Advanced Controls Retrofits For Packaged HVAC Systems in Small and Medium Commercial Buildings – Phase II Report

ET Project Number: ET 12PGE3113

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Issued: **December 11, 2014**

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ACKNOWLEDGEMENTS

Pacific Gas and Electric Company's Emerging Technologies Program is responsible for this project. It was developed as part of Pacific Gas and Electric Company's Emerging Technology – Scaled Field Placement program under internal project number ET12PGE3113.

This technology evaluation for Pacific Gas and Electric Company had overall guidance and management from David Alexander, Keith Forsman, and Mananya Chansanchai. For more information on this project, contact David Alexander at DJAJ@pge.com.

This project was a joint effort by TRC and the Western Cooling Efficiency Center (WCEC). TRC led the technology market assessment, selection of technologies, and compiled the final report with program recommendations. WCEC led the field assessment activities, data analysis, and assisted in the program recommendations for the project.

At WCEC, the project was led by John Markley with support by Claudia Barriga and Sarah Outcault.

At TRC, the project was led by Stephanie Berkland with oversight by Abhijeet Pande.

LEGAL NOTICE

ABBREVIATIONS AND ACRONYMS

SMB	Small and Medium Businesses
RTU	Roof Top Unit
HVAC	Heating Ventilation and Air Conditioning
FDD	Fault Detection and Diagnostics

FIGURES

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EXECUTIVE SUMMARY

PROJECT GOAL

The goal of this study is to provide recommendations for integrating emerging technologies into energy efficiency incentive programs for existing Small and Medium Business (SMB) Packaged heating ventilation and air conditioning (HVAC) applications in Pacific Gas and Electric Company ("PG&E") territory. Recommendations were guided by the results of a technology market assessment (Phase I) and field monitoring study (Phase II).

PROJECT DESCRIPTION

This report is the second phase of a technical assessment evaluating retrofit technologies for existing SMB Packaged HVAC applications. Phase I of this project, completed in 2012, consisted of a market assessment and selection of technologies for field study. Phase II of this project consisted of field installation of a Smart Thermostat and on-site monitoring of energy use, technology evaluation, and program recommendations.

This study is a collaborative effort between TRC and the UC Davis Western Cooling Efficiency Center (WCEC), under two separate contracts with PG&E. TRC conducted the market and technology feasibility assessment (Phase I) to develop a recommended list of products to be tested. Field-testing and analysis of selected controls and retrofit strategies was conducted by WCEC (Phase II), with advisory input by TRC. TRC developed this ET report with inputs from PG&E and WCEC to report on activities conducted during Phase II of the project.

PROJECT FINDINGS/RESULTS

Phase II of the project successfully installed and tested the energy savings and usability of a advanced smart thermostat product at three sites located in northern California. Energy savings due to the smart thermostat retrofit at the three host sites ranged from modestly positive to negative (increased energy use). The smart thermostat is designed to save energy by optimizing set points and thus HVAC operation. However, that requires the thermostat set points and operation of HVAC systems prior to the installation of the smart thermostat to be sub-optimal. This study observed negative savings at one site where the owner/operator was already managing set points and HVAC operation optimally prior to the smart thermostat installation.

Occupant surveys and usability tests showed no changes in thermal comfort and perceived efficacy of the product to be low. However, it should be noted the results of the occupant surveys and usability tests were skewed by occupants at one site having an overall negative experience with the thermostats due to organizational issues (fights over who should control the thermostat) and lack of training on how to operate the thermostat.

PROJECT RECOMMENDATIONS

The energy savings and usability results from this project are indicative of the current savings potential for smart thermostats if they are installed in situations where there are multiple users per site or where the existing operation of thermostats is already good.

Additionally the energy savings and occupant feedback are driven by the general lack of training and support available to the occupants and thermostat users at these sites.

For programs offering incentives for smart thermostats, this study offers seven key considerations:

- **Existing thermostat technology:** The existing thermostat should be non-programmable or programmable with limited features.
- **Existing user operation:** User operation in pre retrofit conditions should be limited to none, meaning if the user has a programmable thermostat, they do not already have aggressive operational settings. Ideal candidates for a program would be users who do not currently have any type of programmable thermostat and manually operate the thermostat.
- **Customers with multiple locations:** The ideal application for this advanced thermostat is a customer with several buildings at one location or multiple buildings in several locations.
- **Trained Contractors:** Installing contractors must be given adequate training on installation and troubleshooting installations.
- **Customer Training:** Occupants and thermostat users need to be educated on how to operate the thermostat and should have a clear understanding of the limits on local adjustment to thermostat set point.
- **Ongoing maintenance:** Ongoing service and support to customers' needs to be provided to ensure savings persistence.

There are other usage scenarios under which the product is likely to perform better, specifically a scenario where a single user can control and operate multiple thermostats across multiple spaces/facilities. Indeed the manufacturer of this smart thermostat claims that this is the ideal installation and operation scenario for the technology. This study however, cannot independently verify these claims. TRC recommends that additional studies should look into this usage scenario.

INTRODUCTION

As part of its efforts towards incorporating Emerging Technologies into energy efficiency incentive programs, Pacific Gas & Electric (PG&E) initiated this study to conduct a market assessment, technical evaluation and field evaluation of advanced system controls, sensors and displays for Small and Medium Commercial Packaged HVAC Applications. Small and Medium Commercial Business (SMB) represent a large portion of PG&E's customer base. This study seeks to offer customers advanced retrofit options not addressed through the existing PG&E HVAC tune-up programs.

This study identifies targeted retrofit devices, controls, and interfaces that optimize existing constant volume packaged air conditioning and heat pump systems in the Small and Medium Business (SMB) segment. The objective was to select (Phase I) and then evaluate technologies through field studies (Phase II) to better understand the relative strengths, weaknesses and opportunities of the technologies in relation to the existing SMB segment.

BACKGROUND

The SMB segment represents a large portion of the buildings in PG&E's service territory and further a majority of these buildings are served by packaged single zone constant volume rooftop units (RTU). Current HVAC tune-up programs and rebates offered by PG&E do not address the energy savings potential for upgrading and/or better utilization of these RTUs. PG&E commissioned a study to evaluate advanced controls, sensors and retrofit products for RTUs in the SMB segment.

This study is a collaborative effort between TRC and the UC Davis Western Cooling Efficiency Center (WCEC), under two separate contracts with PG&E. TRC conducted the market and technology feasibility assessment (Phase I) to develop a recommended list of products to be tested. Field-testing and analysis of selected controls and retrofit strategies (Phase II) was conducted by WCEC, with advisory input by TRC. TRC developed this ET report with inputs from PG&E and WCEC to report on activities conducted during Phase II of the project.

Phase I of this study focused on the market assessment of HVAC retrofit technologies for the SMB market, and selection of technologies for field study (Phase II). The results for the first phase can be found in the Phase I report titled "Advanced Controls Retrofits For Packaged HVAC Systems in Small and Medium Commercial Building," completed in 2012[1]. This report covers the second phase of this study that involves field assessment of the selected technologies.

[1] ET Project Number: ET12PGE1111

ASSESSMENT OBJECTIVES

This section outlines the assessment objectives of each project objective (Phase I and II).

PHASE I

Phase I of this study included the following tasks and objectives:

1. Market Assessment of SMB HVAC Retrofit Technologies:

   The objective was to identify a list of technologies eligible for the study based on:

   a. Promise of energy savings
   b. Potential to reach a broad swath of existing SMB HVAC systems
   c. Reasonable chance of market adoption; and
   d. Maturity of technology development

2. Selection of Technologies for Field Study:

   The objective was to select up to five technologies for scaled field placement based on:

   a. Technology Readiness
   b. Design and Application
   c. Energy Savings
   d. Measurement & Verification
   e. Measure Specification
   f. Cost Effectiveness

PHASE II

Phase II of this study includes the following tasks and objectives:

1. Field Monitoring:

   The objective is to monitor performance of each technology to better understand the energy savings potential on SMB HVAC systems in the PG&E territory.

2. Review Monitored Data:

   The objective is to quantify the performance of each technology and any concerns with installation, commissioning, operations, and any equipment failures as well as performance issues.

3. Program Recommendations:

   The objective is to summarize the findings from the field evaluations and Phase I technology selection memos to provide program recommendations.

EMERGING TECHNOLOGY

In Phase I of the study, the types of technologies and solutions reviewed ranged from a simple retrofit consisting of "Do-it-Your Self" or "Plug & Play" solutions that can be easily installed by the owner/tenant or HVAC contractor or electrician, to complex solutions requiring outside expertise to install and maintain the technology. Covering a wide range of solutions was intentional in order to conduct a broad review of all applicable and relevant technologies and retrofit solutions. Many technologies on the market are stand-alone devices designed to have one function, while others can be paired with other technologies to create a comprehensive retrofit solution for various end uses. The study covers both of these types of solutions.

To aid the technology selection process for field study, each product was categorized based on its functionality and how it retrofits or controls the RTU. These product categories include:

- Advanced Retrofit Solutions: Products in this category are characterized by performing a deep retrofit of an RTU by replacing parts and adding controls to optimize performance.
- Analytics: This type of product is geared towards monitoring runtime behavior to assist building operators on the performance of their HVAC system.
- Auto-DR: This category consists of automated demand management and demand response control technologies.
- BMIS "Middleware": These are products not directly connected to the HVAC system, but link other third party controllers to one central portal enabling control of several end-use devices. They also provide one user interface for each of the controllers plugged into the "middleware" device.
- Controller add-in: Controller add-ins is a device directly added to the HVAC system enabling RTU controls. They also offer retrofits to fans/compressors and provide additional capabilities to the RTU (i.e. add-in economizer).
- Advanced Thermostat: These technologies typically involve a one-for-one replacement of a thermostat and can be installed and operated by in-house staff or HVAC contractor. Many products in this category can be considered mini-EMS's and have the capability to offer scheduling, system optimization, multi-site management, and can be paired with a variety of sensors and controllers.

TRC used a similar process as found in the 2011 BPA E3T Energy Management TAG Report[2] for selecting appropriate technologies and products within each of the product categories described above. This consisted of forming an advisory group consisting of staff from various groups including: PG&E, WCEC, and kW Engineering. Each group member was then asked to score each technology based on the information TRC obtained through a market assessment. A description of the technology selection process can be found in the Phase I report: Advanced Controls Retrofits For Packaged HVAC Systems in Small and Medium Commercial Buildings.

For Phase II, the advisory group made their final decisions to evaluate the five technologies through a field study; however, due to budget constraints only three technologies were

[2] http://www.bpa.gov/energy/n/emerging_technology/pdf/E3T_2011_EM_TAG_Final_Report.pdf

selected. These consisted of a product in the advanced retrofit solutions, controller add-in, and advanced thermostat categories, as to represent both ends of the spectrum. These technologies range from comprehensive retrofit options to simple "do-it-yourself" control options for building owners.

Advanced Retrofit Solution

The advanced retrofit "kit" recommended for field-testing in the Phase I report is a combination of a Variable Frequency Drive (VFD), economizer, and controller that can be remotely monitored. The primary advantage of this retrofit kit in particular is the full variable control of the fan speed in conjunction with optimal economizing. In addition, the retrofit "kit" is capable of providing Fault Detection and Diagnostics (FDD) in the event of a failure, thereby significantly reducing downtime, improving the likelihood of a sustainable correction, and identifying potentially catastrophic failures before they occur.

Recent simulation studies[3] have shown that combining economizers with VFD controlled evaporator motors can save in excess of 60% of the overall energy consumed by an RTU. The bulk of this savings comes from reducing the volume of air moved during ventilation-only operation, along with sustained operation of the RTU's vapor compression cycle at optimum conditions.

As a retrofit solution, a manufacturer-trained contractor would be responsible for installation and commissioning. All hardware is owned by the party responsible for the RTU and may be operated either by the manufacturer in the event of a continued service agreement or by the end user if so inclined.

Controller Add-in

Air side economizers are one of the simplest mechanisms available to take advantage of temperate climate conditions and, when applied properly, can achieve more energy savings in warm and dry climates[4], and will vary by building type. Unfortunately, these simple devices are fraught with complications, ranging from broken to deliberately disconnected equipment, that render 60-90% of small RTU economizers inoperable.

The economizer controller recommended for the field tests in the Phase I report is an add-in economizer controller that is simple to install for a trained technician. The primary advantage of this economizer controller, in particular, is the real time feedback to the installer via a built-in screen that provides diagnostic information during the commissioning process thereby ensuring proper setup and operation. In addition, the economizer controller is capable of providing fault detection and diagnostics (FDD) in the event of a failure, thereby significantly improving the likelihood of a sustainable correction.

The economizer controller chosen for this study is being deployed as a retrofit application, though it is also commonly applied by original equipment manufacturers (OEMs). As a retrofit solution, a licensed and trained contractor would be responsible for procurement from a local supply house, installation, and commissioning. All hardware is owned and operated by the party responsible for the RTU and continuation of service is not required.

[3, 4] Pacific Northwest National Laboratory, "Energy Savings and Economics of Advanced Control Strategies for Packaged Air-Conditioning Units with Gas Heat" (Washington: DOE 2011).

ADVANCED THERMOSTAT

In theory, there is great potential for energy savings from thermostats. Even inexpensive programmable ones have the potential to save 30-50% of energy use from HVAC[5,6]. However, actual savings may fall short of that depending on the occupants programing and use of the thermostat.

Advanced thermostats aim to deliver energy savings by providing the ability to grant differing levels of access to specific users, improving access through web portals, improving users' ability to control the thermostat settings and schedules through more user-friendly web interfaces and contractor engagement, and energy (and cost) savings. Realizing the energy savings requires that a more conservative schedule be implemented upon the change. The implicit assumption is that the previous thermostat was not programmed (nor operated manually in a way that conserved energy) and that the added features mentioned above will increase the likelihood of programming a conservative schedule of setbacks.

This business model essentially circumvents the problem of users' lack of ability or motivation to program a schedule, but the ramifications of this are largely unknown. This study provides some indications of how such a thermostat is utilized and functions in reality.

The thermostat selected for the field test portion of this project was a web-connected, "advanced" thermostat with a basic user interface on the device. A more comprehensive user interface can be found on the manufacturer's web portal, accessible by computer or smart phone through the manufacturer-provided website or application. In addition to setting schedules, the web portal provides access to data on temperature settings, schedules, real-time and historical energy usage, and temperature settings.

According to the business model (typical for similar thermostats), the thermostat is sold to customers through HVAC contractors who install the hardware and instruct customers on how to use it. Ongoing support for usage of the device is offered by the manufacturer, and the contractor retains responsibility for responding to system issues, as indicated by the data output and communicated either to the contractor directly, the customer or both, depending on how it is configured. This business model essentially circumvents the problem of users' lack of ability or motivation to program a schedule. This study provides some indications of how such a thermostat is utilized and functions in reality.

[5] Meier, A., C. Aragon, T. Peffer, D. Perry, and M. Pritoni. (2011). "Usability of residential thermostats: Preliminary investigations." Building and Environment, 46(10), 1891-1898.

[6] Maheshwari, GP., H. Al-Taqi, R&S Al-Murad, and K. Rajinder (2001). "Programmable thermostat for energy saving." Energy and Buildings, 33(7), 667-672.

TECHNOLOGY EVALUATION

Three advanced controller technologies were selected for evaluation through field installations in this Phase II of the project, belonging to these product categories: Advanced Retrofit Solutions, Controller Add-in, and Advanced Thermostat. The field evaluation of each technology includes installation and monitoring of the technology at host sites through energy savings, occupant surveys, and occupant usability tasks.

Due to project limitations, outside of WCEC control, no participation was secured for the controller add-in or advanced retrofit solution technologies. This was mainly due to the high initial costs of the technologies: approximately $1,000/RTU and $4,500/RTU for the controller add-in and the advanced retrofit kit respectively, coupled with uncertain payback periods. One notable large national business with many retail locations in PG&E territory met the technical requirements of the study did agree to participate in both the controller add-in and advanced retrofit kit studies. However, after months of negotiating the substantial legal and contractual issues presented by several interested parties, no progress was made beyond the initial site determinations.

The study team decided to proceed with a modified study plan that only evaluated the advanced thermostat. Several customers agreed to participate in the thermostat study. The primary advantage associated with the thermostat portion of the study was the thermostats were to be given to the user free of charges (hardware & installation were valued at approximately $750/unit) in exchange for agreeing to release their utility data and participate in the study for one year after installation. An additional advantage was that the manufacturer had access to a robust network of service providers and installation technicians who were instrumental in introducing customers considering deploying units in their businesses.

The study approach chosen (explained in detail in the 'Test Methodology' section of this report) utilized field testing methods that allow for evaluation in an operational building with actual occupants; whereas, a lab study is a simulation of occupant schedules and behavior, and assumed HVAC operational conditions. Advanced thermostats HVAC energy savings is ultimately determined by how occupants program and operate the thermostat. For this purpose, field evaluations were conducted at three host sites, in PG&E's service territory, through before and after utility meter data analysis, occupant feedback, and behavior observations. All monitoring activities were conducted by the project team, and advanced thermostats were installed by HVAC contractors. The installation of the advanced thermostats at the host sites allowed for:

- Monitor in-situ performance of advanced thermostats in three host sites.
- Assess the application of the advanced thermostat through acquiring, installing, and programing the thermostat.
- Assess occupant satisfaction and usability of the technology through a survey before installation of the thermostat, and usability tasks after the thermostat was installed.

SITE SELECTION CRITERIA

The original approach by the project team was to investigate several installations of each technology in a light commercial/small business setting. The goal was set to deploy 15 to 20 thermostats in each of the two climate zones (30 to 40 total), 2 economizers (4 total), and 2 retrofit kits (4 total). The targeted site attributes for all three technologies were:

- Single zone RTUs no larger than 20 tons.
- HVAC equipment should be neither new (<5 years) nor old (>15 years), as new equipment may already have many of the proposed energy efficiency measures (EEMs), and old equipment may not have enough usable service life remaining to take full advantage of the EEMs.

FACILITY DESCRIPTIONS

The facilities chosen for field evaluation of the smart thermostats are located in two climate zones within PG&E's service territory. This allowed for broader understanding of the HVAC retrofit technology's impact on a buildings energy use and demand. Figure 1 shows the location of each site; two sites were chosen in climate zone 12 (central valley), Woodland and Stockton, and one in climate zone 4 (Bay Area), Santa Clara.

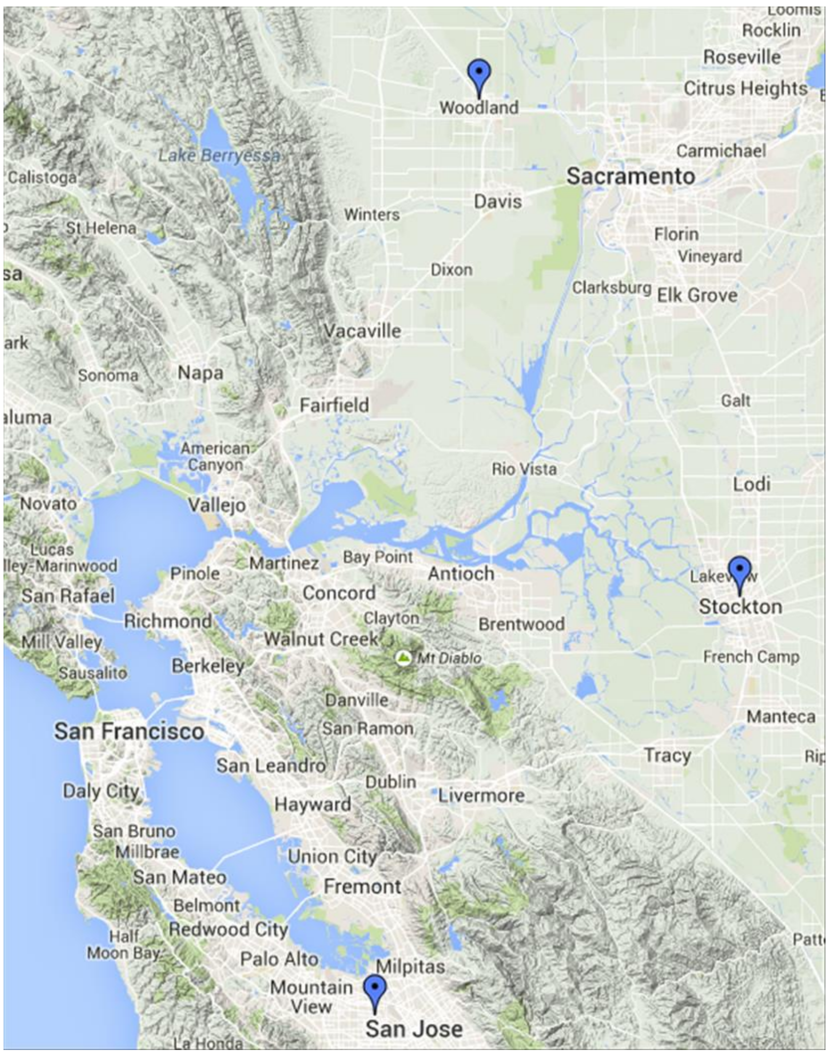


FIGURE 1. HOST SITE LOCATIONS

SITE #1 – STOCKTON

Site #1 is a single story facility located in Stockton, CA in climate zone twelve (CZ12). The facility is used as a country club and has 14 RTUs of comparable vintage, make, and model ranging from 4 to 8 tons of cooling capacity and each individually controlled by one thermostat. The original thermostats (n=14) were mechanical mercury bulb devices, and, when asked, respondents stated explicitly that the thermostats were outdated and needed to be replaced with more advanced alternatives. The thermostats controlled heating and cooling in several rooms, a few of which were used sporadically for club functions. A facilities manager oversaw all building operations, and had access to thermostat control and decision making about scheduling. Other employees and visitors to the club were not supposed to have access to thermostat control. However, in practice, thermostats were operated on an as-needed basis by clubhouse staff.

SITE #2 – WOODLAND

Site #2 is a restaurant located on the first floor of a three story building in Woodland, CA in CZ 12. The entire business was served by four split system heat pumps each controlled individually by programmable thermostats (n=4). Approximately one year prior to the initiation of this study, the facilities manager (and restaurant co-owner) installed state-of-the-art programmable (though not web connected) thermostats in order to maintain tighter control of the costs associated with space conditioning as a response to highly volatile energy bills. They established a schedule of setbacks and conservative set points, which had yielded energy savings. They had complete control over thermostat scheduling and it was his exclusive responsibility to manage it. No one else had access to thermostat control.

SITE #3 – SANTA CLARA

Site #3 is a school campus located in Santa Clara, CA in CZ 4. The campus is made up of primary classroom buildings and a multi-purpose building. The site had a total of 13 RTUs, each with individual thermostats (n=13). The primary classroom building had nine nearly identical RTUs, which were each individually controlled by several types of traditional programmable thermostats located in nine distinct classrooms that were connected by communal spaces and hallways. The secondary building consisted of five rooms including a computer lab, a library, an art room and two multi-purpose meeting rooms. All rooms in the secondary building were conditioned by individual systems, except for the larger of the two multi-purpose rooms that was served by two units due to its size and configurability.

Two distinct sets of users were tied to each of the buildings: 1) teachers, and 2) the local facilities manager. The facilities manager had access to all thermostats but it was not their exclusive responsibility to regulate the units in the primary classroom building or control any policy regarding their use. Rather, the teachers in each of the thermostat-controlled rooms had complete control over the thermostats of the rooms they were using at a given time.

TECHNOLOGY CAPABILITIES

The advanced thermostat installed at the three host sites is considered a mini Energy Management System (EMS). The thermostat is a Wi-Fi enabled thermostat that allows users to monitor and control the settings on a computer or smartphone. The intended applications, according to the manufacturer, for the model field-tested are for buildings 25,000 square feet or less with multiple RTUs. The manufacturer indicates the following small and medium business sectors have seen benefits from the advanced thermostat:

- Quick service restaurants
- Full service restaurants
- Retail
- Schools
- Banks
- Multi-family dwellings
- Religious congregations

In this study, the advanced thermostat was installed and monitored by WCEC at a school, full service restaurant, and country club. Multiple thermostats were deployed at each site.

The thermostat is compatible with conventional (2H/2C), heat pump (4H/2C) including 2-stage auxiliary heat, gas, oil, electric, dual fuel, humidifier, dehumidifier, ventilator, heat recovery ventilators, and energy recover ventilator systems.

This advanced thermostat has more capabilities than a basic programmable thermostat including:

- Touch screen physical interface, with lockout options - The wall-mounted thermostat has a touch screen for users to change set points directly on the wall unit. Lockout options can be set requiring the user to enter a security code to unlock the unit to change settings. User control may also be restricted to only allow the user to adjust the temperature settings up or down by a defined range (e.g. ±1 degree from a preset set point)
- Programming. Program settings are available for the following settings: seven-day (awake work, home, sleep) and vacation/holiday.
- Enterprise level remote access. Allows users to control multiple thermostats at one site, or several locations, from the web portal.
- Humidifier, dehumidifier, economizer, and ventilation control options. These controls allow the user to set on or off, programmable set points, and runtimes for each operation.
- Detailed HVAC reports on system performance. Historical system data is stored on the web portal for up to 2 years. The system collects data in 5-minute intervals on runtime, temperature, and settings. Users can download the data to self-analyze their systems performance.
- Fault Detection Diagnostic capabilities. The thermostat has limited FDD capabilities allowing users to self-analyze historical system information downloadable via the web portal. The system currently does not have automatic FDD settings; however, the manufacturer reported FDD services are available, outside the ongoing service support currently provided.

- Demand Response capability. The user has the option to opt-in to utility sponsored demand response events. If the user has opted to participate in demand response events a signal will be sent to the thermostat before an event occurs, in which the user must accept or reject the event, if the event is voluntary. Note that if the user does not acknowledge the event prior to the start, the system defaults to accepting the event. If the utility event is mandatory, and the user has opted to participate, the user cannot opt-out of the event.
- Reminders and alerts. User can set HVAC maintenance and filter reminders based on time durations. Alerts can be set for low or high temperatures, low or high humidity, and auxiliary heat run-time and auxiliary outdoor temperature alerts (heat pumps only).
- User web portal and physical interface. The user web portal allows users to control the thermostat remotely online or via a smartphone app. The web portal offers the same level of control as the physical interface. The user has the ability to control the following via the web and physical interface:
  - Set temperature (programing and set user ranges)
  - View current temperature
  - Control system and fan settings
  - View system messages regarding the operation of the system
  - Wi-Fi signal connectivity and strength
  - Date and time
  - Displays current outdoor temperature and weather conditions
  - Displays system details humidity levels, furnace fan setting, ventilator, humidifier or dehumidifier settings
  - Program (temperature, schedule, vacation/holiday)
  - Manual overrides and system resume feature
  - Download historical system information (web portal only)

MONITORING TIMELINE

Electricity usage was gathered pre- and post-installation. Data was obtained through Smart Meters for the post-installation period of September/October 2013 to February 2014, and the same period the year prior for pre installation. Surveys were conducted with building occupants and usability tasks were conducted to evaluate whether and how the thermostats enable better control of the RTU. The timeline for each site is outlined below.

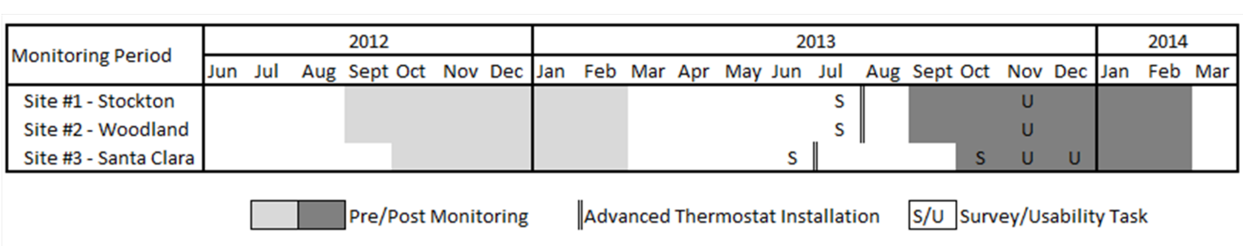


FIGURE 2. MONITORING TIMELINE

TECHNOLOGY IMPLEMENTATION

Installation of thermostats require the following procedure to implement the technology:

1. Acquiring equipment
2. Physical installation
3. Programming and online dashboard setup

The advanced thermostats are sold to customers through HVAC contractors (typical for similar advanced thermostats) who install the hardware and are responsible for instructing the customers on how to use the thermostat. The manufacturer has an approved list of contractors on their website for the customers to choose from; however, an approved contractor is not required to install the thermostat.

The installation of the thermostat requires the HVAC contractor to install the physical thermostat "head" unit on the wall in the user space, in a traditional matter. A relay control board is installed on the RTU. The existing thermostat wiring is used to connect the "head" unit, on the wall in the conditioned space, to the relay board within the cabinet of the unit. This process is different than installing a traditional thermostat, which typically only requires the installer to replace the old "head" unit with the new unit on the wall, in the conditioned space, and no installation at the RTU is required.

Once the physical installation is complete, there are additional steps required to enable proper operation of the thermostat. These steps include:

- Establishing web connectivity for the thermostat - an existing Wi-Fi signal is necessary for the thermostat to connect with the manufacturer's portal and for users to control the thermostat either through that portal or through a smartphone app.
- Commissioning of the software, including system setup
- Establish an online account for the "super" user who can control the thermostat(s)
- Establish additional accounts for other individuals who are to be given access to the thermostat(s)
- Linking all thermostat(s) to appropriate accounts

These steps are to be done in accordance with the guidelines that have been set by the manufacturer for its approved installers.

IMPLEMENTATION CHALLENGES

The installing contractor and the occupants experienced some challenges during the installation and commissioning of the advanced thermostats at the host sites. These challenges include:

- Wi-Fi connectivity issues.

  The installing contractor or occupants were not alerted to Wi-Fi connectivity issues, which affected the thermostats connectivity to the online web portal. If a Wi-Fi connection is not available at the time of installation the thermostat may not be fully accessible to the occupants once the installing contractor leaves. It is important for the installation and ongoing function of the thermostat for the site user to know that a Wi-Fi connection is accessible and operational during the installation of the thermostat.

- Installing contractors' scope is limited.

  The installing contractor's scope is limited to the physical installation of the wall mounted thermostat and switchboard at the HVAC unit, and connecting thermostat to the sites Wi-Fi network. The contractor does not address Wi-Fi connectivity issues, ongoing support, user access issues, or web portal account setup. WCEC also found that the installing contractor provided minimal training to the users on the thermostats functionality or any instructions for ongoing support.

- Establishing user access.

  There are two options for user access: directly on the wall device and remotely via the online portal. During installation, a "super user" can be established via the online portal, which has the capability of limiting and even restricting use at the wall unit. If all occupants are not aware of this, occupants may become frustrated and uncomfortable if the thermostat operation is either locked-out for them or changed remotely without their knowledge. The facilities manager should be aware of the user setting, and how to change them, during installation. Additionally, during installation and setup the installer has the option to set a user pin for access to the wall units. This must be clearly communicated to the facility manager and users so they are able to access the thermostats to make adjustments, otherwise they will be locked out of the units.

- Online web portal setup.

  User accounts should be established before the installation of the thermostats by the user or facilities manager. This was not known to the installing contractor (or WCEC) and the task was outside the scope of the installing contractor.

- On-going support for thermostat unclear.

  Users in this study were unclear how to obtain ongoing support for the thermostats. They were uncertain if the manufacturer or installing contractor would provide support. Understanding how to obtain ongoing support is essential in applications such as at site #3 (school) where a super user is established, which commonly grants occupants limited control via the web portal and wall unit. Users and facility managers should be instructed by the installing contractor where to go for ongoing support needs.

TEST METHODOLOGY

FIELD TESTING PLAN

Evaluation of the advanced thermostat was conducted at three host sites by WCEC using a pre and post installation comparison to determine the energy savings potential and usability of the thermostats. This was done by quantifying energy savings and assessing occupant usability through:

- Energy savings: Utility Smart Meter data (1 per site) was collected for a period of 6 months, depending on the site, pre- and post-installation. Post-installation data was also obtained from the advanced thermostats' web portal. The web portal records energy use and HVAC performance in 5-minute increments (pings system every 5 seconds and rolled into 5 minute segments for reporting). Pre- and post-installation outdoor air temperature data was obtained from the California Irrigation Management Information System (CIMIS). No onsite monitoring was conducted for this evaluation.
- Occupant usability and feedback: Occupant surveys were conducted pre- and post-installation via the online SurveyMonkey tool. Usability tasks were also administered to the occupants throughout the study period via an online message board.

ANALYSIS PLAN

For this study, field evaluations were carried out by WCEC to quantify the energy impacts of the study spaces using utility Smart Meter data. Analysis of the data was done using a regression to relate ambient air temperature to the HVAC kW consumed. In order to determine associated HVAC cooling savings of the advanced thermostats the following methodology was used:

1. Determining a base load schedule for each site, and thus isolating HVAC power draw by subtracting the base load prediction from the total smart-meter measured power draw;

2. Normalizing the HVAC power draw by outside air temperature to account for annual differences between the pre-install and post-install period; and

3. Comparing the normalized HVAC power draw in pre-install and post-install periods to determine if there was an overall energy savings attributable to the advanced thermostat.

Monthly gas usage was available (from billing cycles), which provided insufficient resolution to make a conclusive energy savings determination for heating energy use.

USER EXPERIENCE

An occupant survey was developed and conducted by WCEC, pre and post installation, to document the occupant's level of acceptance and usability of the advanced thermostat. The pre and post installation surveys were conducted online via the SurveyMonkey tool. Additionally, occupants were administered two usability tasks during the post installation period to assess their ability to interact with the thermostat. A copy of the surveys and usability tasks can be found in the Appendix.

RESULTS

To evaluate the energy savings from the advanced thermostat, WCEC conducted an on-site installation of the technology at three host sites (as described earlier). Analysis was conducted for a 6-month study period, the same period a year prior to the installation was use for the pre installation data. This evaluation was done by:

1. Calculating **heating/cooling energy savings**, for each site – pre and post installation using utility Smart Meter data and the technologies 5-minute web portal data.
2. Assessing the occupant's **user experience** of the technology through online surveys.

ENERGY SAVINGS

Advanced thermostats save energy by the use of programmable settings to regulate the temperature and operating hours of a space. In this section the heating/cooling energy savings are summarized for the study period are presented below. Detailed results of each host site can be found in the appendix.

WCEC found energy savings at the three host sites ranged from modestly positive to negative. For all three sites, using the HVAC power draw (kW), a 'hockey stick' regression was used to relate ambient air temperature to the HVAC kW consumed. The motivation for this is that below a certain temperature threshold the AC system should not operate and thus will require a constant, near-zero power draw independent of temperature. As temperature increases beyond this threshold, the HVAC power consumption should increase linearly as a higher average temperature results in a higher average runtime for the HVAC system.

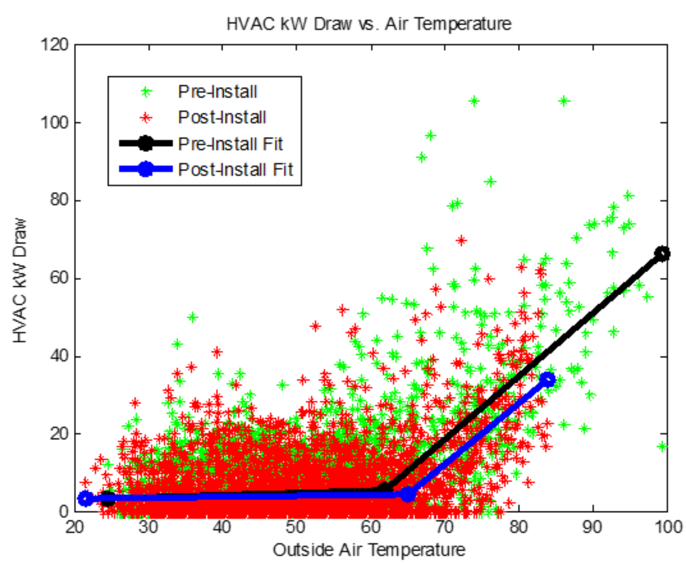


FIGURE 3. SITE #1: H VAC POWER DRAW (KW) VS. AIR TEMPERATURE – COMPARISON OF PRE AND POST INSTALLATION ENERGY USE (SEPT-FEB, 2012/13 AND 2012/2014)

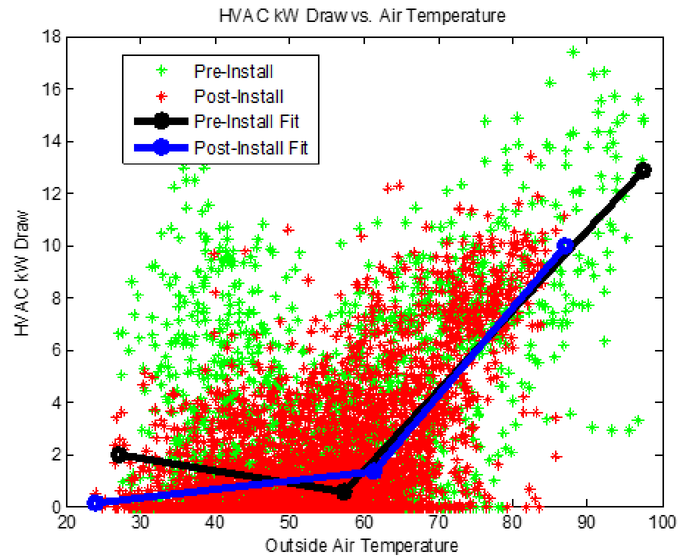


FIGURE 4. SITE #2: HVAC POWER DRAW (KW) VS. AIR TEMPERATURE – COMPARISON OF PRE AND POST INSTALLATION ENERGY USE (SEPT-FEB, 2012/13 AND 2012/2014)

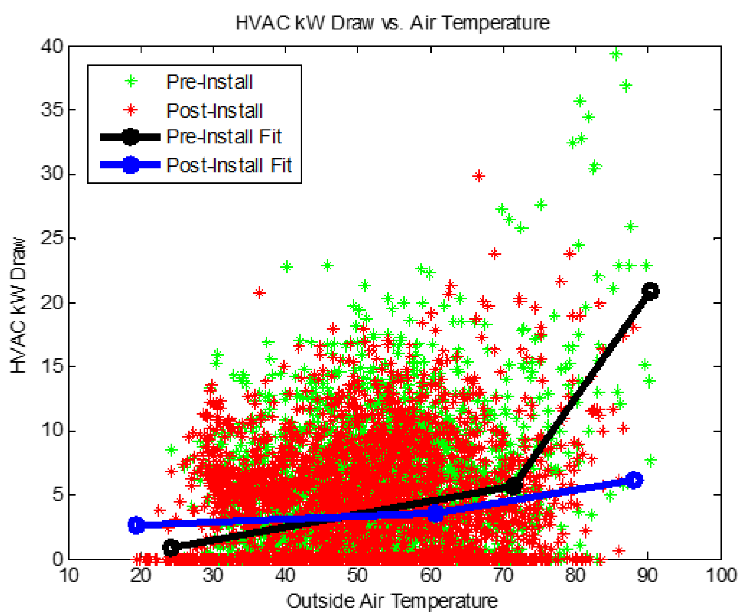


FIGURE 5. SITE #3: H VAC POWER DRAW (KW) VS. AIR TEMPERATURE – COMPARISON OF PRE AND POST INSTALLATION ENERGY USE (OCT-FEB, 2012/13 AND 2012/2014)

Although the variance of the data is large, the resulting regression for site #1 and site #2 does exhibit a low value and near zero slope below a temperature threshold, and a significant rise beyond it. The changeover temperature is consistent with expectations (55 - 65 degrees) and thus lends credibility to the final result. Two regressions were preformed, one for pre-installation, one for post-installation, and the resulting difference between the slopes is used to determine the energy savings due to the thermostats. Inconsistencies in the data resulted inconclusive results for site #3.

Based on the slope differences between the calculated regressions in the HVAC operating region of the plot (> approx. 65F for site #1, > approx. 55 for site #2) the following energy savings were calculated. Standard error was determined for the calculations using the standard deviation normalized about the regression for the operating region of both pre and post installation periods. The results are presented below:

Location	Energy savings/costs (% of HVAC power draw per degree F)	Restrictions	Std. Err.
Site #1 (Country Club)	3.5%	for OAT > 65.1 deg F	1.00%
Site #2 (Restaurant)	-6.7%	for OAT > 60.6 deg F	0.43%
Site #3 (School)	Inconclusive		

Upon installation of the thermostats in site #2, WCEC was able to inform the owner of the precise zoning of the HVAC system. As a result, they were able to achieve greater thermostatic control in the kitchen, which WCEC believes, is the primary driver of the increase in energy use.

It is interesting to note the comparative energy savings between site #1 and site #2. On a qualitative level, the owner and building manager of site #2 was described to be an already extremely conscious energy user, and thus was likely to already be operating their HVAC equipment in a highly efficient manner. Site #1 on the other hand, is a large country club with numerous employees who are, on average, much less concerned with the energy consumption of the site. It is not unreasonable therefore, that the energy savings derived from the thermostats, and smart thermostats at large, is entirely dependent on the previous HVAC control scheme and the energy consciousness of the operator.

USER EXPERIENCE

WCEC assessed occupant acceptance and usability using survey's and usability tasks administered to the occupants. The results of the surveys and usability tasks indicated that the advanced thermostats had a negative occupant acceptance though this is driven by the responses from the occupants in site #3 where there were access control issues for the occupants. Details are provided below.

SURVEY RESULTS

Surveys were administered pre and post installation of the advanced thermostat. The pre installation (n=14) served as a baseline of user experience with their existing thermostats. The survey was administered online and addressed the following topics:

- Perceived product usability: Ease with which users can manipulate the "old" thermostats;
- Perception of efficacy: Users' perceived effectiveness of the thermostats in performing as the occupants intended;
- Barriers to use: Technical and non-technical aspects of thermostats which make them difficult to use effectively;
- Comfort: Self-report of thermal acceptability using sensation (very cold > very hot) and comfort (very comfortable > very uncomfortable) scales;

- Recommended features for potential new thermostats: New features, features to be eliminated, features to be modified; and
- Intent to adopt: Assessment of whether or not the occupant would buy the same (old) thermostat in the future, at what price and in what context;

Follow-up surveys (n=10) were conducted after the users had a chance to operate the thermostats for at least one month. Respondents were asked about the usability and efficacy of the advanced thermostats, using the same set of measures used in the survey for the "old" thermostats. Satisfaction, comfort, usability and efficacy with the old and new thermostats were compared. Only respondents from the school responded to requests to participate in the post-installation online survey.

THERMAL COMFORT

Pre and post installation, participants were asked how often they felt too cold, too hot or comfortable in their space. Overall, ratings under the old and new thermostats indicate a average level of comfort, with little change between the two.

The main change after the new thermostats were installed seems to be a sharp decrease in the number of people that are "almost always" comfortable. Ratings regarding "too hot" or "too cold" feelings remained mostly unchanged, indicating little impact of the thermostats on user comfort. These results are skewed, however, by the fact that the generally more satisfied thermostat users (from site #1 and site #2), did not participate in the follow-up survey.

PERCEIVED EFFICACY

Overall, and particularly in the school (site #3) setting, perceived efficacy of the new thermostat was extremely low, likely due to the absence of training and technical obstacles encountered in the web portal functions. These issues may have resulted in decreased levels of usability, perceived effectiveness and satisfaction with the new thermostats.

On the other hand, employees at the site #1 had their thermostat access stripped upon installation of the advanced thermostats. In essence, they lost all efficacy. Although WCEC is not aware of how this may or may not have been communicated to the staff, WCEC did not receive complaints about this issue. This suggests that as long as comfort is reasonably maintained and occupants' expectations are appropriately managed, occupants/users can adapt to changes in efficacy, or the perception thereof.

DESIRED FEATURES AND INTENT TO ADOPT

When participants were asked, in the pre installation survey, what features or capabilities they would like in a new thermostat, they mentioned locking capabilities, simpler operation, schedule programmability (at site #1, where thermostats were extremely old and not programmable), remote controllability, and energy use reporting. There were also some demands that are not directly related to thermostats, like "cool faster, I feel like the heat works faster than the cooling," which are indicative of knowledge gaps regarding the function of thermostats and the physical operations of heating and cooling.

After the advanced thermostat installation, participants were asked if they would select this new thermostat in case of replacement, responses were mixed and evenly divided. Overall, there seemed to be some willingness to give the new technology a chance – users could see that the thermostats had potential to be useful; however, these responses were tentative, given the difficulties in deployment and the lack of training and information that they experienced during the operation of the thermostats. Intent to adopt or recommend the new technology seemed very tentative. However, during the six months after completing the fieldwork, WCEC did not receive any additional complaints, nor learn of any replacements of the installed thermostats. Results from this study indicate tolerance for and speed of technology adoption varies widely, and programs installing advanced thermostats should anticipate and address that with tiered levels of training and support.

USABILITY RESULTS

Usability assessments were administered to all sites post installation via an online message board and email correspondence with the usability tasks. Only one site (site #3) participated in two usability assessments.

Throughout the study, WCEC sent thermostat task requests to occupants (for example "set the thermostat set point to 65 degrees for two hours), and users sent back the results of their attempt, discussed difficulties they had completing the task, questions they had, and solutions they found to complete the task requested. Users were also encouraged to describe experiences, positive or negative, that they had while using the newly installed thermostats, including problems with comfort. Users were asked whether they were sure, they accomplished the tasks successfully. When possible, feedback provided by the users was compared to online back-end information of the thermostats, which allowed a "check" for whether participants had indeed attempted to complete the task, and done so successfully.

Tasks were planned to address functions that occupants could complete either on their wall thermostat display or on the web portal. These tasks included:

- Task 1:
  - Check the thermostat mode, set it to HEAT (if wintertime, and it had been detected that many thermostats were on COOL mode).
  - Check, record and modify the date and time (since these are essential for appropriate scheduling, and daylight savings time had just commenced).
  - Respondents were also asked to describe the precise steps they followed to accomplish the tasks, any challenges they encountered, and their perceived level of success in executing the tasks.
- Task 2
  - Online access, log on and navigate to a particular area of the manufacturer's website, peruse it, and report on their impressions and experiences executing the tasks.

Detailed usability tasks instructions are presented in the Appendix.

Based on the (limited) participation in the usability tasks, the results suggest that the advanced thermostats posed substantial usability issues for many respondents. The interface on the device itself was not user friendly, and the web interface was difficult to access and not intuitive to navigate. The level of frustration that the occupants experienced, especially at site #3, was a surprise. It is likely some of these issues would have been eliminated if users had been given adequate instructions on how to use the thermostats. None of the respondents at the three test sites received much, if any, training or instruction, indicating a problem with the deployment model that leaves the provision of this essential service entirely up to the installing contractor's discretion. Thus, it appeared that knowledge was a significant barrier to using the new thermostats.

Despite the inadequacy of training on thermostat use, participants' perception of usability varied widely, and this seemed to be driven largely by differing levels of experience with and interest in thermostats. Some found the advanced thermostat easy to use and effective (site #2 owner). Others found it difficult to operate, were confused about how it worked and who had control, and complained about it not working as expected (teachers at site #3). Still, another group (site #1) seemed to adopt the "set it and forget it" model, never interacting with the thermostat after the initial installation and programming.

Actual usage of the thermostats varied widely. The restaurant owner (site #2) exclusively used the web interface to control the advanced thermostats. By contrast, none of the participants from the school (site #3) logged in to the system to set a schedule or make a change, even when they were "locked out" of the wall devices.

COMPARISON STUDY

TRC reviewed other studies implementing and monitoring the advanced thermostats energy savings in similar sectors as a point of comparison to this study. The equipment manufacturer lists a case study where the advanced thermostat was deployed throughout a school district in California. The case study deployed approximately 600 thermostats across 12 schools and saw a district wide savings of approximately 75%.

One variation with that case study, compared to this study, was that approximately 40% of the classrooms were in portables. In addition, the case study schools existing operational conditions relied heavily on janitorial staff changing the thermostats for evening, weekend, or holiday conditions resulting in the schedule prior to installing the advanced thermostats to be solely dependent on staff changes. This resulted in the HVAC systems to be left on for days over holidays or weekends, when the system should have been setback or turned off.

The school in the WCEC field study had different preexisting conditions; programmable thermostats that were controlled by the teacher in the classroom and did not rely on facilities staff to change thermostat settings. The operational conditions and baseline thermostat, in the study provided by the manufacturer, had no programmable settings prior to retrofit, thus contributing to greater savings than the school studied by the WCEC. Additionally, the school (manufacturer study) established a "super user" and restricted teacher's use of the thermostat by allowing a plus or minus 4 degrees temperature adjustment range. Whereas, the teachers in the WCEC field study had full control over their thermostat with no temperature adjustment restrictions.

The above comparison study identifies the advanced thermostat field tested by the WCEC does have the potential to produce energy savings if the baseline thermostat and operational conditions were not previously on schedule or set to an aggressive schedule already. Additionally, the post operational settings have an impact on the scale of energy savings when deployed in several buildings at one location, or several buildings (i.e. school district). Greater energy savings are likely to be achieved, when deployed across multiple locations, if a "super user" makes operational settings with limited control given to occupants (i.e. temperature adjustment range of plus or minus 4 degrees).

EVALUATIONS

The WCEC field study demonstrated that energy savings from installing advanced thermostats are largely dependent on the pre-retrofit thermostat operation, the level of knowledge of thermostat operation and level of training provided to building occupants. In this section, TRC provides further evaluation of the technology for utility implementation in a small and medium business sector incentive program is discussed. These evaluations are based on the field evaluation, user experience, manufacturer interviews, and WCEC's experience implementing the technology at three host sites.

APPLICABILITY AND MARKET BARRIERS

INSTALLATION

The advanced thermostat studied is readily available on the market to serve commercial applications. The thermostats is available through the manufacturer's preferred contractors, from a manufacturer regional sales representative, or direct purchase from the manufacturer. The manufacturer has a network of approximately 5,000 preferred contractors nationwide. If purchased through a preferred contractor, the thermostat is typically installed and setup by the contractor. The manufacturer offers technical support to the customer pre, during, and post service through telephone and onsite field engineers, when requested.

Market barriers to installation were identified through WCEC's field application of the advanced thermostats at three host sites. One market barrier to application was determined to be contractor's limited scope and experience during installation. The installation of this advanced thermostat is more complex relative to other thermostats. Thus, the contractor should receive adequate training from the manufacturer, and be able to handle a wide range of technical issues that may arise during installation. The contractors scope involves connecting the thermostat interface to the wall, switchboard on the RTU, connection to a sites Wi-Fi network. It does not include customer education of the technology or Wi-Fi connectivity issues.

APPLICATIONS

One of the comparative advantages of the thermostat studied is the ability to control and/or access multiple thermostats through a single (web) interface. This offers a very efficient way of making changes to many thermostats at once. Medium sized businesses with dedicated facilities management staff or businesses managing multiple locations would be ideally suited for this technology. The thermostat provides the opportunity to customize the level of access and autonomy at the individual thermostat level. Organizations can therefore create and implement nuanced thermostat policies, establishing different settings and providing varying degrees of autonomy for different room types (e.g., meeting rooms versus offices) or staff ranks. With the proper training and institutional support, such flexibility could be an asset to many medium sized organizations.

This product allows the user to set up alerts (based on time durations) and has limited FDD capabilities – thought these FDD capabilities were not tested in this project. The FDD capabilities are limited to the user's application of the reporting system. The reporting system pings the thermostat every five second and rolls the data into five-minute data points. It can then be downloaded by the user to perform analytics on their system. The manufacturer currently does not offer a standard analytics service with the purchase of the thermostat; however, the service is offered, upon request and for an additional fee, by a data analytics partner of the manufacturer.

NEW PRODUCTS

The advanced (touchscreen) thermostat model evaluated for this study is being phased out. The manufacturer offers a different model currently that has a push button operation with similar functionality and easier installation. The manufacturer reported that the push button model is installed in 95% of commercial applications and is less expensive than the touchscreen model. The installation of the push button model is a five-wire wall connection, and does not require any connection at the HVAC system equipment interface. This results in an easier installation process for any user.

ENERGY SAVINGS

Through this evaluation, all calculated savings were modest and in one case the savings were negative. Nearly all savings generated were a function of the relatively aggressive default setback schedules implemented by the contractors at the behest of the project team.

WCEC found that the determination of energy savings is particularly challenging under certain conditions. These include: a) inconsistencies between scheduled times and actual operating times of a building (i.e. rooms are often booked longer than they may actually be occupied) and, b) large variances in the power use of different types of activities (i.e. due to occupancy, ambient light, indoor vs. outdoor activities, etc.). Both challenges are particularly common among communal use spaces. Thus, the function and usage of a given room whose energy use from HVAC load is being analyzed can greatly affect whether or not the energy savings yielded by the room's thermostat can be precisely estimated.

Advanced thermostats, such as the product tested in this evaluation, have the potential to save energy when applied in enterprise level applications. While advanced thermostats are the easiest retrofit solutions for a roof top packaged unit and may be considered a good "bang for the buck" solution, they offer lower savings comparted to other retrofit strategies such as an advanced retrofit "kit" solution.

PROGRAM IMPLEMENTATION

INSTALLATION

For inclusion in a utility program, TRC and WCEC recommend that utility-approved contractors be required to install the advanced thermostats. In addition to detailed knowledge of the product, becoming an approved contractor would involve retaining knowledge on the conditions of the rebate program, and in particular the approved set points. An on-going relationship with the rebate program should ensure that approved contractors commission thermostats in adherence to policies (i.e., they program it according to the approved set points).

Finally, wireless internet service is a necessary component of the installation process and ongoing functioning of the thermostat. Given that Wi-Fi connectivity falls outside of contractors' domain, organizations themselves will need to be prepared to provide (or obtain) support in that area should issues arise. At a minimum, they should be informed Wi-Fi issues will be theirs alone to address.

ESTABLISHING USER ACCESS

The advanced thermostat provides two modes of accessing their thermostats: on the wall device and remotely via the website. Because the features differ by mode, a determination of the mode of access affects the level of access, too.

The most appropriate mode and level of access to grant users depends on the particular situation of a given site and organization. Customers should be advised to think carefully about the level of access they wish to grant users. Customers participating in a utility program would have to ensure that the program criteria are being met, which would require prohibiting users from changing settings in a way that falls outside the approved range.

For some locations, a facilities manager, acting as a "super user", could program all the thermostats – the manufacturer provides a very efficient way of doing this - and then enable only a limited set of changes (or none at all) to be made by other users (either via the web interface or on the device itself). In locations where they wish to give more autonomy to the occupants/users, they could limit the ability of users to change settings only to the utility program-approved range.

Whatever determination is made about the level of user access, it is recommended that this is clearly communicated by the principal decision-maker to the occupants/users. In two cases in the field study, installation of the new thermostats was used as an opportunity to change the level of control users had over the thermostats. The pushback that ensued at the school is not unique, and customers should be aware they may encounter pushback if they make changes to thermostat access without warning or consultations with the current users of the thermostats.

Finally, access requires more than just permission to use the thermostat. Without the knowledge to operate it, access is moot. Basic instruction or training on how to operate the thermostat is crucial for end users. In addition, customers should be instructed how to make basic changes to the schedule to accommodate deviations in their typical schedule and to feel empowered to control the conditions in their businesses. It is recommended that the manufacturer teach approved contractors how to train users to operate their newly installed advanced thermostats and adjust the content according to the access policy of each organization, in order to reinforce appropriate expectations about access.

ONGOING SERVICE & MONITORING

If the technology is going to be used consistently for energy saving purposes, a utility program should consider a model that includes some form of continuous commissioning by agents that are known and trustworthy to the customers. One option would be to utilize this thermostat technology as an additional entry point to a service contract for programs like Air-Care Plus, in which fault detection through thermostat monitoring is a tack-on service (which may yield substantial energy savings). The thermostat program could also incorporate Demand Response to address grid reliability. A utility program could significantly subsidize hardware and installation costs, and provide on-going rebates for approved thermostat settings, acknowledging, however that energy savings will vary. Contractors, through a maintenance contract, would retain responsibility for addressing system alerts and monitoring prescribed set points. By aligning the incentives and responsibilities appropriately, a program such as this could yield benefits for customers (e.g., technology upgrade, rebate opportunities) and contractors (e.g., maintenance contracts and thermostat transparency), as well as the utility.

RECOMMENDATIONS

The recommendations in this report are based on data available from four onsite evaluations, and the technology market assessment study done as part of Phase 1 of this study.

There were minimal to negative savings found in this study, which is largely due to the nature of the sites and prior operation of thermostats. It is possible that a site with poor prior operation of thermostats and where a central user can control multiple thermostats will result in savings, as seen in the school comparison study.

For programs, it means that qualification criteria for program participation should include the following screens for participation in a program:

- **Existing thermostat technology:** The existing thermostat should be non-programmable or programmable with limited features.
- **Existing user operation:** User operation in pre retrofit conditions should be limited to none, meaning if the user has a programmable thermostat, they do not already have aggressive operational settings. Ideal candidates for a program would be users who do not currently have any type of programmable thermostat and manually operate the thermostat.
- **Customers with multiple locations:** The ideal application for this advanced thermostat is a customer with several buildings at one location or multiple buildings in several locations.

Additional recommended requirements for a utility program should focus on training occupants on the technology and contractor training and follow through (ongoing service). Occupant training should be a priority for programs through the installing contractor to ensure the technologies are being operated under ideal conditions, thus resulting in maximum savings. Contractors participating in a program should be well trained on installation, occupant education, and providing on going customer support through a maintenance program, similar to AirCare Plus.

APPENDICES

This section provides the following appendices:

- Detailed site energy calculations
- Occupant survey pre an post installation
- Usability Task 1
- Usability Task 2

ENERGY SAVINGS CALCULATIONS

The following energy savings caluclations are details from the WCEC field report, submitted to PG&E seperatly.

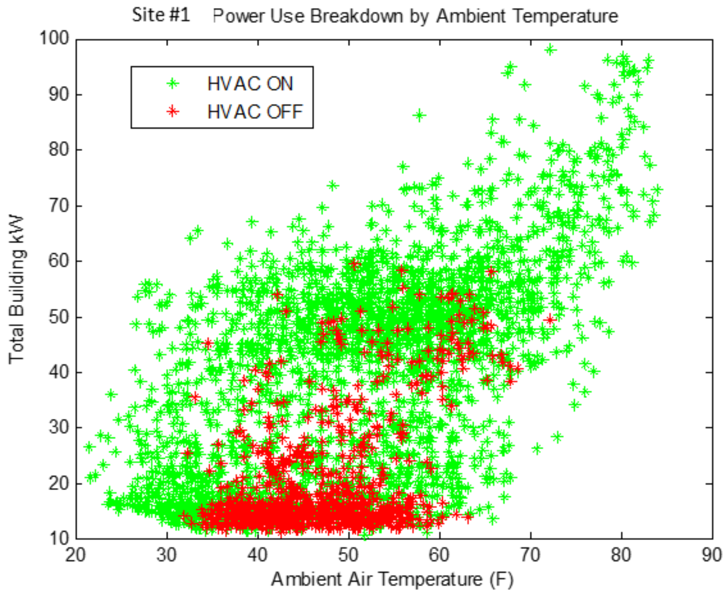
A primary goal in the data analysis methodology was to disaggregate the total site-level energy usage into a 'baseload' (non-HVAC power consumption) and HVAC power component. Based on the assumption that the 'baseload' will remain constant before and after the advanced thermostat install, the effects of the Advanced thermostat on HVAC power draw could be isolated from other energy usage fluctuations. To this end, the overall process for determining the savings potential of the Advanced thermostat thermostat was to:

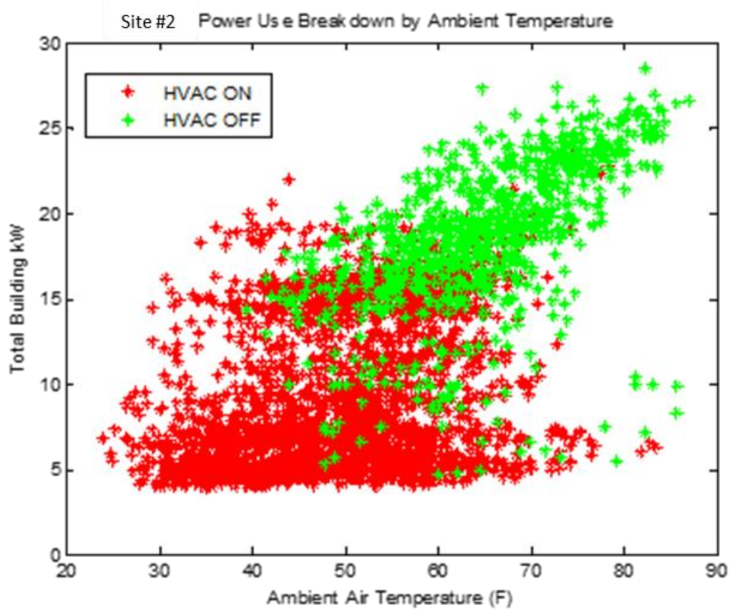
1. Determine a baseload schedule for each site, and thus isolate HVAC power draw by subtracting the baseload prediction from the total SmartMeter measured power draw;
2. Normalize the HVAC power draw by outside air temperature to account for annual differences between the pre-installation and post-installation period; and
3. Compare the normalized HVAC power draw in pre-installation and post-installation periods to determine if there was an overall energy savings attributable to the manufacturer's energy management software (EMS) system.

The fidelity of this analysis is based significantly on the quality of fit of the baseload regression and the (commonly used) assumption that the site's baseload pattern does not change significantly between the pre-installation and post-installation period. Efforts to execute a 'simpler' analysis based only on the total measured power draw (without disaggregating the HVAC component of power draw) were attempted but the wide variance in total power data coupled with the correlations between factors that affect HVAC power (i.e. outside air temperature) and factors that affect baseload power (i.e. time of day) made the results appear unreliable.

The following plots indicate the difference between HVAC power draw and the baseload as a function of temperature for the post-installation period at each site. The plots were developed using run time data from the advanced thermostats for the post-installation period.

It can be seen that for site #2 and site #1 both HVAC and non-HVAC power trend positively with outside air temperature, although the baseload trend is predicted to be a secondary effect based on time of day. Interestingly, there does not appear to be any clear trend between site #3's power use (either HVAC or baseload) and outside air temperature. This lack of pattern in the data will ultimately prevent an effective disaggregation of HVAC power at site #3 and thus preclude the determination of energy savings attributable to the Advanced thermostat thermostat. A lack of correlation between outside air temperature and building energy draw necessitates further discussion and investigation which will be presented later in this paper.


Site #1 Power Use Breakdown by Ambient Temperature
HVAC ON
HVAC OFF
Total Building kW
Ambient Air Temperature (F)
100
90
80
70
60
50
40
30
20
10
20
30
40
50
60
70
80
90


Site #2 Power Use Breakdown by Ambient Temperature
HVAC ON
HVAC OFF
Total Building kW
Ambient Air Temperature (F)
30
25
20
15
10
5
0
20
30
40
50
60
70
80
90

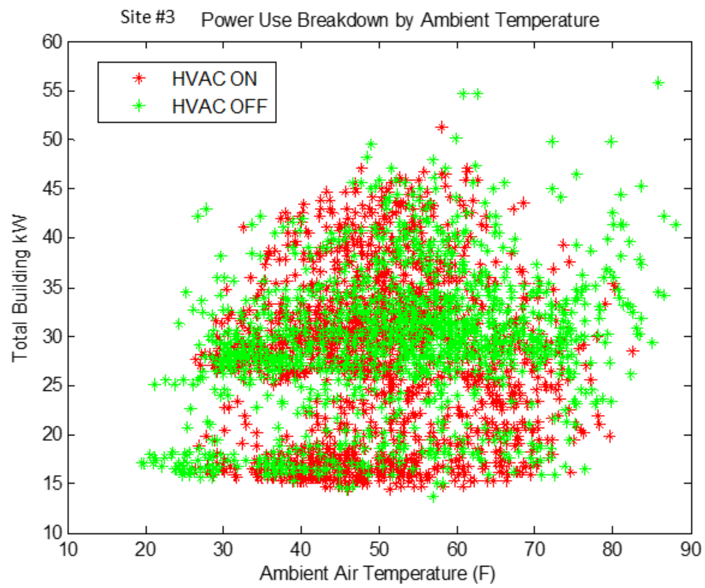


FIGURE 6. COMPARISON OF TOTAL BUILDING POWER DRAW WITH THE HVAC SYSTEM ON AND OFF FOR THE POST INSTALLATION PERIOD AT EACH SITE. NOTE THAT AT SITE #3 THERE IS NOT AN OBSERVABLE TREND BETWEEN AMBIENT AIR TEMPERATURE AND POWER DRAW WITH THE HVAC SYSTEM RUNNING.

It was discovered early in the analysis that Site #1 and Burger Saloon's total kW draw was strongly correlated with the hour of the day and day of the week. This was determined to be due to two effects:

1. The site's baseload (non-HVAC power draw), as correlated to its business hours; and
2. The site's HVAC power draw, as correlated to outdoor air temperature (which is also correlated to time of day).

Attempts were made to identify a similar trend for Site #3's power consumption with marginal success. The following plots indicate the relationship between power draw, time of day, and outside air temperature for each day of the week.

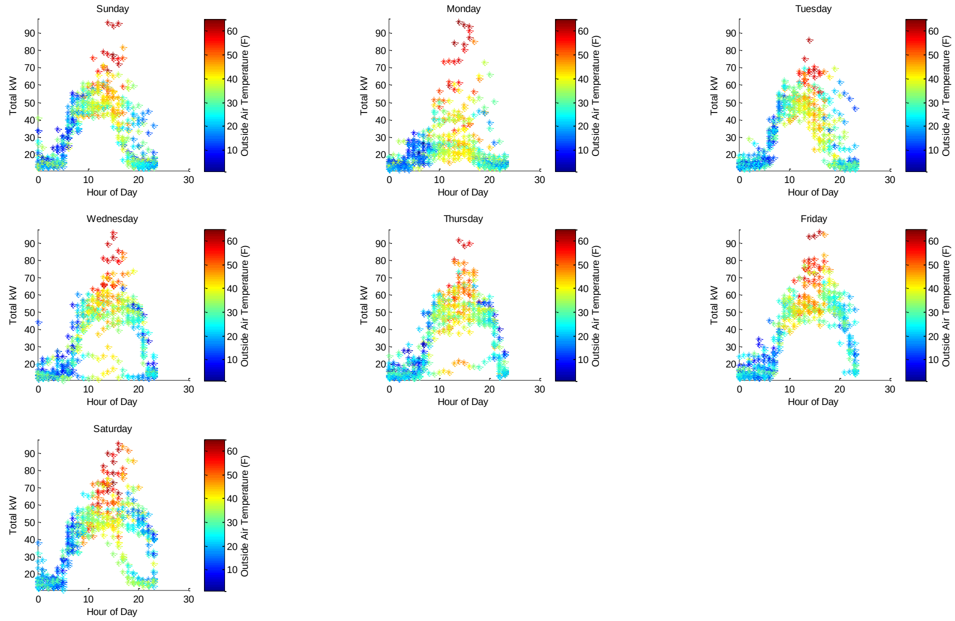


FIGURE 7. DAILY TRENDS IN TOTAL BUILDING POWER CONSUMPTION WITH TIME OF DAY AND OUTSIDE AIR TEMPERATURE AT THE SITE #1

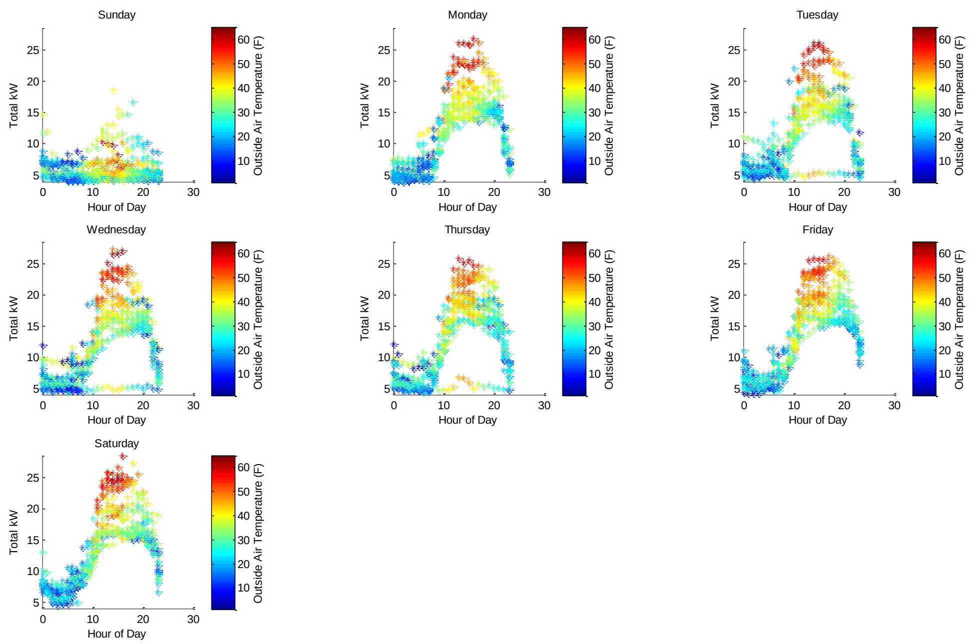


FIGURE 8. DAILY TRENDS IN TOTAL BUILDING POWER CONSUMPTION WITH TIME OF DAY AND OUTSIDE AIR TEMPERATURESITE #2. NOTE THAT THE BUSINESS IS CLOSED ON SUNDAY.

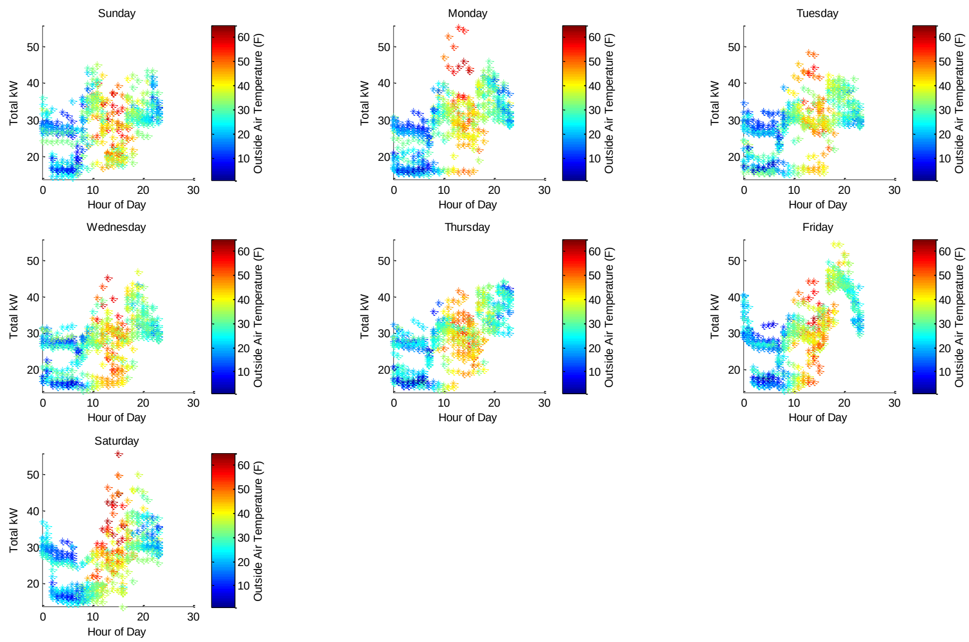


FIGURE 9. DAILY TRENDS IN TOTAL BUILDING POWER CONSUMPTION WITH TIME OF DAY AND OUTSIDE AIR TEMPERATURE AT SITE #3. NOTE THAT DAILY POWER USE CORRELATIONS ARE MUCH LESS CLEAR THAN AT THE OTHER TWO SITES.

For Site #1 and Site # 2it was determined that the HVAC portion of the total site power draw could be approximated using a regression function based on the time of day. A similar attempt was made for Site #3 but the resulting regressions exhibited a poor correlation with the original data. The runtimes on each unit were evaluated and only those units deemed operational were considered in the regression.

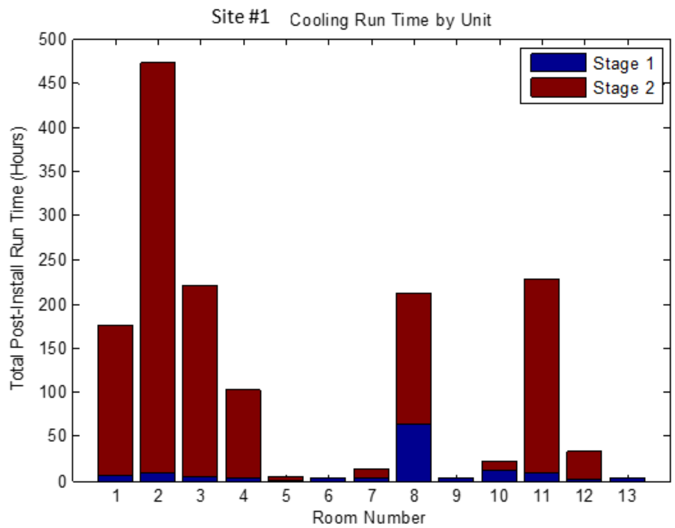


FIGURE 10. SITE #1 COOLING RUN TIME

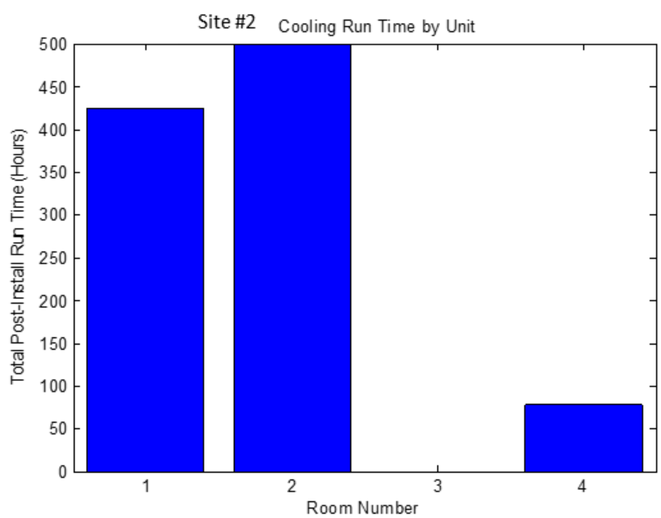


FIGURE 11. SITE #2 COOLING RUN TIME

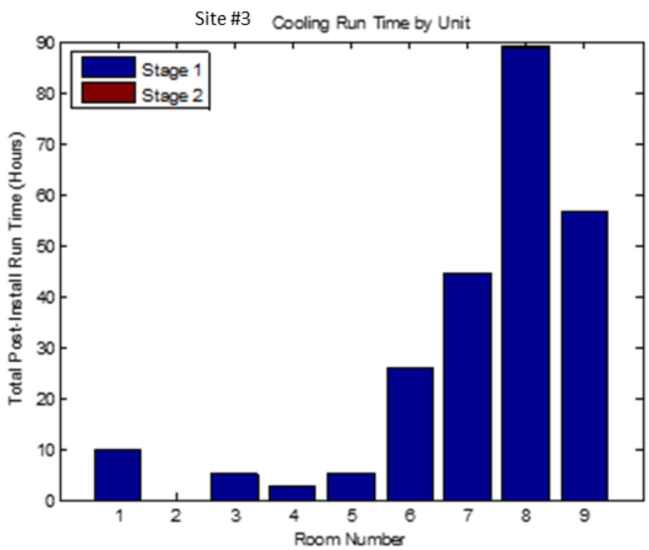


FIGURE 12. SITE #3 COOLING RUN TIME

To fit the regression, the post-installation HVAC runtimes provided by the advanced thermostats were used in conjunction with the PG&E SmartMeter data. This provided two systems of equations that were solved simultaneously to provide both a baseload (non-HVAC) power draw regression as a function of the time of day, and a HVAC power usage as a function of its runtime (a linear relationship which has a slope corresponding to the average power consumption of the HVAC system weighted across operating temperatures). For Burger Saloon, which had only three operating RTU's, there were sufficient data points to isolate the operating power consumption for each of the three units. For site #3 and site #1, which both featured more than ten RTUs, there were insufficient data to isolate the power consumption for each individual RTU and thus only an aggregate HVAC power consumption for all operating units was developed. The RTUs at these locations are similar (if not identical) in size and thus this aggregation should not significantly affect results. At site #2, the individual power draws obtained for each unit were proportional to the unit size, thus lending credibility to the regression method.

For each site, a combination of regressions which best described the overall data was determined. For site #1 and site #3 it was found that the daily power usage varied with each weekday and thus seven regressions were developed to provide the best overall fit. site #2 was found to be extremely consistent and thus one regression was developed for all operating days (Monday – Saturday), and a second for Sunday during which the business was closed. The regressions for site #3 were the worst fit of all three sites, which is predicted to be attributable to the non-standard operating hours of one building on site and lack of any clear relationship between temperature, time of day, and power consumption. An attempt was made to correlate site #3's event calendar with hourly power usage based on total daily 'event hours'. This appeared to show some correlation but an exact relationship could not be determined and was deemed unsuitable as a predictor of baseload power consumption. This is suspected to be due in part to a combination of: a) inconsistencies between scheduled times and actual operating times of a building (i.e. rooms are often booked longer than they may actually be occupied), and b) large variances in the power use of different types of activities (i.e. due to occupancy, ambient light, indoor vs. outdoor activities, etc).

For an example of the differences noted in daily total power draw trends, the regressions for Mondays and Fridays at site #1 are presented. Note that this is a regression for the total power draw (calculated as a function of time of day and measured HVAC runtime) from which the baseload portion is then later extracted.

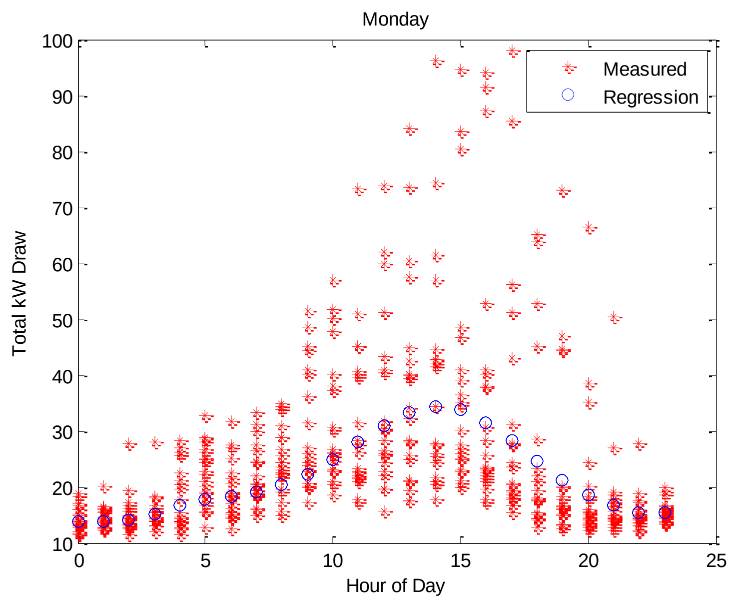


FIGURE 13. TOTAL BUILDING POWER DRAW TREND FOR MONDAYS AT SITE #1

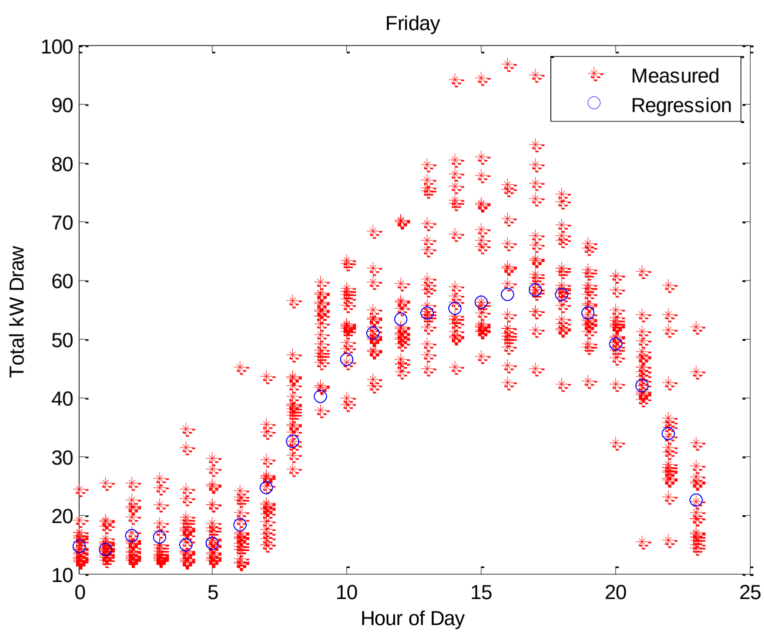


FIGURE 14. TOTAL BUILDING POWER DRAW TREND FOR FRIDAYS AT SITE #1

By extracting only the time of day terms from the disaggregation regression, a regression for the site's baseload can be determined. These are shown in comparison to the site's total measured power draw for when the HVAC system is on (green) and off (red). The regression, if appropriately fit, should correlate to the baseload (HVAC off) regions of the measured power draw. This correlation is strongly observed for site #1 and site #2, and loosely correlated at site #3.

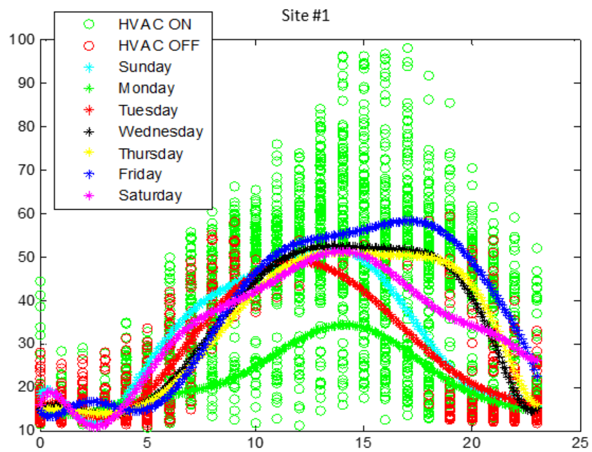


FIGURE 15. SITE #1: DISAGGREGATED REGRESSION BY TIME OF DAY FOR DETERMINING BASELOAD

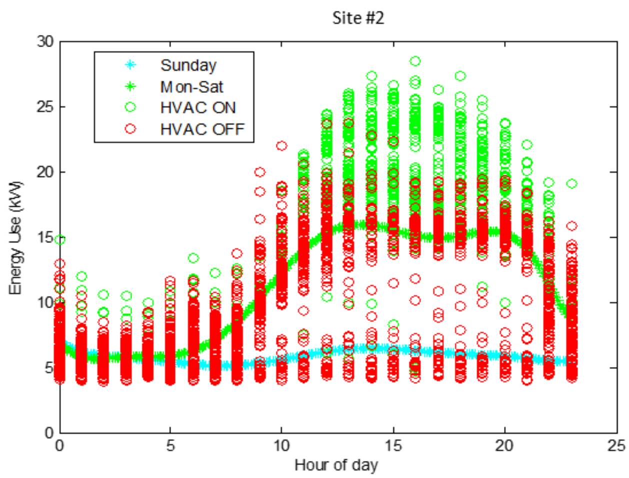


FIGURE 16. SITE #2: DISAGGREGATED REGRESSION BY TIME OF DAY FOR DETERMINING BASELOAD

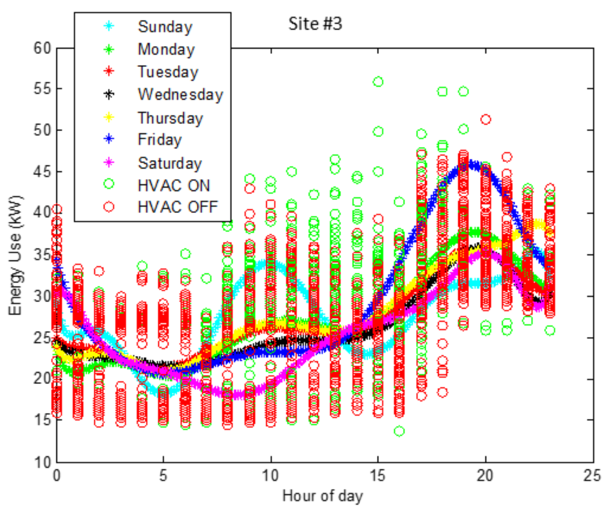
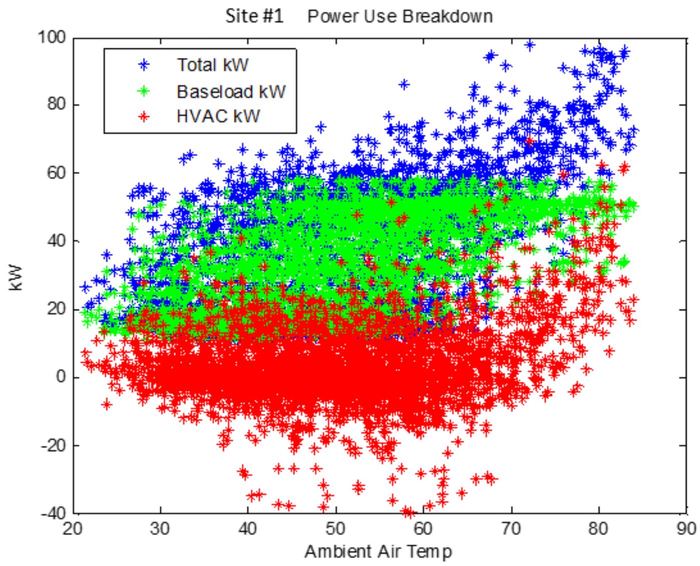


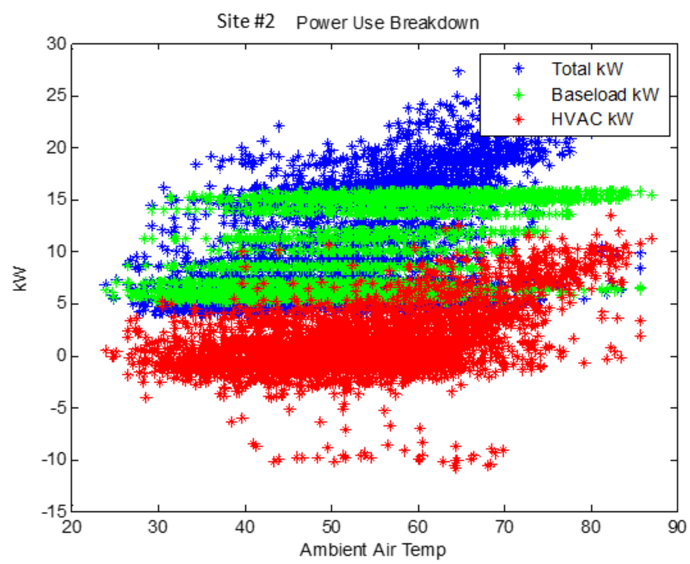
FIGURE 17. SITE #3: DISAGGREGATED REGRESSION BY TIME OF DAY FOR DETERMINING BASELOAD

With the baseload regressions developed it was possible to evaluate the HVAC power consumption and subsequently normalize by temperature to determine any savings attributable to the advanced thermostat system. A breakdown of the total power use is shown below. It should be noted that calculations for the pre-installation period were only performed for the same calendar days as the post-installation period so that the total number of days and the portion of the year being compared are consistent.

	Site #1	Site #2	Site #3
PRE-INSTALL	09/28/2012 - 02/22/2013	09/24/2012 - 02/22/2013	10/9/2012 - 02/22/2013
POST-INSTALL	09/28/2013 - 02/22/2014	09/24/2013 - 02/22/2014	10/9/2013 - 02/22/2014

FIGURE 18. PRE AND POST MONITORING PERIODS FOR EACH SITE





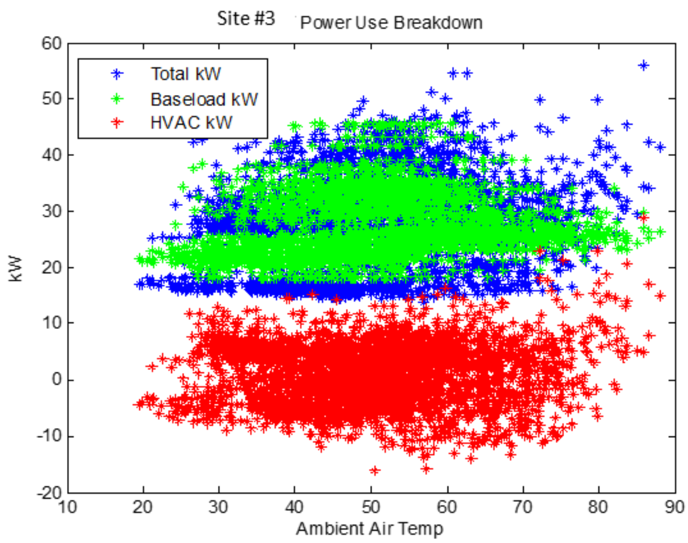


FIGURE 19.POWER USE DIVIDED INTO HVAC AND BASELOAD COMPONENTS USING REGRESSIONS ESTABLISHED ABOVE. NOTE THAT THE HVAC COMPONENT OF POWER HAS A POSITIVE TREND WITH AMBIENT TEMPERATURE WHEREAS THE BASELOAD DOES NOT

Using the HVAC power draw, a 'hockey stick' regression was used to relate ambient air temperature to the HVAC kW consumed. The motivation for this is that below a certain temperature threshold the AC system should not operate and thus will require a constant, near-zero power draw independent of temperature. As temperature increases beyond this threshold the HVAC power consumption should increase linearly as a higher average temperature results in a higher average runtime for the HVAC system. Although the variance of the data is large, the resulting regression for site #1 and site #2 does exhibit a low value and near zero slope below a temperature threshold, and a significant rise beyond it. The changeover temperature is consistent with expectations (55 - 65 degrees) and thus lends credibility to the final result. Two regressions were preformed, one for pre-installation, one for post-installation, and the resulting difference between the slopes is used to determine the energy savings due to the Advanced thermostat thermostats.

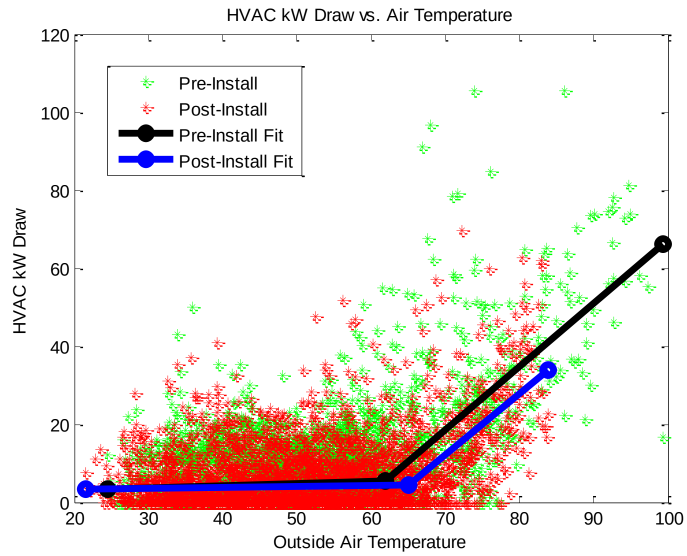


FIGURE 20. HOCKEY STICK REGRESSION SHOWING COMPARISON OF PRE AND POST INSTALLATION ENERGY USAGE AT SITE #1

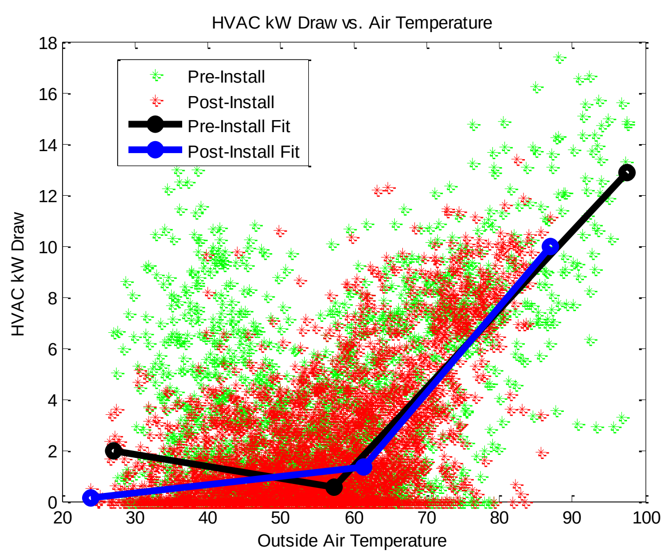


FIGURE 21. HOCKEY STICK REGRESSION SHOWING COMPARISON OF PRE AND POST INSTALLATION ENERGY USE AT SITE #2

In the case of site #3, it has already been established that there is a poor correlation between the measured power draw and either of the two predicted driving variables: ambient air temperature or time of day. Because a correlation could not be established, a resulting value for the energy savings potential of the Advanced thermostat system cannot be derived. Since the site has a baseload that is both high (~30kW, as determined from post-installation data), and variable (+/- 20 kW daily), it is likely that the power draw fluctuations caused by the HVAC system (expected to be ~3kW per unit) are masked by the variance of the baseload. The baseload fluctuations are predicted to be caused by a combination of the Church's irregular hours (occupied hours are correlated to community events), and the schools highly varying lighting loads (i.e. large lighting loads being switched on/off between classes), both of which have an unclear relationship with HVAC usage. An attempt was made to correlate the site #3 data using the same hockey stick regression technique presented above, but results were unsatisfactory.

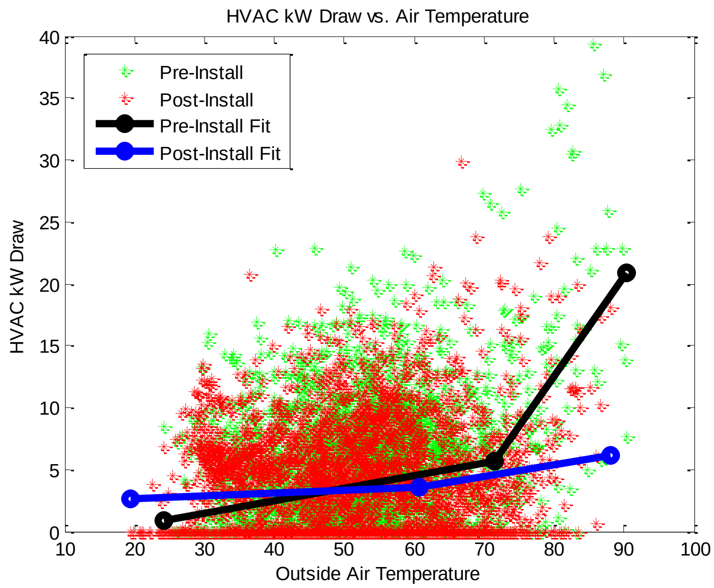


FIGURE 22. ATTEMPT AT HOCKEY STICK REGRESSION AT SITE #3. POOR CORRELATION BETWEEN OUTSIDE AIR TEMPERATURE AND KW DRAW (ESPECIALLY IN THE POST-INSTALLATION PHASE) PREVENT DETERMINATION OF THE SAVINGS POTENTIAL DUE TO ADVANCED THERMOSTAT.

Based on the slope differences between the calculated regressions in the HVAC operating region of the plot (> approx. 65F for Site #1, > approx. 55 for site #2) the following energy savings were calculated. Standard error was determined for the calculations using the standard deviation normalized about the regression for the operating region of both pre and post installation periods. The results are presented below:

Location	Energy savings/costs (% of HVAC power draw per degree F)	Restrictions	Std. Err.
Site #1	3.5%	for OAT > 65.1 deg F	1.00%
Site #2	-6.7%[7]	for OAT > 60.6 deg F	0.43%
Site #3	Inconclusive		

FIGURE 23. AVERAGE ADVANCED THERMOSTAT ENERGY SAVINGS BY SITE

It is interesting to note the comparative energy savings between site #1 and site #2. On a qualitative level, the owner and building manager of site #2 was described to be an already extremely conscious energy user, and thus was likely to already be operating his HVAC equipment in a highly efficient manner. Site #1 on the other hand, is a large country club with numerous employees who are, on average, much less concerned with the energy consumption of the site. It is not unreasonable therefore that the energy savings derived from the Advanced thermostat thermostats, and smart thermostats at large, is entirely dependent on the previous HVAC control scheme and the energy consciousness of the

[7] Upon installation of the Advanced thermostat thermostats, the project team was able to inform the restaurant owner of the precise zoning of this HVAC system. As a result, he was able to achieve greater thermostatic control in the kitchen, which we believe, is the primary driver of the increase in energy use.

operator. In other words, the sites, which stand to achieve the greatest energy savings from a smart thermostat such as Advanced thermostat, are those which do not already have energy conscious users who are able to operate a 'standard' thermostat efficiently.

Advanced Thermostats Pre-Installation Survey

Title of research study: Advanced Thermostats: Human Technology Interaction
Investigator: Kristin Heinemeier

Why am I being invited to take part in a research study?
We invite you to take part in a research study because you are one of the people that will be using the new advanced learning thermostats at this location.

What should I know about a research study?

This document explains this research study to you, including:
-The nature and purpose of the research study.
-The procedures to be followed.
-Any common or important discomforts and risks.
-Any benefits you might expect.

Whether or not you take part is up to you.
-You can choose without force, fraud, deceit, duress, coercion, or undue influence.
-You can choose not to take part.
-You can agree to take part now and later change your mind.

Whatever you decide it will not be held against you.
-You can ask all the questions you want before you decide.
-If you agree to take part, you will be given a copy of this document.

Who can I talk to?
If you have questions, concerns, or complaints, or think the research has hurt you, talk to the research team at 530-752-2779 (Claudia Barriga).

This research has been reviewed and approved by an Institutional Review Board ("IRB"). Information to help you understand research is on-line at http://www.research.ucdavis.edu/IRBAdmin.You may talk to a IRB staff member at (916) 703-9151, IRBAdmin@ucdmc.ucdavis.edu, or 2921 Stockton Blvd, Suite 1400, Room 1429, Sacramento, CA 95817 for any of the following:
• Your questions, concerns, or complaints are not being answered by the research team.
• You cannot reach the research team.
• You want to talk to someone besides the research team.
• You have questions about your rights as a research subject.
• You want to get information or provide input about this research.

Why is this research being done?
This research is being done to understand better how people use this new kind of thermostat, to develop ways to make these thermostats easier to use, and to discover what problems people may face when using these thermostats in a work setting.

How long will the research last?
We expect that you will be in this research study for 6 months. You will take a 30 minute survey at the beginning of the study, then be contacted every three or four weeks to do another brief task and report on it (30 minutes each time). There will be four of these brief tasks. Finally, you will do a final survey (30 minutes) at the end of the six months. In total, given the activities described, we expect you to spend 3 hours in study related activities throughout the six month study period. Time devoted to the study will in no way be more than 5 hours.

How many people will be studied?
We expect about 80 people will be in this research study.

Advanced Thermostats Pre-Installation Survey

What happens if I say yes, I want to be in this research?
After you agree to participate, you will go on to the first survey, which will be conducted online. After you respond to that survey, we will give you a name and password to an online discussion board. All communications for the study from then on will take place through email and/or this board. We will need to have an email to contact you. Every three or four weeks we will alert you to a "study-task". We will ask you to do something with your new thermostat, and to report about it in the discussion board, using the name and password we gave you. At that board, you will also be able to interact with other study participants, and see how they are fulfilling the tasks and what problems or solutions they are finding. The research team will also participate in the board and may answer questions you have. We expect each task to take you no more than thirty minutes to complete and report. You do not need to do that in one continuous chunk of time. There will be 4 tasks throughout the study. We will accommodate the tasks and schedules to times you are able to do them.

What happens if I do not want to be in this research?
You may decide not to take part in the research and it will not be held against you.

What happens if I say yes, but I change my mind later?
You can leave the research at any time and it will not be held against you. We will use only responses and observations made up to the point that you withdraw from a study.

Is there any way being in this study could be bad for me?
We do not expect this study to create any discomfort for you, other than those you might find in your everyday life.

Will being in this study help me in any way?
There are no benefits to you from your taking part in this research. We cannot promise any benefits to others from your taking part in this research. However, possible benefits to others include improved technological development of thermostat usability, leading to energy savings in the long term.
.
What happens to the information collected for the research?
Efforts will be made to limit use or disclosure of your personal information (name, email), including research records, to people who have a need to review this information. We cannot promise complete confidentiality. Organizations that may inspect and copy your information include the IRB and other University of California representatives responsible for the management or oversight of this study. Your identifying information will not be shared with our sponsors at PG&E Emerging Technologies.

We may publish the results of this research. However, we will keep your name and other identifying information confidential.

What else do I need to know?
This research is being funded by Pacific Gas and Electric Emerging Technologies, as part of their research on energy efficiency.

There is no charge for you to participate in this study.

If you agree to take part in this research study, we will compensate you with US100 gift card for your time and effort, when you complete the whole study. If you complete only part of the study you will receive part of the US100 gift card. ($20 if you complete only the initial survey, $40 if you complete the initial survey and some of the tasks, $60 if you complete the initial survey and all 4 tasks, but not the final survey.)

*1. I accept to participate

○ Yes

*2. Please place yourself on the following scale (considering only temperature).

	Too Cold						Too Hot
At this moment, I feel...	○	○	○	○	○	○	○

*3. Please place yourself on the following scale (considering only temperature).

	Comfortable						Uncomfortable
At this moment, I feel...	○	○	○	○	○	○	○

***4. While at work here, how often do you feel:**

	Always	Almost always	Sometimes	Never
Cold	◯	◯	◯	◯
Hot	◯	◯	◯	◯
Comfortable	◯	◯	◯	◯

***5. Please describe in as much detail as you can the thermostat that is currently in your workspace. What does it look like? What functions does it have?**

***6. Please indicate if your thermostat has any of the following:**

	Yes	No	Not sure
Lights	◯	◯	◯
Dials	◯	◯	◯
Buttons	◯	◯	◯
Switches	◯	◯	◯
Cover	◯	◯	◯

***7. Please indicate how sure you are about the following statements (in relation to the current thermostat):**

	Completely unsure	Mostly unsure	Mostly sure	Completely sure
I know how to find out what the current temperature in the room is.	◯	◯	◯	◯
I know how to change the date and time in the thermostat.	◯	◯	◯	◯
I know how to schedule the thermostat to turn on and off at given dates and times.	◯	◯	◯	◯
I know how to set the thermostat to a different schedule for weekends and holidays.	◯	◯	◯	◯
I know how to set the thermostat to run the fan only (not AC).	◯	◯	◯	◯

***8. Thermostats are usually set to a temperature point at which they will start heating (winter) or cooling (summer). Please indicate how sure you are about the following statements (in relation to the current thermostat):**

	Completely unsure	Mostly unsure	Mostly sure	Completely sure
I know how to find out what the current temperature set-point for the room.	○	○	○	○
I know how to change the current set-point for the room.	○	○	○	○
I know how to program a set-point for a future period of time (i.e. vacation, next weekend).	○	○	○	○
I know how to set the thermostat to different set-points for occupied and unoccupied hours.	○	○	○	○

***9. How long do you think it would take you to**

	Less than 1 minute	1-3 minutes	3-5 minutes	5-10 minutes	10-15 minutes	More than 15 minutes
Find out what the current temperature in the room is?	○	○	○	○	○	○
Find out what the current set-point for the room is?	○	○	○	○	○	○
Change the current set-point for the room?	○	○	○	○	○	○
Program a set-point for a future period of time (i.e. vacation, next weekend?)	○	○	○	○	○	○
Set a schedule for weekends and holidays?	○	○	○	○	○	○
Set a schedule for occupied and unoccupied hours (i.e. day an night)	○	○	○	○	○	○
Change the date and time in the thermostat?	○	○	○	○	○	○

***10. Please indicate how much you agree or disagree. My thermostat makes me feel...**

	Strongly disagree	Mostly disagree	Neither agree nor disagree	Mostly agree	Strongly agree
confused	○	○	○	○	○
frustrated	○	○	○	○	○
powerful	○	○	○	○	○
bewildered	○	○	○	○	○
in control	○	○	○	○	○
out of control	○	○	○	○	○
powerless	○	○	○	○	○
angry	○	○	○	○	○
safe	○	○	○	○	○
comfortable	○	○	○	○	○
proud	○	○	○	○	○

***11. Please tell us briefly what situations usually lead you to use the thermostat, and what kinds of things you do when you use it?**

***12. How far from your desk is your current thermostat?**

- ◯ 1-2 Feet
- ◯ 3-4 Feet
- ◯ 5-6 Feet
- ◯ More than 6 Feet

***13. Do you agree with the following statements.**

	Disagree	Mostly Disagree	Mostly Agree	Agree
The thermostat is easy to reach.	◯	◯	◯	◯
The thermostat is lit well enough for me to see and read it.	◯	◯	◯	◯

***14. When you go to the thermostat, what is the most common action you take?**

***15. How often do you use the thermostat? For example, check the temperature, adjust the temperature, change settings (Choose the closest option to your typical use).**

- ◯ More than once a day
- ◯ Once a day
- ◯ Once a week
- ◯ Once every two weeks
- ◯ Once a month
- ◯ Once every two to three months
- ◯ I never use the thermostat

***16. How long did it take you to learn how to use this thermostat?**

- ◯ Less than a week
- ◯ A week
- ◯ Several weeks
- ◯ Several months
- ◯ More than several months
- ◯ I still don't know how to use it

***17. To the best of your knowledge, do you know how to use ALL the features in this thermostat?**

- ◯ Completely unsure
- ◯ Mostly unsure
- ◯ Mostly sure
- ◯ Completely sure

***18. When you use the thermostat, how sure are you that it will do what you want it to do?**

- ◯ Completely unsure
- ◯ Mostly unsure
- ◯ Mostly sure
- ◯ Completely sure

***19. When you reset a temperature in the thermostat, how long does it take for you to reach the comfort level you wanted?**

- ◯ Less than 10 minutes
- ◯ 10-20 minutes
- ◯ 20-30 minutes
- ◯ more than 30 minutes

***20. Imagine that you will be the last person to leave the room for the day. What do you think is the earliest time you could turn off the thermostat and still be comfortable when you go?**

- ◯ 15 minutes before leaving
- ◯ 30 minutes before leaving
- ◯ 45 minutes before leaving
- ◯ 60 minutes before leaving
- ◯ 1.5 hours before leaving
- ◯ 2 hours before leaving
- ◯ 3 hours before leaving

Other (please specify)

[ ]

***21. Do you ever turn off or adjust the thermostat some time before you leave? (Not immediately before, but more than twenty minutes in advance?)**

- ◯ Never
- ◯ Almost never
- ◯ Sometimes
- ◯ Often
- ◯ Always

***22. What factors might make your thermostat easier to use (please select all that apply)?**

- ☐ larger screen size
- ☐ larger font size
- ☐ different location
- ☐ clear labeling of options
- ☐ manual
- ☐ on screen instructions
- ☐ better feedback (confirmation messages)
- ☐ lighting

Other (please specify)

[ ]

***23. Is there anything you would want this thermostat to do that it does not do?**

- ◯ Yes
- ◯ No

24. If you answered yes, please explain.

***25. Have you ever had a conflict with others here over the use of the thermostat? What was it?**

***26. Is there more than one person whose comfort is influenced by this thermostat?**

- ◯ Yes
- ◯ No

***27. If you answered yes, who usually adjusts the thermostat?**

- ◯ Me
- ◯ Someone else
- ◯ Me and someone else

***28. How is the decision made whether or not to adjust it?**

***29. What happens if there is disagreement over the temperature?**

***30. How much do you know about the occupancy schedule in your building (when it is completely empty, when there are extra activities, when the janitorial service is in and out. etc.)**

I know nothing about the building's occupancy schedule	I know almost nothing about the building's occupancy schedule	I know something about the building's occupancy schedule	I know a good amount about the building's occupancy schedule	I know almost everything about the building's occupancy schedule	I know exactly what the occupancy schedule is
◯	◯	◯	◯	◯	◯

31. Does anything prevent you from using the thermostat when you might want/need to?

- ◯ Yes
- ◯ No

32. If you answered yes, please describe.

* **33. What is the best thing about your current thermostat?**

* **34. What is the worst thing about your current thermostat?**

* **35. Please walk over to the thermostat and record the following: What is the current temperature in the room you are in?**

* **36. What is the thermostat's temperature set to (set-point)?**

* **37. A thermostat can do all the things below. Can you rank them from the least essential function (1) of the thermostat to the most essential (5), in your opinion?**

☐	Make space comfortable before people arrive in the building.
☐	Keep all people comfortable while in the building.
☐	Adjust temperature when outdoor temperature conditions change.
☐	Adjust temperature when building temperature conditions change.
☐	Adjust temperature when there are no occupants in the building.

***38. Please answer the following questions:**

	Very unimportant	Mostly unimportant	Mostly important	Very important
When you use this thermostat, how much do you consider saving money?	○	○	○	○
When you use this thermostat, how much do you consider saving energy?	○	○	○	○
In general, how much do you care about saving energy at home?	○	○	○	○
In general, how much do you care about saving energy in your workplace?	○	○	○	○

***39. If it needed to be replaced, would you choose this thermostat to be installed again? Why?**

***40. Does this school have a policy or strategy for saving energy?**

○ Yes

○ No

41. If so, what is it?

***42. Does the energy policy involve using the thermostat in a certain way? What way?**

***43. How closely followed is the energy saving policy/strategy?**

○ Very closely

○ Somewhat closely

○ Not very closely

○ It is not followed

***44. Please provide your name, and email below, so that we can contact you with your discussion board name and password, and eventual gift card delivery.**

Remember that we will only use your email for research purposes, that we will not share it with third parties, and that it will be destroyed when data collection is over.

Thanks!

Name: ________

Room ________

Email Address: ________

YOU ARE DONE!

Thank you so much for helping us with our research, and stay on the lookout for any emails from us!

You can contact the research team at htiresearchgroup@ucdavis.edu with any questions.

HAVE A GREAT DAY :)

Title of research study: Advanced Thermostats: Human Technology Interaction
Investigator: Kristin Heinemeier

Why am I being invited to take part in a research study?
We invite you to take part in a research study because you are one of the people that will be using the new advanced learning thermostats at this location.

What should I know about a research study?

This document explains this research study to you, including:
-The nature and purpose of the research study.
-The procedures to be followed.
-Any common or important discomforts and risks.
-Any benefits you might expect.

Whether or not you take part is up to you.
-You can choose without force, fraud, deceit, duress, coercion, or undue influence.
-You can choose not to take part.
-You can agree to take part now and later change your mind.

Whatever you decide it will not be held against you.
-You can ask all the questions you want before you decide.
-If you agree to take part, you will be given a copy of this document.

Who can I talk to?
If you have questions, concerns, or complaints, or think the research has hurt you, talk to the research team at 530-752-2779 (Claudia Barriga).

This research has been reviewed and approved by an Institutional Review Board ("IRB"). Information to help you understand research is on-line at http://www.research.ucdavis.edu/IRBAdmin.You may talk to a IRB staff member at (916) 703-9151, IRBAdmin@ucdmc.ucdavis.edu, or 2921 Stockton Blvd, Suite 1400, Room 1429, Sacramento, CA 95817 for any of the following:
• Your questions, concerns, or complaints are not being answered by the research team.
• You cannot reach the research team.
• You want to talk to someone besides the research team.
• You have questions about your rights as a research subject.
• You want to get information or provide input about this research.

Why is this research being done?
This research is being done to understand better how people use this new kind of thermostat, to develop ways to make these thermostats easier to use, and to discover what problems people may face when using these thermostats in a work setting.

How long will the research last?
We expect that you will be in this research study for 6 months. You will take a 30 minute survey at the beginning of the study, then be contacted every three or four weeks to do another brief task and report on it (30 minutes each time). There will be four of these brief tasks. Finally, you will do a final survey (30 minutes) at the end of the six months. In total, given the activities described, we expect you to spend 3 hours in study related activities throughout the six month study period. Time devoted to the study will in no way be more than 5 hours.

How many people will be studied?
We expect about 80 people will be in this research study.

What happens if I say yes, I want to be in this research?
After you agree to participate, you will go on to the first survey, which will be conducted online. After you respond to that survey, we will give you a name and password to an online discussion board. All communications for the study from then on will take place through email and/or this board. We will need to have an email to contact you. Every three or four weeks we will alert you to a "study-task". We will ask you to do something with your new thermostat, and to report about it in the discussion board, using the name and password we gave you. At that board, you will also be able to interact with other study participants, and see how they are fulfilling the tasks and what problems or solutions they are finding. The research team will also participate in the board and may answer questions you have. We expect each task to take you no more than thirty minutes to complete and report. You do not need to do that in one continuous chunk of time. There will be 4 tasks throughout the study. We will accommodate the tasks and schedules to times you are able to do them.

What happens if I do not want to be in this research?
You may decide not to take part in the research and it will not be held against you.

What happens if I say yes, but I change my mind later?
You can leave the research at any time and it will not be held against you. We will use only responses and observations made up to the point that you withdraw from a study.

Is there any way being in this study could be bad for me?
We do not expect this study to create any discomfort for you, other than those you might find in your everyday life.

Will being in this study help me in any way?
There are no benefits to you from your taking part in this research. We cannot promise any benefits to others from your taking part in this research. However, possible benefits to others include improved technological development of thermostat usability, leading to energy savings in the long term.
.
What happens to the information collected for the research?
Efforts will be made to limit use or disclosure of your personal information (name, email), including research records, to people who have a need to review this information. We cannot promise complete confidentiality. Organizations that may inspect and copy your information include the IRB and other University of California representatives responsible for the management or oversight of this study. Your identifying information will not be shared with our sponsors at PG&E Emerging Technologies.

We may publish the results of this research. However, we will keep your name and other identifying information confidential.

What else do I need to know?
This research is being funded by Pacific Gas and Electric Emerging Technologies, as part of their research on energy efficiency.

There is no charge for you to participate in this study.

If you agree to take part in this research study, we will compensate you with US100 gift card for your time and effort, when you complete the whole study. If you complete only part of the study you will receive part of the US100 gift card. ($20 if you complete only the initial survey, $40 if you complete the initial survey and some of the tasks, $60 if you complete the initial survey and all 4 tasks, but not the final survey.)

1. We are interested in the way in which you have experienced the installation of the new thermostats. Please tell us what kind of information you received about the new thermostats after the installation.

	1 YES	2 NO	3 NOT SURE/CAN'T REMEMBER
I was given general information about how the new thermostats work.	○	○	○
I was given personal training on the new thermostats.	○	○	○
I was given hands-on training on the new thermostats.	○	○	○
I was given written materials about the new thermostats.	○	○	○
I was directed to online information about the new thermostats.	○	○	○

2. We are interested in the way in which you have discussed the new thermostats with others.

Please tell us how much you agree or disagree with the following statements, using the scale from 1 to 6 where 1 means "strongly disagree" and 6 means "strongly agree."

	1 Strongly Disagree	2 Moderately Disagree	3 Slightly Disagree	4 Slightly Agree	5 Moderately Agree	6 Strongly Agree
I have discussed the new thermostat with other teachers or staff at the school.	○	○	○	○	○	○
I have asked other teachers/staff to help me with the new thermostats.	○	○	○	○	○	○
I have asked technical staff from outside the school for help with the new thermostats.	○	○	○	○	○	○

3. Since the new thermostats were installed, please tell us how often have you felt

	Always	Almost always	Sometimes	Never
Comfortable	○	○	○	○
Too Hot	○	○	○	○
Too Cold	○	○	○	○

4. As you know, thermostats start cooling (or heating) when the temperature in the room reaches a certain set-point. In your opinion, when the room IS OCCUPIED, at what temperature should the system begin to:

	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82
COOL	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
HEAT	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○

5. To the best of your knowledge (guess if necessary), when the room is OCCUPIED, at what temperature is your thermostat set to:

	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82
COOL	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
HEAT	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○

6. Likewise, if the room is NOT OCCUPIED, at what temperature do you think the system should begin to

	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82
COOL	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
HEAT	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○

7. To the best of your knowledge (guess if necessary), when the room is NOT OCCUPIED, at what temperature is your thermostat set to:

	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82
COOL	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
HEAT	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○

***8. Please indicate how sure you are about the following statements (in relation to the new thermostat):**

	Completely unsure	Mostly unsure	Mostly sure	Completely sure
I know what temperatures the new thermostat is set to.	○	○	○	○
I know how to find out what the current temperature in the room is.	○	○	○	○
I know how to change the date and time in the thermostat.	○	○	○	○
I know how to schedule the thermostat to turn on and off at given dates and times.	○	○	○	○
I know how to set the thermostat to a different schedule for weekends and holidays.	○	○	○	○
I know how to set the thermostat to run the fan only (not AC).	○	○	○	○

***9. Thermostats are usually set to a temperature point at which they will start heating (winter) or cooling (summer). Please indicate how sure you are about the following statements (in relation to the new thermostat):**

	Completely unsure	Mostly unsure	Mostly sure	Completely sure
I know how to find out what the current temperature set-point for the room.	○	○	○	○
I know how to change the current set-point for the room.	○	○	○	○
I know how to program a set-point for a future period of time (i.e. vacation, next weekend).	○	○	○	○
I know how to set the thermostat to different set-points for occupied and unoccupied hours.	○	○	○	○

***10. How long do you think it would take you to**

	Less than 1 minute	1-3 minutes	3-5 minutes	5-10 minutes	10-15 minutes	More than 15 minutes
Find out what the current temperature in the room is?	○	○	○	○	○	○
Find out what the current set-point for the room is?	○	○	○	○	○	○
Change the current set-point for the room?	○	○	○	○	○	○
Program a set-point for a future period of time (i.e. vacation, next weekend?)	○	○	○	○	○	○
Set a schedule for weekends and holidays?	○	○	○	○	○	○
Set a schedule for occupied and unoccupied hours (i.e. day an night)	○	○	○	○	○	○
Change the date and time in the thermostat?	○	○	○	○	○	○

***11. Please indicate how much you agree or disagree. Since we returned to class, this new thermostat has made me feel:**

	Strongly disagree	Mostly disagree	Neither agree nor disagree	Mostly agree	Strongly agree
confused	○	○	○	○	○
frustrated	○	○	○	○	○
powerful	○	○	○	○	○
bewildered	○	○	○	○	○
in control	○	○	○	○	○
out of control	○	○	○	○	○
powerless	○	○	○	○	○
angry	○	○	○	○	○
safe	○	○	○	○	○
comfortable	○	○	○	○	○
proud	○	○	○	○	○

***12. How long did it take you to learn how to use this thermostat?**

- ◯ Less than a week
- ◯ A week
- ◯ Several weeks
- ◯ I still don't know how to use it

***13. To the best of your knowledge, do you know how to use ALL the features in this thermostat?**

- ◯ Completely unsure
- ◯ Mostly unsure
- ◯ Mostly sure
- ◯ Completely sure

***14. When you use the new thermostat, how sure are you that it will do what you want it to do?**

- ◯ Completely unsure
- ◯ Mostly unsure
- ◯ Mostly sure
- ◯ Completely sure

15. Since the new thermostats were installed, has anything prevented you from using the thermostat when you might want/need to?

- ◯ Yes
- ◯ No

16. If you answered yes, could you please describe what stopped you from using the new thermostat, in as much detail as you can.

***17. What is the best thing about the new thermostat?**

***18. What is the worst thing about the new thermostat?**

***19. If it needed to be replaced, would you choose this thermostat to be installed again? Why?**

20. Please tell us, in as much detail as you want, anything else you want to say about your experiences with this thermostat so far.

***21. Please provide your name, and email below, so that we can match your answers to previous surveys, and track your participation for the delivery of the gift card at the end of the study.**

Remember that we will only use your email for research purposes, that we will not share it with third parties, and that it will be destroyed when data collection is over.

Thanks!

Name:

Room

Email Address:

YOU ARE DONE!

Thank you so much for helping us with our research, and stay on the lookout for any emails from us!

You can contact the research team at htiresearchgroup@ucdavis.edu with any questions.

HAVE A GREAT DAY :)