Scaled Field Placement of Wireless Pneumatic Thermostats (WPT)

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ABBREVIATIONS AND ACRONYMS

ARRA	American Recovery and Reinvestment Act
AHU	Air Handling Unit
BMS (EMS, BAS)	Building Management System, or Energy Management System, or Building Automation System
CD	Cold Deck/Duct
CRI	Customized Retrofit Incentive, a PG&E Program
Cx	Commissioning
DSP	Duct Static Pressure
DR	Demand Response
EEM	Energy Efficiency Measure
EM&V	Evaluation, Monitoring and Verification
GTA	Global Temperature Adjustment
HD	Hot Deck/Duct
HVAC	Heating, Ventilation, & Air Conditioning
M&V	Measurement and Verification
OAT	Outside Air Temperature
RCx	Retro-Commissioning
SAT	Supply Air Temperature
VFD (VSD)	Variable Frequency Drive, also Variable Speed Drive
WPT	Wireless Pneumatic Thermostat

FIGURES

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EXECUTIVE SUMMARY

Wireless pneumatic thermostats (WPTs) present a retrofit opportunity that can enable energy-saving control strategies to be implemented in commercial buildings with older pneumatic HVAC controls. kW Engineering performed a scaled field placement of WPTs on behalf of PG&E. Our goals were to evaluate the implementation of WPT systems at pilot sites, collect data about their energy performance, and evaluate the feasibility of a hybrid deemed rebate program for the technology.

WPTs are direct replacements for standard pneumatic thermostats, which add wireless data communication enabling centralized control and feedback. Digital control and connectivity to a central WPT hub controller can allow several energy-saving measures to be implemented. These measures are normally associated with a zone-level direct digital control (DDC) upgrade. However, a WPT retrofit is substantially less costly than a zone-level DDC upgrade because the high cost of replacing pneumatic zone components (such as duct terminal boxes) is avoided. WPTs can enable the following energy-saving measures:

- HVAC scheduling and setbacks by zone
- Supply air temperature (SAT) resets based on zone feedback
- Duct static pressure (DSP) resets based on zone feedback
- Thermostat setpoint deadband
- Setpoint enforcement
- Pre-cooling and global temperature adjustment (GTA) strategies
- Retro-commissioning (RCx) using data from WPTs.

kW Engineering studied four pilot sites that were already committed to installing WPTs. PG&E provided a modest reimbursement to the building management for participation and assistance with data collection but did not substantially incentivize the installation through this project. We conducted measurement and verification (M&V) at each site before and after the installation to characterize and quantify energy savings across several possible energy-saving measures. We used logging equipment, BMS trending, and interval and billing data to analyze savings at each site.

Of the four pilot sites, we observed completed installations at two sites, and only partial implementation at the other two. At these sites, we found that the installation of WPTs resulted in few energy-saving measures that were directly attributable to the WPTs. From those measures, there was little quantifiable energy savings. This finding does not speak to limitations of the technology itself, which was generally robust. Rather, the issue is to both, a) apply the technology to good applications, and b) to fully implement controls setup and commissioning (and integration with a central BMS system in some cases) to take advantage of the capabilities of the WPT hardware.

We concluded that installing WPTs on the wall does not in itself save energy, but represents an enabling technology which can then be used to implement new and improved functionalities which can provide energy savings. At the pilot sites studied, these additional steps did not generally occur to the extent necessary to achieve full savings potential.

We observed the following measure results at the pilot sites:

- No additional zone-level scheduling changes occurred beyond the existing fixed schedules. (These sites had consistent, centrally-controlled occupancy schedules.)
- No substantial SAT resets were implemented based on zone information from the WPTs.

- Although all four sites had planned to execute a duct static pressure (DSP) reset, only one site realized a reset based directly on zone information from the WPTs.
- A setpoint deadband was enabled at 3 of the 4 sites, but energy savings could not be quantified for this measure relative to other changes made.
- Setpoints were enforced by building management at 3 of the 4 sites, but energy savings could not be quantified for this measure relative to other changes made.
- One site effectively executed a global temperature adjustment, as a demand response measure.
- All sites reported that WPTs assisted with identifying malfunctioning equipment.

We also observed other energy-saving measures that occurred concurrently with the retrofit but were not enabled by the WPTs.

We also note that site staff and management were generally pleased with the WPT installation projects. The units improved occupant perceptions of comfort and quality, and provided daily operational benefits to staff. WPT installations were relatively unobtrusive, and led to identification of system repair issues.

We recommend that incentive program structure(s) supporting WPTs should be based around the measures implemented (i.e. new control functionalities) rather than the WPT devices alone. A hybrid-deemed program would best be oriented to incentivize implementation of measures themselves as enabled by the WPTs, not just installation of the WPT hardware. Further study is recommended and underway.

We further recommend structuring any incentive program to encourage adopting as many applicable energy-saving measures as possible and to encourage commissioning of these measures. We characterize the installation of WPTs as potentially part of a control overhaul for the building rather than the installation of a piece of equipment. A controls overhaul is a large endeavor, but presents a good opportunity for a broad and ambitious perspective on energy-saving measures.

Of two of the energy-saving measures that can be realized with the WPTs alone, rather than in conjunction with a BMS, our limited data set did not provided any affirmation for measurable energy savings from either deadband or setpoint enforcement. We found the setpoint enforcement measure to be unquantifiable as an isolated energy-saving measure. For the deadband measure, we recommend further study to determine if real energy savings can be quantified. In addition, we found that savings from the retrocommissioning benefits of WPTs (i.e. trouble shooting) are similarly unquantifiable, but often the operational benefits are of great value to the building's engineer.

The installation of WPTs is a great step in the modernization of building control systems. We recommend that any incentive program(s) be structured to make the most of the potential and encourage a comprehensive adoption of controls changes that could result from real energy savings controls measures.

Note: Two of the pilot sites in this study had incomplete installations at the time this report was completed. kW Engineering will conduct a follow-up at these two sites in 2013, which may result in an addendum to this report.

INTRODUCTION

WPTs are direct replacements for standard pneumatic thermostats. They add wireless communication with a central WPT hub controller, enabling centralized control and feedback. Electronic control and central connectivity can allow several energy savings measures to be implemented. These measures are normally associated with a zone-level direct digital control (DDC) upgrade. However, a WPT retrofit is substantially less costly than a zone-level DDC upgrade because the high cost of replacing pneumatic zone components (such as duct terminal boxes) is avoided.

WPTs are currently offered by two companies in the US. Market penetration to date is limited for both companies. The WPT products from each company are similar in function and application.

There are currently no known workpapers documenting the energy savings associated with WPT retrofits, nor are there existing core utility incentive programs. There have been, however, two third-party programs in California which offered financial incentives for WPT installations -- the Energy Technology Assistance Program (ETAP) and Oakland Shines. We included a project from each of these programs in our pilot sites. Both programs were funded under the American Recovery and Reinvestment Act (ARRA) and are now closed.

The work included in this paper was initiated to better understand the WPT technology as it becomes more prevalent in the commercial sector.

BACKGROUND

HVAC CONTROL SYSTEMS

There are two common methods for controlling HVAC systems – pneumatic and digital. Many older buildings built before (and into) the 1990's have pneumatic controls, while newer buildings typically have electronic or direct digital controls (DDC). Many buildings now have a combination of the two as older pneumatic systems are gradually updated to DDC.

Pneumatic control started in the early 1900's and continued being installed until the 1980's. During the 1960's to 1980's, electronic control began to enter building construction, and by the 1990's, most new construction included direct digital control (DDC) of the building's HVAC systems. Pneumatic HVAC controls, however, continue to be used in many buildings today because retrofitting to a full DDC system is expensive.

Pneumatic controls use compressed air as a control signal as well as to effect mechanical motion in building HVAC systems. The compressed air is supplied via air compressors, regulated to a pressure of 15 to 25 psig, and delivered via piping and tubing throughout the building. In a pneumatically controlled thermostat in a typical air distribution system, a bi-metal temperature sensing element regulates a control signal in the form of varying air pressure which then controls the air damper(s) of a duct terminal box (and perhaps a reheat valve) to maintain temperature in the space. The pneumatic air signal varies from 0 to 15 psig, with a middle pressure of about 8 psig meaning no change is needed, while a higher or lower pressure means more or less conditioning (e.g. cooling, heating, airflow) is required.

With pneumatic systems, a key issue is that building operators are "driving blind", with no central control of, or information from, equipment operating in the building. There is no feedback from equipment settings or performance that goes back to the central plant or building operator.

DDC is the automated control of a condition or process by a digital device. All signals and data are carried electronically. All controllers and controlled devices can be connected to a BMS, and the data can be accessed and used for better building operation. For example, the building operator can know the temperature reading of a thermostat as well as the damper position or measured airflow of a terminal box. The electronic signals are transferred through an electrical network wired throughout the building.

In the controls retrofit market, a conversion from pneumatic controls to DDC is generally expensive, so frequently only the central plant equipment is upgraded. It is often cost effective to upgrade the central building plant (i.e. chillers, boilers, and central fan systems) to DDC to take advantage of the energy savings and other opportunities of new controls and modern equipment. It can be cost prohibitive to access all the interior spaces throughout the building to upgrade the zone controls to DDC. A building with a digitally controlled central plant and pneumatically controlled zones is referred to in this report as a hybrid DDC/pneumatic system.

The existing commercial building stock in the US is divided roughly equally[1] among the three controls set-ups: all-pneumatic, hybrid DDC/pneumatic, and full DDC as shown in Figure 2.1. WPT retrofits can be used on all pneumatic or hybrid DDC/pneumatic buildings.

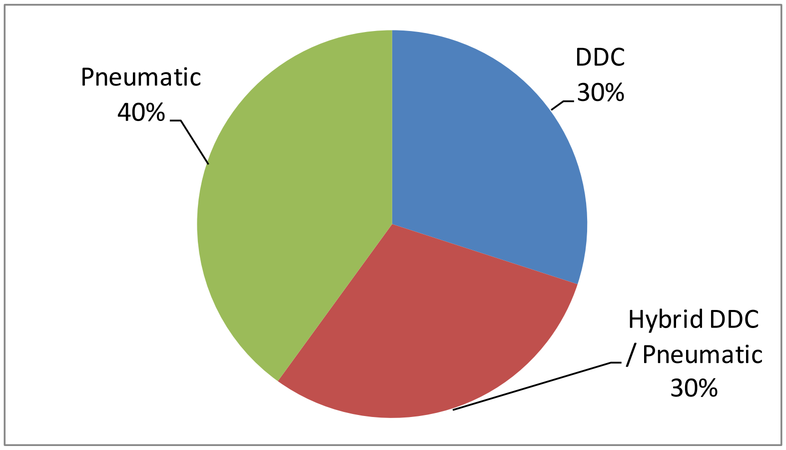


Figure 1: Approximate Division of Control Type for U.S. Commercial Building Stock

THIRD PARTY INCENTIVE PROGRAMS

We identified two third-party programs that offer incentives for WPTs in California: the Energy Technology Assistance Program (ETAP) and Oakland Shines. Both programs are funded through the California Energy Commission (CEC) using American Recovery and Reinvestment Act (ARRA) funds. According to program managers, both programs relied on the data provided by a WPT manufacturer, rather than creating workpapers with independent energy analysis of WPTs. The "emerging" aspect of the WPT technology was apparently a major factor in the programs' approval from the CEC, and the newness of the technology may explain why limited data is available for workpapers. The two programs are discussed below.

ENERGY TECHNOLOGY ASSISTANCE PROGRAM (ETAP)

The Emerging Technology Assistance Program (ETAP) program is designed to accelerate the adoption of emerging technologies for government institutions in California (cities, counties, special districts, public colleges, and universities). The technology focus is on bi-level lighting fixtures, wireless lighting controls, and wireless HVAC controls. The program provides an incentive of $0.18/kWh of estimated annual project energy savings. Funding is provided by an ARRA grant through the CEC's Energy Upgrade California initiative. The program is administered by Energy Solutions (http://www.energy-solution.com/), an energy efficiency and sustainability consulting firm based in Oakland, CA. The ETAP point contact is Forest Kaser. Additional information can be found on the following website: http://energy-solution.com/etap/.

[1] Building stock division based on market assessment provided by a WPT Manufacturer.

OAKLAND SHINES

The Oakland Shines program is designed to reduce energy use and make advanced energy technologies available for downtown Oakland businesses. The program offers free energy assessments, and focuses on the following technologies:

- LED task lighting for office and retail settings
- Task lighting that reduces the need for overhead lighting
- Occupancy-sensing stairwell and garage lighting
- Wireless controls for heating, ventilating and air conditioning systems.

HVAC technologies are incentivized at rates ranging from $0.19 to $0.89/kWh. Funding is provided by an ARRA grant through the CEC's Energy Upgrade California initiative. The program is administered by Quantum Energy Services & Technologies, Inc. (QuEST) (http://www.quest-world.com/), an energy efficiency engineering and program management firm based in Berkeley, CA. The Oakland Shines point contact is Brendan Havenar-Daughton. Additional information can be found on the following website: http://oaklandshines.com/index.php .

EMERGING TECHNOLOGY/PRODUCT

Wireless pneumatic thermostats (WPTs) are direct replacements of wall mounted pneumatic thermostat devices, which provide additional functionality through electronic control and wireless communication capabilities to and from central control systems.

Figure 2: WPT Units from Different Manufacturers

The WPT unit is a small enclosure box (see Figure above) that replaces a standard pneumatic wall thermostat. The WPT contains a temperature sensor, a pneumatic control mechanism, pneumatic ports (on the back of the device), wireless communications, and a battery. A display can show the current temperature or temperature setpoint. Control buttons may allow the user to adjust settings such as the temperature setpoint. In addition to the WPT units themselves, powered wireless relay devices (repeaters) must be installed in the building to carry data and control parameters back to a central WPT hub controller.

The WPTs communicate using the relay devices on a relatively long time interval, typically every 15 minutes, to conserve WPT battery life. The relay devices form a wireless mesh network communicating to the WPT central hub controller. Most measures can be implemented using the WPT central hub controller, but integration may also required between the WPT controller and a central BMS. See the following figure illustrating WPT system architecture from one of the manufacturers.

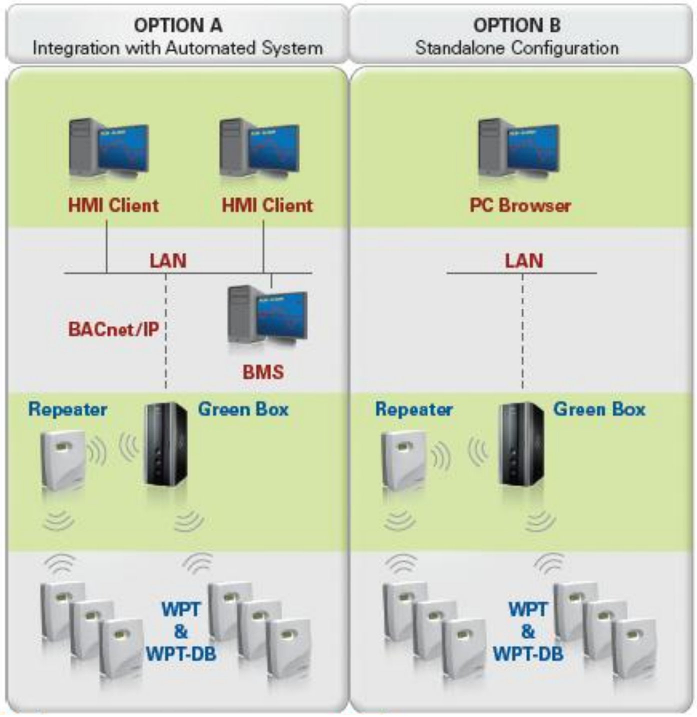


Figure 3: WPT Architecture Options

The WPT provides additional information, connectivity, and control similar to a full DDC system, while still controlling downstream HVAC equipment pneumatically. Each WPT unit plugs into the pneumatic air lines that control the terminal boxes, reheat valves, or other devices which maintain space temperature in the zone where the thermostat is located. These pneumatic devices and components are left in place during a WPT installation. In contrast, a full DDC upgrade requires accessing and replacing the terminal box equipment with digitally controlled equipment, which makes a DDC retrofit more costly. However, the wireless communication between the WPTs and the central controller enables control strategies that can provide many of the energy savings possible with full digital controls.

WPT suppliers can target sales to all buildings that have pneumatic thermostats. The benefits to the building owners, and therefore the sales approach, may vary between buildings that are all pneumatically controlled versus those that are hybrid DDC/pneumatic. For an all pneumatic building, WPTs can be installed in the zones without needing the central plant controls to be upgraded to DDC. A WPT retrofit in an all-pneumatic building offers fewer possible types of EEMs; however, the energy savings potential can still be significant. An example of this would be a building that has no central scheduling because some zones are always occupied. Also, a WPT retrofit in an all-pneumatic building could be combined with a central plant DDC upgrade to make a hybrid DDC/pneumatic control system. For buildings with hybrid systems, WPTs can enable the full range of energy efficiency measures (EEMs). In either building type, owners would typically be choosing WPT's over full DDC because of lower cost and disruption. The choice to consider either WPTs or full DDC is often at least partly motivated by the desire for increased building control and energy savings.

WPTs do not save energy until set-up. They provide the opportunity for control strategies to be implemented that do save energy. Control strategies can be implemented with the WPT central hub controller or the building's BMS. Energy savings measures can be realized from any WPT system installation, either stand-alone or BMS-integrated, if control strategies are implemented. The amount of energy that can be saved is highly dependent on conditions of the building before and after WPTs are installed including: schedule, operation, plant type, setpoints, type of existing thermostats, the amount of commissioning performed to verify and optimize the control strategies are in place, and the involvement and willingness of the building staff. Energy efficiency measures (EEMs) are discussed later in this report. Also note that full DDC installations will typically provide more controls information than WPTs. For example, many DDC terminal box controls can have a damper position sensor, a flow meter, and supply air temperature (SAT) sensor. This additional information can afford marginally more aggressive energy saving strategies than are enabled by a WPT system retrofit.

ASSESSMENT OBJECTIVES

The three main objectives of this report are to:

- Test the reliability and functionality of WPT retrofit technology for building HVAC systems with existing pneumatic zone controls;
- Collect operational information and data to develop energy use simulation models for such projects;
- Determine the feasibility of offering a hybrid deemed rebate program for this technology.

To this end, we selected four pilot sites to monitor the installation of WPTs. We conducted measurement and verification (M&V) at each site before and after the WPT installation. We collected data from both the central plant and sample zones at each site. We also conducted interviews with site staff at each location. The M&V data was used to develop energy savings calculations and temperature bin simulations (spreadsheet models) to model and quantify the energy savings. Methodology is discussed further in the Technical Approach section of this report.

TECHNOLOGY/PRODUCT EVALUATION

PRODUCT AND SITE SELECTION

There are two manufacturers of WPTs and both were included in our study: three pilot sites with WPTs from one manufacturer and a single site with WPTs from the second.

We opted to assess the technology in the field rather than the lab because the enabled energy savings measures are varied and site dependent. A controlled lab approach would have been more appropriate if the energy savings means were straightforward and broadly applicable. However, WPTs enable a variety of measures and we wanted to include in our study how sites select and implement various measures through the retrofit process.

We chose to include test sites that were proceeding with a WPT retrofit on their own means, rather than to control the entire retrofit ourselves, so that we could assess the market opportunity and adoption of WPTs. We identified and selected sites based on leads from WPT manufacturers and third party incentive programs.

We sought sites that would represent as many geographical areas in PG&E territory as possible. However, we had a limited number of choices to select from based on the leads from manufacturers. We had originally intended to monitor five pilot sites, but did not find a fifth site that offered any substantial differentiation in geography or planned measures. Of the four pilot sites, two were in Oakland, one was in San Mateo (San Francisco Peninsula), and one was in Sacramento.

It should be noted that all pilot sites had some form of financial assistance for project costs. Two of the four pilot sites selected received ARRA funding for the retrofits. The third site had applied for On Bill Financing through PG&E and the fourth site was part of a Smart Grip Investment Project through Sacramento Municipal Utility District (SMUD) which covered 50% of project implementation costs. All four sites had applied for an incentive through PG&E's CRI program. (The Sacramento site is eligible for a natural gas incentive through PG&E).

All four sites selected had a hybrid DDC/pneumatic controls system in which the central plant is controlled digitally and the zones are controlled pneumatically. However WPTs can also be applied to all-pneumatic systems using the central WPT hub controller.

kW Engineering was not directly involved in the installation at any site. The installations were handled through either site staff or a controls contractor.

The table below lists some key parameters for the pilot sites studied.

Table 1: Pilot Site Parameters

Pilot Site	Project Initiation	Vendor	Location	Building Type	Size (sq ft)
1	ETAP	Manufacturer 1	East Bay	Office (w courts)	100,000
2	Oakland Shines	Manufacturer 1	East Bay	Office	200,000
3	Vendor	Manufacturer 1	Peninsula	Office	144,000
4	SMUD Smart Grid Investment	Manufacturer 2	Central Valley	Classrooms (w Office)	60,000

Energy Efficiency Measure Evaluation

We identified the following groups of energy efficiency measures, which we used in our evaluation of each site. Energy saving measures which can be enabled with WPT systems can be grouped into 7 types. These types are listed briefly in the table below.

Table 2: EEMs Potentially Enabled by Installation of WPT Systems

EEM	*Short Name*	*Description*
1	Scheduling/Setbacks	Creating programmable setbacks by zone with occupancy override capability
2	SAT Reset	Supply air temperature (SAT) reset based on zone operating conditions
3	DSP Reset	Duct static pressure (DSP) reset based on zone demand
4	Deadband	Separate cooling and heating temperature setpoints with deadband between them.
5	Setpoint Enforcement	Centralized control of the limits of user control
6	GTA (incl Pre-Cooling)	Global temperature adjustment (GTA): Altering zone setpoints throughout the day
7	RCx	Retrocommissioning / Troubleshooting: Using data to identify problems

Scheduling/Setbacks

When spaces are not occupied continuously, the HVAC systems serving those spaces should be scheduled to maintain conditions only during occupied hours. At the zone level, this often means implementing temperature setbacks so the temperature setpoint range of a space is greatly increased during unoccupied hours (e.g. 55-85°F unoccupied vs. 68-74°F occupied).

A standard pneumatic thermostat normally has only one temperature setpoint. The setpoint is fixed and can only be changed at the thermostat itself by either an occupant or building staff person.

WPTs allow individual zone setpoints to be scheduled centrally (remotely) to different values at different times of the day or week. Typically, the temperature setpoints are set back to higher cooling and lower heating setpoint temperatures during unoccupied times. This saves energy used for space conditioning.

This measure provides savings opportunity for sites with variable occupancy, especially variable occupancy for different zones. Scheduling and setbacks can be implemented at the building or system level with all-pneumatic or hybrid DDC/pneumatic HVAC control systems. However, setback controls for each served space requires zone-level control such as offered by WPT systems. Without zone-level control, building or system level setbacks are limited by the needs of individual zones. For example, a central air handler may serve many spaces most of which are unoccupied overnight. But if only one of its served spaces is occupied 24/7, then that air handler must run 24/7. Without zone level setback control, all the served spaces will be maintained to regular conditions 24/7, wasting energy.

Note that WPTs can allow for override capability directly through the buttons on the thermostat units; this can allow the central plant to only turn on when an override button is engaged.

This measure can potentially provide both gas and electricity energy savings, and offers the most potential for savings in the right applications.

This measure can be implemented at sites that are either all pneumatic or hybrid DDC/ pneumatic.

SUPPLY AIR TEMPERATURE (SAT) RESET USING ZONE DATA

Supply air temperature (SAT) reset involves changing the central SAT setpoint based on operating conditions. In a typical variable air volume reheat (VAV-RH) system, the supply fan provides cooling air at a temperature sufficiently cold to cool the zone with the highest heat load. During moderate load conditions, the zones will not need as much cooling, and the SAT can be increased. This reduces both the cooling coil load and the amount of zone reheat, thereby saving energy.

Simple SAT resets are often implemented based on outside air temperature (OAT). The SAT varies inversely with OAT based on a conservative reset schedule. That is, when it is colder outside, the supply air temperature setpoint is increased. See the following example.

Table 3: Sample SAT Reset

OAT (°F)	SAT (°F)
75	55
60	65

In this example, at outside temperatures above 75°F, the SAT setpoint is 55°F. At outside temperatures below 60°F, the SAT setpoint is 65°F. In between, the SAT varies linearly.

When establishing a SAT reset based on OAT, a conservative approach is always necessary because this reset strategy is based only on general outside conditions without active consideration of actual conditions in all spaces served. However with detailed feedback from each zone, the SAT can be reset in real time based on the actual operation of the building. With a WPT system, each thermostat provides data about the pneumatic signal it is sending to its zone equipment, which indicates whether the zone is being cooled or heated and how much (assuming the pneumatic systems are operating as expected – see Retro-commissioning measure below). With this zone data available, a "trim and respond" or similar method for SAT reset control can then be used, whereby the temperature setpoint is adjusted incrementally over a set time interval depending on the number of zones which are cooling or heating (demand). Such a SAT reset based on zone demand saves additional energy over a SAT reset based on OAT because the resets are always optimized to actual conditions.

This WPT measure provides the greatest energy savings opportunity to sites that do not have any SAT resets enabled. However, there is some savings potential for sites that already have SAT resets based on OAT.

This measure can potentially provide both gas and electricity energy savings.

This measure requires integration with the building's central plant equipment.

Duct Static Pressure (DSP) Reset Using Zone Data

Duct static pressure (DSP) reset is the lowering of the air pressure in the main supply duct based on demand. In variable air volume (VAV) systems, the pressure in the supply duct is typically maintained at a constant value which allows the furthest VAV terminal box to maintain its cooling requirements at the maximum design condition. The supply fan speed (or other control method, e.g. inlet vanes) is controlled to maintain this setpoint.

WPTs enable the DSP setpoint to be lowered based on the air demand of each zone's terminal box. During moderate conditions, most terminal boxes do not need their design flow to accomplish the required conditioning. In these situations, the DSP setpoint can be reduced, and the terminal boxes will respond independently to maintain space temperatures. In other words, when all of the VAV box dampers are partly closed, there is no reason to maintain a high DSP setpoint. The DSP setpoint can be lowered, and the VAV box dampers will automatically open to provide the same amount of air to the space. With less air flow restriction in the system from partly-closed dampers, fan energy is saved. The supply fans can operate at a lower speed, while providing the same air flow rate at a reduced total pressure rise across the fan. The DSP can be reset in a "trim and respond" manner based on the positions of the terminal box dampers, applying incremental adjustments over a set time interval between minimum and maximum DSP setpoints.

This measure provides savings potential for hybrid DDC/pneumatic sites. The site must have a VAV system with a VFD-controlled supply fan.

This measure can potentially provide electricity energy savings.

This measure requires integration with the building's central plant equipment.

Setpoint Deadband

Deadband refers to a temperature range in which no heating or cooling is required. Instead of having a single temperature setpoint (e.g. 72°F) that provides heating when the space temperature is lower and cooling when the space temperature is higher, a deadband means there are independent setpoints for heating and cooling (e.g. 70°F heating, 74°F cooling). Although some older pneumatic thermostats have deadband capability, most do not. WPTs can be selected with dual setpoint control (i.e. deadband).

This measure provides energy savings potential for any site that does not currently have dual setpoint thermostats.

This measure can potentially provide both gas and electricity energy savings.

This measure can be implemented at sites that are either all pneumatic or hybrid DDC/ pneumatic.

SETPOINT ENFORCEMENT

Setpoint enforcement refers to the ability to define and enforce a range of acceptable setpoints that an occupant can specify. Rather than occupants being able to adjust the thermostat within its entire physical range, the upper and lower bounds of adjustment are defined by the building staff. This can curtail excessive conditioning energy that would be used to meet extreme setpoints. Many pneumatic thermostats have a setpoint lever that is accessible to the occupant. Some pneumatic thermostats, on the other hand, can only be adjusted by building staff with a special tool.

WPTs enable setpoint enforcement though the remote electronic control of occupant setpoints. Rather than adjusting a physical lever on the thermostat, the WPT interface is through a digital display and the bounds can be controlled centrally.

This measure provides energy savings potential for any site that has user-adjustable thermostats and where the building management intends to further restrict the allowable range of setpoints upon WPT implementation.

This measure can potentially provide both gas and electricity energy savings, but the amount of savings can be difficult to estimate without comprehensive zone temperature monitoring.

This measure can be implemented at sites that are either all pneumatic or hybrid DDC/ pneumatic.

GLOBAL TEMPERATURE ADJUSTMENT (GTA), INCLUDING PRE-COOLING STRATEGIES

Global temperature adjustment (GTA) refers to the ability of building staff to alter zone setpoints throughout the building. GTA is also referred to as global setpoint adjustment (GSA). By altering the setpoints towards a less aggressive conditioning point, the heating and cooling loads are reduced. This measure most typically is applied only occasionally in response to demand response (DR) events when building operators are reacting on a specific day to lower their peak power use.

WPTs enable GTA strategies by allowing building-wide temperature setpoints to be adjusted centrally. Note that GTA strategies tend to require some user and system sophistication to achieve the energy goals without overly affecting occupant comfort.

Pre-cooling in particular refers to reducing the building temperature setpoints in the morning hours to reduce peak cooling needs later in the day. This control strategy is employed in warm weather periods.

This measure provides peak demand reduction potential for any site that installs WPTs. This measure can also provide energy savings.

This measure can be implemented at sites that are either all pneumatic or hybrid DDC/ pneumatic.

RETRO-COMMISSIONING (RCX)

Retro-commissioning (RCx) as a measure refers to the ability of the building operations staff to identify malfunctioning equipment. When temperature information and cooling requests are known and trended by the BAS, patterns can emerge that point to faulty equipment. An example of this is a zone that is consistently hot (above setpoint) because, say, a heating valve is stuck in the open position. With standard pneumatic thermostats, zone temperatures are not known to the building staff unless reported by an occupant. That is, building staff are "driving blind" until they receive cold or hot calls.

WPTs enable RCx energy savings by providing the zone temperatures plus indication of damper and/or heating valve positions to the BAS. [WPTs do not have the actual damper or valve positions, but they do provide the pneumatic control signal being sent to the dampers and valves.] When zone temperatures are trended by the BAS, zones that are not meeting setpoint can be observed. In addition, warning criteria can be automated into the BAS to provide building operators with email or text alerts.

This measure provides energy savings potential for any site that does not currently have zone temperature information. However, it should be noted that buildings with robust maintenance protocols may have limited savings potential.

This measure can potentially provide both gas and electricity energy savings. Savings can only be reasonably calculated on a case by case basis as faults are uncovered.

This measure can be implemented at sites that are either all pneumatic or hybrid DDC/ pneumatic.

TECHNICAL APPROACH/TEST METHODOLOGY

FIELD TESTING OF TECHNOLOGY

In order to achieve our objectives, we selected four pilot sites where WPTs were to be installed, for evaluation based on the following criteria:

- We selected sites from a variety of climates zones in order to assess the WPT under various conditions.
- We selected three sites that had hybrid DDC/pneumatic controls with variable air volume (VAV) systems. This combination of controls and air distribution system enables the full range of EEMs to be verified. (The fourth site installed hybrid DDC/pneumatic controls with a constant volume system.)
- We selected a variety of building types, including two high-rise commercial buildings, a low-rise commercial building, and a college campus building.
- We included at least one site from each of the two major WPT manufacturers.

TEST PLAN

In order to determine the reliability of the WPTs, we interviewed site staff about their experience with the system installation, training, and experience to date with the new systems. Furthermore, we also installed stand alone temperature loggers in a sample of spaces to confirm the basic functionality of the thermostats (i.e. the thermostats accurately measuring the space temperature and controlling the terminal boxes and fan coils to maintain the space temperature).

To quantify the energy savings from the EEMs enabled by the WPT, we used Options B and C from the International Performance Measurement and Verification Protocol (IPMVP).

At each site, we isolated air handler energy usage by measuring the supply fan power or amperage and outside, return, mixed, and supply air temperatures. These parameters allowed us to determine the baseline and post-retrofit heating/cooling load and fan usage of each air handler.

Additionally, we also isolated the chiller power at each site by measuring the input power to each unit.

Lastly, where applicable, we used a whole building approach (IPMVP Option C) to determine the energy savings at the utility meters.

INSTRUMENTATION PLAN

To collect the necessary data to verify the achieved energy savings, we used a combination of standalone data loggers and BAS trend data. The table below provides a summary of the standalone devices used to measure each parameter. For all data collection, a 5-minute sample rate was used.

Table 4: Measurement Parameters, Devices, and Accuracy

Parameter	Expected Range of Parameter	Measurement Device	Accuracy of Measurement Device
Air temperature	40-80°F	Onset HOBO U12 Temperature Data Logger	± 0.63°F from 32° to 122°F
True Power	0 – 250 kW	Dent ElitePro Power Meter	± 2.5 kW (Per Manufacturer 0.5-1%)
Amperage	0 – 100 Amps	Onset HOBO U12 4-Channel External Data Logger with split-core AC current transducers	± 4.5% of full scale 20 amp CTV-A -> ± 0.5 Amps 50 amp CTV-B -> ± 1.3 Amps 100 amp CTV-C -> ± 2.5 Amps

We also collected utility billing data, including 15-minute interval data when available, from PG&E representatives and from site contacts.

RESULTS

The following pages contain the case study results from each of the four pilot sites. The subsequent section, Evaluations, contains aggregate analysis of the case studies.

PILOT SITE #1

LOCATION AND SITE INFORMATION:

- Oakland, CA 94607
- Mixed office, court, and vacant holding cells
- 100,000 sq ft, 4 stories
- CEC Climate Zone 3
- M-F, 4am to 6pm operation
- Annual kWh usage: 648,500
- Annual therms usage: 45,000
- Installed 42 WPT units (Manufacturer 1)

MECHANICAL SYSTEMS:

- Cooling Source: 220-ton chiller
- Heating Source: Steam boiler
- Air Distribution: Dual duct, single fan VAV, 1 air handler
- Variable dual-damper terminal units

PROJECT INITIATION:

This project started out as part of an Automated Demand Response (ADR) project. The original objective of the project was to give the customer the ability to shut off load during demand response events. Although the ADR project costs were covered through PG&E and DOE incentive programs, the WPT portion of the project was not covered and was, therefore, paid for by the site.

This site installed 42 WPTs, covering the entire building. The site had ADR controls installed concurrently with the WPT project.

PLANNED EE MEASURES:

The following list of planned measures is based on discussions that we had with the site staff before the installation occurred.

- Zone-level scheduling
- DSP reset
- Deadband
- Global temperature adjustment, demand response

INSTALLED EE MEASURES

WPT ENABLED

- Cold deck supply air temperature (CD SAT) Reset: A secondary input to the CD SAT was modified to include the average zone temperature from the WPTs. The primary SAT reset is determined by the outside air temperature in both the baseline and post-retrofit cases.

- Deadband: A deadband between separate cooling and heating zone temperature setpoints was installed. A 4°F deadband was initially installed, but the building operators adjusted the setpoints based on occupant feedback. We observed an average deadband of 2.3°F. Occupants can also override the setpoints on a temporary basis.

NON-WPT ENABLED

- Duct static pressure (DSP) reset was programmed based on outside air temperature (OAT). The DSP reset is not based on zone data from the WPTs.

MEASURE SUMMARY TABLE

The following table shows the measures for this pilot site based on category and at different project stages.

Table 5: Pilot Site 1 - Measures

Pilot Site 1

Savings potential:	good	some	little/none

Measures:	Scheduling	SAT Reset	DSP Reset	Deadband	Setpoint Enforcement	DR: GTA (incl Pre-Cooling)	RCx	Other
Proposed	Some improvement expected	Some DDC w temp sensors, already SAT	Yes, expected	Interested in this	Blank face	Signed EnerNOC DR contract	Want to run more efficiently	N/A
Installed	No	Already had	DSP reset based on OA	Observed average 2.3°	N/A	Integration issue	None noted	N/A
WPT Attributable	No	Slight secondary, no change	Based on OA, not zone information	Yes, average 70.4 to 72.7	Private office occupants have control	Incompatable integration	Future potential for MBCx	N/A

FINDINGS

1. The customer installed a slight, secondary (+1°F) adjustment to the cold deck temperature based on average of WPT zone temperatures. The primary input to the SAT reset is the outdoor air temperature; this was unchanged from the baseline to post-retrofit case. Prior to WPT installation, the secondary adjustment was based on the average of a few digital temperature sensors throughout the building. Since both pre- and post-retrofit secondary adjustment was based on building temperatures, the change in operation from this programming modification was negligible.

2. The thermostats were installed with a 4°F deadband, but the site staff adjusted both the setpoints and the range based on occupant feedback.

3. We found that the upper deadband limit varied from 69°F to 75°F, with an average of 72.7°F. The lower deadband limit varied between 67°F and 74°F, with an average of 70.4°F. The deadband amount varied between 1°F and 4°F, with an average of 2.3°F.

4. The user is able to override the thermostat setpoint on a temporary basis; the temperature reverts to the programmed setpoints after a few hours. The deadband remains the same as the setpoints are adjusted.

5. The DSP reset installed was based on OAT, without putting WPT zone information to use to optimize the reset. Thus, this measure was not enabled by the WPT installation..

6. Global temperature adjustment for demand response was not implemented due to a non-WPT related integration issue.

7. Automated demand response (ADR) was implemented at the site concurrently with this project. ADR measures include a DSP reset, economizer reset, and CD SAT reset.

8. The site had intended to go forward with adjusting optimum start programming, which would have contributed to scheduling measure savings, but they were met with resistance from building operators. We cannot speculate as to if the planned optimum start measure would have incorporated information from the WPTs. Our monitoring data showed that no scheduling changes occurred.

MEASUREMENT AND VERIFICATION (M&V)

MONITORING PERIODS

Pre-WPT retrofit:	11/10/2011 to 12/5/2011
Post-WPT retrofit:	6/5/2012 to 6/28/2012

EEM-1: CD SAT RESET

Visual Inspection:

We verified the implementation of the CD SAT reset through BMS screen shots.

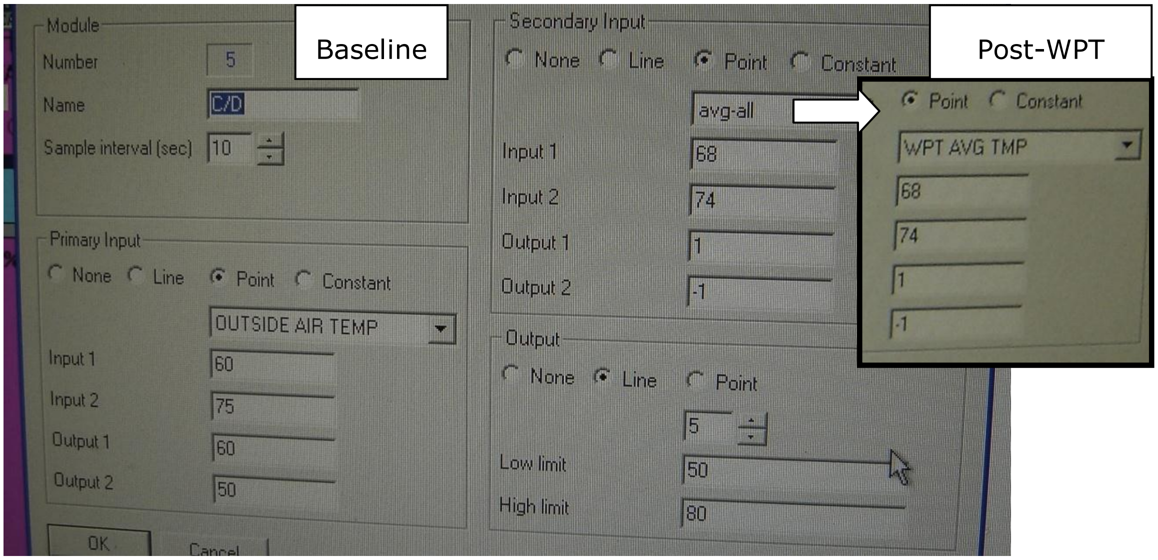


Figure 4: Pilot Site 1- CD SAT Reset Baseline (main) and CD SAT Rest Post-WPT (insert):

Energy Savings Calculations:

We do not expect any savings from the measure because the change occurs on the secondary input of the CD SAT reset and because the input temperature value was not changed between the pre-WPT and post-WPT case. In both cases the average building temperature was calculated from a sample of zone temperatures. In the post-WPT case, there are more sensors contributing to the average (i.e. all zones) but the average should be close to what it was in the pre-retrofit case and would be indistinguishable between the two.

Thus, the savings for this measure is zero.

EEM-2: Zone Temperature Setpoint Deadband:

Visual Inspection:

We verified the implementation of deadband through BMS screen shots.

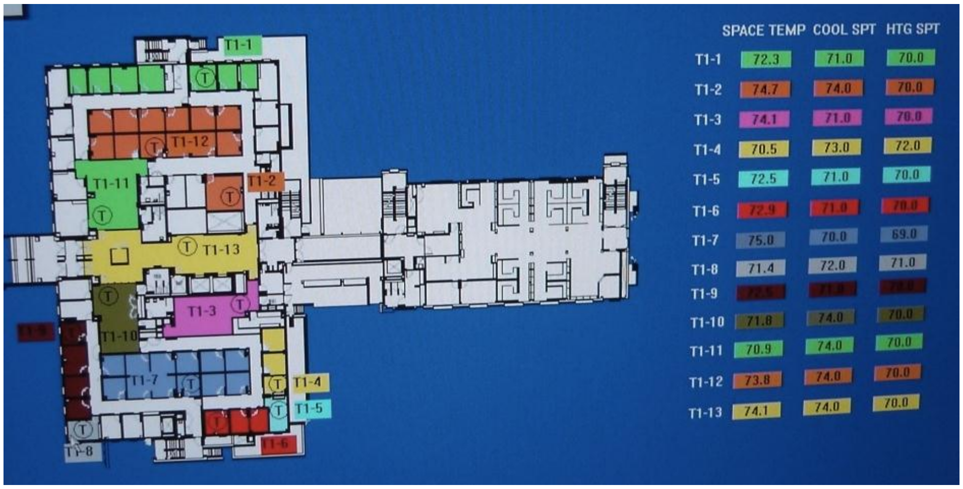


Figure 5: Pilot Site 1 - Thermostat Deadband Setpoints

The figure above shows the space temperature, cooling setpoint and heating setpoint for the various thermostat zones.

When the trending data for an individual thermostat is viewed, the deadband control range is apparent, as seen in the following figure.

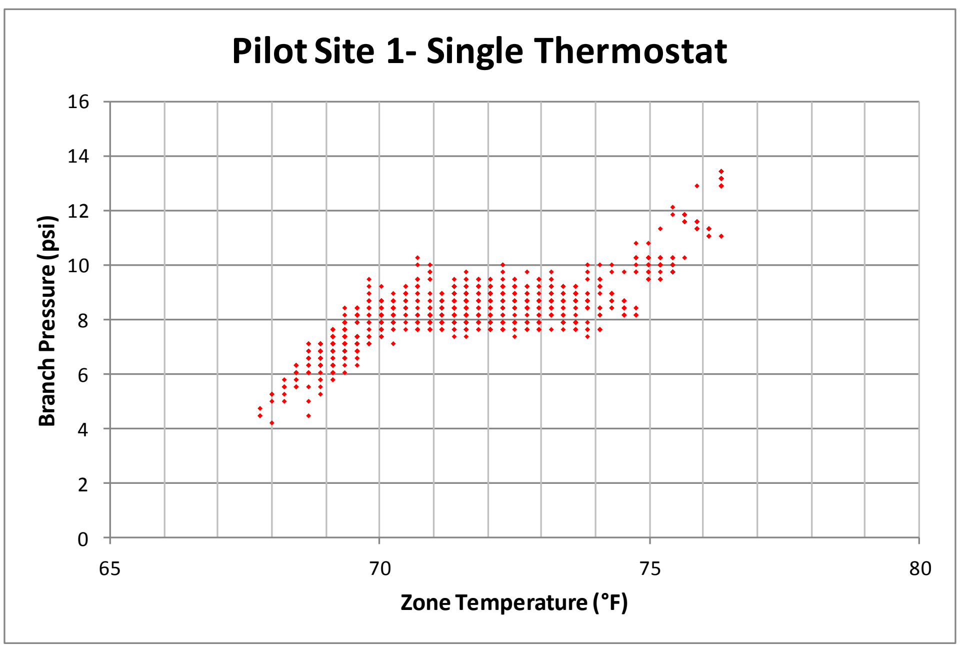


Figure 6: Pilot Site 1- Branch Pressure versus Zone Temperature, single zone

In this figure, between zone temperatures of 70°F to 74°F, the WPT is controlled to a neutral branch pressure, not requesting heating or cooling.

However, when all the zones for the entire building over the post-installation monitoring period are viewed, the deadband is not obvious; see the figure below.

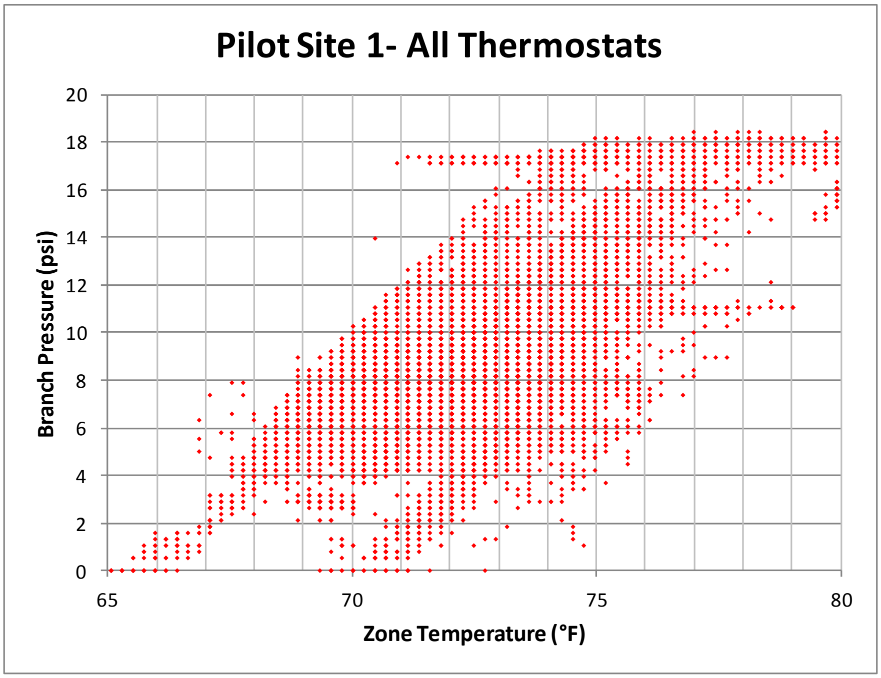


Figure 7: Pilot Site 1- Branch Pressure versus Zone Temperature, all zones

In this figure, which shows all the buildings thermostats in aggregate, the impact of setpoint deadband is not discernible. This is due to the variability in heating and cooling setpoints across the different zones in the building.

Energy Savings Calculations

We expect that the energy savings from the deadband measure will be small because the impact cannot be seen directly. When a thermostat is in the deadband range, the dampers for the heating and cooling duct will be in a more closed position with lower airflow. If enough dampers are at minimum, the fan will turn down to maintain the desired static pressure setpoint. With lower flow, there should also be a small, corresponding reduction of load across the heating and cooling coils due to decreased overlap of heating/cooling between zones. Actual savings, however, is complicated by many factors, including changing zone loads, different setpoints across the building, setpoint overrides, return and mixed air temperatures, and by the single supply fan serving both duct systems.

We can first look for savings in reduction to the fan speed. The figure below shows the average fan power at different outdoor air temperatures.

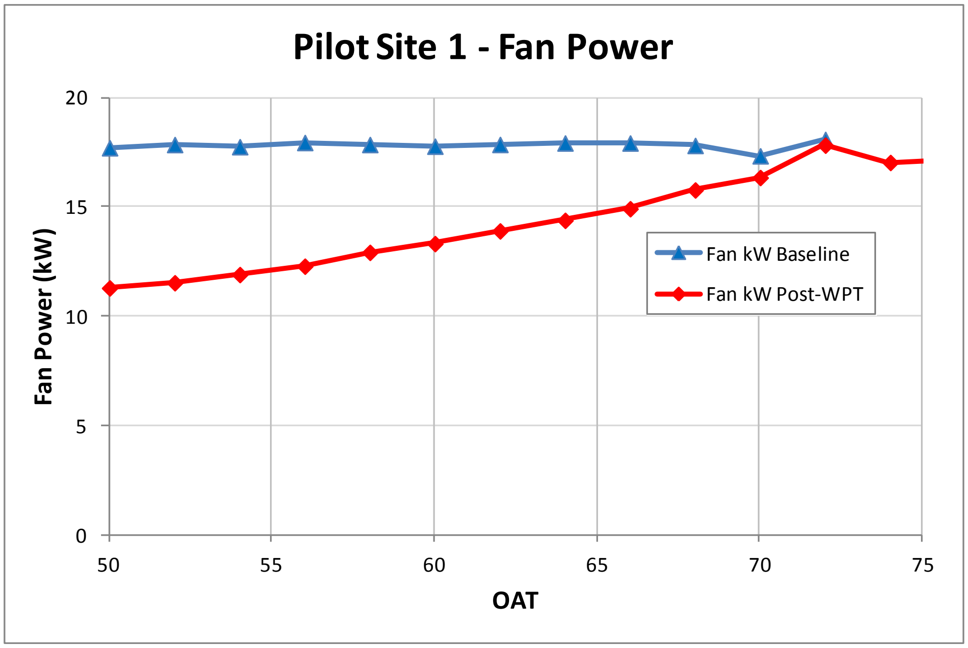


Figure 8: Pilot Site 1– Fan Power

In this figure, we can clearly see the effects of the DSP reset which is based on OAT – this measure is discussed later. There is clear energy savings as a result of the DSP reset, which overshadow any savings from the deadband operation. Temperatures above the DSP reset upper limit (OAT 75°F and greater) might present the opportunity to see the savings from deadband, but unfortunately, we had little data at those conditions, and there are minimal annual operating hours at those conditions anyway.

We can also look for deadband savings in reduced usage of the chiller and boiler. The figure below shows the average boiler power at different outside air temperatures for measured data from both the baseline and post-WPT monitoring periods.

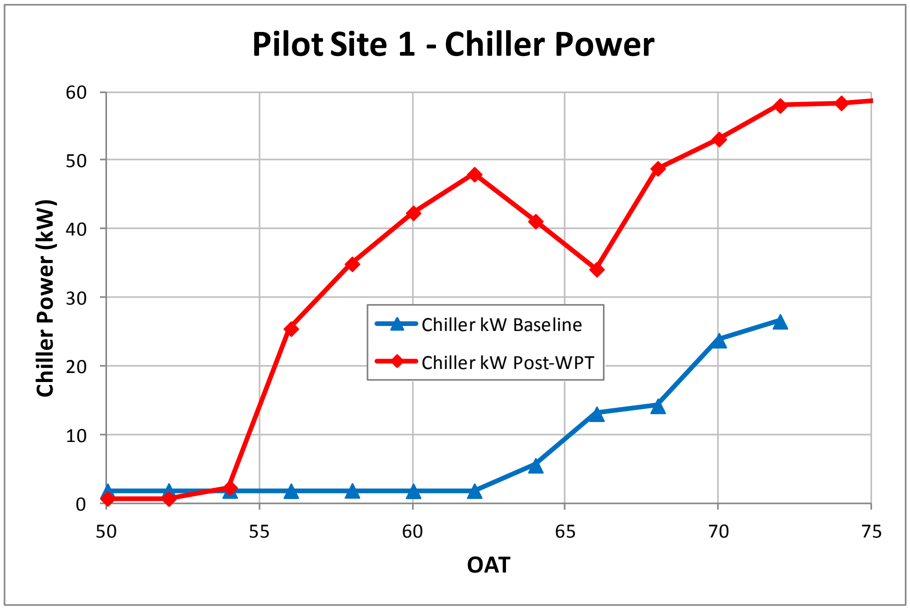


Figure 9: Pilot Site 1 - Chiller Power, Baseline and Post-WPT

In this figure, we observe is that the chiller usage is much higher in the post-WPT case. The post-WPT (red) line in the figure has two noticeable humps. The first one, from OAT 54°F to 66°F, is in economizing range when we would expect to use cool outdoor air instead of mechanical cooling. This indicates that there may be a problem with the economizer or its controls or that the chiller may be being false loaded. The second hump in the figure, from OAT 66°F and higher, indicates that the chiller was, on average, operating more often after the retrofit than before the WPTs installation, resulting in higher energy use. Thus, on a macro scale, it is clear that other building factors impacted chiller energy far more than any possible change from the deadband measure.

On the heating side, we can look for impacts based on logging of the hot deck temperatures. The figure below shows the average measured hot deck and cold deck temperatures. The figure above also includes the annual HVAC operating hours of the site (weekdays 4am to 6pm).

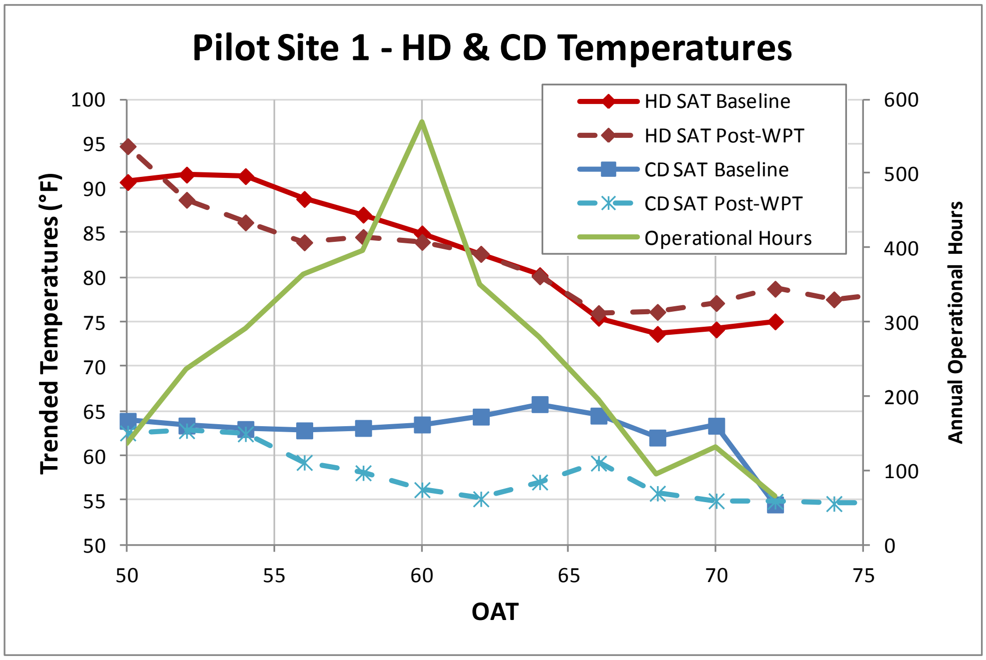


Figure 10: Pilot Site 1 - Hot Deck and Cold Deck Temperatures Trends

In the figure above, we see minimal difference in the hot deck temperature, which is what we would expect since there was no direct control changes to its operation. We also verified that the mixed air temperature performed nearly identically before and after the WPT retrofit.

Thus, based on our analysis, we cannot calculate any energy savings from the deadband measure.

When we incorporate the observed chiller pattern into a temperature bin simulation for this building, we calculated that the energy penalty (higher energy use) was on the order of five times the savings seen from the DSP reset, discussed next.

Other EEM: Dust Static Pressure Reset

Note: DSP Reset measure was not WPT enabled.

Visual Inspection:

We verified the implementation of DSP reset through BMS screen shots.

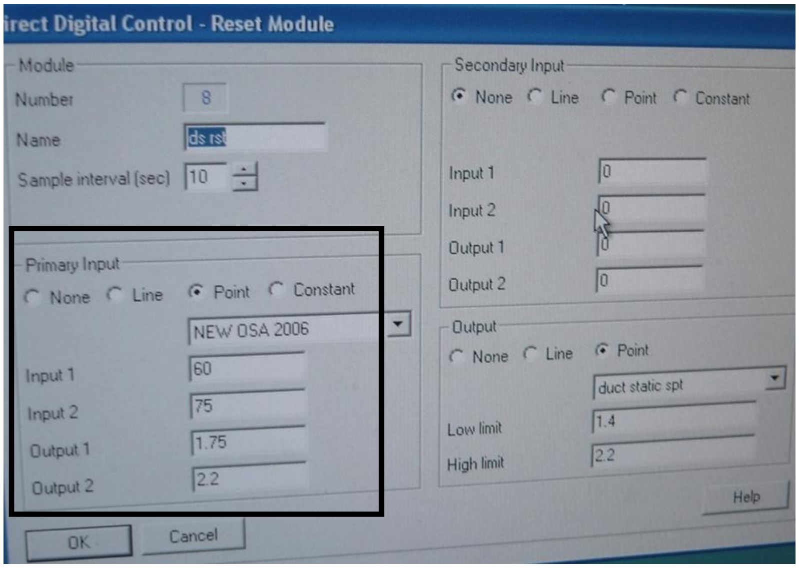


Figure 11: Pilot Site 1- DSP Reset based on OAT, not Zone Information

This figure shows that the DSP setpoint is adjusted between 1.75 and 2.2 in. sp. based on the outdoor air temperature ranging between 60 and 75°F.

Energy Savings Calculations:

The reduction in fan power was verified through fan power measurements and logging.

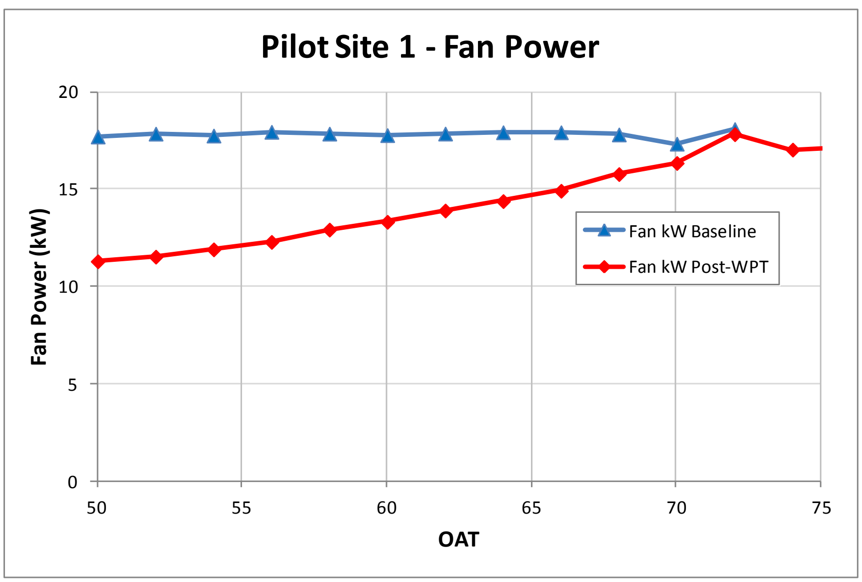


Figure 12: Pilot Site 1– Fan Power

This figure shows a clear DSP reset affecting fan speed at various outdoor air temperatures.

Using temperature bin simulations based on the trended fan performance, we calculated the annual electric energy savings of this measure to be 16,000 kWh.

Again, note that this measure was <u>not</u> enabled by the installation of WPTs.

INCENTIVES

Customized Retrofit Incentive: The savings amounts for the CRI program are shown in the table below. (Disclosure: kW Engineering performed the CRI savings calculations.) The savings were calculated using a temperature bin simulation. Because the outdoor air temperature sensor was installed prior to the retrofit, the DSP measure was not eligible for a CRI incentive. Thus, the only approved measure was a zone setpoint deadband. The incentive from the CRI program was $3,007. It should be noted that the calculation methodology for this CRI incentive was not an M&V approach. Rather, the program approves engineering calculations before the retrofit and modifies those calculations based on observations after the installation.

Table 6: Pilot Site 1 - CRI Program Savings Amounts

	kW	kWh	Therms
CRI Calculated Incentive (PA)	9.97	53,762	2,441
CRI Verified Savings (IR)	5.74	11,110	1,433

Emerging Technology Assistance Program (ETAP): The savings amounts from the ETAP program are shown in the table below. An engineering review was performed prior to the project start and was not revised upon completion. The incentive from the ETAP program was $8,564.

Table 7: Pilot Site 1 - ETAP Program Savings Amounts

	kW	kWh	Therms
ETAP Program Savings Amounts	10	47,580	2,149

COMMENTS AND OBSERVATIONS FROM SITE STAFF

- The building management is not looking to quantify the savings in any discrete way: "hard to see in bills".
- The installation contractors performed a formal training session with building staff of approximately 2 hours.
- The site had difficulty supplying power to the wireless repeaters. The site had intended to hardwire the repeater power supply, but they could not run the wiring due to asbestos issues. They opted for a plug in power supply to available outlets.
- A site contact noted that the pneumatic tubing was difficult to install due to the copper-to-plastic fittings taking up too much room. Building maintenance had to go back to fix about 2 dozen kinked tubes.
- The WPT wall unit installations left open patchwork on walls that needed to be repainted.

FUTURE POTENTIAL

Site staff commented that the initial application of controls using the WPT installation was conservative, but that their goal is to adjust the setpoints and integration at a later point to be more aggressive. However, the site contact also commented that constrained resources might make future modifications unlikely. The site is participating in ongoing commissioning, so the WPT information may assist with troubleshooting problems that are identified through the commissioning process.

This site did not opt to adjust their hot deck and cold deck SAT resets based on WPT zone information. This measure could result in a reduction in simultaneous heating and cooling, but the control strategy is not trivial for the building's dual duct HVAC system.

Finally, data shows other possible building issues not likely related to the WPT installation. For example, the figure below shows the outside air temperature (black) and chiller operation (red) during the three-week post-retrofit monitoring period. It is clear that the chiller is routinely coming on during cool early morning temperatures. We can also see that the chiller is cycling on and off during a few of the days.

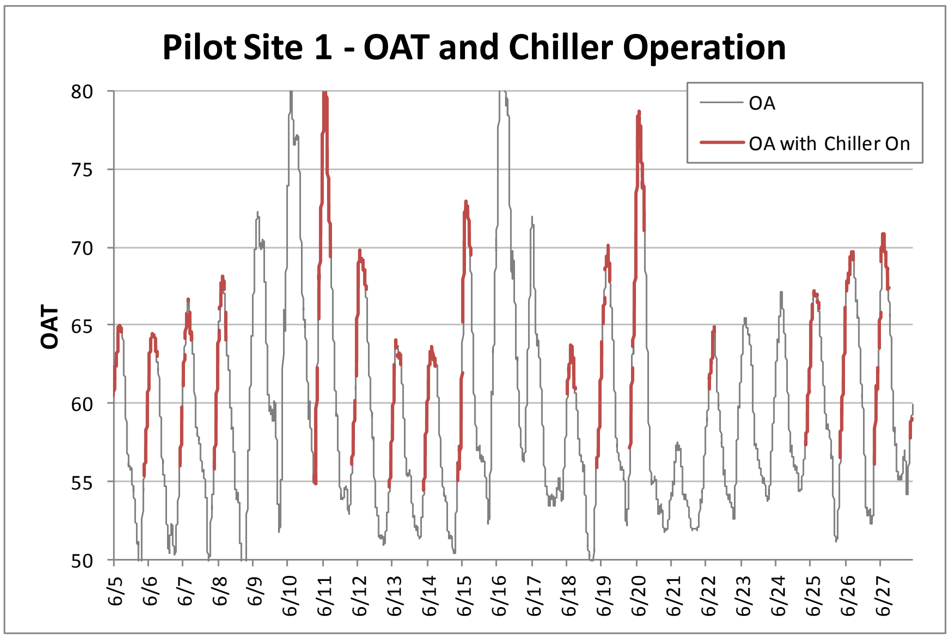


Figure 13: Pilot Site 1– Cycling Chiller Operation

PILOT SITE #2

LOCATION AND SITE INFORMATION:

- Oakland, CA 94612
- Multi-tenant office
- 200,000 sq ft, 9 stories
- CEC Climate Zone 3
- M-F, 6 am to 6 pm operation
- Annual kWh usage: 1,891,000
- Annual therms usage: 24,000
- Installed 190 WPT units (Manufacturer 1)

MECHANICAL SYSTEMS:

- Cooling Source: 100-ton air-cooled chillers, 2 units
- Heating Source: 3,280 kBtu/hr hot water boiler
- Air Distribution: 80,000 cfm VAV air handlers w/o economizers, 2 units. There is minimal return air, so the systems are essentially 100% outside air. Fan-powered boxes along perimeter of building provide additional heating at zone level.

PROJECT INITIATION:

The Oakland Shines program initiated this project and provided an incentive as well as project management assistance. The project intended to reduce energy consumption.

The site installed 190 WPTs, replacing all of the existing pneumatic thermostats in the building's core but left some existing digital thermostats that control perimeter reheat fan coils. The project scope also included the installation of a new BMS (Johnson Controls Facility Explorer System) for central systems.

PLANNED EE MEASURES:

The following list of planned measures is based on discussions that we had with the site staff before the installation occurred.

- Shutting down airflow to unoccupied (vacant) zones
- SAT reset
- DSP reset
- Deadband

INSTALLED EE MEASURES

WPT ENABLED

- DSP reset based on average zone temperatures only
- Cooling stage lockouts

NON-WPT ENABLED

- Pre-Heat Temperature Reduction: The pre-heat air temperature was reduced to 67°F.
- Boiler Temperature Reset: A heating hot water temperature reset strategy was added with the new central BMS.

MEASURE SUMMARY TABLE:

The following table shows the measures for this pilot site based on category and at different project stages.

Table 8: Pilot Site 2 – Measures

Pilot Site 2

Savings potential:	good	some	little/none

Measures:	Scheduling	SAT Reset	DSP Reset	Deadband	Setpoint Enforcement	DR: GTA (incl Pre-Cooling)	RCx	Other
Proposed	Set office schedule	Currently fixed, plan on install	Will implement, new DSP sensors	Yes, currently none	Have full control, will limit	Nothing planned	1 year of proactive bldg operator	N/A
Installed	Closed unoccupied zones	Not implemented	Based on average building temperature	No, single setpoint	Occupants have control	N/A	Yes, generated a punchlist	Pre-heat setpoint reduction
WPT Attributable	Closed unoccupied zones	Not implemented	Tenants control setpoint, 70 to 74	No, single setpoint	Occupants have control	N/A	40 boxes to check	Could see zone response to preheat adjust

FINDINGS

1. A DSP reset was implemented based on average building temperature. This average temperature is obtained from averaging all the zone temperatures reported by the WPTs throughout the building. It does not, however, use the detailed WPT zone demand information (pneumatic signal) to determine the level/quantity of calls for heating and cooling.

2. The new BMS integrated two cooling stage lockouts, which were previously controlled manually. These lockouts are based on both the outdoor air temperature and the average zone temperature.

3. When we conducted our post-installation monitoring, no zones had been scheduled off or unoccupied.

4. The site installed single-setpoint thermostats rather than the deadband model.

5. The occupants were given control of the thermostat setpoint, rather than it being set by the building operation staff. The occupants have control in the range of 70-74°F. According to site staff, the occupants have expressed that their comfort has improved greatly since the installation.

6. The site reduced their pre-heat supply air temperature setpoint. This adjustment remains a manual setting rather than an automated, controlled value. This is partially attributable to the installation of WPTs because the building engineer is able to observe the space temperatures of the building as he adjusts this setpoint.

7. A heating hot water temperature reset strategy was added with the new BMS. This reset does not depend on the WPTs for feedback.

8. A SAT reset was not implemented at the site. We suspect that the scope for this measure was not clearly defined at the project onset and, therefore, was not included.

9. Installation of the WPTs led to discovery of several problems with zone pneumatics, which were causing comfort issues. These RCx-type repair problems were expected to take several months for site personnel to address.

MEASUREMENT AND VERIFICATION (M&V)

MONITORING PERIODS

Pre-WPT retrofit: 12/2/2012 to 1/3/2012

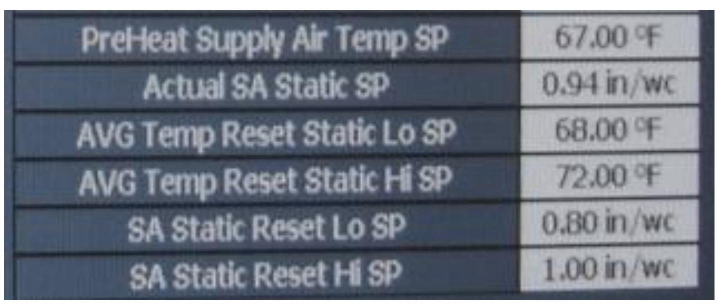
Installation: 1/3/2012 to 3/30/2012

Post-WPT retrofit: 4/4/2012 to 4/27/2012

EEM-1: DUCT STATIC PRESSURE RESET

Visual Inspection:

We verified the implementation of DSP reset through BMS screen shots.



PreHeat Supply Air Temp SP	67.00 °F
Actual SA Static SP	0.94 in/wc
AVG Temp Reset Static Lo SP	68.00 °F
AVG Temp Reset Static Hi SP	72.00 °F
SA Static Reset Lo SP	0.80 in/wc
SA Static Reset Hi SP	1.00 in/wc

Figure 14: Pilot Site 2 - DSP Reset Based on Average Building Temperature

We can see in this figure that the static pressure setpoint is reset between 0.8 and 1.0 in w.c. based on the average building temperature varying between 68°F and 72°F.

Energy Savings Calculations:

The DSP reset is based on the average building temperature. It does not use WPT information on the demand for heating and cooling from each zone (i.e. zone branch pressures). Because the building tenants have control of their setpoint temperatures (within the range of 70°F to 74°F), we do not expect the building temperature to vary significantly during occupied periods. However, we should still expect savings during heating-dominated periods (morning warm up and at cold outside air temperatures).

The DSP reset and corresponding reduction in fan speed is clearly visible in trending data. Although the reset is based directly on building temperature, it is readily apparent when plotted against outdoor air temperature.

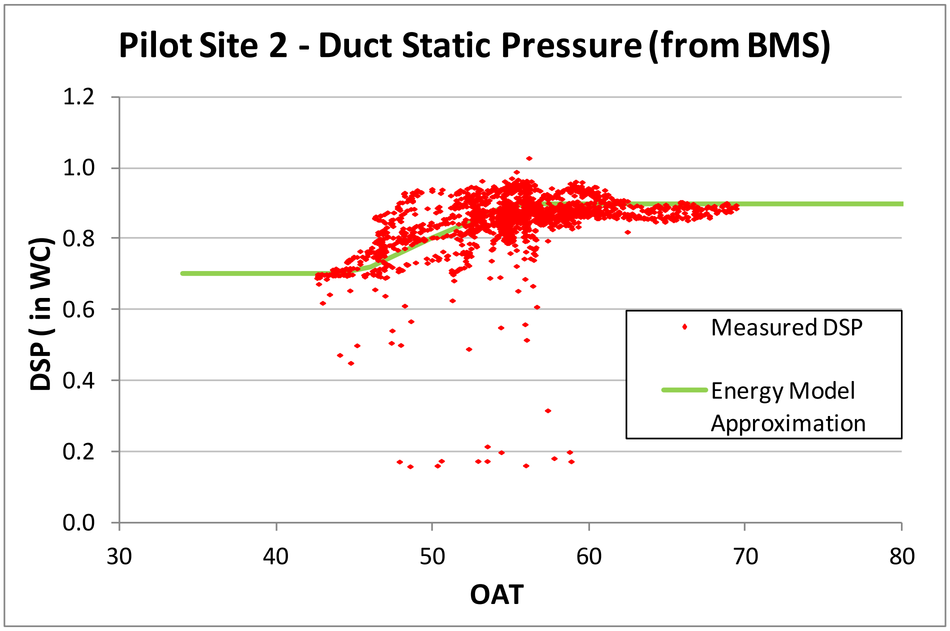


Figure 15: Pilot Site 2 - BMS Trended DSP

The figure above shows the DSP plotted against outdoor air temperature (OAT) and the effect of the DSP reset can be clearly seen. Data from the fan speed monitoring for both air handlers showed that the fan speed went down approximately 5% on average as a result of the duct static pressure reset.

Using temperature bin simulations based on the trended fan performance, we calculated the annual electric energy savings of this measure to be 76,000 kWh. Peak demand savings are zero since the building would be operating at high outdoor air temperatures.

EEM-2: Cooling Stage Lockouts

Visual Verification:

We verified the implementation of cooling stage lockouts through BMS screen shots.

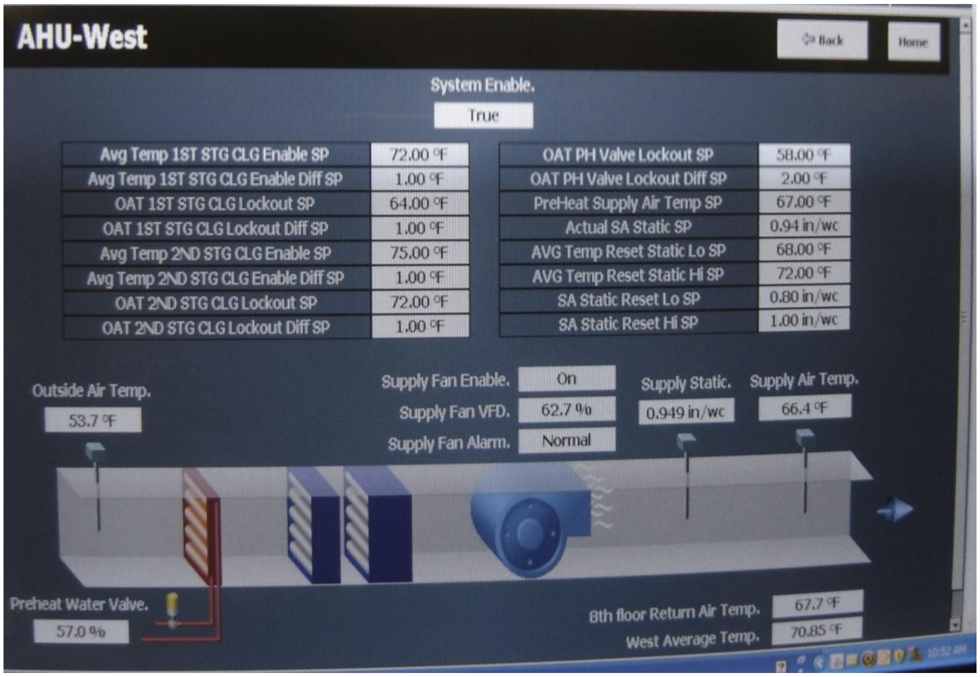


Figure 16: Pilot Site 2 - Cooling Stage Lockout based on OAT and Average Building Temperature

Energy Savings Calculations:

In the pre-WPT retrofit condition, the cooling stage lockouts were adjusted as needed by the building staff based on outdoor air temperature (OAT), using manually adjustable control modules in the fan rooms. After the WPT retrofit, these OAT lockouts were automated using the new central BMS. An additional, secondary lockout based on the average building temperature from the WPTs was added.

Any effects specifically resulting from the added secondary lockout based on building temperature are difficult to isolate based on trending information. We would not expect to see a substantial difference from the pre to post-case since presumably, the building cooling is operated to meet the required load. Only if the manually adjusted setpoints were set higher by the occupants, would the load be changed slightly.

We can however, look for energy savings on a macro scale. This facility mechanical equipment is supplied by a separate meter that has interval metering, so we were able to perform a detailed, hourly demand regression to calculate electric energy savings on the mechanical systems. We obtained hourly demand data representing 87% of the hour-temperature bins for Oakland and covering more than a 6 month time period after the installation. The figure below shows the weekday demand savings at a given outdoor air temperature and day-hour. The kW savings is listed, with positive savings highlighted green.

Weekday Demand Savings (kW)

OSA F	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
94																								
92																								
90														11										
88														49		30	24							
86													45		37	74	83	55						
84													82	60	48		41							
82												72	85	58	167	133		1	142					
80												52	56	-8	85	100	2	44		1				
78											-1	75	-29	21	-58	71	-29	24		1	1			
76											43	23	-34	8	58	31	9	-19	-109	1	1			
74										30	-23	-41	14	52	-8	-12	75	-7	14	0	1	1		
72										23	-14	0	49	-12	-13	-18	3	28	-45	-2	0	0		
70										-20	15	37	-35	-7	5	20	-13	-13	9	-1	-2	0	0	
68	0	-1							-13	26	82	-13	-7	4	11	3	13	5	-4	5	-1		0	-1
66	0	0	-1						28	-6	-16	-27	5	30	31	11	0	20	-11	1	8	-2		-1
64	-1	-1	-1	-1	0	0	-61	-50	-7	-10	-29	-1	16	19	9	-3	-16	-5	2	0	0	5	7	
62	0	0	5	-1	-1	0	-66	6	1	4	15	19	16	35	48	27	30	-18	8	1	3	4	6	5
60	3	3	2	3	2	3	3	30	17	12	21	25	39	17	-2	1	16	30	9	3	2	0	-1	2
58	1	0	1	1	1	1	-14	11	11	17	17	14	7	26	30	12	20	17	2	2	3	2	2	2
56	1	1	1	1	1	3	-10	9	10	12	9	13	15	14	12	30	8	37	12	-3	-1	1	1	1
54	1	-1	0	1	1	0	-14	9	11	18	19	18	3	1	-5			24	2	1	-1	-1	0	0
52	-2	1	-1	-1	-2	0	-13	7	23	21	17	9	2						9	-2	-2	0	-2	0
50	-2	1	4	-1	-1	-2	-9	35	62	22	12	10								-6	4	-5	0	1
48	0	8	8	8	6	2	3	43	39	18											1	-4	-4	-5
46	5	-3	-3	9	6	5	10	41	28															
44		9	3	5	5	3		58	23															
42			-5	-4		-3	-9	41																
40				-5	-5			25																
38					-2	-6	-18																	
36							2																	
34																								
32																								
30																								

Figure 17: Pilot Site 2 – Average Annual Hourly Demand Savings

Based on this analysis, we estimated that the site would save 45,000 kWh annually in electric usage. However, this whole building analysis approach also includes savings from the DSP Reset, which we calculated to be 76,000 kWh. Thus we do not see savings any greater than the DSP reset savings, and in fact, observe less savings based on this analysis approach. Thus, we estimate that the changes to the cooling stage lockouts are minimal, and may in fact be negative.

We estimated the annual electric energy savings of this measure are zero.

OTHER EEMS: PRE-HEAT TEMPERATURE REDUCTION AND HOT WATER RESET

Note: These measures are <u>not</u> WPT enabled.

Visual Inspection:

We verified the implementation of the pre-heat temperature reduction and hot water temperature reset through BMS screen shots.

Figure 18: Pilot Site 2 – Pre-heat Supply Air Temperature Setpoint

We can see in this figure that the pre-heat supply air temperature is set to 67°F.

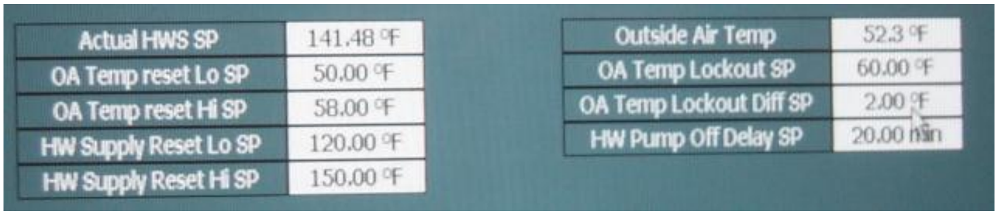


Figure 19: Pilot Site 2 - Boiler Reset Schedule Based on OA

We can see in this figure that the hot water setpoint is reset between 120°F and 150°F based on the outside air temperature varying between 50°F and 58°F.

Energy Savings Calculations:

We can clearly see the effect of the reduced pre-heat temperature in the trending data.

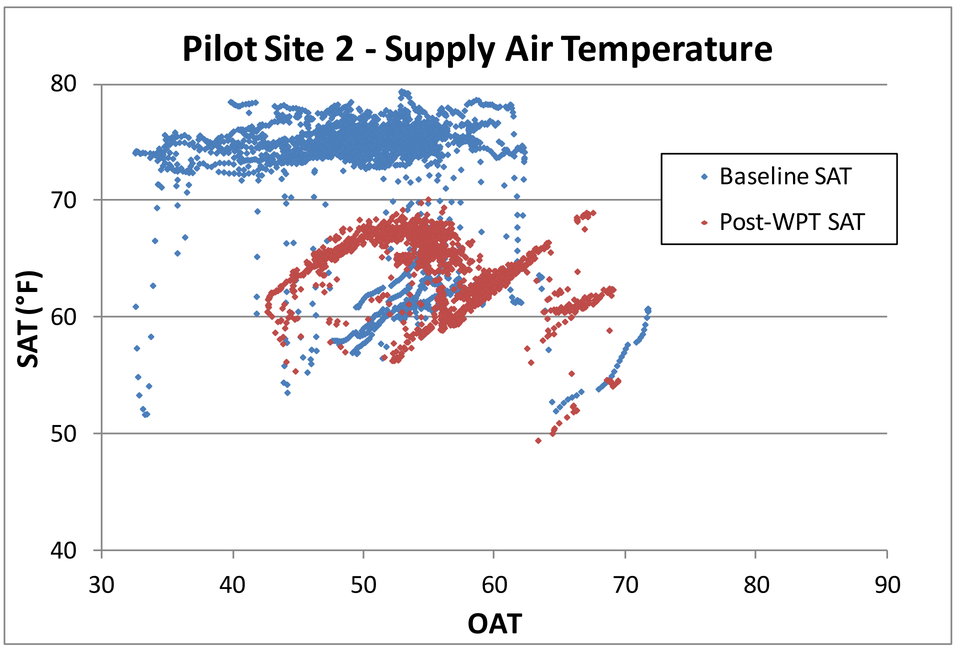


Figure 20: Pilot Site 2 - Baseline and Post-Retrofit SAT

The figure above clearly shows the high SAT during low outdoor air temperatures in the baseline pre-retrofit case. In the post-retrofit case, this data cluster is not apparent.

Both these measures should result in some gas savings. We calculated gas savings using a utility billing regression model to correlate heating degree days, cooling degree days, and monthly gas usage, see table below.

Table 9: Pilot Site 2 - Gas Savings Regression Analysis

				Metered Usage		Modelled Use	
	Days	HDD	CDD	kWh	Therms	kWh	Therms
Baseline	363	2,936	129		22,005		22,203
Post-WPT	213	536	206		3,875		3,884
Post-WPT (Annualized)	363	2,936	129				25,839
					Savings		-3,637
					% of Baseline:		-17%
					Balance Point:	65	

The table above shows that negative gas savings were calculated using the billing regression model. Unfortunately, we only had post-retrofit monthly gas billing data for warmer months with little to no heating degree days. Most of the annual gas usage (80%) occurs during the winter months, for which we did not have post retrofit usage history; see figure below.

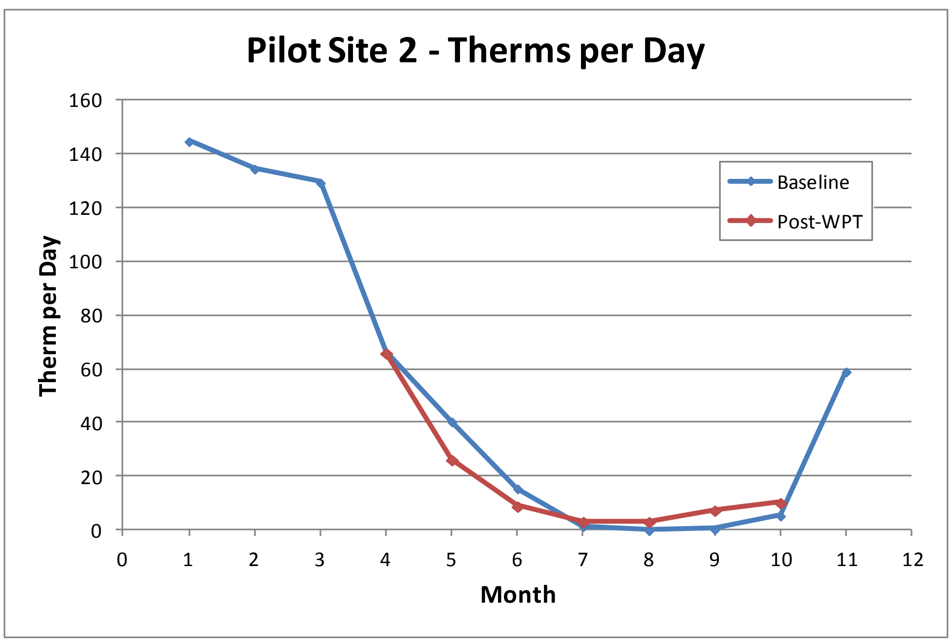


Figure 21: Pilot Site 2 – Monthly Gas Usage

The figure above shows the monthly average gas use in therms per day. This chart shows that post-WPT data has not been collected for the four of the five months with highest gas use. Without more data, it is difficult to calculate gas savings effectively.

Based on our analysis, we cannot calculate an annual gas energy savings from these measures.

Note again that these measures are <u>not</u> enabled by the WPTs.

INCENTIVES

The site received two incentives for a total incentive amount of $117,189.

Customized Retrofit Incentive: The CRI program savings amounts are listed in the table below. The CRI program incentive was $26,971.

Table 10: Pilot Site 2 - CRI Program Savings Amounts

	kW	kWh	Therms
CRI Calculated Incentive (PA)	117.00	149,130	1,850
CRI Verified Savings (IR)	174.00	183,180	1,550

Oakland Shines: The savings amounts from the Oakland Shines program are shown in the table below. The savings amounts were based on spreadsheet calculations. The Oakland Shines program incentive was $90,218.

Table 11: Pilot Site 2 – Oakland Shines Program Savings Amounts

	kW	kWh	Therms
Oakland Shines program	133.00	175,063	2,686

COMMENTS AND OBSERVATIONS FROM SITE STAFF

- The owners are happy with the system. They expect to see savings in reduced energy bills.
- Tenants have found the temperature more consistent. The building management staff has already noticed receiving less complaint calls, and is able to check temperatures and operation centrally before going to the problem zone.
- The installation process (units on the wall) took longer than they had thought, more than 2 days per floor.
- The installation process generated a punch-list of 40 boxes to check in the building. This was seen as a benefit to the installation allowing problems to be identified (although maybe not for the building engineer who has to do the repairs).
- Unit installation was estimated at 3 to 4 weeks out of a total project length of 6 weeks to 2 months.
- At the time we discussed it with them, the building staff had not addressed having a controls contractor on a maintenance contract. However, they suspected that they would use the WPT installation contractor for any future controls work.
- They would like to pursue LEED® certification next year.

FUTURE POTENTIAL

This site selected single setpoint thermostats, and it would be cost prohibitive to replace these with deadband models at any point in the near future. This site could potentially modify the SAT reset to be based on actual zone temperatures, rather than on average building temperature.

PILOT SITE #3

LOCATION AND SITE INFORMATION:

- San Mateo, CA 94401
- Multi-tenant office building
- 144,000 sq feet, 15 stories
- CEC Climate Zone 3
- Schedule: 7am to 6pm, M-F
- Annual kWh usage: 1,045,000
- Annual Therms usage: 145,000 (high due to cogen)
- Installed 300 WPT units (Manufacturer 1)

MECHANICAL SYSTEMS:

- Cooling Source: Most cooling is through a condenser water loop, but chillers provide cooling on hotter days.
- Heating Source: On-site cogeneration (micro-turbines) provides the heating hot water (HHW).
- Air Distribution: Variable speed floor AHUs with perimeter reheat, 15 units

PROJECT INITIATION:

The customer worked with the WPT vendor to develop this project. The project intended to reduce energy consumption.

This site installed 300 WPTs, covering the entire building. The site planned to replace the BMS system in conjunction with the WPT installation but this was not installed at the time we conducted our post-installation verification.

PLANNED EE MEASURES:

The following list of proposed measured is based on discussions that we had with the site staff before the installation occurred.

- Duct Static Pressure (DSP) Reset
- Deadband
- Setpoint Enforcement
- Global Temperature Adjustment

INSTALLED EE MEASURES:

WPT ENABLED

- Deadband

NON-WPT ENABLED

- Curtailment of morning warm-up (Scheduling).

MEASURE SUMMARY TABLE:

The following table shows the measures for this pilot site based on category and at different project stages.

Table 12: Pilot Site 3 - Measures

Pilot Site 3

Savings potential:	good	some	little/none

Measures:	Scheduling	SAT Reset	DSP Reset	Deadband	Setpoint Enforcement	DR: GTA (incl Pre-Cooling)	RCx	Other
Proposed	Very fixed office schedule	Already based on digital sensor/floor	Yes, may also replace sensors	Management wants to have control	Want to remove occupant control	Very interested	Hope to reduce service calls	N/A
Installed	Curtailed morning warm up.	N/A	Will implement with planned new BMS	Yes, 70-75	Concurrent with deadband	Possibly planned with new BMS	Yes, generated a punchlist	N/A
WPT Attributable	Curtailed morning warm up.	N/A	Will implement with planned new BMS	Yes, 70-75	Concurrent with deadband	Possibly planned with new BMS	Yes, generated a punchlist	N/A

FINDINGS

1. The site implemented a deadband, typically 70°F to 75°F. The building presumably decided on a higher heating setpoint than is typical (70°F vs 68°F) since they have free heating from their cogeneration microturbines and would not see realized savings from a lower heating setpoint. In the pre-retrofit case, the thermostat setpoints were adjustable by the tenants.

2. Scheduling Curtailment of Morning Warm-up. Concurrently with the WPT installation, the building operations staff adjusted the time at which the HVAC system is enabled. The central plant schedule was set to a 7am to 6pm operation. The baseline varied but equipment started as early as 3:30am. Although the building engineer was able to verify space temperatures from the WPTs, this measure was <u>not</u> enabled by the WPT installation.

3. A new central system BMS (Tridium Niagara) will be installed in late 2012 or early 2013 and is expected to include DSP reset based on zone information from the WPTs, and possibly an altered SAT reset based on zone information. The new system may also address global temperature adjustment.

MEASUREMENT AND VERIFICATION (M&V)

MONITORING PERIODS

Pre-WPT retrofit: 3/16/2012 to 4/26/2012

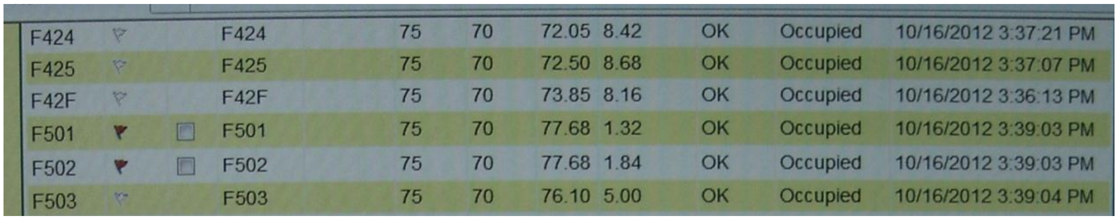
Installation: 8/1/2012 to 10/15/2012

Post-WPT retrofit: 10/16/2012 to 11/5/2012

EEM-1: DEADBAND

Visual Verification:

We verified the implementation of deadband through BMS screen shots.



F424			F424	75	70	72.05	8.42	OK	Occupied	10/16/2012 3:37:21 PM
F425			F425	75	70	72.50	8.68	OK	Occupied	10/16/2012 3:37:07 PM
F42F			F42F	75	70	73.85	8.16	OK	Occupied	10/16/2012 3:36:13 PM
F501			F501	75	70	77.68	1.32	OK	Occupied	10/16/2012 3:39:03 PM
F502			F502	75	70	77.68	1.84	OK	Occupied	10/16/2012 3:39:03 PM
F503			F503	75	70	76.10	5.00	OK	Occupied	10/16/2012 3:39:04 PM

Figure 22: Pilot Site 3 - Deadband Thermostat Setting

The figure above shows the heating and cooling setpoints of 70°F and 75°F respectively. This deadband range was implemented essentially throughout the entire building. We can see the deadband clearly in the aggregate zone branch pressure trending.

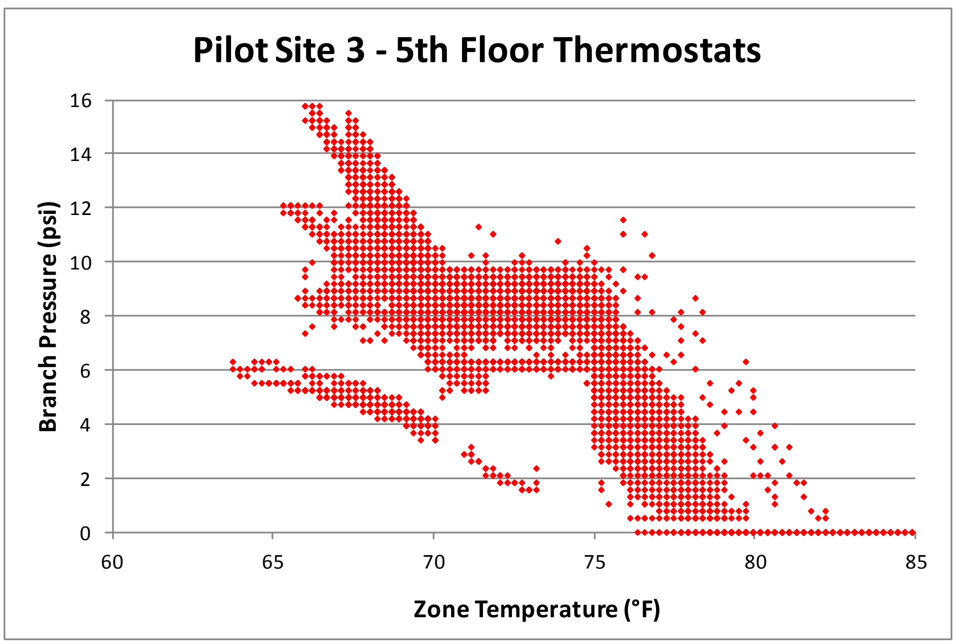


Figure 23: Pilot Site 3 - 5th floor Zone Temperature versus Branch Pressure

Energy Savings Calculations:

Since the only measure installed at this site is a setpoint deadband, we had the opportunity to try to isolate the energy savings from this measure.

The site adopted a high deadband range, 70°F to 75°F, presumably because it has a "free" heating source from its micro-turbine waste heat. However, on the cooling side, the building uses a condenser water loop for most of its cooling needs; this system is fairly efficient. On hotter days of the year, a chiller is needed to meet the cooling loads. We observed chiller operation during both our pre and post-monitoring periods.

We obtained hourly interval data for the building. The figure below shows the interval demand data plotted against outdoor air temperature.

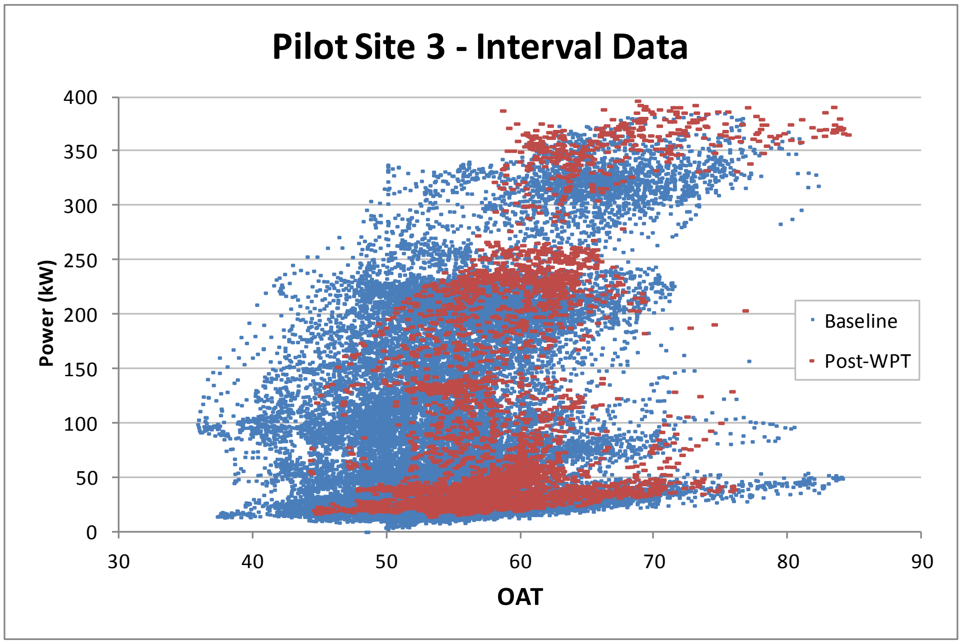


Figure 24: Pilot Site 3 - Building Operating Power versus OAT

The figure above shows all hours of the building operation. Three clusters of data are visible: the top cluster represents operation when the chiller is on, the middle cluster represents non-chiller building operation, and the lowest cluster represents overnight operation.

We performed an hourly demand regression using the interval data. The figure below shows the 15-minute interval data plotted against outdoor air temperature.

Weekday Demand Savings (kW)

OAT F	Hour 0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
86																								
84																								
82																	-45	-62						
80															-13		-10	-76						
78														-23	-23	-30		-1						
76														-33	-25		-11	-15	-10					
74													-39	-39		-45	-31	-13	-26					
72												-28	-22	-26	-53			20	33	31				
70											-30	-29	-56		-102	2	69	-1	41	40	36	42	49	
68										-16	-35	-56	-72	-91	45	-40	13		1		41	35	29	
66		51						-150	-61	26	-57		48	38	0	-23	-30	-2	22	8	17		42	
64	35	31	34	54	77				10	38	-7	46	5	14	8	13	-8	-30	1		14		18	8
62	13	23	16	43	72	37	14	-47	-32	-32	-1	-34	-29	-31	-23	-19	3	28	3	-3	-5	-3	-7	-8
60	1	6	24	49	33	-20	-28	-95	-75	-23	-17	-35	-19	-3	-19	-133	27	-29	15	3	6	6	6	-8
58	5	-1	27	46	49	5	-56	-49	-14	-23	-17	20	28	1			-93	-33	5	17	10	6	7	0
56	3	8	21	40	60	16	-9	-21	-12	3	35	39	11	-20	-27	-15	-18	70	31	3	0	-2	-6	0
54	8	11	24	48	67	22	-3	-12	-10	-9	-4	-18					-11	-11	23	8	7	-6	-5	-16
52	-6	-6	20	36	16	-3	-41	-25	-9	-6								5	39	14	13	11	2	-4
50	14	16	31	45	72		9	6	-12												23	18	19	12
48	14	14	28	57	69	56	-10	-14																
46			34	63	81		-5	-11																
44					72	37	-4																	
42																								
40																								

Figure 25: Pilot Site 3 – Average Weekday Demand Savings in Hourly Bins

In the figure above, we can see demand savings (highlighted green) in the morning and evening hours, whereas much of the daytime hours have negative savings (highlighted red). We had post-WPT retrofit data representing 85% of the annual temperature bin hours for this location, even though we only had approximately a month of post retrofit data. This represents the fact that a wide range of temperatures were observed. None the less, the data set is limited.

Based on this approach, we calculated an annual energy savings of negative 29,000 kWh, an increase in energy use. Other building factors likely impacted these results.

Thus, we were not able to calculate any energy savings from this measure.

Other EEM: Curtailment of Morning Warm-Up

Note: this measure is not WPT enabled.

Visual Verification:

We verified the curtailment of morning warm-up through BMS trending data. The figure below shows the operation of the condenser water (CW) pump, which serves the cooling coils when the chillers are not operational.

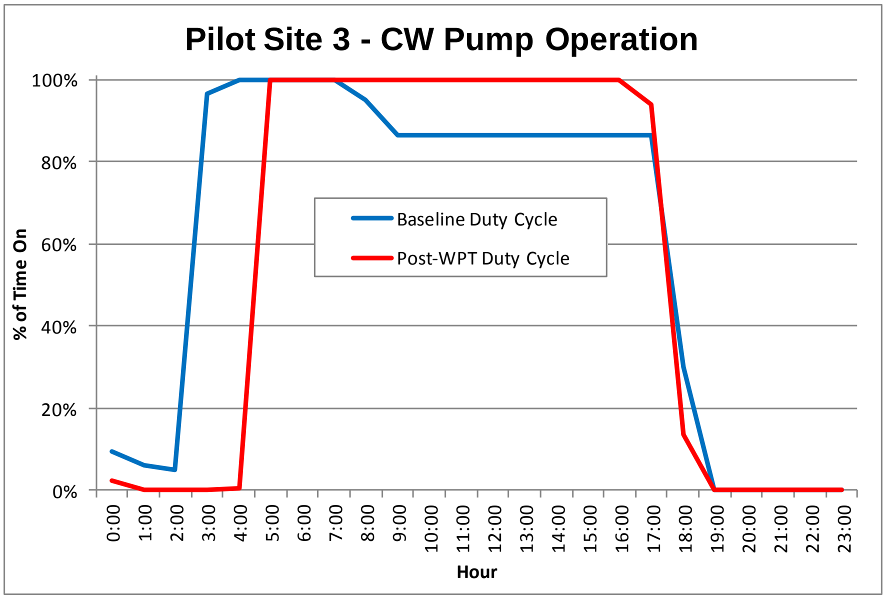


Figure 26: Pilot Site 3 – Condenser Water Pump Operation

The figure above shows that the condenser water pump is coming on about 2 hours later in the morning in the post-WPT condition.

The curtailment of morning warm up can also be clearly see in Figure 25, discussed earlier.

Energy Savings Calculations

Because this measure is not enabled by the WPTs, we did not calculate annual energy savings. However, it should be noted that the savings from this measure would be included in the hourly demand regression, performed above. That analysis resulted in a negative savings amount.

INCENTIVES

Customized Retrofit Incentive and Retro-Commissioning Program: Calculations submitted to the CRI program were prepared by the WPT Vendor. (Disclosure: the Reviewer was kW Engineering). The project was subject to a parallel review by the CPUC. Per the CPUC Energy Division's review of the CRI PA, the project was moved to the RCx program. The RCx verified savings were not available at the time of this report, but the estimated savings is provided in the table below.

Table 13: Pilot Site 3 - Incentive Program Savings Amounts (Estimated)

	kW	kWh	Therms
RCx preliminary incentive (estimated)	*26.35*	*94,000*	*0*

It should also be noted that the site's building management pursued on-bill financing as part of the incentive application.

Comments and Observations from Site Staff

- Site staff experienced a lot of trouble due to the tenants seeing the space temperature. The chief engineer received dozens of calls from occupants upset that the temperature on the thermostat was too high - even when they did not feel too uncomfortable. To address this issue, the site has decided to replace dozens of the WPT cover plates with blank covers, at an added cost.
- The installation went quicker than they thought. It took approximately 15 minutes per thermostat.

Future Potential

This site still has a major portion of the total project left to install -- a new BMS and associated controls. The site is planning on implementing a SAT reset, DSP reset, and possibly a GTA.

PILOT SITE # 4

- Sacramento, CA 95619
- Classroom and office building on college campus
- 60,000 sq. ft., 5 stories
- CEC Climate Zone 12
- Annual kWh: 800,000
- Annual Therms: N/A, campus steam not metered
- Installed 116 WPT units (Manufacturer 2)

MECHANICAL SYSTEMS:

- Cooling Source: Campus chiller water, not metered
- Heating Source: Campus steam, not metered
- Air Distribution: Constant Volume Reheat AHU, 2 main units

PROJECT INITIATION:

This project was initiated as part of a Smart Grid Investment Project, a demand response Program with SMUD. The program provided half of the project installation costs. The primary objective of the project was to give the customer the ability to shut off load during demand response events.

This site installed 116 WPTs, covering the entire building. The site also installed a new central systems BMS as part of the project (Niagara Tridium). Additionally, a chilled water valve was replaced during the installation period.

PLANNED EE MEASURES:

The following list of proposed measured is based on discussions that we had with the site staff before the installation occurred.

- SAT Reset
- Fan speed limiting: Although the air distribution is constant volume, the fans have VFDs.
- Deadband
- Global temperature adjustment, as a demand response measure

INSTALLED EE MEASURES:

WPT ENABLED

- SAT reset, but not functioning at time of our monitoring
- Fan Speed Limiting
- Deadband, but not functioning at time of our monitoring
- Demand response: Global temperature adjustment and fan speed limiting

NON-WPT ENABLED

None

MEASURE SUMMARY TABLE:

The following table shows the measures for this pilot site based on category and at different project stages.

Table 14: Pilot Site 4 - Measures

Pilot Site 4

Savings potential:	good	some	little/none

Measures:	Scheduling	SAT Reset	DSP Reset	Deadband	Setpoint Enforcement	DR: GTA (incl Pre-Cooling)	RCx	Other
Proposed	Yes, variable due to school occupancy	More aggressive that OAT	Limiting VFD Speed	Will implement, weird because CV	No control, no planned control	Yes DR, no Pre-cooling	Respond to complaints currently	N/A
Installed	No, very fixed schedule	Yes	Choked Fan Speed	Yes, 68 to 74	N/A	Yes	Identified various box and wiring problems	N/A
WPT Attributable	N/A	Little observed, still comissioning	Choked Fan Speed	Not functioning	N/A	Yes	Identified various box and wiring problems	N/A

FINDINGS

The installation at this site had not been fully commissioned at the time of the post-retrofit monitoring. Although the main installation period was during the summer of 2012, the contractor was still actively working on controls integration and troubleshooting. A couple of factors contributed to an extended commissioning period. This building was part of a larger project that included several buildings on campus, and priorities and resources were shifted between buildings and tasks multiple times. Also, much of the controls work for this building involves the heating systems, and the controls contactor waited until the campus heating steam was turned on in the fall before addressing operational issues.

1. A SAT reset was programmed in the controls sequences, however, the sequences were still being modified at the conclusion of our post-installation monitoring period. We did not observe a clear reset strategy in our trending data.

2. The supply fans were operating at reduced speeds relative to the pre-installation trending. The sequences controlling the fan speed were unclear from our observations and were still being modified by the contractor.

3. A deadband was installed throughout all building spaces. The typical deadband setpoints were 74°F in cooling mode and 68°F in heating mode. We observed that the deadband was not functioning correctly at the time of our monitoring.

4. A demand response control sequence was installed. A staged sequence first adjusts the zone temperature setpoints and then limits the fan speeds, depending on what ADR level is called for.

MEASUREMENT AND VERIFICATION (M&V)

MONITORING PERIODS

Pre-WPT retrofit: 3/26/2012 to 4/23/2012

Post-WPT retrofit: 10/18/2012 to 11/9/2012

EEM-1: SAT RESET

Visual Inspection:

The following figures show the BMS control screens for AH-A at the start and the end of the post-WPT monitoring period.

In the following figure, we can see that the SAT setpoint temperature is not within the range of minimum and maximum setpoints, indicating a possible manual override.

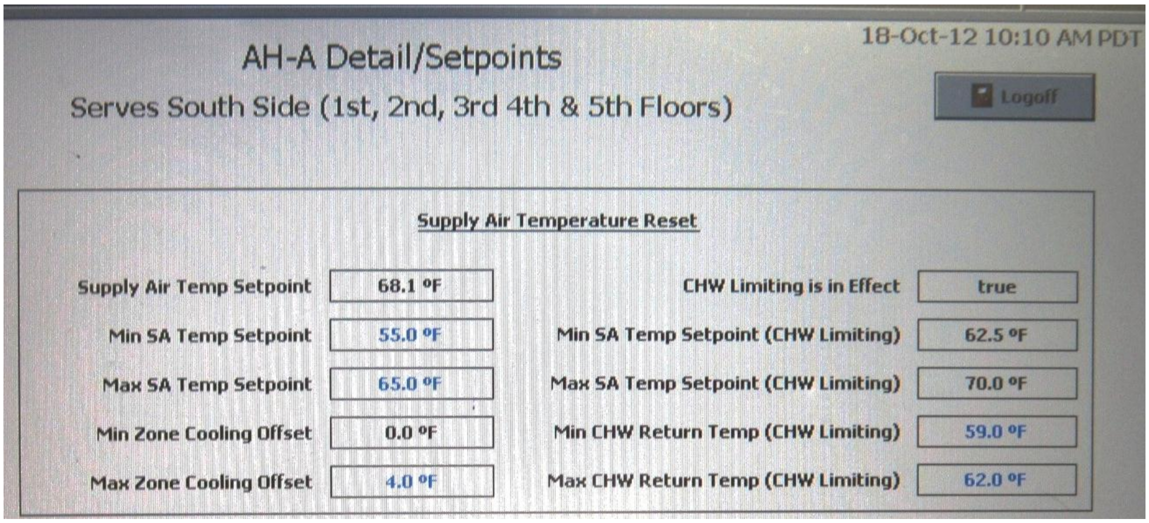


Figure 27: Pilot Site 4 – SAT Control Screen at the Start of the Post-WPT Monitoring Period

In the following figure, it appears that a control sequence was added: the average cooling differential from the zone temperatures is being used to set the supply air temperature. However, the controls contractor indicated that this sequence was still being implemented.

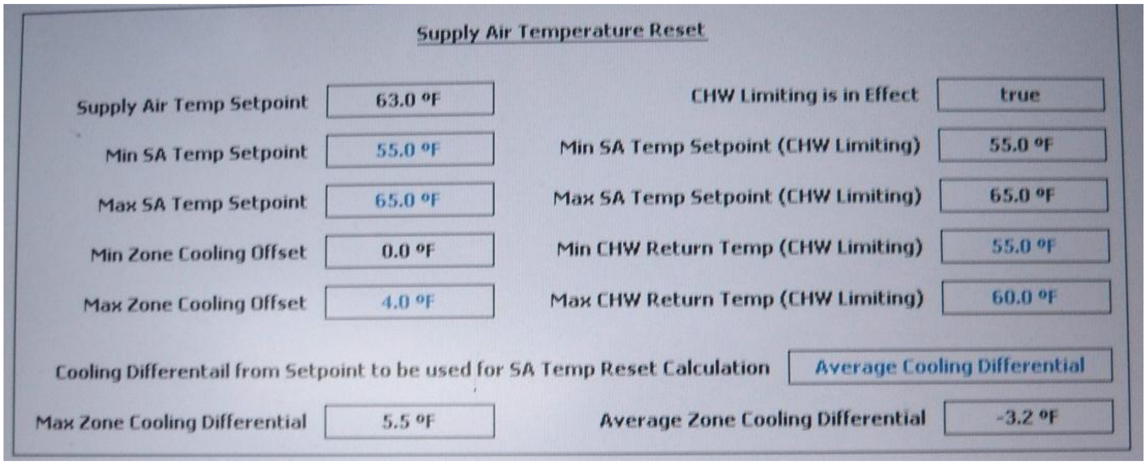


Figure 28: Pilot Site 4 – SAT Control Screen at the End of the Post-WPT Monitoring Period

The following figure shows BMS trending for the air handler. We observe that the setpoint is not changing in a controlled manner.

The following figure also shows that setpoint is rarely being met, and some cycling behavior is indicated at the later end of the time series. As discussed, the controls sequencing was still being commissioned at the time of the monitoring. Additionally, the chilled water valve was replaced during the monitoring period, which could have contributed to erratic behavior.

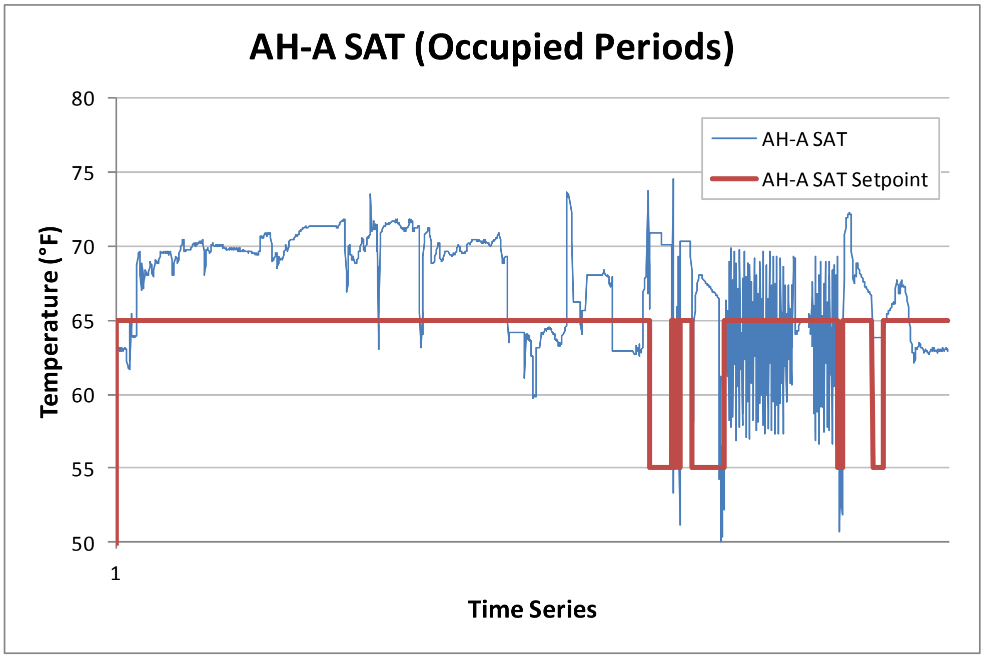


Figure 29: Pilot Site 4 – SAT Setpoint and Measures Temperature After WPT Retrofit, Occupied Times

Finally, when we compare the observed supply air temperatures relative to outside air temperatures from before and after the WPT retrofit, we do not observe any significant difference. See the following figure.

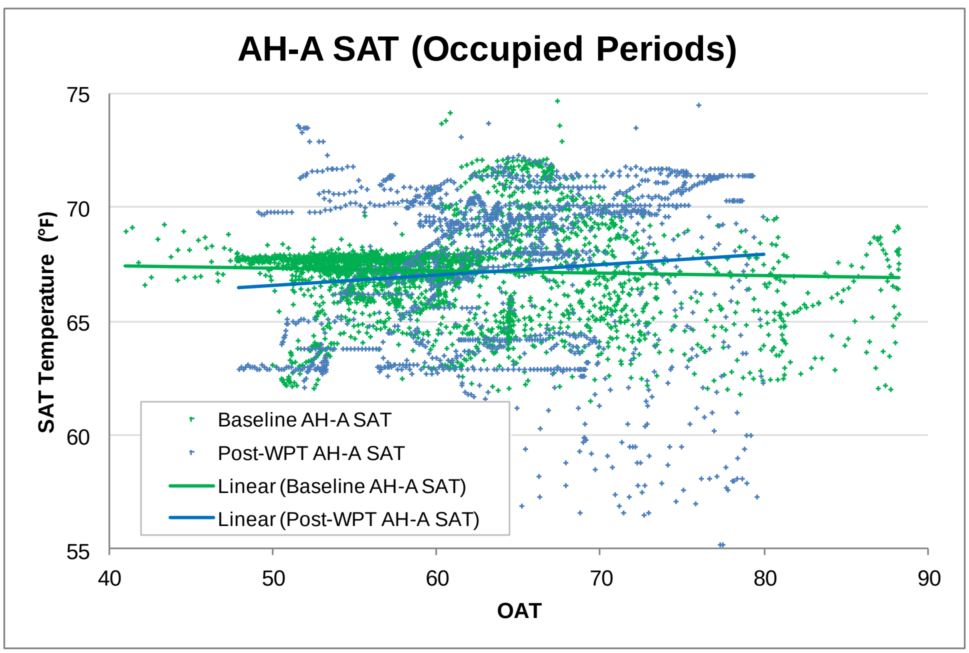


Figure 30: Pilot Site 4 – Measured SAT Before and After WPT Retrofit

It should be noted that we observed similar performance issues with AH-B.

Energy Savings Calculations

Based on our observations, the SAT reset was not functioning during our post-retrofit monitoring period and we did not observe any noticeable difference in the SATs relative to the pre-retrofit period.

Thus, we did not calculate any energy savings for this measure.

EEM-2: Fan Speed Limiting

Visual Inspection:

The following figures show the fan speed control from the BMS control screens for AH-A at the start and the end of the post-WPT monitoring period.

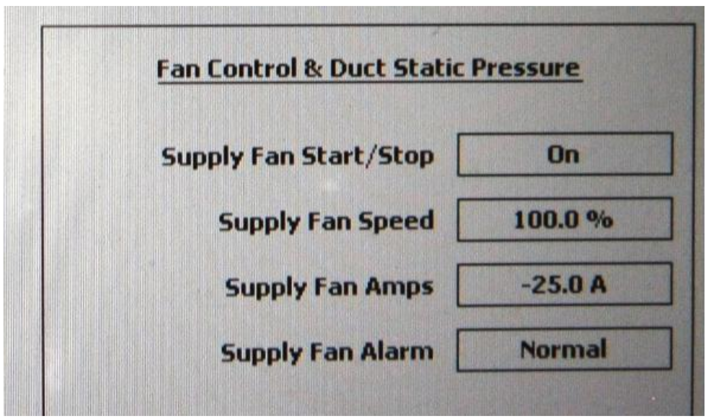


Figure 31: Pilot Site 4 – Fan Speed Control at the Start of the Post-WPT Monitoring Period

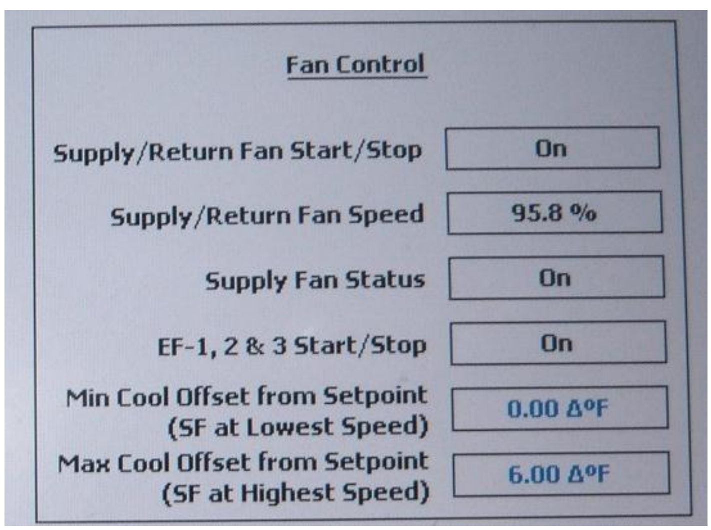


Figure 32: Pilot Site 4 –Fan Speed Control at the End of the Post-WPT Monitoring Period

In the figure above, we can see that fan speed control was added to the BMS. The control screen seems to indicate that the fan speed will be controlled based on the maximum cooling offset from the WPT zone information. However, in speaking to the controls contractor, the controls sequencing was not completely programmed at the end of the post-retrofit monitoring period.

Energy Savings Calculations

Thus, we did not calculate any energy savings for this measure.

EEM-3: Deadband

Visual Verification:

The following figure shows the zone view for Room 261. The graphic shows an occupied cooling setpoint of 74°F and an occupied heating setpoint of 68°F.

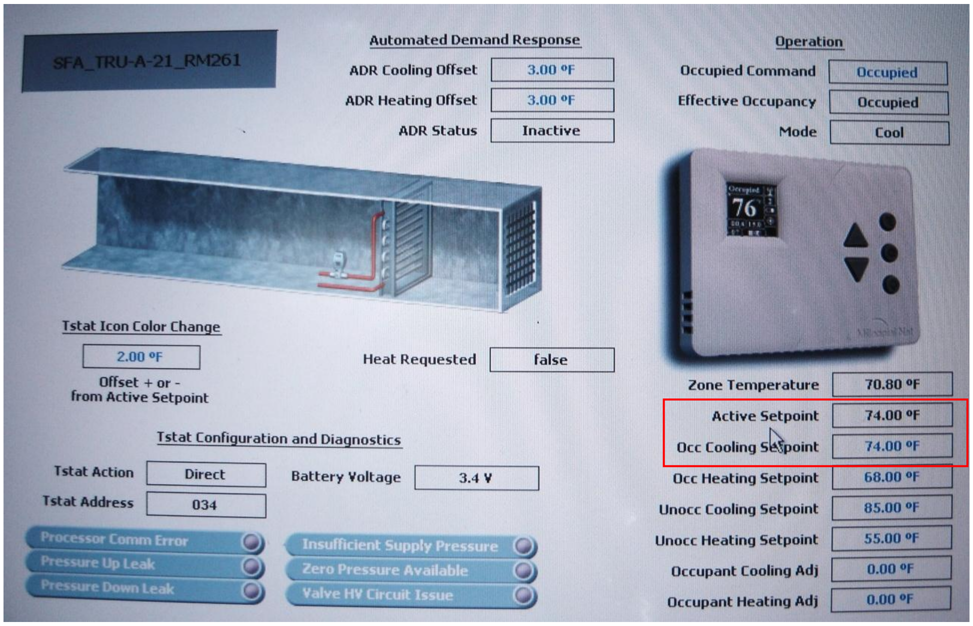


Figure 33: Pilot Site 4 – Deadband Visible in Zone Graphic

The figure above also shows that the zone temperature is within the deadband range; however, the operation mode is set to 'cool'. The following figure shows a different view of this same zone taken at the same time. Here, we can see that the temperature in Room 261 is registered as being below the active setpoint, which should translate into being in heating mode. Thus, we can see that the deadband is not functioning as desired and there are some controls changes needed.

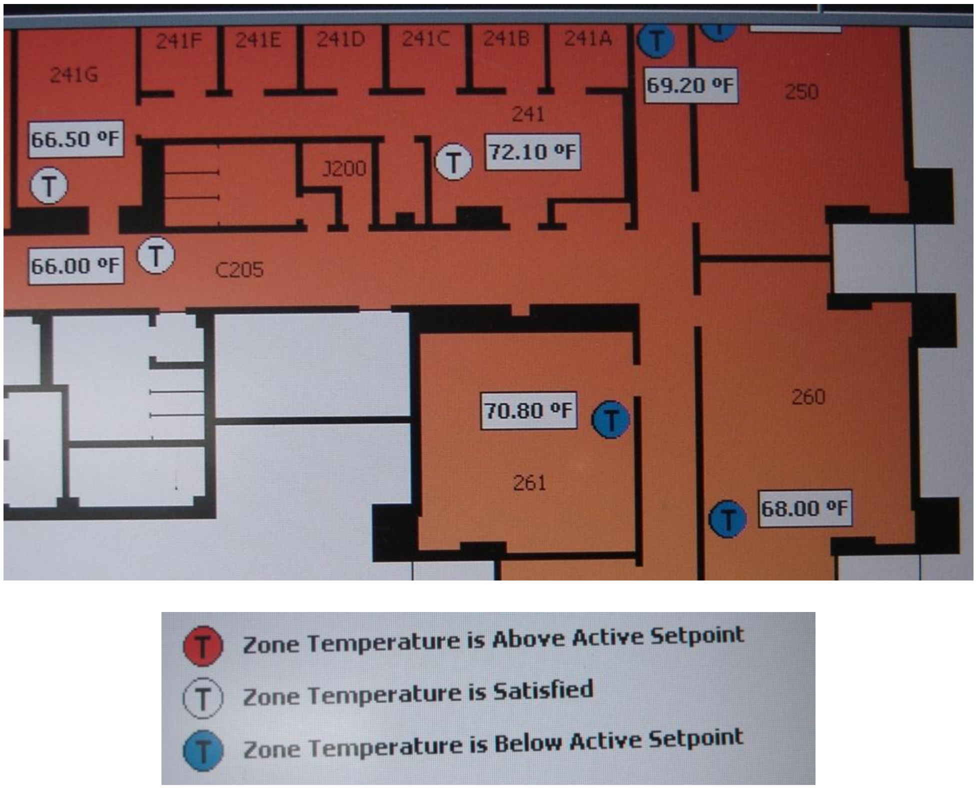


Figure 34: Pilot Site 4 – Detail of 2nd Floor BMS Screen (top) and Thermostat Color Key (bottom)

Furthermore, the following figure shows the branch pressure for the reheat valve in Room 261. We can see that the branch pressure is not in a neutral range of about 8 psi, but rather, is a low pressure of 4.2 psi - this zone is sending a heating request to open the reheat coil valve.

rea Served	Supply Fan	TRU #	Effective Occupancy	Mode	Zn Tmp	Active Spt	Occ Heat Spt	Occ Cool Spt	Unocc Heat Spt	Unocc Cool Spt	Req Branch Press	Meas Branch Press
RM 240	SF-A	TRU-A-4	Occupied	Cool	69.60 °F	74.00 °F	68.00 °F	74.00 °F	55.00 °F	85.00 °F	3.0 psi	2.2 psi
RM 261	SF-A	TRU-A-21	Occupied	Cool	70.10 °F	74.00 °F	68.00 °F	74.00 °F	55.00 °F	85.00 °F	3.2 psi	4.2 psi
RM 217	SF-B	TRU-B-7	Occupied	Heat	58.80 °F	68.00 °F	68.00 °F	74.00 °F	55.00 °F	85.00 °F	3.0 psi	4.2 psi

Figure 35: Pilot Site 4 – BMS Graphic of WPT Data, Partial View including Rm 261

From the figure above, it also appears that the display is incorrectly listing the Mode as 'Cool' instead of as heating. Furthermore, it appears that the active setpoint is equal to the occupied cooling setpoint for Room 261.

We observed this inconsistent or incomplete deadband implementation throughout the zones of Pilot Site 4 .

Energy Savings Calculations

With deadband not functioning, and commissioning ongoing, we did not calculate an energy savings for this measure.

EEM-4: Demand Response: Global temperature adjustment and fan speed limiting

Visual Verification:

According to project contacts, three ADR levels were implemented at Pilot Site 4. The first level increases all the zone setpoints by three degrees. The second level reduces the Fan speed to 80%, and the third level further reduces the fan speed to 70%. The site chooses what level to employ. We also confirmed with site contacts that the ADR functionality had been tested with SMUD. The following figure shows the BMS control screen for ADR.

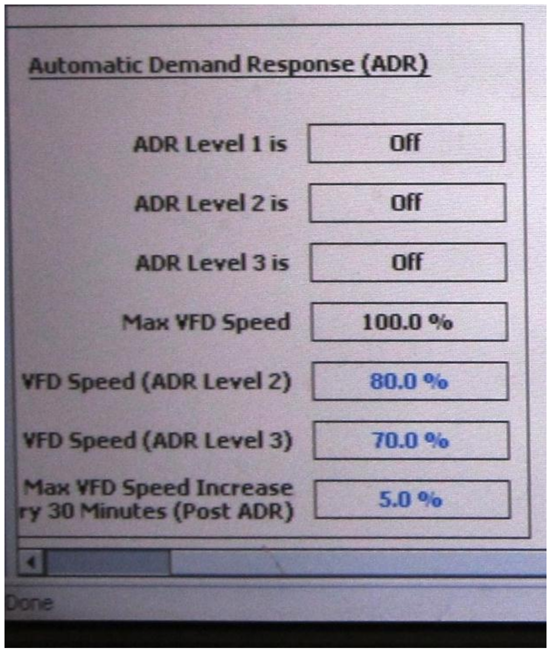


Figure 36: Pilot Site 4 – Demand Response Fan Speed Control

Energy Savings Calculations:

For ADR Level 1, a raise in the zone setpoints could reduce demand by reducing the amount of airflow and cooling that is needed.

For ADR Levels 2 and 3, we calculated the energy savings based on the measure's fan power. We calculated a supply fan demand reduction of 18.0 kW for ADR Level 2. We calculated a supply fan demand reduction of 27.3 kW for ADR Level 3.

Incentives

Customized Retrofit Incentive: Pilot Site 4 is eligible for a CRI incentive because it purchases gas from PG&E. The table below shows the gas savings approved before the project was initiated. The installation verified savings amount was not available at the time this report was written.

Table 15: Pilot Site 4 - CRI Program Savings Amounts

	kW	kWh	Therms
CRI Calculated Incentive (PA)	N/A	N/A	1,827

The site also received incentives amounting to 50% of the project costs from SMUD.

Comments and Observations from Site Contacts

- Their staged installation caused multiple problems. Campus heat was not on when first installed and then they had to validate the DR setback separately from doing the energy savings measures.
- The contractor estimated that installing WPTs at Pilot Site 4 was about half the cost of installing DDC to the zone.
- The WPTs allow equipment problems to be identified, such as leaky valves. Multiple problems had already been identified and acted on.

Future Potential

Given the building's constant volume air handling system, the site is pursuing an impressively broad range of energy efficiency measures through the installation of WPTs. We observed an intent to complete all the planned measures. Unfortunately, the project implementation was spread out and staged, resulting in an incomplete commissioning at the time of the inspection.

EVALUATION

OVERVIEW

This study of four pilot site installations of wireless pneumatic thermostats (WPTs) generally confirmed that the WPT technology itself is robust. The units function as expected, and can provide many of the operational benefits achieved with a zone-level DDC upgrade. Compared to replacing pneumatic with DDC zone equipment (i.e. terminal boxes), the cost and disruption to install WPTs is lower. However, as with a DDC upgrade, the energy savings achieved depend on the measures implemented, not just on the hardware itself.

The thermostat units themselves are fairly easy and unobtrusive to install, and perform as expected. At the four sites, WPTs from two manufacturers successfully replaced existing pneumatic thermostats of many types. Their wireless technologies worked as expected with no communication issues reported.

However, at each of the pilot sites, the potential advantages of WPT technology were not fully realized. Achieved energy savings attributable to the WPTs were low or nonexistent. Installing WPTs on the wall does not in itself provide energy savings. At the pilot sites, the additional steps of measure implementation and commissioning, using the WPT central hub controller (and sometimes requiring integration with central system BMS controls), were not fully completed. The WPTs are an enabling technology which can then be used to add or improve control functionalities, which can in turn save energy.

The best potential energy savings enabled by WPTs could be achieved in applications where:

- Inconsistent and variable occupancy provides opportunities for zone-level scheduling;
- SAT and DSP resets are not yet in place, or are compromised by zone-level load variations;
- Existing pneumatic thermostats have no deadband, and/or occupants tend to adjust setpoints to extreme settings; and building management is prepared to manage setpoint enforcement and/or to implement daily global temperature adjustment strategies;
- Pneumatic systems are old and not fully maintained, so that the data from WPTs is particularly useful to identify system problems for repair.

Overall, the operational benefits of implementing WPTs are largely similar to those of retrofitting DDC controls to the zone level. Both upgrades provide building operators with information about conditions and HVAC demand in each zone, and enable operators to control zones centrally (remotely). With WPTs the zone information is less complete - the WPT communicates its branch pressure only, which indicates whether it is "trying" to make its space warmer or cooler; whereas a full zone DDC system indicates the actual damper or valve positions, and often the measured airflow, at each zone terminal.

Similarly, the energy savings from implementing WPTs depend on the control measures implemented and integrated, as is the case when installing DDC zone equipment.

However, with WPTs there remains the continued need to operate and maintain and troubleshoot the pneumatic zone equipment. Dry compressed air must be supplied, and pneumatic devices (generally old) require particular maintenance and troubleshooting. The WPTs do provide information to help identify problems, which is a significant improvement over regular pneumatic thermostats. WPTs will also require routine battery replacement, expected every 2 years by both WPT manufacturers.

In sum, WPTs are an attractive, cost-effective alternative to pneumatic-to-DDC zone upgrades for the right applications where their capabilities will be put to good use.

EVALUATION OF IMPLEMENTED MEASURES

The following table shows the planned measures and savings potential for the four pilot sites.

Table 16: Proposed Measures for All Pilot Sites

Proposed Measures

Savings potential:	good	some	little/none

Measures:	Scheduling	SAT Reset	DSP Reset	Deadband	Setpoint Enforcement	DR: GTA (incl Pre-Cooling)	RCx	Other
Pilot Site 1	Some improvement expected	Some DDC w temp sensors, already SAT	Yes, expected	Interested in this	Blank face	Signed EnerNOC DR contract	Want to run more efficiently	N/A
Pilot Site 2	Set office schedule	Currently fixed, plan on install	Will implement, new DSP sensors	Yes, currently none	Have full control, will limit	Nothing planned	1 year of proactive bldg operator	N/A
Pilot Site 3	Very fixed office schedule	Already based on digital sensor/floor	Yes, may also replace sensors	Management wants to have control	Want to remove occupant control	Very interested	Hope to reduce service calls	N/A
Pilot Site 4	Yes, variable due to school occupancy	More aggressive that OAT	Limiting VFD Speed	Will implement, weird because CV	No control, no planned control	Yes DR, no Pre-cooling	Respond to complaints currently	N/A

The following table shows the installed, WPT-attributable measures and savings potential for the four pilot sites.

Table 17: Installed, WPT-Attributable Measures for All Pilot Sites

WPT-Attributable Measures

Savings potential:	good	some	little/none

Measures:	Scheduling	SAT Reset	DSP Reset	Deadband	Setpoint Enforcement	DR: GTA (incl Pre-Cooling)	RCx	Other
Pilot Site 1	No	Slight secondary, no change	Based on OA, not zone information	Yes, average 70.4 to 72.7	Private office occupants have control	Incompatable integration	Future potential for MBCx	N/A
Pilot Site 2	Closed unoccupied zones	Not implemented	Tenants control setpoint, 70 to 74	No, single setpoint	Occupants have control	N/A	40 boxes to check	Could see zone response to preheat adjust
Pilot Site 3	Curtailed morning warm up.	N/A	Will implement with planned new BMS	Yes, 70-75	Concurrent with deadband	Possibly planned with new BMS	Yes, generated a punchlist	N/A
Pilot Site 4	N/A	Little observed, still comissioning	Choked Fan Speed	Not functioning	N/A	Yes	Identified various box and wiring problems	N/A

EVALUATION BY MEASURE

SCHEDULING / SETBACKS

We found that scheduling savings were not directly enabled by WPTs for any of the four pilot sites evaluated. The ideal site that would benefit from scheduling savings would be one that has a long operational hours with limited or variable occupancy. For example, a site that has the HVAC system operation for long hours to accommodate possible tenants occupancy, could reduce operational hours if the WPTs were used to turn central plant equipment on, rather than having it operational just in case. None of the pilot sites evaluated could have benefitted from this measure since they all had very fixed occupancy schedules that were already reflected in the central plant operation.

We originally expected that the school location (Pilot Site 4) would benefit from zone-level scheduling controls, but further investigation revealed that the site has a very fixed occupancy schedule determined from classroom schedules. Additionally, the ventilation system is constant volume, so it must run at a fixed speed when any portion of the building is occupied. The site did not pursue any changes to the control systems that would have resulted in energy savings from scheduling.

However, two sites took advantage of WPT information in an indirect way towards energy savings. At Pilot Site 2, zone temperature data was used to confirm that an adjustment to the pre-heat temperature did not adversely affect the spaces. At Pilot Site 3, zone temperature data was used to confirm that central plant equipment start times could be adjusted closer to when the building is occupied.

Finally, in theory, the WPT devices can be programmed so that the user interface on each unit can control central plant equipment operation, but this functionality was not enabled at any of the pilot sites.

Even though the pilot sites in this study could not have benefitted from any scheduling improvement, the scheduling measure presents significant energy savings potential that should not be overlooked. Additionally, this measure can be implemented at sites that are all pneumatic, making it broadly applicable to a large number of buildings including small and medium sized commercial buildings. Unfortunately, this study did not include any of these types of sites.

SUPPLY AIR TEMPERATURE (SAT) RESET USING ZONE DATA

We found that a SAT reset measure was not directly implemented at any of the four pilot sites, but future implementation is planned at two of the sites.

For Pilot Site 1, the site already had a SAT reset based primarily on OAT, with a slight secondary input based on the average space temperature from a few digital sensors in the space. Post-retrofit, this slight, secondary adjustment was modified to be the average of the average floor temperatures from the WPTs. The site did not install CD and HD SAT resets based on the WPT zone information, such as through a trim and respond sequence. This type of strategy would have involved some detailed control work, and we speculate that the project budget and scope did not allow for this.

For Pilot Site 2, the site had intended to implement a SAT reset, but it was not executed. The site did base the DX cooling stage incremental lock out on average zone temperatures, but this strategy did not fundamentally change between pre and post retrofit so there was little energy savings potential. Similar to Pilot Site 1, we suspect that this oversight was due to limited project budget and incomplete scope.

For the other two pilot sites, both plan on implementing a SAT reset in future. At Pilot Site 3, we understand that the site plans to implement a SAT reset based on WPT zone temperature information, but the site already resets SAT based on a digital temperature sensor on each floor, so any energy savings would be incremental. Pilot Site 4 has included coding and a control screen indicating a SAT reset, but the strategy was not yet apparent or realized when we conducted our post field monitoring.

A SAT reset based on zone information could provide energy savings potential, but we did not observe this measure implemented at any of the pilot sites.

Duct Static Pressure (DSP) Reset Using Zone Data

We found DSP resets either installed or planned at all four sites, but did not observe a reset that utilized WPT zone information. All four pilot sites had intended to implement a DSP reset, presumably based on zone information.

At Pilot Site 1, the site had intended to implement a DSP reset based on zone information. Instead, a DSP reset based on outdoor air temperature was installed. Although this measure results in real energy savings, the WPTs were not necessary for its implementation. We do not know the reason behind this deviation, but suspect that it was based on insufficient budget for full integration and commissioning.

At Pilot Site 2 , the DSP reset was based on the average building temperature, as determined from the WPTs. Our calculations showed energy savings from this measure.

For Pilot Site 3 , a DSP reset is planned for the future, but was not executed at the time of our post field data collection. However, the site currently resets its DSP based on the return air temperature, so any savings will be incremental.

For Pilot Site 4, we observed limited fan speed control in our data logging, but the reset strategy was not discernible. Fan speed limiting is an integral part of a demand response measure, as discussed later, but whether a reset strategy will be part of the daily operations is unclear.

A DSP reset can save energy without any negative effects on tenants, in theory at least, when terminal boxes are pressure independent and zone heating and cooling calls are used. We did not observe any branch pressure zone information (which serves as a proxy for heating and cooling requests) being used for a DSP reset at any of the pilot sites.

Setpoint Deadband

A temperature setpoint deadband was implemented at three of the four pilot sites, but we were not able to quantify any energy savings directly attributable to this measure.

A deadband was implemented at Pilot Site 1, but the deadband range and setpoints were adjusted by the building operators to accommodate requests from the tenants.

A deadband was implemented at Pilot Site 3 , but we were not able to calculate any energy savings from either the interval billing data or the zone trending data.

A deadband was not fully installed at Pilot Site 4 due to the project still being commissioned.

SETPOINT ENFORCEMENT

Energy savings from this measure implies that in the pre-retrofit condition, extreme thermostat setpoints caused energy waste. We did not observe anything in our study that would indicate that energy savings can be quantified from this measure at the pilot sites. Three of the four pilot sites had thermostat setpoints that were already set by building operators in the pre-retrofit condition. The fourth site had user-controlled thermostats in both the pre-retrofit and post-WPT conditions.

GLOBAL TEMPERATURE ADJUSTMENT (GTA)

Two pilot sites originally planned to implement a global temperature adjustment, but only one has implemented it.

At Pilot Site 1, there was an integration issue that prevented the implementation of global temperature adjustment. According to site staff, the issue was not related to the WPT hardware or software.

Pilot Site 4 implemented a global temperature adjustment and a fan speed adjustment as demand response measures only.

RETROCOMMISSIONING (RCX)

All four pilot sites indicated that WPTs were instrumental in identifying malfunctioning terminal box components in their buildings. Furthermore, building operators at all sites were appreciative that problem zones were identified.

We consider this to be a valuable benefit of WPTs, and one that will continue to be useful for building operators as the pneumatic equipment and components get older.

(In addition, building engineers at all sites commented on the operational advantages of being able to see all the zone temperatures in the building. Whereas they previously only had a few temperature sensors, or none at all, this new information will likely be used to improve the daily operation of the building.)

However, the quantification of any energy savings from retrocommissioning measures is very difficult.

INSTALLATION OBSERVATIONS

WPT manufacturers claim that the installation of the WPTs is quick and unobtrusive to building tenants. From our observations and discussions with sites staff, we believe this claim to be generally true. All sites commented that the initial installation of the WPT units was a quick process. For two of the sites, however, building operators had to revisit the pneumatic connection for a couple of dozen units to fix kinked pneumatic tubes or leaky/loose connections. At one site, the possibility of any kinked tubing was lessened by using a tube with a spring insert from an after-market pneumatic parts kit. Some sites commented on the overlooked need to cover up the marks on the wall left by the old thermostat, which were exposed due to the new thermostat's different form factor.

We did not note any problems with the installation of the wireless network at any of the pilot sites. One site had problems supplying power to the wireless repeaters, but it was due to asbestos interfering with the ability to install new electric power wiring in the building.

COSTS

We calculated an average installed project cost of $780 per WPT across the four pilot sites. In three of the four cases, this amount includes the installation of a new central BMS and associated controls programming.

TRAINING

Site contacts from all four pilot sites noted that they felt sufficiently comfortable with the operation of the WPT units. Many also expressed that they had either already used or knew about a support line with the WPT manufacturer. We were made aware of one formal training of building operators. We suspect that other training occurred during the installation process.

STUDY NEUTRALITY

Note that we, kW Engineering, remained a neutral observer during the planning and execution of the WPT retrofits. At no point did we require or specify any portion of the equipment, controls specifications or commissioning procedures.

RECOMMENDATIONS

In making the following recommendations, it is important to revisit some of the limitations of this study. The study observed only partial installations at two of the four pilot sites. Follow-up study is recommended and planned in future to understand the full scope of measures ultimately implemented at the sites. Also, all pilot sites had hybrid DDC/pneumatic control systems, and were larger buildings of 60,000 to 200,000 sq.ft. or more, whereas WPTs can be applied to all-pneumatic and smaller buildings as well. Three of the four pilot sites implemented controls strategies via BMS integration rather than through the WPT central hub controller. Finally, all pilot sites received some (often substantial) financial assistance from various programs.

CORE RECOMMENDATIONS

Based on our findings and evaluations, we have the following three core recommendations around structuring an incentive program supporting WPTs:

1. **Incentives should be based on the measures successfully implemented rather than the WPT technology alone.**

   A hybrid-deemed program would best be oriented to incentivize implementation of measures themselves as enabled by the WPTs, not just installation of the WPT hardware.

   We observed very unique pilot site installations, driven by different objectives and constrained by different systems. The WPT installations were not a one size fits all application, but rather, they enabled a broad range of energy savings measures. Any incentive program should be focused on the control measures enabled and achieved rather than the technology that's used to enable them.

   This approach is contrary to that of the WPT manufacturers, who are selling widgets not measures. For almost all enabled measures, controls setup and commissioning is required in addition to the installation of the WPT hardware, even if it is as simple as programming schedules.

   Achieved energy savings is a result of new control functionality, not just the installation of the WPT hardware. Further study is needed to fully characterize the measures and address baseline and implementation scenarios. This work was beyond the scope of this study.

2. **An incentive program should recognize that the addition of WPTs may often represent a controls system overhaul rather than only the installation of a new piece of equipment.**

   Incentive programs should encourage the adoption of as many controls measures as possible. The controls contractor plays a major role in the installation, and commissioning is an important element in installation. It may be appropriate to have separate incentive paths for the WPT hardware itself, and for full commissioning and optimization of controls enabled by the WPT. For example, the customer might be incented using a straightforward hybrid-deemed rebate for purchase of the WPT system, even if it is relatively small. Then additional incentives might be offered direct to installer (contractors) to perform complete setup and commissioning. This requires further study.

An overhaul represents a unique chance to take a broader perspective in looking at the building control systems. If some elements are missed or overlooked, it may be difficult to add other functionality at a later time. We recommend incentive structure(s) that encourage building operators to take full advantage of the WPT system capabilities to implement as many measures as possible, by including full setup, commissioning, and integration (as needed) in the overall project scope. Other educational material could also help with this, such as: measures lists, educational resources, common controls sequences, varied case studies, etc.

At the pilot sites, the controls contractor was the major player in the installation of WPTs. The WPT manufacturer supplied the new equipment, but the setup and integration of that equipment was the most important part for achieving savings. We noticed overwhelmingly that the controls contractor did not play an integral part in the project planning process. Involving the controls contractor up front would help ensure that the planned measures are executed.

We observed that commissioning was lacking at several of the sites. Had proper commissioning been an integral part of the project, we believe that more energy savings measures would have been properly defined and realized. As with any major retrofit, a commissioning agent, involved from the beginning of the project, can be an important part of a successful project. There are some incentive programs that have a tiered incentive payout based on if an independent commissioning agent is used. We recommend encouraging the realization of commissioning.

3. **Further study is needed to validate and quantify energy savings derived from setpoint enforcement and deadband measures.**

Based on our observations at the pilot sites, we could not quantify energy savings from these two measures. Savings for these measures are being claimed by the manufacturers, but we were not able to substantiate savings in this study.

Our research did not directly identify any savings from deadband alone. In theory, this measure can provide energy savings by avoiding cycling of heating and cooling around a single setpoint. However, the amount of savings is small and may be indistinguishable from the noise of other variables. Additionally, the way that deadband is implemented can vary across sites (e.g. if tenant input is used when setting the setpoints or if common points are used throughout a building). We recommend that a rigorous, controlled study is needed if this measure is to be incentivized. We recommend that a standardized approach to deadband be applied across all incentive programs.

To characterize energy savings from the setpoint enforcement measure would require further study, which may not be cost-justified. Furthermore, any savings that could be quantified, may not be applicable to other sites depending on varying baseline conditions (e.g. if a thermostat is operable by a tenant versus building engineer, and tenant temperature preferences). At this point we recommend that this measure not be incentivized.

OTHER RECOMMENDATIONS

Very large, complex, integrated WPT controls projects may need to be incentivized through the M&V-focused RCx program. Larger installations of WPTs in combination with implementing multiple, overlapping measures (i.e. new control functionalities) require IPMVP-appropriate M&V to determine actual savings achieved. These projects are likely best incentivized through an M&V-focused program such as Core RCx.

The installation of non-deadband thermostats should not be incentivized. The installation of thermostats that are capable of a deadband, separate heating and cooling setpoints, is required by Title 24 code. We believe that a controls overhaul, such as from the installation of WPTs, should comply with the code intent. Although a legal code enforcement is not triggered with a thermostat retrofit, we believe that an incentive program could help realize the code intent by not incentivizing non-deadband WPTs. Although we did not quantify any energy savings from deadband, and recommend further study on this measure, we still believe that having a deadband theoretically provides energy savings and therefore, should be encouraged.

The graphics displaying WPT zone temperature information can be improved. We suggest that any supporting utility program could provide samples of successful graphic displays.

For Pilot Site 2, we observed that the BMS did not contain a graphical view of the thermostat locations. Instead, only a list of thermostat numbers was provided. If the site engineer wanted to identify the location of the thermostat, he had to cross reference a hard-copy floor plan with the locations written on it, see figure below.

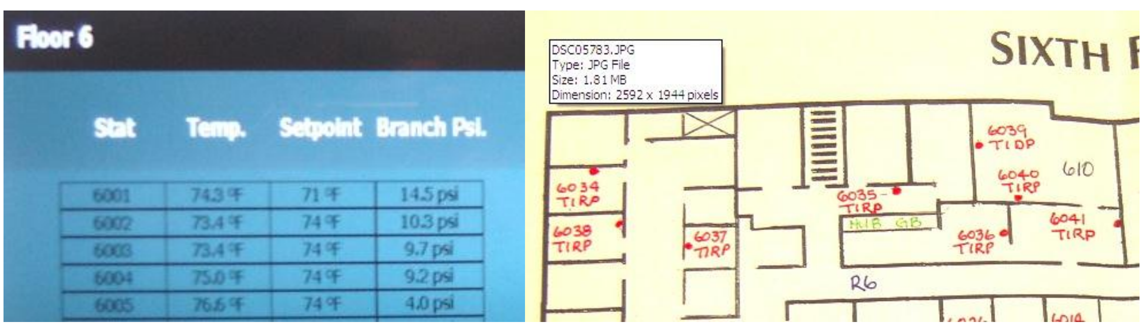


Figure 37: BMS List of WPTs by Floor (left) and Hard-Copy Map of WPT Locations (right)

The figure above shows what we consider to be a poor display of WPT information because the thermostat locations are not shown graphically on the BMS screen.

The figure below, on the other hand, uses a graphical floor plan display and color-coded the thermostats to indicate their status.

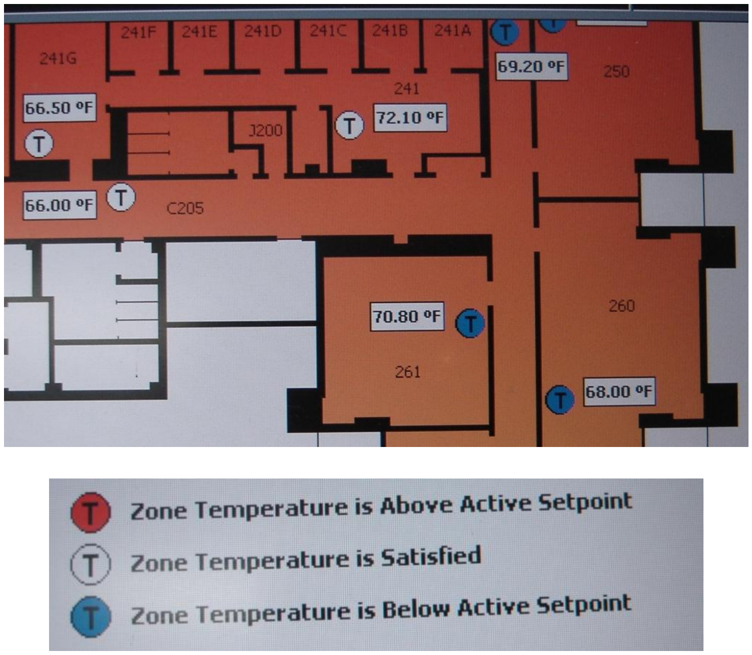


Figure 38: Example of Zone Map with Color-Coded Thermostats (above) and Key (below)

We recommend:

- Providing both a list and map view in the BMS.
- Color coding both the list and the map with deadband, heating, and cooling mode colors.
- Including an easily identifiable marker to distinguish between direct-acting and reverse-acting branch pressure control if a building contains both types of equipment.

The most cost effective way to include these types of graphical displays in the project is if they are specified in the beginning. An incentive program could provide suggested graphics in educational material to building owners pursuing WPT installations.