	13600	128	18375	-17%	4647	-45%
Building Size B: 2346 ft2									
Baseline 1	2175	4956	1517	21503	200	30350		8647	
Baseline 2 (Central Only)	5550	5086	1525	21503	200	33864	12%	12161	41%
Fan Only vs B2 (Central Only)	1550	3978	3992	21503	200	31225	-8%	9519	-22%
Baseline 3	7047	5394	1606	21503	200	35750		14047	
EFAF Offset vs B3	3719	4597	1000	21503	200	31019	-13%	9317	-34%
Stages vs B3	4917	4900	1214	21503	200	32733	-8%	11031	-21%
Complex Schedule vs B3	2931	3775	594	21503	200	29003	-19%	7300	-48%

Table 31. Energy Use and Savings in National for CZ5Dry (DHP with Zonal Heating and Cooling)

Control Scenarios	Heating (kwh)	Cooling (kWh)	Fans (kWh)	Interior Equipment (kWh)	Interior Lighting (kWh)	Total End Uses (kWh)	Total Energy saving %	HVAC Energy Usage (kWh)	HVAC Energy Saving %
Building Size A: 1493 ft2									
Baseline 1	3128	3617	247	13600	128	20719		6992	
Bedroom Setback	1636	2781	253	13600	128	18394	-11%	4669	-33%
Power Transfer Fan	1136	2831	264	14914	128	19272	-7%	4231	-39%
Complex Schedule	1106	2689	244	13600	128	17764	-14%	4039	-42%
Building Size B: 2346 ft2									
Baseline 1	5503	4639	339	21503	200	32183		10481	
Bedroom Setback	2900	3483	342	21503	200	28428	-12%	6725	-36%
Power Transfer Fan	2233	3483	356	22817	200	29092	-10%	6072	-42%
Complex Schedule	2169	3353	331	21503	200	27556	-14%	5853	-44%

Table 32. Energy Use and Savings in National for CZ5Dry (DHP with Central System)

Control Scenarios	Heating (kwh)	Cooling (kWh)	Fans (kWh)	Interior Equipment (kWh)	Interior Lighting (kWh)	Total End Uses (kWh)	Total Energy Saving %	HVAC Energy Usage (kWh)	HVAC Energy Saving %
Building Size A: 1493 ft2									
Baseline 1	1464	3653	1378	13600	128	20225		6494	
Baseline 2 (Central Only)	2831	3689	1364	13600	128	21611	7%	7883	21%
Fan Only vs B2 (Central Only)	808	3042	3553	13600	128	21133	-2%	7403	-6%
Baseline 3	3308	3806	1406	13600	128	22247		8519	
EFAF Offset vs B3	1761	3317	769	13600	128	19578	-12%	5847	-31%
Stages vs B3	2300	3519	1025	13600	128	20572	-8%	6844	-20%
Complex Schedule vs B3	1336	2736	450	13600	128	18250	-18%	4522	-47%
Building Size B: 2346 ft2									
Baseline 1	2408	4636	1889	21503	200	30636		8933	
Baseline 2 (Central Only)	5419	4733	1881	21503	200	33739	10%	12033	35%
Fan Only vs B2 (Central Only)	1478	3775	4631	21503	200	31586	-6%	9883	-18%
Baseline 3	7097	4947	2011	21503	200	35758		14056	
EFAF Offset vs B3	3519	4175	1122	21503	200	30519	-15%	8817	-37%
Stages vs B3	4742	4472	1450	21503	200	32367	-9%	10664	-24%
Complex Schedule vs B3	2678	3475	667	21503	200	28525	-20%	6819	-51%

Table 33. Energy Use and Savings in National for CZ5Moist (DHP with Zonal Heating and Cooling)

Control Scenarios	Heating (kwh)	Cooling (kWh)	Fans (kWh)	Interior Equipment (kWh)	Interior Lighting (kWh)	Total End Uses (kWh)	Total Energy saving %	HVAC Energy Usage (kWh)	HVAC Energy Saving %
Building Size A: 1493 ft2									
Baseline 1	4972	3267	217	13600	128	22183		8456	
Bedroom Setback	3014	2422	219	13600	128	19386	-13%	5656	-33%
Power Transfer Fan	2281	2444	233	14914	128	20003	-10%	4958	-41%
Complex Schedule	2592	2342	214	13600	128	18875	-15%	5147	-39%
Building Size B: 2346 ft2									
Baseline 1	8853	4375	297	21503	200	35228		13525	
Bedroom Setback	5392	3144	303	21503	200	30542	-13%	8839	-35%
Power Transfer Fan	4481	3086	319	22817	200	30906	-12%	7886	-42%
Complex Schedule	4825	3033	292	21503	200	29853	-15%	8150	-40%

Table 34. Energy Use and Savings in National for CZ5Moist (DHP with Central System)

Control Scenarios	Heating (kwh)	Cooling (kWh)	Fans (kWh)	Interior Equipment (kWh)	Interior Lighting (kWh)	Total End Uses (kWh)	Total Energy Saving %	HVAC Energy Usage (kWh)	HVAC Energy Saving %
Building Size A: 1493 ft2									
Baseline 1	2564	3169	1306	13600	128	20764		7039	
Baseline 2 (Central Only)	5217	3222	1283	13600	128	23447	13%	9722	38%
Fan Only vs B2 (Central Only)	1911	2592	3092	13600	128	21322	-9%	7594	-22%
Baseline 3	6022	3350	1342	13600	128	24442		10714	
EFAF Offset vs B3	3664	2869	883	13600	128	21142	-14%	7417	-31%
Stages vs B3	4689	3050	1067	13600	128	22533	-8%	8806	-18%
Complex Schedule vs B3	3075	2364	514	13600	128	19678	-19%	5953	-44%
Building Size B: 2346 ft2									
Baseline 1	4517	4153	1781	21503	200	32153		10450	
Baseline 2 (Central Only)	9953	4281	1764	21503	200	37703	17%	15997	53%
Fan Only vs B2 (Central Only)	3822	3278	4017	21503	200	32819	-13%	11117	-31%
Baseline 3	12261	4558	1858	21503	200	40383		18678	
EFAF Offset vs B3	7767	3819	1286	21503	200	34572	-14%	12872	-31%
Stages vs B3	9542	4100	1489	21503	200	36833	-9%	15131	-19%
Complex Schedule vs B3	6053	3103	744	21503	200	31603	-22%	9900	-47%

Table 35. Energy Use and Savings in National for CZ6Dry (DHP with Zonal Heating and Cooling)

Control Scenarios	Heating (kwh)	Cooling (kWh)	Fans (kWh)	Interior Equipment (kWh)	Interior Lighting (kWh)	Total End Uses (kWh)	Total Energy saving %	HVAC Energy Usage (kWh)	HVAC Energy Saving %
Building Size A: 1493 ft2									
Baseline 1	5081	2886	244	13600	128	21939		8211	
Bedroom Setback	2939	2153	247	13600	128	19069	-13%	5339	-35%
Power Transfer Fan	2256	2175	258	14914	128	19733	-10%	4689	-43%
Complex Schedule	2378	2078	239	13600	128	18419	-16%	4694	-43%
Building Size B: 2346 ft2									
Baseline 1	8914	3642	328	21503	200	34583		12883	
Bedroom Setback	5178	2633	331	21503	200	29847	-14%	8142	-37%
Power Transfer Fan	4300	2614	344	22817	200	30278	-12%	7258	-44%
Complex Schedule	4439	2522	319	21503	200	28986	-16%	7281	-43%

Table 36. Energy Use and Savings in National for CZ6Dry (DHP with Central System)

Control Scenarios	Heating (kwh)	Cooling (kWh)	Fans (kWh)	Interior Equipment (kWh)	Interior Lighting (kWh)	Total End Uses (kWh)	Total Energy Saving %	HVAC Energy Usage (kWh)	HVAC Energy Saving %
Building Size A: 1493 ft2									
Baseline 1	2592	2903	1531	13600	128	20750		7025	
Baseline 2 (Central Only)	4833	2922	1508	13600	128	22989	11%	9264	32%
Fan Only vs B2 (Central Only)	1867	2378	3578	13600	128	21550	-6%	7822	-16%
Baseline 3	5550	2994	1558	13600	128	23828		10103	
EFAF Offset vs B3	3394	2558	892	13600	128	20575	-14%	6844	-32%
Stages vs B3	4247	2733	1167	13600	128	21872	-8%	8147	-19%
Complex Schedule vs B3	2706	2111	542	13600	128	19086	-20%	5358	-47%
Building Size B: 2346 ft2									
Baseline 1	4372	3592	2078	21503	200	31747		10042	
Baseline 2 (Central Only)	9036	3658	2047	21503	200	36444	15%	14742	47%
Fan Only vs B2 (Central Only)	3444	2875	4586	21503	200	32608	-11%	10906	-26%
Baseline 3	11467	3872	2219	21503	200	39264		17558	
EFAF Offset vs B3	6875	3139	1336	21503	200	33053	-16%	11350	-35%
Stages vs B3	8544	3406	1667	21503	200	35317	-10%	13617	-22%
Complex Schedule vs B3	5344	2639	806	21503	200	30492	-22%	8789	-50%

Table 37. Energy Use and Savings in National for CZ6Moist (DHP with Zonal Heating and Cooling)

Control Scenarios	Heating (kwh)	Cooling (kWh)	Fans (kWh)	Interior Equipment (kWh)	Interior Lighting (kWh)	Total End Uses (kWh)	Total Energy saving %	HVAC Energy Usage (kWh)	HVAC Energy Saving %
Building Size A: 1493 ft2									
Baseline 1	5808	2717	206	13600	128	22458		8731	
Bedroom Setback	3528	2011	211	13600	128	19475	-13%	5750	-34%
Power Transfer Fan	2725	2022	222	14914	128	20014	-11%	4969	-43%
Complex Schedule	3078	1942	203	13600	128	18947	-16%	5222	-40%
Building Size B: 2346 ft2									
Baseline 1	10244	3558	281	21503	200	35786		14083	
Bedroom Setback	6261	2547	286	21503	200	30797	-14%	9094	-35%
Power Transfer Fan	5242	2483	303	22817	200	31044	-13%	8028	-43%
Complex Schedule	5664	2447	275	21503	200	30092	-16%	8386	-40%

Table 38. Energy Use and Savings in National for CZ6Moist (DHP with Central System)

Control Scenarios	Heating (kwh)	Cooling (kWh)	Fans (kWh)	Interior Equipment (kWh)	Interior Lighting (kWh)	Total End Uses (kWh)	Total Energy Saving %	HVAC Energy Usage (kWh)	HVAC Energy Saving %
Building Size A: 1493 ft2									
Baseline 1	3056	2647	1303	13600	128	20736		7006	
Baseline 2 (Central Only)	6194	2689	1278	13600	128	23889	15%	10161	45%
Fan Only vs B2 (Central Only)	2403	2156	2978	13600	128	21261	-11%	7536	-26%
Baseline 3	7158	2778	1333	13600	128	24997		11269	
EFAF Offset vs B3	4486	2339	883	13600	128	21436	-14%	7708	-32%
Stages vs B3	5678	2506	1061	13600	128	22969	-8%	9244	-18%
Complex Schedule vs B3	3692	1967	508	13600	128	19894	-20%	6167	-45%
Building Size B: 2346 ft2									
Baseline 1	5458	3378	1761	21503	200	32300		10597	
Baseline 2 (Central Only)	11656	3489	1739	21503	200	38589	19%	16883	59%
Fan Only vs B2 (Central Only)	4833	2661	3828	21503	200	33025	-14%	11322	-33%
Baseline 3	14433	3733	1828	21503	200	41697		19994	
EFAF Offset vs B3	9489	3044	1267	21503	200	35503	-15%	13800	-31%
Stages vs B3	11411	3306	1458	21503	200	37883	-9%	16175	-19%
Complex Schedule vs B3	7197	2528	756	21503	200	32183	-23%	10481	-48%

Table 39. Energy Use and Savings in National for CZ7 (DHP with Zonal Heating and Cooling)

Control Scenarios	Heating (kwh)	Cooling (kWh)	Fans (kWh)	Interior Equipment (kWh)	Interior Lighting (kWh)	Total End Uses (kWh)	Total Energy saving %	HVAC Energy Usage (kWh)	HVAC Energy Saving %
Building Size A: 1493 ft2									
Baseline 1	8336	2256	208	13600	128	24525		10800	
Bedroom Setback	5347	1647	214	13600	128	20933	-15%	7208	-33%
Power Transfer Fan	4533	1658	225	14914	128	21456	-13%	6417	-41%
Complex Schedule	4875	1586	206	13600	128	20394	-17%	6667	-38%
Building Size B: 2346 ft2									
Baseline 1	14639	2872	283	21503	200	39497		17794	
Bedroom Setback	9519	2014	286	21503	200	33525	-15%	11819	-34%
Power Transfer Fan	8533	1972	303	22817	200	33825	-14%	10808	-39%
Complex Schedule	8903	1925	275	21503	200	32806	-17%	11103	-38%

Table 40. Energy Use and Savings in National for CZ7 (DHP with Central System)

Control Scenarios	Heating (kwh)	Cooling (kWh)	Fans (kWh)	Interior Equipment (kWh)	Interior Lighting (kWh)	Total End Uses (kWh)	Total Energy Saving %	HVAC Energy Usage (kWh)	HVAC Energy Saving %
Building Size A: 1493 ft2									
Baseline 1	5536	2250	1475	13600	128	22986		9261	
Baseline 2 (Central Only)	9456	2283	1431	13600	128	26900	17%	13169	42%
Fan Only vs B2 (Central Only)	4908	1781	3022	13600	128	23436	-13%	9711	-26%
Baseline 3	10642	2311	1486	13600	128	28169		14439	
EFAF Offset vs B3	7500	1914	1053	13600	128	24194	-14%	10467	-28%
Stages vs B3	9019	2067	1228	13600	128	26042	-8%	12314	-15%
Complex Schedule vs B3	6086	1603	631	13600	128	22047	-22%	8319	-42%
Building Size B: 2346 ft2									
Baseline 1	10111	2775	1975	21503	200	36564		14861	
Baseline 2 (Central Only)	17519	2869	1914	21503	200	44006	20%	22303	50%
Fan Only vs B2 (Central Only)	9675	2128	3819	21503	200	37328	-15%	15622	-30%
Baseline 3	21350	3072	2028	21503	200	48150		26450	
EFAF Offset vs B3	15706	2422	1492	21503	200	41322	-14%	19619	-26%
Stages vs B3	17939	2667	1675	21503	200	43983	-9%	22281	-16%
Complex Schedule vs B3	11906	2011	950	21503	200	36569	-24%	14867	-44%

Table 41. Energy Use and Savings in National for CZ8 (DHP with Zonal Heating and Cooling)

Control Scenarios	Heating (kwh)	Cooling (kWh)	Fans (kWh)	Interior Equipment (kWh)	Interior Lighting (kWh)	Total End Uses (kWh)	Total Energy saving %	HVAC Energy Usage (kWh)	HVAC Energy Saving %
Building Size A: 1493 ft2									
Baseline 1	13061	1931	222	13600	128	28942		15214	
Bedroom Setback	8994	1408	228	13600	128	24358	-16%	10631	-30%
Power Transfer Fan	8833	1411	244	14914	128	25531	-12%	10489	-31%
Complex Schedule	8594	1361	222	13600	128	23906	-17%	10178	-33%
Building Size B: 2346 ft2									
Baseline 1	21533	2397	294	21503	200	45931		24225	
Bedroom Setback	15131	1703	300	21503	200	38839	-15%	17133	-29%
Power Transfer Fan	15189	1667	317	22817	200	40189	-13%	17172	-29%
Complex Schedule	14608	1633	292	21503	200	38236	-17%	16533	-32%

Table 42. Energy Use and Savings in National for CZ8 (DHP with Central System)

Control Scenarios	Heating (kwh)	Cooling (kWh)	Fans (kWh)	Interior Equipment (kWh)	Interior Lighting (kWh)	Total End Uses (kWh)	Total Energy Saving %	HVAC Energy Usage (kWh)	HVAC Energy Saving %
Building Size A: 1493 ft2									
Baseline 1	12219	1883	1822	13600	128	29653		15925	
Baseline 2 (Central Only)	16486	1894	1769	13600	128	33875	14%	20150	27%
Fan Only vs B2 (Central Only)	11744	1550	3344	13600	128	30367	-10%	16639	-17%
Baseline 3	17775	1939	1836	13600	128	35275		21550	
EFAF Offset vs B3	14189	1664	1478	13600	128	31061	-12%	17331	-20%
Stages vs B3	16081	1772	1622	13600	128	33203	-6%	19475	-10%
Complex Schedule vs B3	11150	1372	1014	13600	128	27261	-23%	13536	-37%
Building Size B: 2346 ft2									
Baseline 1	21414	2331	2414	21503	200	47861		26158	
Baseline 2 (Central Only)	29019	2367	2353	21503	200	55442	16%	33739	29%
Fan Only vs B2 (Central Only)	21094	1842	4275	21503	200	48914	-12%	27211	-19%
Baseline 3	31536	2397	2436	21503	200	58072		36369	
EFAF Offset vs B3	25775	1978	1975	21503	200	51431	-11%	29728	-18%
Stages vs B3	28628	2136	2142	21503	200	54608	-6%	32906	-10%
Complex Schedule vs B3	20047	1656	1464	21503	200	44869	-23%	23167	-36%

4.2 New York Results

Table 43. Energy Use and Savings in New York for CZ4Moist (DHP with Zonal Heating and Cooling)

Control Scenarios	Heating (kwh)	Cooling (kWh)	Fans (kWh)	Interior Equipment (kWh)	Interior Lighting (kWh)	Total End Uses (kWh)	Total Energy saving %	HVAC Energy Usage (kWh)	HVAC Energy Saving %
Building Size A: 1493 ft2									
Baseline 1	3236	3564	208	13600	128	20736		7008	
Bedroom Setback	1739	2650	211	13600	128	18328	-12%	4600	-34%
Power Transfer Fan	1211	2692	225	14914	128	19172	-8%	4128	-41%
Complex Schedule	1314	2558	206	13600	128	17803	-14%	4078	-42%
Building Size B: 2346 ft2									
Baseline 1	5914	4778	283	21503	200	32678		10975	
Bedroom Setback	3228	3436	286	21503	200	28656	-12%	6950	-37%
Power Transfer Fan	2497	3386	303	22817	200	29203	-11%	6186	-44%
Complex Schedule	2608	3311	275	21503	200	27897	-15%	6194	-44%

Table 44. Energy Use and Savings in New York for CZ4Moist (DHP with Central System)

Control Scenarios	Heating (kwh)	Cooling (kWh)	Fans (kWh)	Interior Equipment (kWh)	Interior Lighting (kWh)	Total End Uses (kWh)	Total Energy Saving %	HVAC Energy Usage (kWh)	HVAC Energy Saving %
Building Size A: 1493 ft2									
Baseline 1	1436	3456	1153	13600	128	19772		6044	
Baseline 2 (Central Only)	3378	3525	1147	13600	128	21778	10%	8050	33%
Fan Only vs B2 (Central Only)	886	2828	2942	13600	128	20386	-6%	6656	-17%
Baseline 3	3933	3642	1189	13600	128	22492		8764	
EFAF Offset vs B3	1992	3128	694	13600	128	19542	-13%	5814	-34%
Stages vs B3	2714	3333	892	13600	128	20667	-8%	6939	-21%
Complex Schedule vs B3	1589	2572	406	13600	128	18294	-19%	4567	-48%
Building Size B: 2346 ft2									
Baseline 1	2475	4517	1558	21503	200	30253		8550	
Baseline 2 (Central Only)	6639	4678	1564	21503	200	34583	14%	12881	51%
Fan Only vs B2 (Central Only)	1828	3575	3814	21503	200	30919	-11%	9217	-28%
Baseline 3	8514	4964	1650	21503	200	36828		15128	
EFAF Offset vs B3	4425	4167	1011	21503	200	31308	-15%	9603	-37%
Stages vs B3	5892	4464	1239	21503	200	33300	-10%	11594	-23%
Complex Schedule vs B3	3400	3383	600	21503	200	29086	-21%	7383	-51%

Table 45. Energy Use and Savings in New York for CZ5Moist (DHP with Zonal Heating and Cooling)

Control Scenarios	Heating (kwh)	Cooling (kWh)	Fans (kWh)	Interior Equipment (kWh)	Interior Lighting (kWh)	Total End Uses (kWh)	Total Energy saving %	HVAC Energy Usage (kWh)	HVAC Energy Saving %
Building Size A: 1493 ft2									
Baseline 1	5161	2939	206	13600	128	22033		8306	
Bedroom Setback	3111	2183	211	13600	128	19233	-13%	5506	-34%
Power Transfer Fan	2342	2200	225	14914	128	19808	-10%	4767	-43%
Complex Schedule	2683	2108	203	13600	128	18722	-15%	4994	-40%
Building Size B: 2346 ft2									
Baseline 1	9228	3864	283	21503	200	35078		13375	
Bedroom Setback	5597	2778	286	21503	200	30364	-13%	8661	-35%
Power Transfer Fan	4628	2711	303	22817	200	30661	-13%	7642	-43%
Complex Schedule	5008	2672	275	21503	200	29661	-15%	7956	-41%

Table 46. Energy Use and Savings in New York for CZ5Moist (DHP with Central System)

Control Scenarios	Heating (kwh)	Cooling (kWh)	Fans (kWh)	Interior Equipment (kWh)	Interior Lighting (kWh)	Total End Uses (kWh)	Total Energy Saving %	HVAC Energy Usage (kWh)	HVAC Energy Saving %
Building Size A: 1493 ft2									
Baseline 1	2481	2858	1247	13600	128	20314		6586	
Baseline 2 (Central Only)	5442	2906	1225	13600	128	23300	15%	9572	45%
Fan Only vs B2 (Central Only)	1881	2331	2967	13600	128	20906	-10%	7178	-25%
Baseline 3	6325	3008	1281	13600	128	24342		10614	
EFAF Offset vs B3	3831	2553	836	13600	128	20947	-14%	7219	-32%
Stages vs B3	4936	2728	1011	13600	128	22403	-8%	8675	-18%
Complex Schedule vs B3	3189	2136	486	13600	128	19542	-20%	5811	-45%
Building Size B: 2346 ft2									
Baseline 1	4500	3664	1703	21503	200	31569		9867	
Baseline 2 (Central Only)	10414	3792	1683	21503	200	37592	19%	15889	61%
Fan Only vs B2 (Central Only)	3908	2897	3825	21503	200	32333	-14%	10631	-33%
Baseline 3	12933	4047	1767	21503	200	40450		18747	
EFAF Offset vs B3	8272	3342	1214	21503	200	34533	-15%	12828	-32%
Stages vs B3	10106	3617	1408	21503	200	36833	-9%	15131	-19%
Complex Schedule vs B3	6342	2753	717	21503	200	31514	-22%	9811	-48%

Table 47. Energy Use and Savings in New York for CZ6Moist (DHP with Zonal Heating and Cooling)

Control Scenarios	Heating (kwh)	Cooling (kWh)	Fans (kWh)	Interior Equipment (kWh)	Interior Lighting (kWh)	Total End Uses (kWh)	Total Energy saving %	HVAC Energy Usage (kWh)	HVAC Energy Saving %
Building Size A: 1493 ft2									
Baseline 1	5203	2650	206	13600	128	21783		8058	
Bedroom Setback	3092	1972	208	13600	128	19003	-13%	5272	-35%
Power Transfer Fan	2317	1975	222	14914	128	19556	-10%	4514	-44%
Complex Schedule	2647	1897	203	13600	128	18475	-15%	4747	-41%
Building Size B: 2346 ft2									
Baseline 1	9250	3486	278	21503	200	34717		13014	
Bedroom Setback	5497	2492	283	21503	200	29975	-14%	8272	-36%
Power Transfer Fan	4528	2431	297	22817	200	30272	-13%	7256	-44%
Complex Schedule	4892	2386	272	21503	200	29253	-16%	7550	-42%

Table 48. Energy Use and Savings in New York for CZ6Moist (DHP with Central System)

Control Scenarios	Heating (kwh)	Cooling (kWh)	Fans (kWh)	Interior Equipment (kWh)	Interior Lighting (kWh)	Total End Uses (kWh)	Total Energy Saving %	HVAC Energy Usage (kWh)	HVAC Energy Saving %
Building Size A: 1493 ft2									
Baseline 1	2519	2586	1289	13600	128	20119		6394	
Baseline 2 (Central Only)	5367	2622	1261	13600	128	22978	14%	9250	45%
Fan Only vs B2 (Central Only)	1867	2108	3008	13600	128	20711	-10%	6983	-25%
Baseline 3	6297	2714	1319	13600	128	24058		10331	
EFAF Offset vs B3	3786	2269	828	13600	128	20611	-14%	6883	-33%
Stages vs B3	4861	2433	1019	13600	128	22042	-8%	8314	-20%
Complex Schedule vs B3	3136	1919	483	13600	128	19264	-20%	5539	-46%
Building Size B: 2346 ft2									
Baseline 1	4428	3306	1747	21503	200	31183		9481	
Baseline 2 (Central Only)	10253	3419	1719	21503	200	37094	19%	15392	62%
Fan Only vs B2 (Central Only)	3789	2608	3842	21503	200	31944	-14%	10239	-33%
Baseline 3	12989	3689	1833	21503	200	40211		18511	
EFAF Offset vs B3	8117	2961	1197	21503	200	33981	-15%	12275	-34%
Stages vs B3	9936	3233	1417	21503	200	36289	-10%	14586	-21%
Complex Schedule vs B3	6181	2481	697	21503	200	31064	-23%	9358	-49%

4.3 California results

Table 49. Energy Use and Savings in California for CA1 (DHP with Zonal Heating and Cooling)

Control Scenarios	Heating (kwh)	Cooling (kWh)	Fans (kWh)	Interior Equipment (kWh)	Interior Lighting (kWh)	Total End Uses (kWh)	Total Energy saving %	HVAC Energy Usage (kWh)	HVAC Energy Saving %
Building Size A: 1493 ft2									
Baseline 1	1136	2697	167	13600	128	17728		4000	
Bedroom Setback	408	1978	169	13600	128	16281	-8%	2556	-36%
Power Transfer Fan	225	2019	181	14914	128	17464	-1%	2425	-39%
Complex Schedule	108	1894	167	13600	128	15897	-10%	2169	-46%
Building Size B: 2346 ft2									
Baseline 1	2056	3347	208	21503	200	27314		5611	
Bedroom Setback	736	2311	211	21503	200	24961	-9%	3258	-42%
Power Transfer Fan	456	2331	222	22817	200	26025	-5%	3008	-46%
Complex Schedule	258	2181	203	21503	200	24347	-11%	2642	-53%

Table 50. Energy Use and Savings in California for CA1 (DHP with Central System)

Control Scenarios	Heating (kwh)	Cooling (kWh)	Fans (kWh)	Interior Equipment (kWh)	Interior Lighting (kWh)	Total End Uses (kWh)	Total Energy Saving %	HVAC Energy Usage (kWh)	HVAC Energy Saving %
Building Size A: 1493 ft2									
Baseline 1	419	2667	781	13600	128	17592		3867	
Baseline 2 (Central Only)	1008	2694	781	13600	128	18211	4%	4483	16%
Fan Only vs B2 (Central Only)	147	2158	2592	13600	128	18625	2%	4897	9%
Baseline 3	1331	2683	803	13600	128	18544		4817	
EFAF Offset vs B3	464	2222	300	13600	128	16717	-10%	2986	-38%
Stages vs B3	614	2422	453	13600	128	17217	-7%	3489	-28%
Complex Schedule vs B3	239	1911	172	13600	128	16050	-13%	2322	-52%
Building Size B: 2346 ft2									
Baseline 1	689	3233	994	21503	200	26622		4917	
Baseline 2 (Central Only)	2031	3353	1000	21503	200	28086	5%	6383	30%
Fan Only vs B2 (Central Only)	319	2503	3142	21503	200	27664	-2%	5964	-7%
Baseline 3	3689	3619	1094	21503	200	30106		8403	
EFAF Offset vs B3	931	2750	386	21503	200	25767	-14%	4067	-52%
Stages vs B3	1536	3094	594	21503	200	26931	-11%	5225	-38%
Complex Schedule vs B3	558	2378	244	21503	200	24883	-17%	3181	-62%

Table 51. Energy Use and Savings in California for CA2 (DHP with Zonal Heating and Cooling)

Control Scenarios	Heating (kwh)	Cooling (kWh)	Fans (kWh)	Interior Equipment (kWh)	Interior Lighting (kWh)	Total End Uses (kWh)	Total Energy saving %	HVAC Energy Usage (kWh)	HVAC Energy Saving %
Building Size A: 1493 ft2									
Baseline 1	642	3858	208	13600	128	18436		4708	
Bedroom Setback	236	2883	214	13600	128	17061	-7%	3333	-29%
Power Transfer Fan	128	2925	228	14914	128	18322	-1%	3281	-30%
Complex Schedule	64	2803	211	13600	128	16803	-9%	3078	-35%
Building Size B: 2346 ft2									
Baseline 1	1197	5036	283	21503	200	28219		6517	
Bedroom Setback	444	3633	289	21503	200	26069	-8%	4367	-33%
Power Transfer Fan	275	3594	303	22817	200	27189	-4%	4172	-36%
Complex Schedule	147	3508	281	21503	200	25639	-9%	3936	-40%

Table 52. Energy Use and Savings in California for CA2 (DHP with Central System)

Control Scenarios	Heating (kwh)	Cooling (kWh)	Fans (kWh)	Interior Equipment (kWh)	Interior Lighting (kWh)	Total End Uses (kWh)	Total Energy Saving %	HVAC Energy Usage (kWh)	HVAC Energy Saving %
Building Size A: 1493 ft2									
Baseline 1	253	3836	892	13600	128	18706		4981	
Baseline 2 (Central Only)	603	3881	894	13600	128	19103	2%	5378	8%
Fan Only vs B2 (Central Only)	69	3106	3075	13600	128	19975	5%	6250	16%
Baseline 3	839	4003	950	13600	128	19517		5792	
EFAF Offset vs B3	297	3472	458	13600	128	17956	-8%	4228	-27%
Stages vs B3	367	3706	589	13600	128	18392	-6%	4661	-20%
Complex Schedule vs B3	242	2869	244	13600	128	17083	-12%	3356	-42%
Building Size B: 2346 ft2									
Baseline 1	444	4942	1200	21503	200	28289		6586	
Baseline 2 (Central Only)	1353	5053	1228	21503	200	29336	4%	7633	16%
Fan Only vs B2 (Central Only)	147	3853	3989	21503	200	29694	1%	7989	5%
Baseline 3	2231	5314	1303	21503	200	30550		8847	
EFAF Offset vs B3	561	4461	583	21503	200	27311	-11%	5606	-37%
Stages vs B3	842	4850	783	21503	200	28178	-8%	6475	-27%
Complex Schedule vs B3	422	3678	333	21503	200	26139	-14%	4433	-50%

Table 53. Energy Use and Savings in California for CA3 (DHP with Zonal Heating and Cooling)

Control Scenarios	Heating (kwh)	Cooling (kWh)	Fans (kWh)	Interior Equipment (kWh)	Interior Lighting (kWh)	Total End Uses (kWh)	Total Energy saving %	HVAC Energy Usage (kWh)	HVAC Energy Saving %
Building Size A: 1493 ft2									
Baseline 1	369	3531	189	13600	128	17814		4089	
Bedroom Setback	97	2569	194	13600	128	16589	-7%	2861	-30%
Power Transfer Fan	44	2619	208	14914	128	17911	1%	2872	-30%
Complex Schedule	19	2489	189	13600	128	16425	-8%	2697	-34%
Building Size B: 2346 ft2									
Baseline 1	750	4483	244	21503	200	27181		5478	
Bedroom Setback	211	3156	247	21503	200	25317	-7%	3614	-34%
Power Transfer Fan	106	3133	264	22817	200	26522	-2%	3503	-36%
Complex Schedule	50	3019	242	21503	200	25017	-8%	3311	-40%

Table 54. Energy Use and Savings in California for CA3 (DHP with Central System)

Control Scenarios	Heating (kwh)	Cooling (kWh)	Fans (kWh)	Interior Equipment (kWh)	Interior Lighting (kWh)	Total End Uses (kWh)	Total Energy Saving %	HVAC Energy Usage (kWh)	HVAC Energy Saving %
Building Size A: 1493 ft2									
Baseline 1	111	3469	747	13600	128	18058		4328	
Baseline 2 (Central Only)	367	3500	747	13600	128	18342	2%	4614	7%
Fan Only vs B2 (Central Only)	19	2808	2831	13600	128	19386	6%	5658	23%
Baseline 3	489	3544	764	13600	128	18525		4797	
EFAF Offset vs B3	136	3050	381	13600	128	17294	-7%	3567	-26%
Stages vs B3	161	3278	486	13600	128	17650	-5%	3925	-18%
Complex Schedule vs B3	111	2528	208	13600	128	16575	-11%	2847	-41%
Building Size B: 2346 ft2									
Baseline 1	214	4342	969	21503	200	27228		5525	
Baseline 2 (Central Only)	850	4461	975	21503	200	27992	3%	6286	14%
Fan Only vs B2 (Central Only)	56	3369	3547	21503	200	28675	2%	6972	11%
Baseline 3	1594	4731	1025	21503	200	29053		7350	
EFAF Offset vs B3	272	3833	450	21503	200	26261	-10%	4556	-38%
Stages vs B3	442	4256	608	21503	200	27008	-7%	5306	-28%
Complex Schedule vs B3	192	3231	267	21503	200	25392	-13%	3689	-50%

Table 55. Energy Use and Savings in California for CA4 (DHP with Zonal Heating and Cooling)

Control Scenarios	Heating (kwh)	Cooling (kWh)	Fans (kWh)	Interior Equipment (kWh)	Interior Lighting (kWh)	Total End Uses (kWh)	Total Energy saving %	HVAC Energy Usage (kWh)	HVAC Energy Saving %
Building Size A: 1493 ft2									
Baseline 1	461	4069	206	13600	128	18464		4736	
Bedroom Setback	161	3006	211	13600	128	17106	-7%	3378	-29%
Power Transfer Fan	86	3089	228	14914	128	18444	0%	3403	-28%
Complex Schedule	33	2925	208	13600	128	16897	-8%	3167	-33%
Building Size B: 2346 ft2									
Baseline 1	864	5264	278	21503	200	28108		6406	
Bedroom Setback	303	3778	283	21503	200	26064	-7%	4364	-32%
Power Transfer Fan	181	3783	300	22817	200	27281	-3%	4264	-33%
Complex Schedule	75	3647	278	21503	200	25706	-9%	4000	-38%

Table 56. Energy Use and Savings in California for CA4 (DHP with Central System)

Control Scenarios	Heating (kwh)	Cooling (kWh)	Fans (kWh)	Interior Equipment (kWh)	Interior Lighting (kWh)	Total End Uses (kWh)	Total Energy Saving %	HVAC Energy Usage (kWh)	HVAC Energy Saving %
Building Size A: 1493 ft2									
Baseline 1	175	4011	828	13600	128	18742		5014	
Baseline 2 (Central Only)	428	4053	828	13600	128	19039	2%	5308	6%
Fan Only vs B2 (Central Only)	44	3303	2994	13600	128	20069	5%	6342	19%
Baseline 3	592	4194	864	13600	128	19378		5650	
EFAF Offset vs B3	200	3664	483	13600	128	18072	-7%	4347	-23%
Stages vs B3	244	3900	603	13600	128	18475	-5%	4747	-16%
Complex Schedule vs B3	175	3003	253	13600	128	17156	-11%	3431	-39%
Building Size B: 2346 ft2									
Baseline 1	308	5128	1094	21503	200	28236		6531	
Baseline 2 (Central Only)	964	5247	1103	21503	200	29017	3%	7314	12%
Fan Only vs B2 (Central Only)	100	4072	3869	21503	200	29744	3%	8042	10%
Baseline 3	1581	5528	1122	21503	200	29933		8231	
EFAF Offset vs B3	367	4681	589	21503	200	27339	-9%	5636	-32%
Stages vs B3	572	5075	764	21503	200	28114	-6%	6411	-22%
Complex Schedule vs B3	283	3842	333	21503	200	26161	-13%	4458	-46%

Table 57. Energy Use and Savings in California for CA5 (DHP with Zonal Heating and Cooling)

Control Scenarios	Heating (kwh)	Cooling (kWh)	Fans (kWh)	Interior Equipment (kWh)	Interior Lighting (kWh)	Total End Uses (kWh)	Total Energy saving %	HVAC Energy Usage (kWh)	HVAC Energy Saving %
Building Size A: 1493 ft2									
Baseline 1	664	3736	194	13600	128	18319		4594	
Bedroom Setback	242	2708	200	13600	128	16875	-8%	3150	-31%
Power Transfer Fan	128	2814	211	14914	128	18194	-1%	3153	-31%
Complex Schedule	44	2631	194	13600	128	16597	-9%	2869	-38%
Building Size B: 2346 ft2									
Baseline 1	1231	4708	256	21503	200	27897		6194	
Bedroom Setback	447	3292	258	21503	200	25703	-8%	3997	-35%
Power Transfer Fan	275	3325	275	22817	200	26892	-4%	3875	-37%
Complex Schedule	108	3164	253	21503	200	25228	-10%	3525	-43%

Table 58. Energy Use and Savings in California for CA5 (DHP with Central System)

Control Scenarios	Heating (kwh)	Cooling (kWh)	Fans (kWh)	Interior Equipment (kWh)	Interior Lighting (kWh)	Total End Uses (kWh)	Total Energy Saving %	HVAC Energy Usage (kWh)	HVAC Energy Saving %
Building Size A: 1493 ft2									
Baseline 1	250	3733	850	13600	128	18561		4833	
Baseline 2 (Central Only)	592	3772	847	13600	128	18939	2%	5211	8%
Fan Only vs B2 (Central Only)	69	3008	2847	13600	128	19653	4%	5925	14%
Baseline 3	828	3853	864	13600	128	19275		5544	
EFAF Offset vs B3	289	3322	433	13600	128	17775	-8%	4044	-27%
Stages vs B3	367	3556	564	13600	128	18211	-6%	4486	-19%
Complex Schedule vs B3	192	2706	222	13600	128	16847	-13%	3119	-44%
Building Size B: 2346 ft2									
Baseline 1	433	4656	1100	21503	200	27894		6189	
Baseline 2 (Central Only)	1289	4789	1106	21503	200	28886	4%	7183	16%
Fan Only vs B2 (Central Only)	158	3592	3603	21503	200	29056	1%	7353	2%
Baseline 3	2242	5042	1128	21503	200	30117		8411	
EFAF Offset vs B3	556	4114	517	21503	200	26889	-11%	5186	-38%
Stages vs B3	867	4544	706	21503	200	27822	-8%	6117	-27%
Complex Schedule vs B3	347	3369	292	21503	200	25714	-15%	4008	-52%

Table 59. Energy Use and Savings in California for CA6 (DHP with Zonal Heating and Cooling)

Control Scenarios	Heating (kwh)	Cooling (kWh)	Fans (kWh)	Interior Equipment (kWh)	Interior Lighting (kWh)	Total End Uses (kWh)	Total Energy saving %	HVAC Energy Usage (kWh)	HVAC Energy Saving %
Building Size A: 1493 ft2									
Baseline 1	47	4406	200	13600	128	18381		4653	
Bedroom Setback	8	3267	208	13600	128	17208	-6%	3483	-25%
Power Transfer Fan	3	3339	225	14914	128	18608	1%	3567	-23%
Complex Schedule	0	3167	206	13600	128	17100	-7%	3372	-28%
Building Size B: 2346 ft2									
Baseline 1	108	5769	264	21503	200	27844		6142	
Bedroom Setback	28	4147	269	21503	200	26147	-6%	4444	-28%
Power Transfer Fan	8	4142	292	22817	200	27458	-1%	4442	-28%
Complex Schedule	3	4003	267	21503	200	25975	-7%	4272	-30%

Table 60. Energy Use and Savings in California for CA6 (DHP with Central System)

Control Scenarios	Heating (kwh)	Cooling (kWh)	Fans (kWh)	Interior Equipment (kWh)	Interior Lighting (kWh)	Total End Uses (kWh)	Total Energy Saving %	HVAC Energy Usage (kWh)	HVAC Energy Saving %
Building Size A: 1493 ft2									
Baseline 1	14	4289	733	13600	128	18761		5036	
Baseline 2 (Central Only)	67	4342	725	13600	128	18861	1%	5133	2%
Fan Only vs B2 (Central Only)	0	3569	2864	13600	128	20164	7%	6433	25%
Baseline 3	97	4433	719	13600	128	18981		5250	
EFAF Offset vs B3	25	3933	494	13600	128	18181	-4%	4453	-15%
Stages vs B3	28	4164	572	13600	128	18489	-3%	4764	-9%
Complex Schedule vs B3	89	3225	267	13600	128	17308	-9%	3581	-32%
Building Size B: 2346 ft2									
Baseline 1	31	5531	939	21503	200	28206		6500	
Baseline 2 (Central Only)	172	5719	925	21503	200	28519	1%	6817	5%
Fan Only vs B2 (Central Only)	3	4447	3639	21503	200	29789	4%	8089	19%
Baseline 3	386	6008	889	21503	200	28986		7283	
EFAF Offset vs B3	56	5167	583	21503	200	27508	-5%	5806	-20%
Stages vs B3	75	5597	669	21503	200	28044	-3%	6342	-13%
Complex Schedule vs B3	114	4225	339	21503	200	26381	-9%	4678	-36%

Table 61. Energy Use and Savings in California for CA7 (DHP with Zonal Heating and Cooling)

Control Scenarios	Heating (kwh)	Cooling (kWh)	Fans (kWh)	Interior Equipment (kWh)	Interior Lighting (kWh)	Total End Uses (kWh)	Total Energy saving %	HVAC Energy Usage (kWh)	HVAC Energy Saving %
Building Size A: 1493 ft2									
Baseline 1	39	4736	203	13600	128	18706		4978	
Bedroom Setback	6	3561	208	13600	128	17503	-6%	3775	-24%
Power Transfer Fan	3	3631	228	14914	128	18903	1%	3861	-22%
Complex Schedule	0	3458	206	13600	128	17392	-7%	3664	-26%
Building Size B: 2346 ft2									
Baseline 1	83	6269	267	21503	200	28322		6619	
Bedroom Setback	17	4572	272	21503	200	26567	-6%	4861	-27%
Power Transfer Fan	6	4553	297	22817	200	27875	-2%	4856	-27%
Complex Schedule	0	4428	269	21503	200	26403	-7%	4697	-29%

Table 62. Energy Use and Savings in California for CA7 (DHP with Central System)

Control Scenarios	Heating (kwh)	Cooling (kWh)	Fans (kWh)	Interior Equipment (kWh)	Interior Lighting (kWh)	Total End Uses (kWh)	Total Energy Saving %	HVAC Energy Usage (kWh)	HVAC Energy Saving %
Building Size A: 1493 ft2									
Baseline 1	11	4586	758	13600	128	19081		5356	
Baseline 2 (Central Only)	47	4653	747	13600	128	19175	0%	5447	2%
Fan Only vs B2 (Central Only)	0	3839	2842	13600	128	20408	6%	6681	23%
Baseline 3	75	4781	744	13600	128	19328		5600	
EFAF Offset vs B3	19	4253	536	13600	128	18536	-4%	4808	-14%
Stages vs B3	19	4489	614	13600	128	18853	-2%	5122	-9%
Complex Schedule vs B3	81	3508	289	13600	128	17603	-9%	3878	-31%
Building Size B: 2346 ft2									
Baseline 1	22	5964	972	21503	200	28664		6958	
Baseline 2 (Central Only)	119	6183	950	21503	200	28958	1%	7253	4%
Fan Only vs B2 (Central Only)	3	4836	3619	21503	200	30161	4%	8458	17%
Baseline 3	281	6494	903	21503	200	29381		7678	
EFAF Offset vs B3	42	5650	633	21503	200	28028	-5%	6325	-18%
Stages vs B3	56	6089	719	21503	200	28567	-3%	6864	-11%
Complex Schedule vs B3	106	4633	369	21503	200	26811	-9%	5108	-33%

Table 63. Energy Use and Savings in California for CA8 (DHP with Zonal Heating and Cooling)

Control Scenarios	Heating (kwh)	Cooling (kWh)	Fans (kWh)	Interior Equipment (kWh)	Interior Lighting (kWh)	Total End Uses (kWh)	Total Energy saving %	HVAC Energy Usage (kWh)	HVAC Energy Saving %
Building Size A: 1493 ft2									
Baseline 1	94	4939	225	13600	128	18986		5258	
Bedroom Setback	22	3747	231	13600	128	17728	-7%	4000	-24%
Power Transfer Fan	6	3836	253	14914	128	19136	1%	4094	-22%
Complex Schedule	3	3661	228	13600	128	17617	-7%	3892	-26%
Building Size B: 2346 ft2									
Baseline 1	211	6589	300	21503	200	28803		7100	
Bedroom Setback	53	4911	308	21503	200	26975	-6%	5272	-26%
Power Transfer Fan	17	4894	333	22817	200	28261	-2%	5244	-26%
Complex Schedule	6	4775	303	21503	200	26786	-7%	5083	-28%

Table 64. Energy Use and Savings in California for CA8 (DHP with Central System)

Control Scenarios	Heating (kwh)	Cooling (kWh)	Fans (kWh)	Interior Equipment (kWh)	Interior Lighting (kWh)	Total End Uses (kWh)	Total Energy Saving %	HVAC Energy Usage (kWh)	HVAC Energy Saving %
Building Size A: 1493 ft2									
Baseline 1	28	4833	853	13600	128	19439		5714	
Baseline 2 (Central Only)	117	4889	847	13600	128	19578	1%	5853	2%
Fan Only vs B2 (Central Only)	0	4083	3150	13600	128	20961	7%	7233	24%
Baseline 3	164	5025	864	13600	128	19781		6053	
EFAF Offset vs B3	44	4539	578	13600	128	18889	-5%	5161	-15%
Stages vs B3	50	4758	664	13600	128	19200	-3%	5472	-10%
Complex Schedule vs B3	97	3683	300	13600	128	17808	-10%	4081	-33%
Building Size B: 2346 ft2									
Baseline 1	61	6364	1128	21503	200	29256		7553	
Baseline 2 (Central Only)	292	6508	1122	21503	200	29625	1%	7922	5%
Fan Only vs B2 (Central Only)	6	5222	4075	21503	200	31006	5%	9303	17%
Baseline 3	558	6817	1125	21503	200	30203		8500	
EFAF Offset vs B3	92	6022	722	21503	200	28539	-6%	6836	-20%
Stages vs B3	122	6411	831	21503	200	29069	-4%	7364	-13%
Complex Schedule vs B3	136	4894	403	21503	200	27136	-10%	5433	-36%

Table 65. Energy Use and Savings in California for CA9 (DHP with Zonal Heating and Cooling)

Control Scenarios	Heating (kwh)	Cooling (kWh)	Fans (kWh)	Interior Equipment (kWh)	Interior Lighting (kWh)	Total End Uses (kWh)	Total Energy saving %	HVAC Energy Usage (kWh)	HVAC Energy Saving %
Building Size A: 1493 ft2									
Baseline 1	178	5125	239	13600	128	19269		5542	
Bedroom Setback	50	3892	247	13600	128	17917	-7%	4189	-24%
Power Transfer Fan	19	3983	267	14914	128	19311	0%	4269	-23%
Complex Schedule	6	3800	242	13600	128	17778	-8%	4047	-27%
Building Size B: 2346 ft2									
Baseline 1	369	6831	325	21503	200	29231		7525	
Bedroom Setback	106	5100	333	21503	200	27244	-7%	5539	-26%
Power Transfer Fan	47	5086	358	22817	200	28508	-2%	5492	-27%
Complex Schedule	17	4953	328	21503	200	27000	-8%	5297	-30%

Table 66. Energy Use and Savings in California for CA9 (DHP with Central System)

Control Scenarios	Heating (kwh)	Cooling (kWh)	Fans (kWh)	Interior Equipment (kWh)	Interior Lighting (kWh)	Total End Uses (kWh)	Total Energy Saving %	HVAC Energy Usage (kWh)	HVAC Energy Saving %
Building Size A: 1493 ft2									
Baseline 1	58	5050	928	13600	128	19761		6036	
Baseline 2 (Central Only)	181	5097	922	13600	128	19928	1%	6200	3%
Fan Only vs B2 (Central Only)	6	4272	3372	13600	128	21375	7%	7650	23%
Baseline 3	247	5281	958	13600	128	20214		6486	
EFAF Offset vs B3	78	4769	619	13600	128	19197	-5%	5467	-16%
Stages vs B3	86	4994	719	13600	128	19531	-3%	5800	-11%
Complex Schedule vs B3	111	3850	317	13600	128	18006	-11%	4278	-34%
Building Size B: 2346 ft2									
Baseline 1	117	6656	1239	21503	200	29714		8011	
Baseline 2 (Central Only)	436	6783	1236	21503	200	30158	1%	8456	6%
Fan Only vs B2 (Central Only)	17	5472	4408	21503	200	31603	5%	9897	17%
Baseline 3	767	7119	1269	21503	200	30861		9156	
EFAF Offset vs B3	150	6292	781	21503	200	28928	-6%	7222	-21%
Stages vs B3	208	6675	922	21503	200	29511	-4%	7806	-15%
Complex Schedule vs B3	167	5097	431	21503	200	27400	-11%	5694	-38%

Table 67. Energy Use and Savings in California for CA10 (DHP with Zonal Heating and Cooling)

Control Scenarios	Heating (kwh)	Cooling (kWh)	Fans (kWh)	Interior Equipment (kWh)	Interior Lighting (kWh)	Total End Uses (kWh)	Total Energy saving %	HVAC Energy Usage (kWh)	HVAC Energy Saving %
Building Size A: 1493 ft2									
Baseline 1	297	5028	228	13600	128	19281		5553	
Bedroom Setback	97	3844	236	13600	128	17906	-7%	4178	-25%
Power Transfer Fan	44	3961	253	14914	128	19300	0%	4258	-23%
Complex Schedule	17	3758	231	13600	128	17731	-8%	4006	-28%
Building Size B: 2346 ft2									
Baseline 1	581	6678	314	21503	200	29275		7572	
Bedroom Setback	192	4997	322	21503	200	27214	-7%	5511	-27%
Power Transfer Fan	106	5017	344	22817	200	28483	-3%	5467	-28%
Complex Schedule	36	4856	317	21503	200	26911	-8%	5208	-31%

Table 68. Energy Use and Savings in California for CA10 (DHP with Central System)

Control Scenarios	Heating (kwh)	Cooling (kWh)	Fans (kWh)	Interior Equipment (kWh)	Interior Lighting (kWh)	Total End Uses (kWh)	Total Energy Saving %	HVAC Energy Usage (kWh)	HVAC Energy Saving %
Building Size A: 1493 ft2									
Baseline 1	106	4989	939	13600	128	19761		6033	
Baseline 2 (Central Only)	275	5058	933	13600	128	19992	1%	6267	4%
Fan Only vs B2 (Central Only)	19	4197	3219	13600	128	21161	6%	7436	19%
Baseline 3	458	5375	1003	13600	128	20564		6836	
EFAF Offset vs B3	133	4792	628	13600	128	19281	-6%	5553	-19%
Stages vs B3	164	5044	742	13600	128	19675	-4%	5950	-13%
Complex Schedule vs B3	161	3872	314	13600	128	18072	-12%	4347	-36%
Building Size B: 2346 ft2									
Baseline 1	206	6567	1261	21503	200	29739		8033	
Baseline 2 (Central Only)	656	6725	1261	21503	200	30344	2%	8642	8%
Fan Only vs B2 (Central Only)	44	5375	4256	21503	200	31378	3%	9675	12%
Baseline 3	1136	7139	1294	21503	200	31272		9569	
EFAF Offset vs B3	256	6275	775	21503	200	29008	-7%	7306	-24%
Stages vs B3	378	6669	936	21503	200	29686	-5%	7983	-17%
Complex Schedule vs B3	233	5033	419	21503	200	27389	-12%	5686	-41%

Table 69. Energy Use and Savings in California for CA11 (DHP with Zonal Heating and Cooling)

Control Scenarios	Heating (kwh)	Cooling (kWh)	Fans (kWh)	Interior Equipment (kWh)	Interior Lighting (kWh)	Total End Uses (kWh)	Total Energy saving %	HVAC Energy Usage (kWh)	HVAC Energy Saving %
Building Size A: 1493 ft2									
Baseline 1	1000	4953	250	13600	128	19931		6203	
Bedroom Setback	386	3867	256	13600	128	18233	-9%	4508	-27%
Power Transfer Fan	214	3981	272	14914	128	19508	-2%	4467	-28%
Complex Schedule	131	3753	247	13600	128	17858	-10%	4131	-33%
Building Size B: 2346 ft2									
Baseline 1	1900	6572	344	21503	200	30519		8817	
Bedroom Setback	744	5008	350	21503	200	27808	-9%	6103	-31%
Power Transfer Fan	483	5039	369	22817	200	28911	-5%	5892	-33%
Complex Schedule	314	4836	339	21503	200	27192	-11%	5489	-38%

Table 70. Energy Use and Savings in California for CA11 (DHP with Central System)

Control Scenarios	Heating (kwh)	Cooling (kWh)	Fans (kWh)	Interior Equipment (kWh)	Interior Lighting (kWh)	Total End Uses (kWh)	Total Energy Saving %	HVAC Energy Usage (kWh)	HVAC Energy Saving %
Building Size A: 1493 ft2									
Baseline 1	406	5022	1178	13600	128	20333		6606	
Baseline 2 (Central Only)	978	5089	1183	13600	128	20978	3%	7250	10%
Fan Only vs B2 (Central Only)	111	4197	3475	13600	128	21511	3%	7783	7%
Baseline 3	1158	5297	1242	13600	128	21425		7697	
EFAF Offset vs B3	442	4722	650	13600	128	19544	-9%	5814	-24%
Stages vs B3	539	4969	856	13600	128	20094	-6%	6364	-17%
Complex Schedule vs B3	275	3822	331	13600	128	18158	-15%	4428	-42%
Building Size B: 2346 ft2									
Baseline 1	725	6572	1614	21503	200	30617		8911	
Baseline 2 (Central Only)	2139	6717	1653	21503	200	32211	5%	10508	18%
Fan Only vs B2 (Central Only)	253	5344	4606	21503	200	31906	-1%	10203	-3%
Baseline 3	2942	7017	1722	21503	200	33383		11681	
EFAF Offset vs B3	842	6150	894	21503	200	29589	-11%	7886	-32%
Stages vs B3	1281	6517	1186	21503	200	30686	-8%	8983	-23%
Complex Schedule vs B3	569	4981	494	21503	200	27744	-17%	6044	-48%

Table 71. Energy Use and Savings in California for CA12 (DHP with Zonal Heating and Cooling)

Control Scenarios	Heating (kwh)	Cooling (kWh)	Fans (kWh)	Interior Equipment (kWh)	Interior Lighting (kWh)	Total End Uses (kWh)	Total Energy saving %	HVAC Energy Usage (kWh)	HVAC Energy Saving %
Building Size A: 1493 ft2									
Baseline 1	831	4625	231	13600	128	19414		5686	
Bedroom Setback	322	3531	236	13600	128	17817	-8%	4089	-28%
Power Transfer Fan	183	3614	253	14914	128	19092	-2%	4050	-29%
Complex Schedule	94	3431	231	13600	128	17483	-10%	3756	-34%
Building Size B: 2346 ft2									
Baseline 1	1544	6103	314	21503	200	29667		7961	
Bedroom Setback	606	4547	319	21503	200	27175	-8%	5472	-31%
Power Transfer Fan	392	4528	339	22817	200	28275	-5%	5258	-34%
Complex Schedule	208	4386	311	21503	200	26611	-10%	4906	-38%

Table 72. Energy Use and Savings in California for CA12 (DHP with Central System)

Control Scenarios	Heating (kwh)	Cooling (kWh)	Fans (kWh)	Interior Equipment (kWh)	Interior Lighting (kWh)	Total End Uses (kWh)	Total Energy Saving %	HVAC Energy Usage (kWh)	HVAC Energy Saving %
Building Size A: 1493 ft2									
Baseline 1	350	4614	1036	13600	128	19725		6000	
Baseline 2 (Central Only)	786	4678	1039	13600	128	20228	3%	6503	8%
Fan Only vs B2 (Central Only)	92	3817	3281	13600	128	20917	3%	7189	11%
Baseline 3	992	4872	1092	13600	128	20683		6956	
EFAF Offset vs B3	383	4300	578	13600	128	18989	-8%	5261	-24%
Stages vs B3	467	4553	753	13600	128	19500	-6%	5772	-17%
Complex Schedule vs B3	253	3508	292	13600	128	17781	-14%	4053	-42%
Building Size B: 2346 ft2									
Baseline 1	608	6000	1403	21503	200	29714		8011	
Baseline 2 (Central Only)	1725	6142	1433	21503	200	31006	4%	9300	16%
Fan Only vs B2 (Central Only)	214	4803	4294	21503	200	31014	0%	9311	0%
Baseline 3	2561	6469	1500	21503	200	32236		10531	
EFAF Offset vs B3	711	5600	764	21503	200	28778	-11%	7075	-33%
Stages vs B3	1086	5981	1014	21503	200	29789	-8%	8081	-23%
Complex Schedule vs B3	486	4544	425	21503	200	27158	-16%	5456	-48%

Table 73. Energy Use and Savings in California for CA13 (DHP with Zonal Heating and Cooling)

Control Scenarios	Heating (kwh)	Cooling (kWh)	Fans (kWh)	Interior Equipment (kWh)	Interior Lighting (kWh)	Total End Uses (kWh)	Total Energy saving %	HVAC Energy Usage (kWh)	HVAC Energy Saving %
Building Size A: 1493 ft2									
Baseline 1	711	5244	242	13600	128	19925		6197	
Bedroom Setback	289	4106	250	13600	128	18369	-8%	4644	-25%
Power Transfer Fan	161	4222	269	14914	128	19692	-1%	4653	-25%
Complex Schedule	86	3986	242	13600	128	18042	-9%	4314	-30%
Building Size B: 2346 ft2									
Baseline 1	1303	7025	336	21503	200	30364		8664	
Bedroom Setback	531	5386	342	21503	200	27961	-8%	6258	-28%
Power Transfer Fan	342	5417	364	22817	200	29142	-4%	6122	-29%
Complex Schedule	192	5203	331	21503	200	27428	-10%	5725	-34%

Table 74. Energy Use and Savings in California for CA13 (DHP with Central System)

Control Scenarios	Heating (kwh)	Cooling (kWh)	Fans (kWh)	Interior Equipment (kWh)	Interior Lighting (kWh)	Total End Uses (kWh)	Total Energy Saving %	HVAC Energy Usage (kWh)	HVAC Energy Saving %
Building Size A: 1493 ft2									
Baseline 1	303	5247	1072	13600	128	20350		6622	
Baseline 2 (Central Only)	653	5319	1075	13600	128	20775	2%	7047	6%
Fan Only vs B2 (Central Only)	86	4453	3378	13600	128	21642	4%	7917	12%
Baseline 3	836	5594	1139	13600	128	21297		7569	
EFAF Offset vs B3	336	5008	672	13600	128	19744	-7%	6017	-21%
Stages vs B3	417	5256	831	13600	128	20231	-5%	6503	-14%
Complex Schedule vs B3	208	4108	344	13600	128	18386	-14%	4661	-38%
Building Size B: 2346 ft2									
Baseline 1	519	6931	1458	21503	200	30614		8908	
Baseline 2 (Central Only)	1406	7089	1478	21503	200	31678	3%	9972	12%
Fan Only vs B2 (Central Only)	183	5717	4469	21503	200	32072	1%	10369	4%
Baseline 3	2058	7500	1539	21503	200	32803		11097	
EFAF Offset vs B3	617	6633	886	21503	200	29842	-9%	8136	-27%
Stages vs B3	914	7003	1114	21503	200	30733	-6%	9031	-19%
Complex Schedule vs B3	408	5417	494	21503	200	28022	-15%	6319	-43%

Table 75. Energy Use and Savings in California for CA14 (DHP with Zonal Heating and Cooling)

Control Scenarios	Heating (kwh)	Cooling (kWh)	Fans (kWh)	Interior Equipment (kWh)	Interior Lighting (kWh)	Total End Uses (kWh)	Total Energy saving %	HVAC Energy Usage (kWh)	HVAC Energy Saving %
Building Size A: 1493 ft2									
Baseline 1	1217	5069	253	13600	128	20267		6539	
Bedroom Setback	533	3878	258	13600	128	18400	-9%	4669	-29%
Power Transfer Fan	336	4117	278	14914	128	19772	-2%	4731	-28%
Complex Schedule	194	3778	253	13600	128	17953	-11%	4225	-35%
Building Size B: 2346 ft2									
Baseline 1	2219	6622	353	21503	200	30897		9194	
Bedroom Setback	992	4944	358	21503	200	27997	-9%	6294	-32%
Power Transfer Fan	706	5119	378	22817	200	29222	-5%	6203	-33%
Complex Schedule	461	4797	347	21503	200	27311	-12%	5606	-39%

Table 76. Energy Use and Savings in California for CA14 (DHP with Central System)

Control Scenarios	Heating (kwh)	Cooling (kWh)	Fans (kWh)	Interior Equipment (kWh)	Interior Lighting (kWh)	Total End Uses (kWh)	Total Energy Saving %	HVAC Energy Usage (kWh)	HVAC Energy Saving %
Building Size A: 1493 ft2									
Baseline 1	519	5200	1231	13600	128	20678		6950	
Baseline 2 (Central Only)	1089	5269	1225	13600	128	21311	3%	7583	9%
Fan Only vs B2 (Central Only)	203	4389	3517	13600	128	21833	2%	8108	7%
Baseline 3	1469	5650	1297	13600	128	22144		8417	
EFAF Offset vs B3	611	4997	753	13600	128	20092	-9%	6361	-24%
Stages vs B3	808	5281	961	13600	128	20778	-6%	7050	-16%
Complex Schedule vs B3	400	3917	369	13600	128	18414	-17%	4686	-44%
Building Size B: 2346 ft2									
Baseline 1	903	6736	1678	21503	200	31022		9317	
Baseline 2 (Central Only)	2247	6900	1678	21503	200	32528	5%	10825	16%
Fan Only vs B2 (Central Only)	414	5564	4686	21503	200	32367	0%	10664	-1%
Baseline 3	3217	7303	1736	21503	200	33958		12256	
EFAF Offset vs B3	1178	6369	989	21503	200	30242	-11%	8536	-30%
Stages vs B3	1725	6758	1272	21503	200	31458	-7%	9756	-20%
Complex Schedule vs B3	825	4981	544	21503	200	28053	-17%	6350	-48%

Table 77. Energy Use and Savings in California for CA15 (DHP with Zonal Heating and Cooling)

Control Scenarios	Heating (kwh)	Cooling (kWh)	Fans (kWh)	Interior Equipment (kWh)	Interior Lighting (kWh)	Total End Uses (kWh)	Total Energy saving %	HVAC Energy Usage (kWh)	HVAC Energy Saving %
Building Size A: 1493 ft2									
Baseline 1	328	7211	272	13600	128	21539		7811	
Bedroom Setback	125	5764	281	13600	128	19897	-8%	6169	-21%
Power Transfer Fan	69	5972	306	14914	128	21386	-1%	6347	-19%
Complex Schedule	19	5603	275	13600	128	19622	-9%	5897	-25%
Building Size B: 2346 ft2									
Baseline 1	617	9806	383	21503	200	32508		10806	
Bedroom Setback	236	7675	392	21503	200	30006	-8%	8303	-23%
Power Transfer Fan	156	7794	419	22817	200	31386	-3%	8369	-23%
Complex Schedule	47	7447	383	21503	200	29581	-9%	7878	-27%

Table 78. Energy Use and Savings in California for CA15 (DHP with Central System)

Control Scenarios	Heating (kwh)	Cooling (kWh)	Fans (kWh)	Interior Equipment (kWh)	Interior Lighting (kWh)	Total End Uses (kWh)	Total Energy Saving %	HVAC Energy Usage (kWh)	HVAC Energy Saving %
Building Size A: 1493 ft2									
Baseline 1	139	7522	1183	13600	128	22569		8844	
Baseline 2 (Central Only)	317	7622	1178	13600	128	22844	1%	9117	3%
Fan Only vs B2 (Central Only)	31	6197	3567	13600	128	23522	3%	9794	7%
Baseline 3	439	8117	1261	13600	128	23547		9817	
EFAF Offset vs B3	164	7375	892	13600	128	22161	-6%	8431	-14%
Stages vs B3	194	7692	1022	13600	128	22636	-4%	8908	-9%
Complex Schedule vs B3	139	5842	422	13600	128	20128	-15%	6403	-35%
Building Size B: 2346 ft2									
Baseline 1	256	10164	1617	21503	200	33742		12036	
Baseline 2 (Central Only)	711	10372	1625	21503	200	34414	2%	12708	6%
Fan Only vs B2 (Central Only)	72	8161	4822	21503	200	34756	1%	13056	3%
Baseline 3	1025	10944	1669	21503	200	35342		13639	
EFAF Offset vs B3	303	9922	1161	21503	200	33089	-6%	11386	-17%
Stages vs B3	422	10367	1342	21503	200	33836	-4%	12131	-11%
Complex Schedule vs B3	225	7761	597	21503	200	30286	-14%	8583	-37%

Table 79. Energy Use and Savings in California for CA16 (DHP with Zonal Heating and Cooling)

Control Scenarios	Heating (kwh)	Cooling (kWh)	Fans (kWh)	Interior Equipment (kWh)	Interior Lighting (kWh)	Total End Uses (kWh)	Total Energy saving %	HVAC Energy Usage (kWh)	HVAC Energy Saving %
Building Size A: 1493 ft2									
Baseline 1	2747	3703	244	13600	128	20422		6694	
Bedroom Setback	1392	2708	250	13600	128	18081	-11%	4350	-35%
Power Transfer Fan	1003	2783	264	14914	128	19089	-7%	4050	-40%
Complex Schedule	933	2622	244	13600	128	17525	-14%	3800	-43%
Building Size B: 2346 ft2									
Baseline 1	4722	4733	325	21503	200	31486		9781	
Bedroom Setback	2383	3394	331	21503	200	27811	-12%	6108	-38%
Power Transfer Fan	1856	3389	344	22817	200	28608	-9%	5589	-43%
Complex Schedule	1767	3267	319	21503	200	27056	-14%	5353	-45%

Table 80. Energy Use and Savings in California for CA16 (DHP with Central System)

Control Scenarios	Heating (kwh)	Cooling (kWh)	Fans (kWh)	Interior Equipment (kWh)	Interior Lighting (kWh)	Total End Uses (kWh)	Total Energy Saving %	HVAC Energy Usage (kWh)	HVAC Energy Saving %
Building Size A: 1493 ft2									
Baseline 1	1247	3703	1350	13600	128	20025		6300	
Baseline 2 (Central Only)	2306	3719	1342	13600	128	21094	5%	7367	17%
Fan Only vs B2 (Central Only)	736	3069	3514	13600	128	21050	0%	7319	-1%
Baseline 3	2797	3875	1400	13600	128	21797		8072	
EFAF Offset vs B3	1442	3383	747	13600	128	19297	-11%	5572	-31%
Stages vs B3	1842	3586	1011	13600	128	20167	-7%	6439	-20%
Complex Schedule vs B3	1072	2703	414	13600	128	17917	-18%	4189	-48%
Building Size B: 2346 ft2									
Baseline 1	2003	4644	1789	21503	200	30139		8436	
Baseline 2 (Central Only)	4328	4722	1769	21503	200	32522	8%	10819	28%
Fan Only vs B2 (Central Only)	1319	3756	4450	21503	200	31228	-4%	9525	-12%
Baseline 3	6081	5011	1892	21503	200	34686		12983	
EFAF Offset vs B3	2819	4211	1025	21503	200	29761	-14%	8056	-38%
Stages vs B3	3806	4528	1328	21503	200	31367	-10%	9661	-26%
Complex Schedule vs B3	2164	3433	603	21503	200	27903	-20%	6200	-52%

5.0 Sensitivity Analysis of Air Leakage Rate

Envelope tightness has a significant impact on HVAC energy usage. In the sensitivity analysis, a range of air leakage rates were selected to conduct a sensitivity analysis: 2 air change per hour (ACH), 5 ACH, 8 ACH, and 11 ACH @ 50 Pascals. A house with a higher ACH value means more air leakage; thus these homes typically yield larger energy usage. However, from Table 81 and Table 82, it can be seen that the energy saving percentages remain relatively the same or similar regardless of the envelope tightness, although the energy usage has been increased significantly for houses with leakier envelope.

Table 81. Energy Use and Savings in CZ5B (DHP with Central system)

Row Labels	Heating (kwh)	Cooling (kWh)	Fans (kWh)	Interior Equipment (kWh)	Interior Lighting (kWh)	Total End Uses (kWh)	Total Energy Saving %	HVAC Energy Usage (kWh)	HVAC Energy Saving %
2 ACH									
Baseline1	886	3864	1197	13600	128	19675		5947	
Baseline 2 (Central Only)	1558	3892	1186	13600	128	20364	4%	6636	12%
Fan Only vs B2 (Central Only)	353	3278	3447	13600	128	20806	2%	7078	7%
Baseline 3	1858	4006	1244	13600	128	20833		7108	
EFAF Offset vs B3	961	3544	625	13600	128	18858	-9%	5131	-28%
Stages vs B3	1200	3736	867	13600	128	19531	-6%	5803	-18%
Complex Schedule vs B3	647	2964	356	13600	128	17694	-15%	3967	-44%
5 ACH									
Baseline1	1464	3653	1378	13600	128	20225		6494	
Baseline 2 (Central Only)	2831	3689	1364	13600	128	21611	7%	7883	21%
Fan Only vs B2 (Central Only)	808	3042	3553	13600	128	21133	-2%	7403	-6%
Baseline3	3308	3806	1406	13600	128	22247		8519	
EFAF Offset vs B3	1761	3317	769	13600	128	19578	-7%	5847	-21%
Stages vs B3	2300	3519	1025	13600	128	20572	-3%	6844	-8%
Complex Schedule vs B3	1336	2736	450	13600	128	18250	-14%	4522	-39%
8 ACH									
Baseline1	2050	3478	1550	13600	128	20806		7078	
Baseline 2 (Central Only)	4319	3519	1528	13600	128	23092	11%	9367	32%
Fan Only vs B2 (Central Only)	1322	2856	3664	13600	128	21569	-7%	7842	-16%
Baseline3	4958	3636	1558	13600	128	23881		10153	
EFAF Offset vs B3	2725	3136	914	13600	128	20503	-5%	6775	-14%
Stages vs B3	3611	3344	1181	13600	128	21861	1%	8136	4%
Complex Schedule vs B3	2214	2558	536	13600	128	19036	-12%	5308	-32%
11 ACH									
Baseline1	2636	3333	1706	13600	128	21400		7675	
Baseline 2 (Central Only)	5994	3375	1672	13600	128	24769	16%	11042	44%
Fan Only vs B2 (Central Only)	1950	2703	3778	13600	128	22158	-11%	8431	-24%

Baseline 3	6708	3494	1703	13600	128	25631		11906	
EFAF Offset vs B3	3836	2989	1053	13600	128	21606	-2%	7878	-7%
Stages vs B3	5039	3197	1322	13600	128	23283	5%	9558	13%
Complex Schedule vs B3	3211	2414	611	13600	128	19964	-10%	6236	-26%

Table 82. Energy Use and Savings in CZ5B (DHP with Zonal Heating and Cooling)

Row Labels	Heating (kwh)	Cooling (kWh)	Fans (kWh)	Interior Equipment (kWh)	Interior Lighting (kWh)	Total End Uses (kWh)	Total energy saving %	HVAC Energy Usage (kWh)	HVAC energy Saving %
2 ACH									
Baseline 1	1939	3833	239	13600	128	19739		6011	
Bedroom Setback	1056	3019	244	13600	128	18047	-9%	4319	-28%
Power Transfer Fan	675	3061	258	14914	128	19036	-4%	3994	-34%
Complex Schedule	519	2922	236	13600	128	17406	-12%	3678	-39%
5 ACH									
Baseline 1	3128	3617	247	13600	128	20719		6992	
Bedroom Setback	2036	2792	250	13600	128	18806	-9%	5078	-27%
Power Transfer Fan	1589	2839	261	14914	128	19733	-5%	4689	-33%
Complex Schedule	1353	2694	242	13600	128	18017	-13%	4289	-39%
8 ACH									
Baseline 1	4397	3436	256	13600	128	21817		8089	
Bedroom Setback	3125	2608	256	13600	128	19717	-10%	5989	-26%
Power Transfer Fan	2669	2661	269	14914	128	20642	-5%	5600	-31%
Complex Schedule	2422	2514	250	13600	128	18914	-13%	5186	-36%
11 ACH									
Baseline 1	5714	3281	267	13600	128	22989		9261	
Bedroom Setback	4278	2458	264	13600	128	20728	-10%	7000	-24%
Power Transfer Fan	3806	2517	278	14914	128	21642	-6%	6600	-29%
Complex Schedule	3583	2369	256	13600	128	19939	-13%	6208	-33%

6.0 Conclusions

Overall, the national analysis and sensitivity analysis showed a few trends:

- In general, energy savings are achieved in all climate zones when a DHP is used in conjunction with a central system or with zonal equipment. The more the DHP gets used to provide heating/cooling, the more energy savings will be achieved.
- Between central and zonal equipment, using a DHP in conjunction with a central system uses less energy. This is likely due to the fact that in the zonal system, each heating and cooling unit tries to maintain the individual bedroom's thermostat, while a central system will only maintain one central thermostat. The zonal system will provide more thermal comfort while using more energy.
- Complex scheduling provides the greatest savings for both systems in all IECC climate zones (up to about 48% for the zonal system and up to 57% for the central system). While such a schedule can be maintained manually, it can be efficiently automated using a smart controller with a preset schedule or occupancy-based temperature reset.
- For the zonal system, all IECC climate zones except CZ 1 and CZ 8 will see significant energy savings using various control strategies. The bedroom setback control strategy saves the least but can easily be done in practice since zonal equipment comes with its own thermostat and does not need an additional smart controller. In all climate zones, the complex schedule control strategy saved the most energy (up to about 48%) over the zonal Baseline 1 (both the DHP and the bedroom zonal heaters are set to the same set point).
- For the central system, energy can be saved by using a bedroom setpoint setback strategy (eFAF offset), especially in the colder climate zones (3,4,5,6). The highest energy savings, up to 57% over Baseline 3 (DHP controlled by living room thermostat and central system controlled by master bedroom thermostat), can be achieved by using the complex schedule. This can also be easily automated with a smart controller.
- For either scenario, in CZ 8, when it is too cold outside, the DHP may not provide much benefit due to the defrost cycle.

In conclusion, based on the trends described above, installing the DHP with the complex schedule control would provide the best energy saving potential in existing homes.

7.0 References

ASHRAE 2014 Guideline 14-2014: Measurement of Energy, Demand and Water Savings

ASHRAE. 2013. ASHRAE Standard 55-2013: Thermal environmental conditions for human occupancy (pp. 12).

Ashley, T. Metzger, C. E., Kolln, J., Sullivan, G. 2019. Maximizing the Use of Ductless Mini-Splits in the PNNL Lab Homes, PNNL report, December 2019.

Bonneville Power Administration. 2016. HVAC Market Intelligence Report.

Christensen, D. et al. 2011. Field Monitoring Protocol: Mini-Split Heat Pumps. *National Renewable Energy Laboratory*.

Conzemius, S. et al. 2016. Northwest Ductless Heat Pump Initiative: Market Progress Evaluation Report #5. *Northwest Energy Efficiency Alliance*.

Dentz, J. et al. 2014. Mini-Split Heat Pumps Multifamily Retrofit Feasibility Study. *National Renewable Energy Laboratory.*

Dieckmann, J. 2008. Improving humidity control with energy recovery ventilation. *ASHRAE Journal, 50*(8), 38.

Geraghty, K. et al. 2009. Residential Ductless Mini-Split Heat Pump Retrofit Monitoring. *Bonneville Power Administration.*

Logsdon, M. et al. 2016. Assessment of Ductless Mini-Split Heat Pump Energy Savings in Stack House Apartments.

Metzger, CE et al. 2018. Are Ducted Mini-Splits Worth It? *ASHRAE Journal,* 2018. 60: p. 22-31.

Northwest Energy Efficiency Alliance. 2009. Report: Northwest Ductless Heat Pump Pilot Project, Market Progress Evaluation Report #1. Portland, OR: Northwest Energy Efficiency Alliance. Report #E10-215.

Pacific Northwest National Laboratory. 2018. PNNL Lab Homes. Retrieved from https://labhomes.pnnl.gov/

Pang Z., Y. Chen, C.E. Metzger, C. Dymond, and J. Zhang. 2019. "Maximize the energy performance of the ductless heat pump in residential buildings with existing ac equipment " In *Building Simulation 2019*. PNNL-SA-140942.

Roth, K. et al. 2013. *Ductless Mini-Split Heat Pump Comfort Evaluation*: US Department of Energy, Office of Energy Efficiency and Renewable Energy, Building Technologies Program.

Roth, K. et al. 2006. Ductless split systems. *ASHRAE Journal, 48*(7), 115.

Ueno, K. et al. 2015. Long-Term Monitoring of Mini-Split Ductless Heat Pumps in the Northeast. *National Renewable Energy Laboratory.*

Winkler, J. 2011a. Laboratory Test Report for Fujitsu 12RLS and Mitsubishi FE12NA Mini-Split Heat Pumps. *National Renewable Energy Laboratory.*

Winkler, J. 2011b. Laboratory test report for Fujitsu 12RLS and Mitsubishi FE12NA mini-split heat pumps. *National Renewable Energy Laboratory.*

Pacific Northwest National Laboratory

902 Battelle Boulevard
P.O. Box 999
Richland, WA 99354
1-888-375-PNNL (7665)

www.pnnl.gov