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Maximizing The Effectiveness Of Ductless Heat Pumps In Existing Homes By Demonstrating Integrated Controls: Measurement And Verification Plan

Florida Solar Energy Center

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Creating Energy Independence

Maximizing the Effectiveness of Ductless Heat Pumps in Existing Homes by Demonstrating Integrated Controls

Measurement and Verification Plan

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Contents

List of Tables

1 Introduction

There is a trend for homeowners to install efficient ductless air-source heat pumps (ASHP) as a supplement to less efficient existing space conditioning systems, with most homeowners adding one unit in a central living area. Because of the potential for ASHPs to save energy by providing a large portion of the space conditioning, utilities have incentivized this strategy. However, post installation evaluations suggest ASHPs are not reaching their full potential because the existing heating system continues to operate more than necessary. This project aims to maximize savings from supplemental ASHPs by demonstrating how integrated controls can manage the interaction of multiple space conditioning systems to improve performance. Three strategies will be demonstrated: two will focus on integrating operation of the ASHP with a central forced air furnace, and one will integrate operation of the ASHP with a zonal hydronic system.

2 Experimental Plan

The primary research question is: What is the effect of an integrated control strategy that manages interactions between the central system and the ASHP on thermal distribution and energy savings, compared to an un-controlled situation?

2.1 Technical Approach

Twelve demonstration retrofit installations will be recruited. The sites will be divided into three groups of four homes each (two groups with central forced air furnace and one group with zonal hydronic). An integrated control system will be installed at each site, such that there are three groups of four sites, each with one control strategy deployed.

Monitoring equipment shall be installed at each site to collect detailed data on central and ASHP system energy use, runtime and indoor environmental conditions for 8 to 12 months, with and without the integrated control system operating over alternating periods of two to four weeks. Data on outdoor environmental conditions will be collected from a nearby weather station.

Data on energy savings resulting from addition of integrated control retrofits will be collected and analyzed for each control strategy to determine the effectiveness of each strategy and potential for improvement over the baseline uncontrolled approach. Control strategies may be refined in the course of the demonstrations to maximize savings and/or in response to occupant feedback. In addition, our analysis will consider the price impacts of the control strategy at each site. We may also tweak settings to achieve better economic results (e.g. adjust changeover set points). However, due to the lack of availability of commercial controls that automate price optimization, the general approach focuses on optimization of energy savings rather than economics.

3 Measurements and Equipment

Table 1 summarizes the measurements and equipment that will be used to conduct field tests and acquire project data. The project team will inform NYSERDA of any substitutions deemed necessary as the project develops.

Table 1. Monitoring equipment and accuracy

Measurement	Equipment	Accuracy
ASHP energy, Central Air Conditioner energy, and general data acquisition	SiteSage Energy Monitor with Current Transformers	±1% of rated current
Fuel fired furnace / boiler runtime: AC current of fuel valve	SiteSage Sensor Pod with Acuamp ACTR Series AC current transducer	±1% of full scale
Indoor temperature and relative humidity: real time monitoring	Pointsix 3008-04-V6 WiFi transmitter	±0.4°C, ±3% RH
Indoor temperature and relative humidity: analysis purposes	Onset HOBO UX100-011A	±0.21°C, ±2.5% RH

Sample intervals: Energy data will be collected on a 1-minute time step and temperature and relative humidity data on a 15-minute time step. Energy data will be retrieved daily from the Internet via homeowner broadband connection. Temperature and relative humidity data will be monitored using the Pointsix real time monitoring device, but analysis will rely on the more accurate HOBO device, with data manually retrieved from the sites during periodic visits. Redundant temperature and relative humidity devices will be deployed in some homes to retrieve data daily from the Internet via broadband connection at the 15-minute time step. Outdoor temperature and relative humidity will be obtained from nearby weather stations.

Data sources and accuracy: National Weather Service measurements used for outdoor temperature and relative humidity are obtained from the nearest available station, typically less than 20 miles away from the test homes. The stated accuracy of the outdoor temperature measurements by the National Weather Service is ±1°F. Indoor temperatures are measured using Onset HOBO UX100-011A portable loggers with a stated accuracy of ±0.21°C for temperature and ±2.5% RH for relative humidity up to 90%, and using the Point Six wireless transmitter with the Sensirion SHT71, with stated accuracy of ± 0.4°C, at 25°C and ±3% RH (from 20-80%). Each site will have four to six HOBO temperature and RH sensors deployed, one in each bedroom and in all main living areas excluding the kitchen. Point Six temperature and humidity loggers will also be deployed in select bedrooms and main living area of the homes. Temperature and humidity monitors will be placed on interior walls, away from direct sun light, about head height, and away from mechanical system supplies and other heat-generating devices, and will follow the placement guidelines provided in the Building America Indoor Temperature and Humidity measurement Protocol (Metzger & Norton). Energy use is measured by SiteSage loggers, with included current transformers. These have a stated accuracy of ±1% between 10% and 130% of their rated output. The relative error becomes an artifact of the load itself. For a 3,000-watt (W) compressor at a given point, this would result in approximately ±30 W in measurement uncertainty for evaluating absolute measurements (kilowatt-hours [kWh] for one site compared to another). For retrofit measurements (before/after), the measurement equipment-related variation is much lower, such that measurements should be ±0.5% or better. For example, if the air conditioning (AC) in a home was using 25 kWh/day, the average load would be 1,042 W with an absolute uncertainty of 0.5 kWh/day. If the estimate was between pre- and post-retrofit periods (the situation in this evaluation), the uncertainty would be 0.12 kWh/day, although this can be computed for individual cases if the results are in doubt.

Rather than measure natural gas and fuel oil flow directly, energy use of central forced air furnace and hydronic system will be determined via monitoring of the fuel valve at the space conditioning appliance using a low current, Accuamp current transformer. This will allow monitoring of the actuation of the valve, which will yield an indication of whether the appliance is "on" or "off". Fuel flow during active space conditioning will be observed at the fuel meter to determine the rate of consumption, and used to convert the monitored value actuation into fuel flow[1]. While not as accurate as a direct measurement of fuel flow, past experience has shown that for a single stage, non-modulating burner, the method is sufficiently accurate when comparing energy use in a pre-/post situation. While fluctuations in line pressure as a result of delivery pressure, or simultaneous fuel flow to other appliances can add error to the estimation, individual appliances typically have fuel regulators that act to deliver a relatively constant fuel flow according to appliance needs.

Data content and format: The Florida Solar Energy Center has developed an Experimental Database Management System (EDBMS) designed to automate acquisition, management, and analysis of all field and laboratory digital research data. Data management and quality assurance is a central element of this automated system and multiple levels of quality control are built into the system. Data is automatically downloaded from data logging equipment by a central processing and archival computer. This is done on a predefined periodic basis, depending on the application. Generally, periodic downloading is performed at daily intervals in order to minimize potential data losses. The central equipment that perform these functions have auxiliary power and equipment and software redundancy built into the system. As the field data come into the central system they are subjected to discrete bounds checking. The discrete bounds can be either static or dynamic and can include data manipulation and standard statistical analysis if necessary. Electronic mail messages are automatically generated to notify researchers of any identified anomalies. The data are then stored in secure electronic databases in standard format and made available for retrieval and analysis via standard web browsers.

4 Analysis

Evaluation of the room-to-room thermal distribution pre- and post- installation of integrated controls will involve comparing measured thermostat-to-room variation of temperature and relative humidity data, including hourly averages and extremes. Relative humidity will be evaluated for the percentage of time over 60%. As benchmarks for thermal distribution issues, thermostat-to-room temperature difference will be compared to ACCA Manual RS recommendations, and the indoor relative humidity will be compared to thresholds of 3% higher than pre-retrofit and less than 60% at all hours the supplemental MSHP is operational.

[1] https://buildingsfieldtest.nrel.gov/indirect_natural_gas_flow_measurement

Linear regression analysis will be used to evaluate energy savings pre- and post- installation of integrated controls. The general model normalizes the measured cooling and heating energy and models this against outdoor weather conditions. Statistical evaluation from past studies shows that the average daily space conditioning energy has the strongest statistical power to evaluate against weather—much stronger than hourly data because of the time lag posed by temperature on building elements. Averaging the hourly temperatures into daily averages has also been found to be a better statistical predictor of space-conditioning energy than estimating heating degree days and cooling degree days at a 65°F base for the same periods. The coefficients of determination tend to be much superior, mainly because heating degree days and cooling degree day periods with zero or negative numbers that are truncated by the degree-day procedure actually influence daily space-conditioning needs. For example, predawn periods with temperatures below 65°F actually reduce the required cooling, whereas the degree day calculations assume that these hours have a cooling degree day value of zero; thus, daily average temperatures will be used for this analysis. Space-conditioning energy is then plotted against average outdoor temperature, and the daily average balance temperature for heating and cooling is determined.

Similar past studies that have established the most robust statistical formulation to predict space heating and cooling depending on weather (Sutherland, 2016) use the same method independently identified by Haberl et al. (2005). This is currently recommended in the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. (ASHRAE) “tool kit” -- recommendations for methods to estimate savings from retrofit measures applied to buildings. The following theoretical model based on suggested ASHRAE protocols (ASHRAE 2002) will be applied for predicting energy use:

Energy = A + B(Tamb – Tint)

Where:

A = regression error or intercept term

B = coefficient for house heat gain (UA)/coefficient of performance (COP) of cooling system (outdoor temperature – indoor temperature; Delta T)

An alternative model with a substitute B term may also be used that looks at outdoor temperature rather than outdoor-indoor temperature difference. Analysis will generally use the simplest model that shows stable and reliable results with strong explanatory power. Past studies show that typically outdoor temperature yields better results than outdoor temperature minus indoor temperature, in °F (Delta T) unless the interior temperature profile was altered between the pre- and post-retrofit observation periods. However, past evaluations of supplemental ASHP have not used Delta T because of expected behavioral changes. Differences in interior temperature are likely with the ASHP because uniform interior room temperatures do not typically yield the greatest comfort. Brand (1987) found that space-conditioning systems that facilitate zoning have significantly lower energy use. When supplemental ASHP systems are added, it becomes easy—and even likely—that occupants maintain different heating and cooling conditions in different rooms of the home.

To estimate pre- and post-retrofit annual heating and cooling energy use, the regressions are used to normalize daily average temperatures against monitored daily HVAC energy use; then the same outside temperatures (from either the pre- or the post- period) are applied to the resulting site-specific, pre- and post-retrofit regression results. This allows for an evaluation of how energy use changed after the installation of integrated control, without the confounding effect of varying weather. In addition, for each site, the relevant typical meteorological year 3 (TMY3) weather data will be used to extrapolate the savings. This allows the savings estimates to be extended to the various locations of interest. The pre- and post-retrofit regression results from the weather-normalization evaluation described above are applied to TMY3 weather data to predict space-heating and space-cooling energy use for the pre- and post-retrofit periods.

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