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Wireless Pneumatic Thermostat Evaluation Ronald Reagan Building and International Trade Center Washington, DC

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The Green Proving Ground program leverages GSA's real estate portfolio to evaluate innovative sustainable building technologies and practices. Findings are used to support the development of GSA performance specifications and inform decision-making within GSA, other federal agencies, and the real estate industry. The program aims to drive innovation in environmental performance in federal buildings and help lead market transformation through deployment of new technologies.

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Table of Contents

List of Figures

List of Tables

I. Executive Summary

A. Background

To be effective at maintaining indoor air conditions, a building heating, ventilation, and air conditioning (HVAC) system needs to be controlled in some fashion. The control system needs to sense the temperature of a space, feeding it to a control system, and manipulate the HVAC equipment to maintain desired temperatures for the occupants.

Within the portfolio of buildings under the jurisdiction, custody, or control of the General Services Administration (GSA), approximately 20% have HVAC systems that are operated by pneumatic control systems. These buildings are under the same energy conservation mandates as all federal facilities. Unfortunately, the major drawback to pneumatic systems is that they are not capable of implementing automated energy-saving control strategies. They can't automatically change the thermostat setting at night and on weekends in the same way as more modern control systems such as direct digital controls (DDCs). Converting a building from a pneumatic control system to DDCs is typically cost prohibitive.

The wireless pneumatic thermostat (WPT) is a new technology designed to mimic the capabilities of DDCs. Vendors claim WPTs can be retrofitted to existing pneumatic control systems in a cost-effective fashion. WPTs allow facilities to exercise energy-saving control strategies such as setting thermostats back at night. If capable of satisfactorily performing such functions, the WPT could be a valuable technology for use in GSA and other facilities to help reduce energy consumption and meet related goals.

The purpose of this study is to evaluate the ability of the WPT to implement energy-saving control strategies in an actual building that currently has a pneumatic control system. If this ability is proven in a field demonstration, energy modeling will be used to estimate the potential energy savings and economic benefits from this technology in typical buildings across the GSA portfolio.

B. Overview of the Technology

The core piece of equipment in a pneumatic HVAC control system is the thermostat, which mounts to the wall of a space, detects space temperature, and sends this information via pneumatic tubing to the HVAC system.

The WPT technology operates from a straightforward premise: replace the conventional pneumatic thermostat with a device that not only detects space temperature and sends information via existing pneumatic tubing, but also can be adjusted and controlled by a central energy management system (EMS) through a wireless network. By using the EMS to control thermostat settings wirelessly, the building manager is able to implement energy-saving control strategies heretofore not possible with conventional pneumatic controls.

As an example, look at a typical office space where indoor temperature is maintained at 72°F. Below that point the HVAC system provides warm air to the space, and above that point cool air is supplied. With a conventional pneumatic control system, the HVAC system will maintain these conditions all day, every day, and on weekends and holidays too. That is because the thermostats are mechanical devices that must be manually adjusted to change their settings. True, an HVAC technician could walk around every night and morning to manually change the temperature to a more energy-saving setpoint, but that is expensive in terms of labor costs.

With the WPT technology installed, the manufacturer claims that the space temperature settings can be changed automatically through the central EMS. If the EMS is programmed, the building's thermostats can be set back to a range of 68°F to 79°F at 5:00 p.m., when occupants go home. They can then be reset to 72°F and 75°F at 7:00 a.m. to make the space more comfortable as occupants return. In this fashion, the building's HVAC system will not work as hard overnight and thereby save energy.

By implementing a control strategy such as this (commonly called an "occupied/unoccupied schedule"), the HVAC system keeps occupants comfortable while they are in the building but allows energy to be saved when the building is not occupied. Energy saving goals are supported, and a site's utility costs go down.

The commercial potential for this product, if these energy-/cost-saving claims are verified, is substantial. As said before, 20% of GSA buildings use pneumatic devices to control their HVAC systems. Pneumatics are typically used in existing buildings built before 1999 that are multistory and more than 20,000 ft^2. It is less common to see pneumatic control systems in single story offices, strip malls, or big-box retail establishments as they typically use rooftop units that directly control the space below. Smaller buildings, less than 20,000 ft^2, also tend to use packaged units rather than a central plant with zone thermostat control.

C. Study Design and Objectives

The Woodrow Wilson Center (WWC) was selected as the site to demonstrate the WPT technology. The center is located within the Ronald Reagan Building and International Trade Center in Washington, DC. This demonstration site was selected for several reasons. First, its HVAC system is controlled by a fairly new pneumatic control system (the building opened in 1998) that functions well. A system such as this represents the type which the WPT technology can be installed on to improve performance.

Second, WWC floor space consists of a variety of office spaces, including individual offices, conference rooms, open cubicles, and common areas. This type of mixed use is typical in the majority of facilities under GSA control.

Third, the evaluation team had complete access to all areas so that they could take measurements, install data loggers, and freely evaluate how well the WPT performed its tasks. The space at WWC had no "secure areas" that were off limits to the evaluation team.

The evaluation of the WPT technology consisted of two stages, a performance evaluation followed by an energy and economic evaluation. The former would be conducted at WWC. The latter would be accomplished via computer modeling of energy use and economics.

The goal for the performance evaluation was to answer the question, "Does the WPT technology have the ability to control the thermostat temperature settings in individual spaces?" The plan for the performance evaluation is very straightforward. Temperature data loggers would be placed in select spaces at WWC to record space temperatures in 5-minute intervals. These loggers would record space temperatures during two phases. First, temperatures would be logged when the space was being controlled by the existing pneumatic control system. These data would be graphed and the temperature pattern noted.

Second, the WPT system would be installed under a turnkey contract, an occupied/unoccupied schedule would be set by the technology's controller, and the building's space temperatures again logged. If the WPT were operating as promised, the loggers would see the space temperatures change during the unoccupied hours to a more energy-conserving setpoint. In the winter, the spaces would grow colder. In the summer, spaces would grow warmer.

If the WPT passed the performance test and proved that it had the ability to control space temperatures remotely and implement energy-saving control strategies on a pneumatic control system, the economic evaluation would be implemented.

The energy and economic evaluation goal was to answer the question, “Given the ability to exercise energy-saving control strategies, how much energy could potentially be saved by operating an occupied/unoccupied schedule on typical buildings in the GSA portfolio located in various places around the country?”

To answer this question, Oak Ridge National Laboratory (ORNL) researchers would use the DOE-2 energy modeling software to calculate potential energy savings. Within the program, ORNL would look at the three standard models of “typical” office buildings shown in Table ES-1.

Table ES-1. Standard Models of Typical Office Buildings (used in energy-savings calculations)

Building Type	Area (ft^2)	Floors	Window to Wall Ratio (%)	Plug Load (W/ft^2)	Lighting (W/ft^2)
Small Office	5,500	1	21	1	1.8
Medium Office	53,630	3	33	1	1.6
Large Office	498,500	12	38	1	1.5

These models were developed by Pacific Northwest National Laboratory in conjunction with the US Department of Energy (DOE) and are widely used as standards when modeling various energy-saving technologies and techniques.

Each of the three models would be evaluated in 16 different cities with their respective climate patterns.

For each combination of building type and city (e.g., a small office located in Houston, Texas), the energy consumption would be modeled using five different thermostat schedules. The baseline would calculate energy consumption if the thermostat settings were set to 69°F heating and 75°F cooling, with no setbacks at night or on weekends.

For comparison, the model would then be run four more times; each time the unoccupied thermostat setting would be changed to a more energy-saving unoccupied setting from 6:00 p.m. to 6:00 a.m. The thermostat setting combinations would be as follows.

- 66°F heating and 79°F cooling
- 62°F heating and 83°F cooling
- 58°F heating and 87°F cooling
- 54°F heating and 91°F cooling

The cooling and heating energy consumption for each unoccupied setting would be compared to the baseline consumption. The savings would be calculated and displayed in both graphical and tabular form for use by GSA building managers considering installation of the WPT technology. (Note: Tables and graphs of results are shown in Appendix B.)

D. Project Results/Findings

In this project, data gathered showed that the WPT technology does, in fact, have the ability to implement energy-saving control strategies on HVAC systems that use pneumatic control systems. Further, economic analysis showed that the technology is financially viable across a wide spectrum of typical facilities. It should be noted that energy modeling looked at the energy-saving potential of only the most basic occupied/unoccupied control strategy. If other strategies are implemented, the potential for energy savings is much greater, with an even greater financial viability of the technology.

Table ES-2 gives a summary of the financial simple paybacks that were derived from the energy modeling and economic analysis. (The following installation costs were used to generate the payback ranges: small office, \$3,850 to \$6,600; medium office, \$32,200 to \$59,000; large office, \$249,000 to \$449,000.)

Table ES-2. Composite Data for Simple Payback Periods

Climate Zone	City	Large Office (498,500 ft^2) Simple Payback Range (years)		Medium Office (53,630 ft^2) Simple Payback Range (years)		Small Office (5,500 ft^2) Simple Payback Range (years)	
		Low	High	Low	High	Low	High
1A	Miami, FL	3.6	6.5	3.7	6.8	1.9	3.3
2A	Houston, TX	3.7	6.7	4.5	8.2	2.9	5.0
2B	Phoenix, AZ	4.6	8.2	4.0	7.3	2.5	4.3
3A	Atlanta, GA	3.0	5.4	3.5	6.4	2.6	4.5
3B-coast	Los Angeles, CA	2.8	5.1	3.7	6.8	3.7	6.3
3B	Las Vegas, NV	5.3	9.5	5.0	9.2	3.1	5.4
3C	San Francisco, CA	3.0	5.5	3.8	7.0	3.2	5.5
4A	Baltimore, MD	2.8	5.0	3.3	6.0	2.7	4.7
4B	Albuquerque, NM	5.4	9.7	6.0	10.9	3.5	5.9
4C	Seattle, WA	3.6	6.5	4.5	8.2	4.3	7.4
5A	Chicago, IL	3.1	5.6	3.8	7.0	2.8	4.8
5B	Boulder, CO	5.0	8.9	5.7	10.5	3.7	6.4
6A	Minneapolis, MN	4.6	8.3	5.7	10.5	3.7	6.3
6B	Helena, MT	3.9	7.1	4.6	8.4	3.3	5.7
7	Duluth, MN	4.3	7.8	5.3	9.7	3.7	6.3
8	Fairbanks, AK	4.2	7.6	5.2	9.5	3.1	5.3

E. Conclusions and Deployment Guidelines

WPTs have strong potential to support energy savings in a variety of federal and commercial facilities (Table ES-3).

Deployment Priority 1 would be any facility that currently has a pneumatic HVAC control system that is operating properly. While this may sound like an oversimplification of the situation, the WPT technology is such that it has potential to help any building of this type, and individual factors should be evaluated for each individual building.

Deployment Priority 2 should be facilities that have high per-unit costs of energy, especially if they have high dollar-per-kilowatt-hour costs.

There does not appear to be a Deployment Priority associated with a particular climate zone. The technology appears to work equally well across the spectrum of climate zones.

Table ES-3. Performance Objectives

Quantitative Objectives	Metrics and Data Requirements	Success Criteria	Measurement and Verification Results	Best-Case Deployment Scenario
Exercise wireless control over HVAC systems controlled by pneumatic control systems.	Space temperatures are measured under baseline and test conditions to determine whether their temperatures do, in fact, change based upon the wireless pneumatic thermostat (WPT) technology providing that control.	If successful, the space temperatures would show a pattern of change consistent with the energy-saving control strategy that the WPT was programmed to implement.	Space temperature logs did show the temperature changes that indicate that the WPT technology can control space temperatures and operate energy-saving strategies.	A building with a properly operating pneumatic control system in a city with high per-unit utility costs would be the best candidate to have this technology deployed.
Reduce Costs	Cost reduction will be through reduced energy consumption and costs that are a result of the technology's ability to exercise control strategies.			
Reduce Emissions	Emission reductions will be through reduced energy consumption.			
Qualitative Objectives				
Ease of Installation	Feedback from maintenance personnel during installation.	No major problems reported during installation.	Feedback was positive from personnel.	
Ease of Use	Maintenance logs during operation.	No problems reported during use.	Customer has reported positive experiences with the technology.	

Table ES-4. Greenhouse Gas Emissions for Regional and National Average Utility Fuel Mixes ($kg\ CO_2$ equivalent/f^2/year)

Site	Regional Utility Fuel Mix	National Utility Fuel Mix
Baltimore, Maryland	0.435	0.466
Atlanta, Georgia	0.650	0.516
San Francisco, California	0.094	0.165

Note: Greenhouse gas (GHG) figures calculated from energy savings for a single building, as determined through energy modeling conducted as part of this study. Parameters were a large office building (495,000 f^2) at 16°F setback during unoccupied hours. GHG per kilowatt-hour savings found in the US Environmental Protection Agency's eGrid, 9th ed., Version 1.0, Year 2010 Summary Tables.

II. Introduction

A. Problem Statement

To be effective at maintaining indoor air conditions, a building heating, ventilation, and air conditioning (HVAC) system needs to be controlled in some fashion. In simplest terms, there needs to be a way of sensing the temperature of a space, feeding that information to a control system, and then manipulating the HVAC equipment so that the space temperature is maintained within a comfortable range for the occupants.

From the early twentieth century into the 1980s, the principal technology for performing this task in large buildings was the pneumatic control system. Systems of this type use pressurized air in various components to both detect space conditions and to operate the HVAC equipment that serves the area. Pneumatic control systems were state-of-the-art before the development of electronic and digital control systems.

The major drawback to pneumatic systems is that they are not capable of implementing automated energy-saving control strategies. They cannot automatically change the thermostat setting at night and on weekends or detect whether a person is in the space and needs the "occupied" temperature setting. Currently, a more modern control system such as direct digital controls (DDCs) is required to perform such energy-saving functions. Converting a building from a pneumatic control system to DDCs is typically cost prohibitive due to significant modifications required within the building.

The wireless pneumatic thermostat (WPT) is a new technology designed to mimic the capabilities of DDCs. Vendors claim WPTs can be retrofitted to existing pneumatic control systems in a cost-effective fashion. WPTs allow a facilities to exercise energy-saving control strategies such as setting thermostats back at night. If capable of performing such functions, the WPT could be a valuable technology for use in US General Services Administration (GSA) and other facilities to help reduce energy consumption and meet related goals.

The purpose of this study is to evaluate the ability of the WPT to implement energy-saving control strategies in an actual building that currently has a pneumatic control system. If this ability is proven in a field demonstration, energy modeling will be used to estimate the potential energy savings and economic benefits from this technology in typical buildings across the GSA portfolio.

B. Opportunity

Within the portfolio of buildings under the jurisdiction, custody, or control of GSA, about 20% have HVAC systems that are operated by pneumatic control systems. These buildings are under the same energy conservation mandates as all federal facilities. Also, based on anecdotal observations, about 25% of commercial office space is still controlled by pneumatic control systems. In other words, energy-saving control strategies for HVAC systems in about one-fourth of domestic office buildings cannot be implemented with their current controls technology.

According to the US Department of Energy (DOE), within the American commercial building sector, space heating, cooling, and ventilation account for 3.75 quads of energy consumption per year. This is roughly equal to the energy found in 135,000,000 tons of coal. (Note: 1 quad = 10^{15} Btu or 1,000,000,000,000,000 Btu.)

Using rough figures, if 25% of commercial buildings (a conservative estimate of those currently served by pneumatic controls) could exercise energy-saving strategies and save just 10% per year on HVAC costs, about 0.0938 quads (93.8×10^{12} Btu) could be saved per year.

The WPT technology is supposed to be able to provide the capability of exercising such control strategies.

A literature search showed that the WPT technology is available from at least two vendors. This technology has been commercially available since 2008.

The major benefit claimed for this technology is the ability to implement energy-saving control strategies as described above.

The technology has not been widely deployed yet. Some leading-edge companies have installed the technology within a few buildings, but a literature search showed no third-party evaluations that had been conducted to date.

There is relatively little risk of implementing this technology. Should a facility install WPTs, and the devices not work as advertised, it is a simple matter to remove the devices and reinstall the original pneumatic thermostats that were in the building. There is virtually no risk of the technology causing an "incident" which causes damage to a facility.

One barrier to deploying this technology is the fact that it uses wireless signals to communicate with the thermostats. Certain facilities have restrictions on what sort of wireless receivers and transmitters can be used therein, typically due to security reasons. If a facility has security restrictions of this type, it will be important to evaluate the technology from a security perspective before proceeding with installation.

III. Methodology

A. Technology Description

The core piece of equipment in a pneumatic HVAC control system is the thermostat, which mounts to the wall of a space, detects space temperature, and sends this information via pneumatic tubing to the HVAC system. The HVAC system can then provide warm or cool air to the space to adjust the temperature to a comfortable range.

The WPT technology operates from a straightforward premise: replace the conventional pneumatic thermostat with a device that not only can detect space temperature and send information via existing pneumatic tubing, but also can be adjusted and controlled by a central energy management system (EMS) through a wireless network. By using the EMS to wirelessly control thermostat settings, the building manager is then able to implement energy-saving control strategies heretofore not possible with conventional pneumatic controls.

As an example, look at a typical office space where indoor temperature is maintained between 69°F and 75°F. Below that range the HVAC system provides warm air to the space, and above that range cool air is supplied. With a conventional pneumatic control system, the HVAC system will maintain these conditions all day, every day, including weekends and holidays too. That is because the thermostats are mechanical devices that must be manually adjusted to change their settings. True, an HVAC technician could walk around every night and morning to manually change the temperature to a more energy-saving setpoint, but that is expensive in terms of labor.

With the WPT technology installed, the manufacturer claims that the space temperature settings can be changed automatically through a central EMS. If the EMS is programmed, the building's thermostats can be set back to a range of 65°F to 79°F at 5:00 p.m. when occupants go home. They can then be reset to 69°F and 75°F at 7:00 a.m. to make the space more comfortable as occupants arrive. In this fashion, the building HVAC system will not work as hard over night and thereby save energy.

By implementing a control strategy such as this (commonly called an "occupied/unoccupied schedule"), the HVAC system keeps occupants comfortable while they are in the building but allows energy to be saved when the building is not occupied. Energy saving goals are supported, and a site's utility costs go down.

The commercial potential for this product, if its claims are verified, is substantial. As said before, 20% of GSA buildings use pneumatic devices to control their HVAC systems. Informal surveys indicate that the ratio of commercial buildings with pneumatic systems is roughly the same.

B. Technical Objectives

The principal question to be evaluated within this study is, "Does the WPT technology have the ability to implement energy-saving control strategies on an HVAC system that heretofore was controlled solely by a conventional pneumatic control system?"

To test this question, the WPT system will be programmed such that an "occupied-unoccupied" thermostat schedule will be implemented. That is to say, the space temperature will be maintained within normal comfort settings during hours when the building is occupied, but it will be allowed to drift to a point where energy is conserved when the space is unoccupied.

The metric which will answer this question is the ambient temperature inside offices within the selected buildings. Data loggers will be used to keep track of the temperature in 5-minute intervals, 24 hours/day. Before installation of the WPTs, data loggers should show that space temperatures are maintained within a relatively narrow band all day, every day. After the WPT system is installed, space temperatures should show a pattern where they maintain that same narrow temperature band during the day, but at night and on weekends the temperatures swing to a wider point (warmer in summer and cooler in winter) that can be maintained while consuming less energy in the HVAC system.

Figure 1 is an example of what happens to space temperatures when an occupied-unoccupied schedule is in place. The figure shows the summer interior space temperatures of a GSA facility in Phoenix, Arizona. This facility has a DDC system with an aggressive occupied/unoccupied thermostat schedule. During the day, space temperatures are maintained between 75°F and 77°F, but at night conditions are allowed to drive the temperature as high as 84°F. The graph shows 5 weekdays where temperatures are maintained in the close range. Each night, the HVAC system is adjusted so that space temperatures can rise while not requiring much energy from the HVAC system. At around 5:00 a.m. each weekday, the controls system calls for the HVAC system to lower the temperature back to the tighter range so that occupants are comfortable. During the weekend, temperatures are allowed to drift widely before being reset on Monday morning.

If data recorded by the temperature loggers show that the WPT technology demonstrates an ability to exercise this occupied/unoccupied energy-saving schedule, energy modeling will be used to evaluate the potential for saving energy and energy costs at representative GSA facilities in 16 climate zones around the country. Details of this economic analysis are included in Section IV., "Measurement and Verification Evaluation Plan."

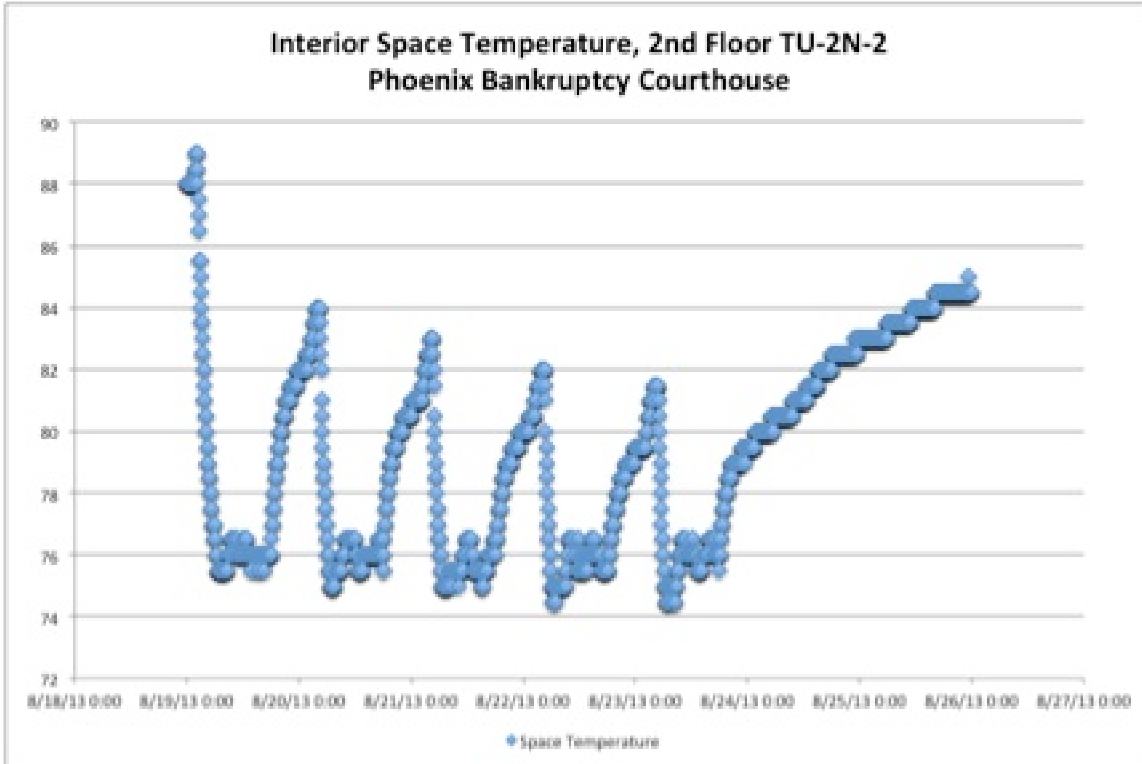


Figure 1. Temperature Fluctuations Under an Occupied/Unoccupied Schedule.

C. Demonstration Project Location

To find an ideal location for evaluating WPT performance, the following criteria were used to screen potential buildings.

- Does the building have well-operating pneumatic controls on its HVAC system?
- Does the building have a variety of offices that are consistent with what is found in most GSA buildings?
- Will the evaluation team have access to the office areas in order to install data loggers to measure trends in space temperatures and humidities?
- Will the evaluation team have access to the air handlers and other mechanical equipment that serve the spaces in question?
- Are there any restrictions that would prohibit using wireless technology within the building? For example, some federal agencies have "secure areas" that impact the use of such technologies in surrounding spaces.

With these criteria, GSA regions around the country were asked to submit candidate facilities for consideration.

IV. Measurement and Verification Evaluation Plan

A. Facility Description

The Woodrow Wilson Center (WWC) was selected as the site to demonstrate the WPT technology. The center is located within the Ronald Reagan Building and International Trade Center in Washington, DC. This demonstration site was selected for several reasons. First, its HVAC system is controlled by a fairly new pneumatic control system that functions well. A system such as this represents the type upon which the WPT technology can be installed to improve performance.

Second, the WWC floor space consists of a variety of office spaces. Within the mix are individual offices, conference rooms, open cubicles, and common areas throughout the space. This type of use is typical of what is found in the majority of facilities controlled by GSA.

Third, the evaluation team had complete access to all areas so that they could take measurements, install data loggers, and freely evaluate how well the WPT performed its tasks. The space at WWC had no secure areas that were off limits to the evaluation team.

The specific areas of the WWC used for the demonstration were Floors 3–8. Each floor has about 15,000 ft^2 of space. The north, east, and south sides of the WWC are exterior walls. The west side leads into another interior space.

The evaluated technology was installed solely as part of the demonstration/evaluation project.

B. Technology Specification

The WPT system consists of three primary components.

The first component is the WPT, which replaces the conventional pneumatic thermostat. This device is installed on the wall of a given HVAC zone, and it connects to the existing pneumatic tubing that previously connected the standard thermostat to the facility's HVAC control system. Included within this component is a means to electronically measure the space temperature, a device which translates this data to a pneumatic signal to interface with existing controls, and a wireless transmitter/receiver to interact with other thermostats and the WPT technology's central controller.

The second component of this system is the central controller. This device interacts with the wireless thermostats mentioned in the previous paragraph and controls their settings. It should be noted that the central controller can operate as a stand-alone device that is not directly integrated with the facility's building automation system. When operating in this stand-alone configuration, it can perform the following energy-saving control strategies.

- Programmable scheduled occupied/unoccupied setpoints
- Temperature setpoint policy enforcement (high/low limits)
- Ongoing commissioning alarm/notification and automatic calibration
- Deadband (heat below and cool above setpoints)

- Zone level automated demand response using OpenADR (i.e., Open Automated Demand Response Communication Standards)
- Zone level precooling and load shifting/peak reduction

The central controller can also be integrated with a facility's building automation system. When operated in this mode, additional energy-saving control strategies can be implemented.

- Optimal start-stop
- Supply air/chilled water temperature reset
- Duct static pressure reset (throttling variable frequency drive fans)
- Central plant level auto-demand response.

The third component of the WPT system is a wireless repeater. These devices are placed throughout the facility to ensure that wireless signals are transmitted reliably between the thermostats and the central controller.

The vendor provided an estimate of installation costs for this system. These estimates are based upon the proposed facility's total floor area.

- Small buildings (<10,000 ft^2): \$0.70–\$1.20/ft^2
- Medium buildings (between 10,000 and 300,000 ft^2): \$0.60–\$1.10/ft^2
- Large buildings (>300,000 ft^2): \$0.50 –\$0.90/ft^2

Several factors can influence whether an installed price is near the higher or lower range of these estimates. The single biggest factor is the density of wireless thermostat devices needed for a facility. If there are a large number of individual offices, each with its own HVAC zone and thermostat, the cost will tend to be higher. On the flip side, in a facility with large open areas served by a single HVAC zone, the cost will tend to be lower.

A secondary factor that influences the price is local labor rates to install the technology.

The third factor is the facility's construction type. If its walls are made of plaster or block, as opposed to conventional drywall, it will take more time and cost more to install each wireless thermostat. Also, a heavier construction type such as concrete will impede the transmission of wireless signals. This will dictate that more wireless repeater devices be installed to be able to transmit the signals reliably.

C. Technology Deployment

The WPT system was deployed on six floors of the WWC.

During the first step of installation, the technology vendor evaluated the building, its six floors, and various areas of each floor to determine the quantity, type, and locations of conventional pneumatic thermostats that would need to be replaced with its wireless device. The vendor also evaluated the building to determine how well wireless signals could be transmitted through various structural elements on each floor. This information, coupled with the thermostat locations, gave the vendor information to determine how many wireless repeaters would be needed and where to locate them.

The second step was to determine where to locate the central controller. This decision is based upon having a location that supports its ability to communicate with the wireless repeaters. Also, the central controller needs to be located appropriately to communicate with the computer or building management system.

The third step was to install the wireless thermostats in place of the existing pneumatic devices. This step took about 30 minutes per thermostat and did not require any special skills beyond those that a trained HVAC technician should possess. This step was followed by installation of the wireless repeaters and the central controller.

Finally, the vendor commissioned the entire WPT system to ensure that all connections were working properly.

Figure 2 shows the locations of the wireless repeaters (in red) on the fifth floor of the WWC. It is representative of locations found on the other five floors which were tested. The central controller was located on the fourth floor near an existing hub to the building management system. Thermostats were located one per zone.

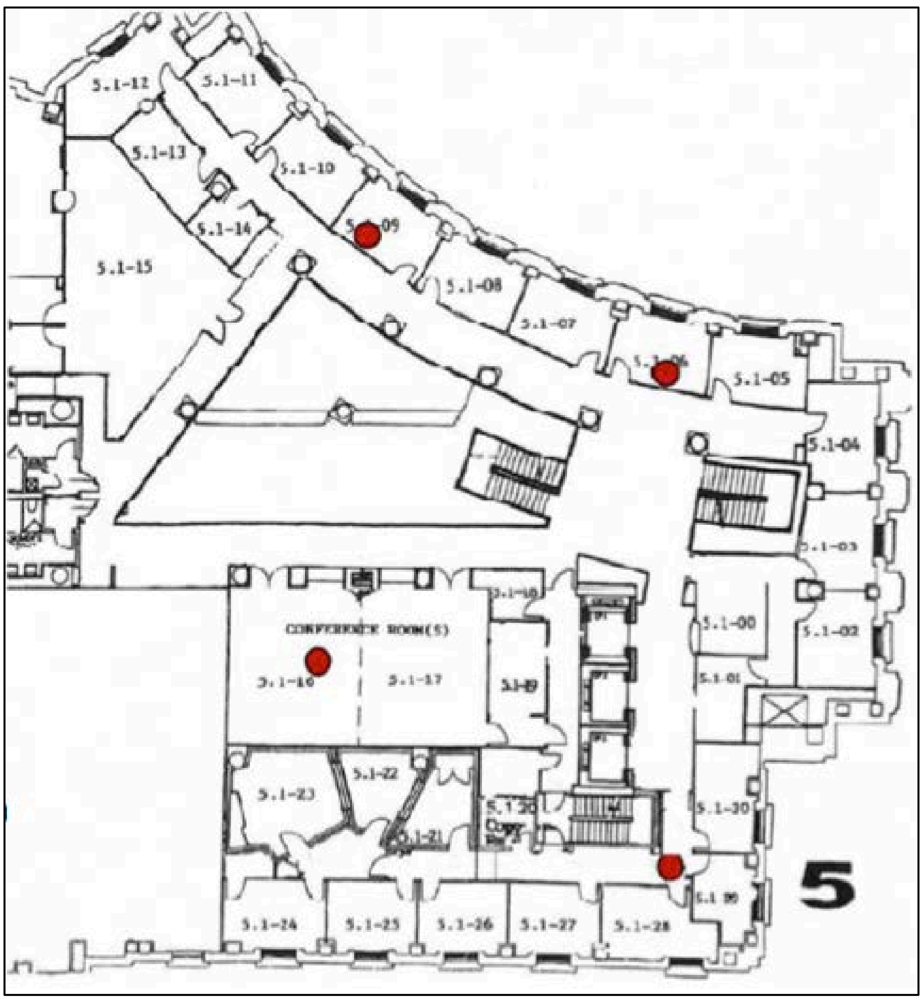


Figure 2. Locations of the Wireless Repeaters (indicated in red) on the Fifth Floor of the Woodrow Wilson Center. (The fifth floor is representative of the other floors.)

D. Test Plan

The evaluation of the WPT technology consisted of two stages, a performance evaluation followed by an economic evaluation. The former would be conducted at the WWC. The latter would be accomplished via computer modeling of energy use and economics.

The performance evaluation's goal was to answer the question, "Does the WPT system have the ability to control the thermostat temperature settings in individual spaces and to operate them using energy-saving control strategies?"

If the central controller could perform this task satisfactorily, then building managers would have a new technology that would allow them to conserve energy without having to replace their entire pneumatic control system.

The plan to conduct the performance evaluation is straightforward. Temperature data loggers would be placed in select spaces at the WWC to record space temperatures in 5-minute intervals. These loggers would record space temperatures during two phases. First, temperatures would be logged when the space was being controlled by the existing pneumatic control system. This data would be graphed and the temperature pattern noted.

Temperature data would be downloaded from the data loggers by GSA personnel and transmitted to Oak Ridge National Laboratory (ORNL) for analysis.

Second, the WPT system would be installed, an occupied/unoccupied schedule would be set by the building's management system, and the building's space temperatures again logged. If the WPT were operating as promised, the loggers would see the space temperatures change during the unoccupied hours to a more energy-conserving setpoint. In the winter, the spaces would be allowed to grow colder. In the summer, spaces would be allowed to grow warmer.

If the WPT passed the performance test and proved that it had the ability to control space temperatures remotely and implement energy-saving control strategies on a pneumatic control system, the economic evaluation would be implemented.

The economic evaluation's goal was to answer the question, "Given the ability to exercise energy-saving control strategies, how much energy could potentially be saved by operating an occupied/unoccupied schedule on typical buildings in the GSA portfolio located in various places around the country?"

To answer this question, ORNL researchers would use the DOE-2 energy modeling software to calculate potential energy savings. Within the program, ORNL would look at three standard models of "typical" office buildings, described in Table 1.

Table 1. Standard Models of Typical Office Buildings (used in energy-savings calculations)

Building Type	Area (ft^2)	Floors	Window to Wall Ratio (%)	Plug Load (W/ft^2)	Lighting (W/ft^2)
Small Office	5,500	1	21	1	1.8
Medium Office	53,630	3	33	1	1.6
Large Office	498,500	12	38	1	1.5

These models were developed by the Pacific Northwest National Laboratory in conjunction with DOE and are widely used as standards when modeling various energy-saving technologies and techniques.

Each of the three models would be evaluated in 16 different cities with their respective climate patterns.

For each combination of building type and city (e.g., a small office located in Houston, Texas), the energy consumption would be modeled using five different thermostat schedules. The baseline would calculate energy consumption if the thermostat settings were set to 69°F heating and 75°F cooling, with no setbacks at night or on weekends.

For comparison, the model would then be run four more times; each time the unoccupied thermostat setting would be changed to a more energy-saving unoccupied setting from 6:00 p.m. to 6:00 a.m. The thermostat setting combinations would be as follows.

- 66°F heating and 79°F cooling
- 62°F heating and 83°F cooling
- 58°F heating and 87°F cooling
- 54°F heating and 91°F cooling

The cooling and heating energy consumption for each unoccupied setting would be compared to the baseline consumption. The savings would be calculated and displayed in both graphical and tabular form for use by GSA building managers considering installation of the WPT technology. (Tables and graphs of results are shown in Appendix B.)

It should be noted that while the modeling effort focused on a straightforward occupied/unoccupied control strategy, the WPT technology is capable of several other strategies that have potential to save more energy than the one modeled. These strategies were discussed earlier in Section IV.B., "Technology Specification."

E. Instrumentation Plan

The instrumentation plan consisted of installing temperature data loggers within the building. The HVAC zones initially selected were high-traffic common areas where most occupants could be expected to spend time during any given day.

The variables being monitored by these loggers were space temperature and relative humidity. The expected range of temperatures measured was between 55°F and 90°F. The expected range of relative humidity was 30%–90% RH.

Note: The initial instrumentation plan called for data loggers to be placed on the air handlers serving the WWC to record data points such as chilled water flow rate, chilled water temperature differences, fan amperage, and the like. The purpose was to try and quantify a change in HVAC energy consumption due to installation of the WPT system. After initial analysis of this, it became apparent that it would be near impossible to isolate what energy changes were due solely to the WPT technology. Therefore, these data were set aside and the study focused on using space temperatures to validate whether the WPT system could actively control thermostat settings and execute energy-saving control strategies.

V. Results

A. Technical Performance Results

Collection of temperature data, without the WPT installed, began in February 2013. From February until May, temperature and humidity data were collected from spaces. As mentioned before, data were also collected from the air handlers serving this area.

In June 2013, the WPT system was installed at the WWC, and data were collected by the loggers during the summer months.

In September 2013 a preliminary data analysis meeting was held among all parties. Figures 3–6 are from that meeting and summarize the data up to that time. A discussion follows the images.

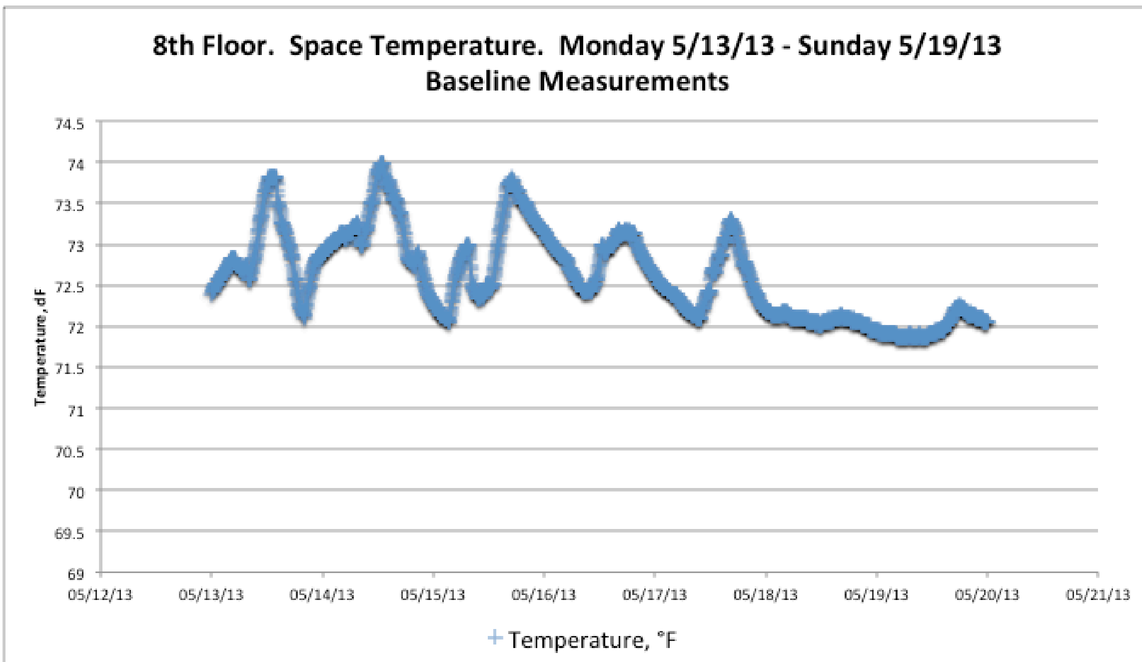


Figure 3. Eighth Floor Baseline (i.e., before wireless pneumatic thermostat installation) Temperature Measurements, May 13 Through May 19, 2013.

The baseline space temperature data (Figure 3) were exactly what was expected. The temperature varied within a narrow band (72°F–74°F). On weekends, the temperature lingered at the low end of this band due to the lack of internal heat sources (people, office equipment, lights) that would be present during weekdays.

The baseline air-handling unit (AHU) supply fan amperage (Figure 4) also showed what was expected. As the space temperatures slowly heated due to occupants entering, office electronics turning on, sunlight entering the windows, and outside air warming, the air handler slowly changed its output to provide appropriate cooling to the space. It's important to emphasize that the air handler output was changing *slowly*. This is due to the fact that the temperature setpoint in the space remained constant, and the heat inputs (occupants, electronics, etc.) were changing slowly.

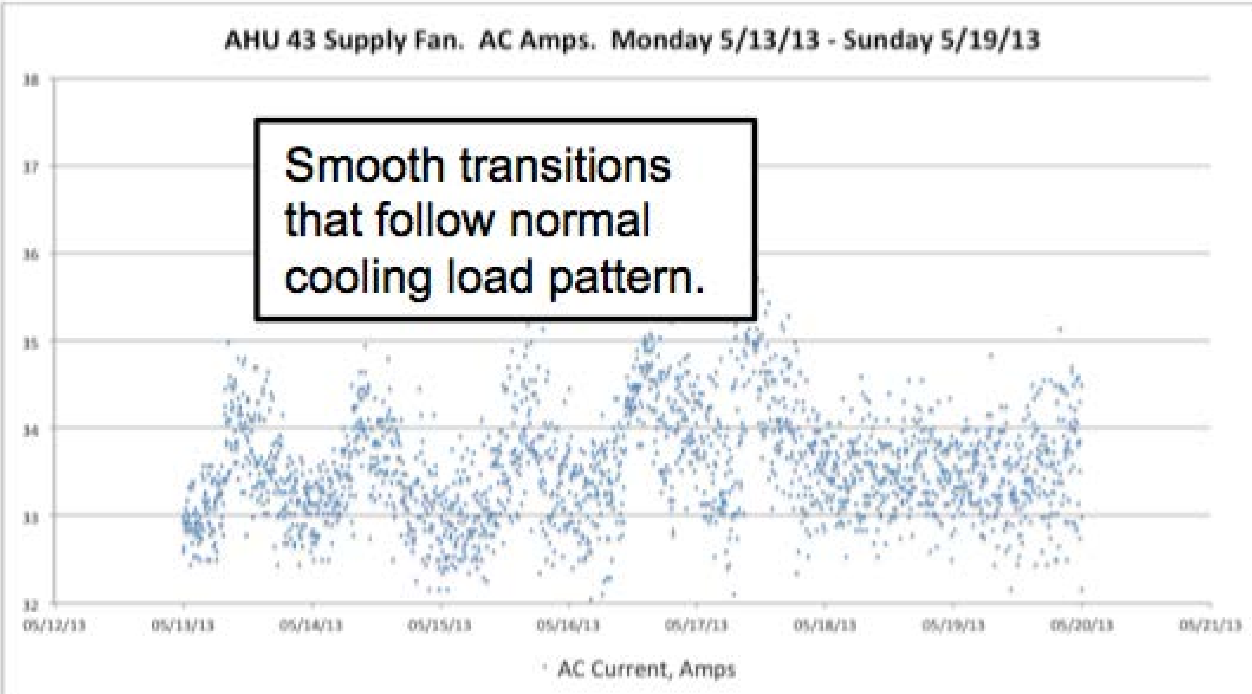


Figure 4. Baseline Air-Handling Unit (AHU) Supply Fan Amperage, May 13 Through May 19, 2013.

After installation of the WPT system, the technology was programmed so that the temperature settings would change based upon the time of day and week when the space was most likely to be occupied. Between 6:00 a.m. and 7:00 p.m., the temperature was controlled between 70°F and 75°F to keep occupants comfortable. However, between 7:00 p.m. and 6:00 a.m., temperatures were allowed to float between 68°F and 80°F, thereby reducing the load on the HVAC system and the amount of energy consumed by it.

The initial set of data collected after installation of the WPT system showed some unusual findings. The first observation came when looking at data from the AHU supply fan amperage (Figure 5). In this graph, the amperage draw showed distinct jumps occurring on a cyclical daily basis. The team looked at all factors that might be causing these rhythmic patterns and what might have changed between the baseline and test periods. The building occupancy and office electronics had stayed the same. Exterior sunlight was coming through windows at a higher angle than during the baseline. However, the sun still rose, moved across the sky, and set in a predictably constant pattern and could not have caused the step changes seen in the air handler power graph. Outside air temperature was warmer during the test period than the baseline period. But as with the sunlight angle, it still changed in a slow pattern and would not have caused what the data were showing.

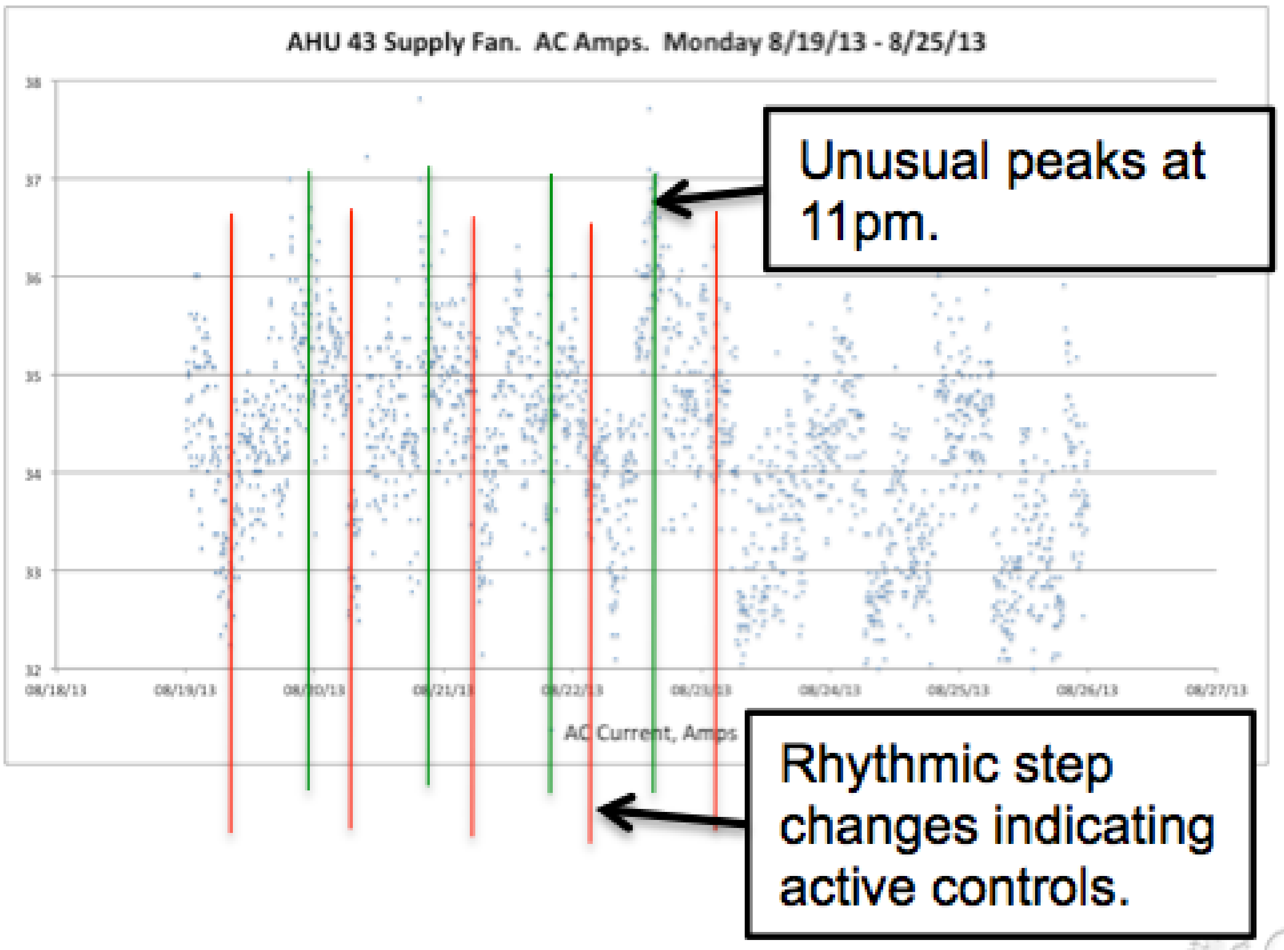


Figure 5. Air-Handling Unit (AHU) Supply Fan Amperage, August 19 Through August 25, 2013 (initial data collected after installation of wireless pneumatic thermostat).

After sorting through variables, it was determined that the only thing that would cause the rhythmic step changes in power draw would be for the space temperature setpoint to be changed on a daily schedule. As part of installing the WPT system, the cooling temperature setpoints in the spaces were set at 75°F during the occupied day period but allowed to drift to 80°F at night. As the setpoint jumped back and forth between the two, the air handler fan would see a sudden change in fan power draw, which is what is reflected in the graph.

This daily pattern of fan amperage change was a clear indication that the WPT system was exercising active control over space temperatures.

However, looking over the space temperature graphs from the data loggers showed that most of the temperature loggers did not show a dramatic pattern of space temperature changes consistent with an occupied/unoccupied schedule. (Figure 6 is typical of the temperature data that were gathered.) The temperatures remained consistent throughout the day, night, and weekends. It was as if the WPT system were not exercising any sort of energy-saving thermostat schedule. These data were puzzling to the research team, especially in light of the air handler fan power readings, which gave clear indication that the thermostats were being adjusted on a daily basis.

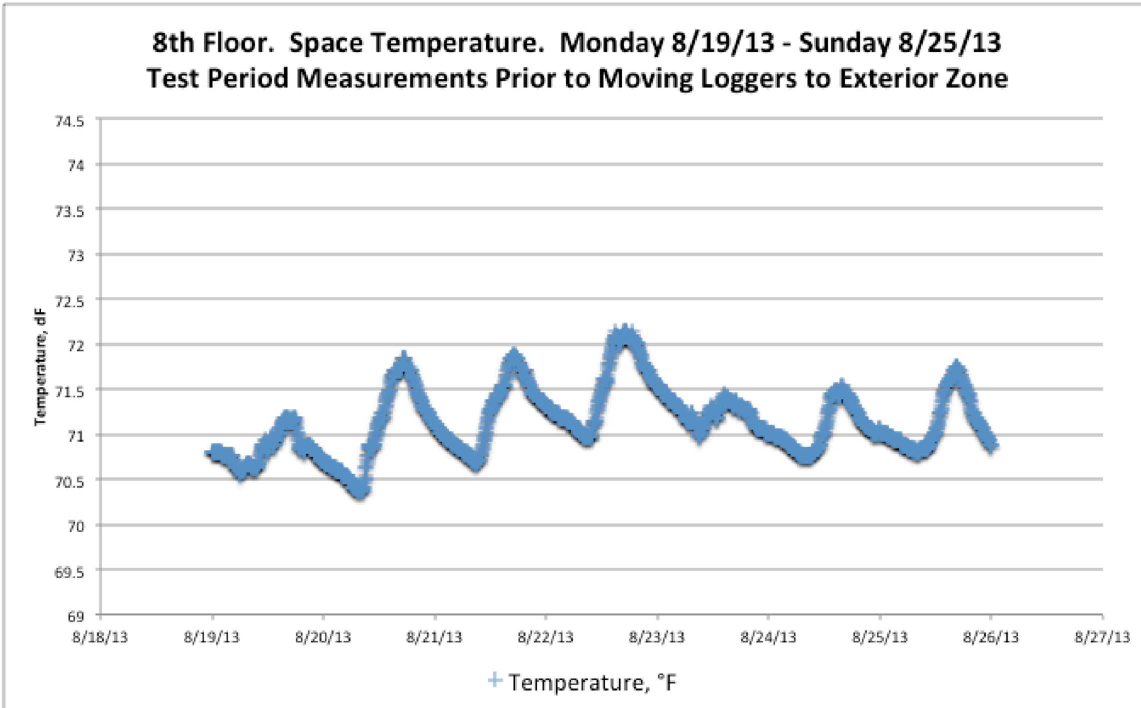


Figure 6. Eighth Floor Temperature Measurements, August 19 Through August 25, 2013 (initial data collected after installation of wireless pneumatic thermostat).

The team explored deeper into this issue and noticed that the temperature loggers that showed this odd trend were all located in areas that were in interior HVAC zones. There were common areas where many people walked and worked during the day, but at night and on weekends they were empty. No electronics were operating. Lights were turned off. No people walking through. In short, there were no heat sources within the space to possibly push the space temperature higher, toward the unoccupied setpoint. Also, WWC is constructed of concrete and steel, which surrounded the interior spaces. This caused these areas to have a high thermal mass, which would further slow down changes in temperature within the spaces.

As part of the technology evaluation, the team wanted tangible evidence that the WPT system was allowing space temperatures to fluctuate on an energy-saving schedule, and these data sets did not provide that evidence. After considering all options, the team decided to move the temperature data loggers to exterior zones and continue measuring temperature. In exterior zones during unoccupied periods, space temperature would still be influenced by the outside air temperature and sunlight coming through the windows. Even when the space had no people or electronics to change the space temperature, there were factors that would cause temperature changes to show up on the data loggers. Also, because the exterior zones had a wall with large glass surfaces instead of being surrounded by concrete and steel, the zones would have less thermal mass, and therefore the temperatures would tend to change more rapidly based upon other heat sources.

The data loggers were moved in October 2013 to exterior zones. October has moderate temperatures in Washington, DC, but data were set to be collected through the winter months. The team reasoned that if the WPT were exercising an occupied/unoccupied schedule, the space temperature at night and on weekends would go lower than during the day. If the WPT system could demonstrate the ability to exercise this energy-saving control strategy during the winter, it would follow logically that it could also execute such a strategy during the summer when space temperatures would go higher when unoccupied.

As fortune would have it, the winter of 2014 was one of the coldest on record in Washington, DC, and gave a perfect opportunity to see whether the WPT system could control space temperatures and exercise the occupied/unoccupied schedule. If it were doing so, exterior space temperature logs would show a clear pattern of comfortable temperatures during the day but cooler space temperatures at night, which reduces the amount of heat energy needed.

Figure 7 shows space temperatures as they were in an eighth floor exterior zone from Friday, December 6, through Wednesday, December 11, 2013. In this figure, one sees that space temperatures declined during the unoccupied weekend such that they were maintained between 70.0°F and 69.5°F. Around 6:00 a.m. Monday, the WPT technology initiated a controls sequence that requested the HVAC system raise the space temperature to its occupied setting. The temperature recorder shows the distinct change in temperature at this time.

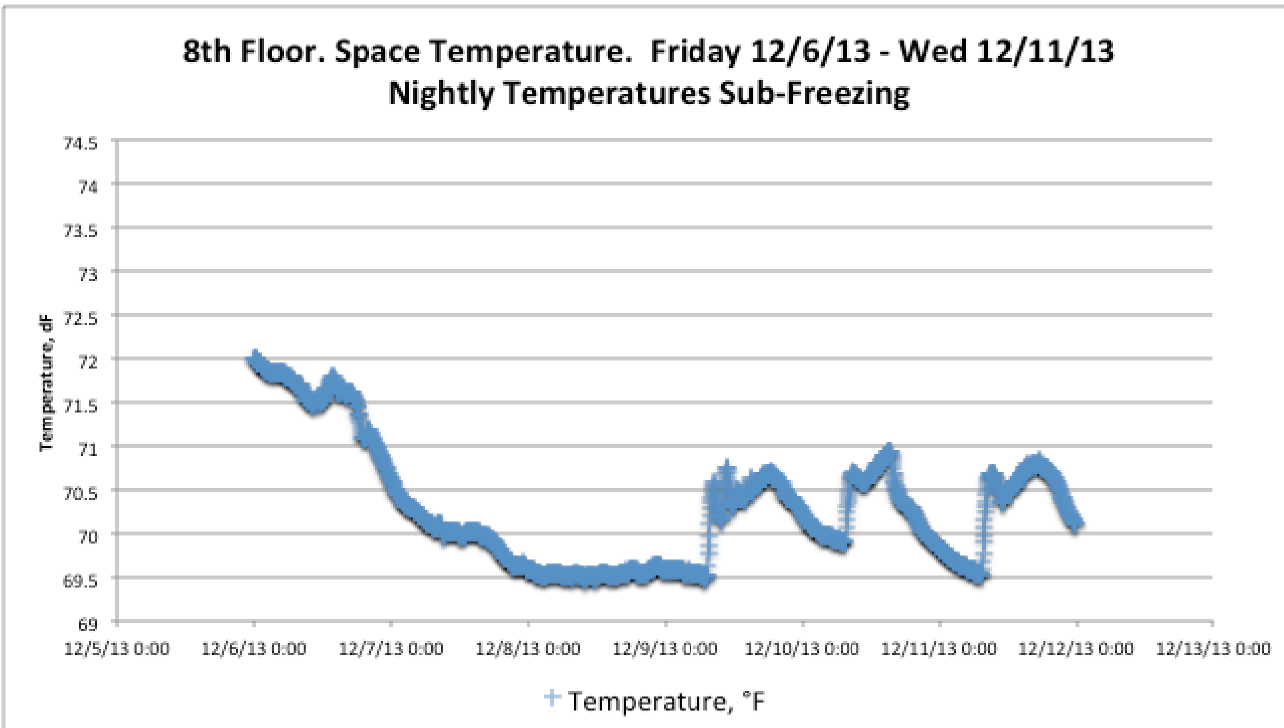


Figure 7. Space Temperatures in an Eighth Floor Exterior Zone from December 6 Through December 11, 2013 (nightly temperatures subfreezing).

During the occupied hours, the temperature stayed consistently at 70.5°F. For the temperature to stay so consistent and not fluctuate within the dead band indicates that there was sufficient heat loss within the room such that the room's HVAC system had to constantly provide heat just to maintain it at this lower point of the thermostat range.

If there had been a large heat source inside the room, such as sunlight through a window, large electronics, or a lot of people, the temperature would have fluctuated more within the occupied temperature dead band and would have risen above 70.5 for parts of the day.

Around 6:00 p.m. on Monday, December 9, the WPT technology initiated a step change that allowed the space temperature to lower toward an unoccupied energy-saving setting. The graph shows a very clear step change where the space temperature begins to lower immediately at that point. The downward slope of that line is more gradual than the dramatic upward jump in the morning. This is due to the fact heat is being lost at a slower rate through the window to cold outside air.

The graph shows space temperature falling until 6:00 a.m., when the WPT technology again calls for a rise in space temperature back to its occupied setting.

This repeated pattern of low temperature during the unoccupied weekend, a steep rise when the HVAC controls switch to occupied mode, followed by stable temperatures during the day, and concluding with a gradual temperature decline of space temperature as it goes back to its unoccupied setpoint is clear indication that the WPT technology is providing active energy saving control sequences on the building's pneumatic HVAC system.

Figure 8 depicts temperatures within the same eighth floor space, except this time it is an entire week of data from a Monday through the following Sunday. The same pattern seen in Figure 7 is repeated here: a very steep rise in temperature each weekday morning as the WPT technology begins an occupied period, a relatively stable daytime temperature, and a gradual decrease in temperature for weekday nights and for the weekend period.

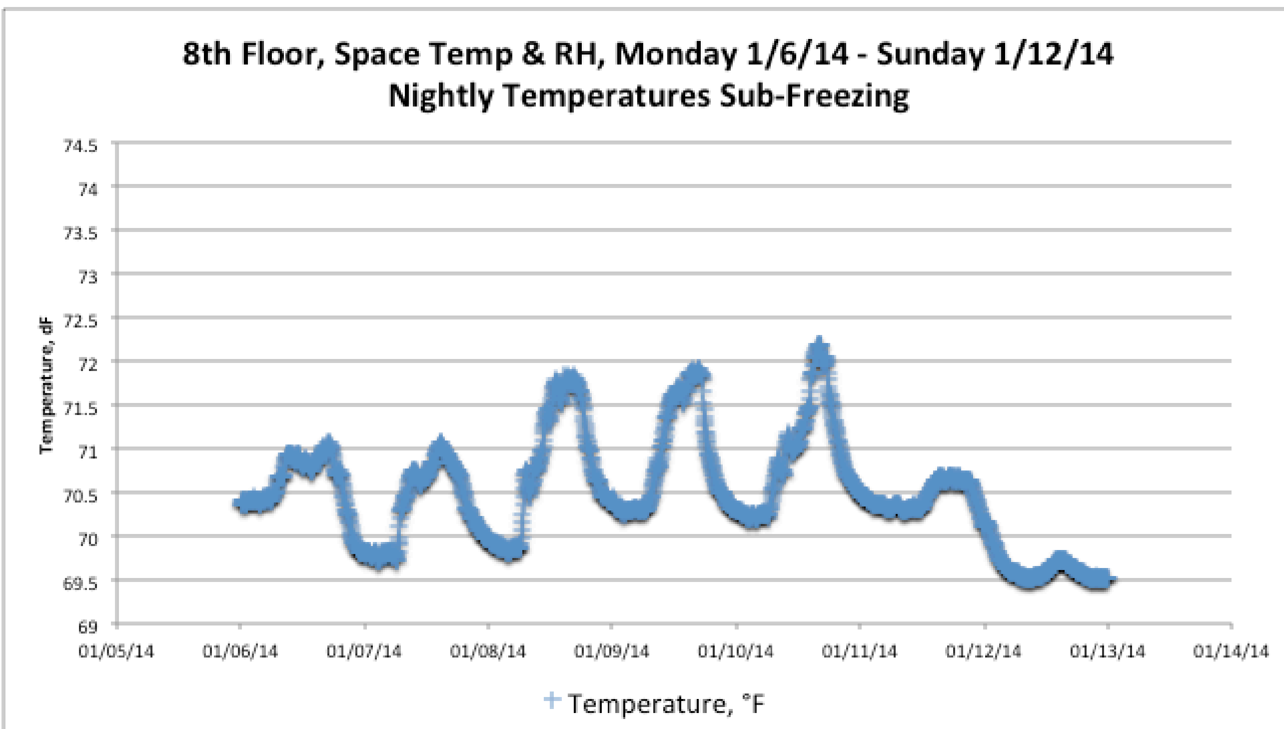


Figure 8. Space Temperatures in an Eighth Floor Exterior Zone from January 6 Through January 12, 2013 (nightly temperatures subfreezing). Note: These data are for the same space depicted in Figure 7 except that it is an entire week of data from Monday through Sunday.

B. Economic Performance Results

With the WPT system's technical performance validated, the team moved forward to determine the economic viability of the technology. Because the goal of Green Proving Ground evaluations is not just to provide a case study at one location but to provide information about a technology's viability at facilities around the country, energy models were used to evaluate the technology's economics in a wide variety of locations.

ORNL researchers used the DOE-2 energy analysis software as the platform to conduct the economic evaluation. Within this platform, they looked at models of three standard building types. These models were developed by Pacific Northwest National Laboratory and are used as a standard in many types of energy comparative analyses. Descriptions of the models are in Table 1.

Figure 9 is a map of the 16 climate zones in which the three building types were modeled.

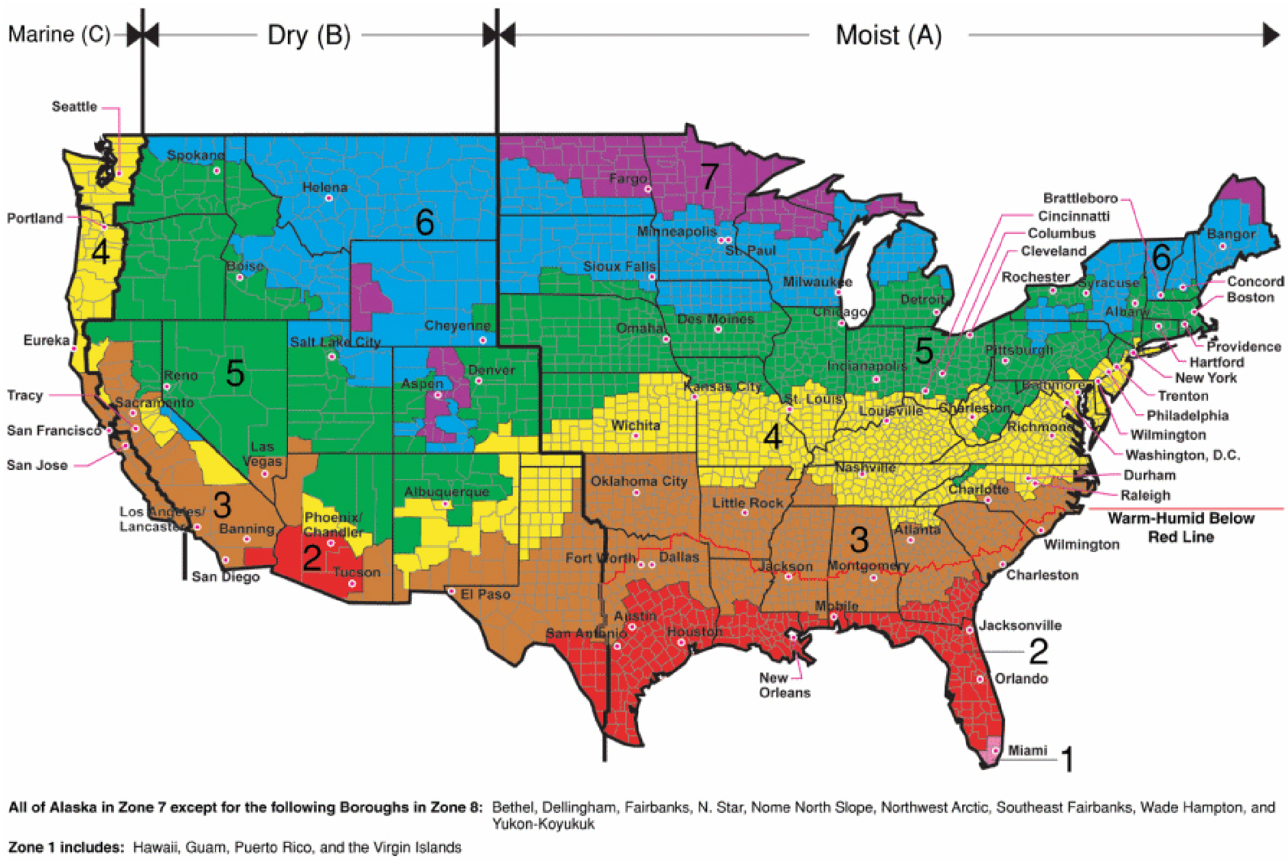


Figure 9. Map of the 16 Climate Zones in Which the Three Building Types Were Modeled.

The details of the energy modeling are given in Section IV.D. of this report, and results of the 48 iterations (three building types in 16 climate zones each) are given in Appendix B. This section will now focus on the economic viability of the technology and how individual site managers throughout the country can use the data to determine whether this technology is appropriate for their sites.

To estimate the cost of installing a WPT system at a site, the vendor provided the following cost data.

- Small office (5,500 ft^2): \$0.70 to \$1.20 per square foot
- Medium office (53,630 ft^2): \$0.60 to \$1.10 per square foot
- Large office: (498,500 ft^2): \$0.50 to \$0.90 per square foot

The cost per square foot range is mainly driven by the density of thermostats in a building. The vendor has seen some buildings with one thermostat for every 250 ft^2 and other buildings with one per 1,000 ft^2. Offices with large open cubicle spaces tend to have lower thermostat density vs. offices with a lot of enclosed rooms. The denser the thermostat count, the higher the cost naturally. The national average is about one thermostat per 900 ft^2, and 80% of the buildings are within ±15% of this density. This density factor accounts for about 80% of the variability in per square foot installed cost.

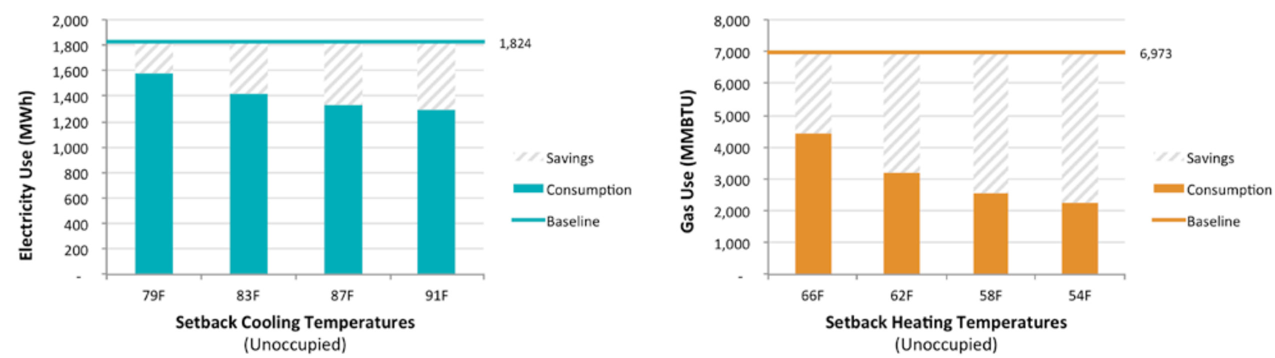
Labor is a secondary factor affecting cost. In some older buildings with concrete walls instead of sheet rock, it takes longer to mount the thermostats and connect the pneumatic tubes while maintaining aesthetics. Also, local labor rates are higher in major cities. Overall, labor accounts for about 20% of the variability in the per square foot cost.

The estimated cost is for a turnkey installation, including all material, software, and labor for a standalone WPT system such as the one at WWC. To get the estimated cost for a turnkey installation, simply multiply the facility's respective square footage by the range of costs per square foot.

- Small office: (5,500 ft^2) × (\$0.70 to \$1.20 per ft^2) = **\$3,850 to \$6,600 installed cost**.
- Medium office: (53,630 ft^2) × (\$0.60 to \$1.10 per ft^2) = **\$32,200 to \$59,000 installed cost.**
- Large office: (498,500 ft^2) × (\$0.50 to \$0.90 per ft^2) = **\$249,000 to \$449,000 installed cost.**

The next step to determine the technology's economic viability at a site is to look at the potential energy savings and the corresponding energy cost savings at a particular site. For demonstration purposes, this section will look at the energy savings calculated by the model for a large office in Atlanta, Georgia. (Results for all facilities and locations are shown in Appendix B.) Figure 10 shows the results for the large office in Atlanta, Georgia.

3A. Atlanta, GA. Large Office.



Annual Electricity Savings (kWh)			
Setback Cooling Temperatures (Unoccupied)	Consumption	Savings	Savings (%)
79F	1,574,040	249,971	13.7%
83F	1,419,507	404,503	22.2%
87F	1,334,799	489,211	26.8%
91F	1,299,216	524,794	28.8%
75F Baseline	1,824,010	-	-

Annual Gas Savings (kBTU)			
Setback Heating Temperatures (Unoccupied)	Consumption	Savings	Savings (%)
66F	4,452,897	2,520,191	36.1%
62F	3,190,650	3,782,439	54.2%
58F	2,535,830	4,437,259	63.6%
54F	2,254,528	4,718,561	67.7%
69F Baseline	6,973,089	-	-

Figure 10. Results of the Energy-Savings Calculations for the Large Office in Atlanta, Georgia.

For this example, look at the energy savings if the unoccupied setpoints were allowed to be 83°F in the cooling season and 62°F in the heating season. The charts show that this facility can expect to save 404,503 kWh in the cooling season and 3,782,000 kBtu during the heating season.

According to the US Energy Information Administration (EIA) Electric Power Monthly online, the average commercial electricity rate in Atlanta is $0.1059/kWh. To determine the energy cost savings during cooling season associated with this technology, simply multiply the energy saved, 404,503 kWh, by the unit cost of electricity, $0.1059/kWh.

- 404,503 kWh × $0.1059/kWh = **$42,800/year in electricity cost savings.**

The same process is used to calculate energy cost saving during the heating season. With a 62°F unoccupied setpoint, the large office in Atlanta can expect to save 3,782,000 kBtu. The latest EIA natural gas price surveys (2014) show the average commercial unit price of natural gas in Atlanta to be $10.77 per thousand cubic feet. One thousand cubic feet of natural gas is equivalent to 1,000 kBtu, giving the gas unit price of $0.01077/kBtu. Using the same process as calculating electricity cost savings, multiply the natural gas amount saved by the unit cost.

- 3,782,000 kBtu × $0.01077/kBtu = **$40,700 in natural gas cost savings.**

Adding the electrical and natural gas annual cost savings gives a total of

- **$42,800 + $40,700 = $83,500 in annual energy savings by using the WPT and implementing an occupied/unoccupied thermostat schedule that allows space temperatures to drift to 83°F in the cooling season and 62°F in the heating season.**

The final step to look at the WPT system's economic viability is to compare the potential cost savings to the cost of installing the technology. In the case of a large office in Atlanta, the installed cost was between $249,000 and $449,000 (refer to installed cost calculations earlier in this section), with annual energy cost savings of $83,500/year.

The most straightforward economic comparison is a technique called "simple payback." It is simply dividing the installed cost of technology by the annual savings per year. The result is the number of years it would take for the technology to pay for itself with cost savings.

For the large office in Atlanta, the calculation would look like this:

- Installed Cost: $249,000 to $449,000
- Annual Energy Cost Savings: $83,500/year
- Simple Payback Period: ($249,000 to $449,000) ÷ ($83,500/year) = 3.0 to 5.4 years

As a general rule, a simple payback period of less than 5 years is considered to be a strong indicator of economic viability. The WPT technology in this situation shows a simple payback that is mostly within that threshold, and it would be a viable option to save energy in this facility based upon energy savings.

These energy cost savings and simple payback calculations were performed on each of the three building types in each of the 16 climate zones. The results are shown in Tables 2–4. It should be noted that as discussed in Section IV.D., these savings are based solely on modeling the energy savings that would result from a simple occupied/unoccupied thermostat schedule. If other control strategies were implemented, which is quite possible with this technology, greater savings would result. The greater energy cost savings would result in even lower simple payback periods.

Table 2. Tabulated Data for Large Office Buildings

Climate Zone	City	Annual Electricity Savings (kWh/year)	Unit Cost of electricity ($/kWh)	Annual Electricity Cost Savings ($/year)	Annual Heat Energy Saved (1,000 Btu/year)	Unit Cost of Natural Gas ($/MCF)	Annual Natural Gas Cost Savings ($/year)	Total Annual Energy Cost Savings ($/year)	Simple Payback Range (years)		
									Low	Mid	High
1A	Miami, FL	615,750	0.10	61,206	651,502	11.99	7,812	69,017	3.6	5.1	6.5
2A	Houston, TX	502,786	0.08	40,625	2,828,689	9.23	26,109	66,734	3.7	5.2	6.7
2B	Phoenix, AZ	235,378	0.11	25,115	2,960,910	9.95	29,461	54,576	4.6	6.4	8.2
3A	Atlanta, GA	404,503	0.11	42,837	3,782,439	10.77	40,737	83,574	3.0	4.2	5.4
3B-coast	Los Angeles, CA	305,511	0.27	51,418	4,158,290	8.90	37,009	88,426	2.8	3.9	5.1
3B	Las Vegas, NV	145,671	0.09	13,722	4,010,482	8.35	33,488	47,210	5.3	7.4	9.5
3C	San Francisco, CA	152,772	0.17	25,712	6,313,901	8.90	56,194	81,905	3.0	4.3	5.5
4A	Baltimore, MD	332,204	0.11	37,207	4,359,986	12.05	52,538	89,745	2.8	3.9	5.0
4B	Albuquerque, NM	116,220	0.11	12,656	4,137,753	8.12	33,599	46,255	5.4	7.5	9.7
4C	Seattle, WA	125,012	0.08	9,538	6,625,027	8.97	59,426	68,965	3.6	5.1	6.5
5A	Chicago, IL	170,974	0.09	15,131	4,924,071	13.07	64,358	79,489	3.1	4.4	5.6
5B	Boulder, CO	93,652	0.11	10,452	4,569,352	8.72	39,845	50,296	5.0	6.9	8.9
6A	Minneapolis, MN	160,618	0.10	16,512	4,567,715	8.20	37,455	53,967	4.6	6.5	8.3
6B	Helena, MT	81,368	0.01	7,811	5,085,454	10.86	55,228	63,039	3.9	5.5	7.1
7	Duluth, MN	88,482	0.10	9,076	5,875,484	8.20	48,179	57,255	4.3	6.1	7.8
8	Fairbanks, AK	73,889	0.18	13,130	6,920,554	6.68	46,229	59,359	4.2	5.9	7.6

Table 3. Tabulated Data for Medium Office Buildings

Climate Zone	City	Annual Electricity Savings (kWh/year)	Unit Cost of electricity ($/kWh)	Annual Electricity Cost Savings ($/year)	Annual Heat Energy Saved (1,000 Btu/year)	Unit Cost of Natural Gas ($/MCF)	Annual Natural Gas Cost Savings ($/year)	Total Annual Energy Cost Savings ($/year)	Simple Payback Range (years)		
									Low	Mid	High
1A	Miami, FL	73,391	0.10	7,295	118,271	11.99	1,418	8,713	3.7	5.2	6.8
2A	Houston, TX	54,318	0.08	4,389	305,767	9.23	2,822	7,211	4.5	6.3	8.2
2B	Phoenix, AZ	41,878	0.11	4,468	363,045	9.95	3,612	8,081	4.0	5.6	7.3
3A	Atlanta, GA	44,438	0.11	4,706	422,769	10.77	4,553	9,259	3.5	4.9	6.4
3B-coast	Los Angeles, CA	24,761	0.17	4,167	512,587	8.90	4,562	8,729	3.7	5.2	6.8
3B	Las Vegas, NV	27,783	0.09	2,617	457,809	8.35	3,823	6,440	5.0	7.1	9.2
3C	San Francisco, CA	13,324	0.17	2,242	695,133	8.90	6,187	8,429	3.8	5.4	7.0
4A	Baltimore, MD	35,813	0.11	4,011	483,341	12.05	5,824	9,835	3.3	4.6	6.0
4B	Albuquerque, NM	15,656	0.11	1,705	455,525	8.12	3,699	5,404	6.0	8.4	10.9
4C	Seattle, WA	10,314	0.08	787	716,035	8.97	6,423	7,210	4.5	6.3	8.2
5A	Chicago, IL	14,201	0.09	1,257	551,537	13.07	7,209	8,465	3.8	5.4	7.0
5B	Boulder, CO	10,778	0.11	1,203	507,275	8.72	4,423	5,626	5.7	8.1	10.5
6A	Minneapolis, MN	13,649	0.10	1,403	516,123	8.20	4,232	5,635	5.7	8.1	10.5
6B	Helena, MT	8,660	0.10	831	572,151	10.86	6,214	7,045	4.6	6.5	8.4
7	Duluth, MN	7,695	0.10	789	648,993	8.20	5,322	6,111	5.3	7.5	9.7
8	Fairbanks, AK	6,884	0.18	1,223	745,442	6.68	4,980	6,203	5.2	7.3	9.5

Table 4. Tabulated Data for Small Office Buildings

Climate Zone	City	Annual Electricity Savings (kWh/year)	Unit Cost of electricity ($/kWh)	Annual Electricity Cost Savings ($/year)	Annual Heat Energy Saved (1,000 Btu/year)	Unit Cost of Natural Gas ($/MCF)	Annual Natural Gas Cost Savings ($/year)	Total Annual Energy Cost Savings ($/year)	Simple Payback Range (years)		
									Low	Mid	High
1A	Miami, FL	20,014	0.10	1,989	374	11.99	4	1,994	1.9	**2.6**	3.3
2A	Houston, TX	13,645	0.08	1,103	23,653	9.23	218	1,321	2.9	**4.0**	5.0
2B	Phoenix, AZ	12,769	0.11	1,362	16,683	9.95	166	1,528	2.5	**3.4**	4.3
3A	Atlanta, GA	9,661	0.11	1,023	41,961	10.77	452	1,475	2.6	**3.5**	4.5
3B-coast	Los Angeles, CA	5,368	0.17	903	15,577	8.90	139	1,042	3.7	**5.0**	6.3
3B	Las Vegas, NV	10,091	0.09	951	33,884	8.35	283	1,234	3.1	**4.2**	5.4
3C	San Francisco, CA	4,448	0.17	749	50,690	8.90	451	1,200	3.2	**4.4**	5.5
4A	Baltimore, MD	6,098	0.11	683	60,704	12.05	731	1,414	2.7	**3.7**	4.7
4B	Albuquerque, NM	6,599	0.11	719	48,446	8.12	393	1,112	3.5	**4.7**	5.9
4C	Seattle, WA	3,839	0.08	293	66,823	8.97	599	892	4.3	**5.9**	7.4
5A	Chicago, IL	4,828	0.09	427	72,223	13.07	944	1,371	2.8	**3.8**	4.8
5B	Boulder, CO	4,672	0.11	521	58,412	8.72	509	1,031	3.7	**5.1**	6.4
6A	Minneapolis, MN	4,391	0.10	451	72,946	8.20	598	1,050	3.7	**5.0**	6.3
6B	Helena, MT	4,311	0.10	414	68,815	10.86	747	1,161	3.3	**4.5**	5.7
7	Duluth, MN	3,235	0.10	332	86,390	8.20	708	1,040	3.7	**5.0**	6.3
8	Fairbanks, AK	3,069	0.18	545	106,190	6.68	709	1,255	3.1	**4.2**	5.3

Another operating cost associated with any technology is the cost to maintain that technology. Looking at maintenance required by the existing conventional pneumatic thermostats and the new WPT system, there was no indication that there is any difference in maintenance required by either system. They both are robust and reliable.

VI. Summary Findings and Conclusions

A. Overall Technology Assessment at Demonstration Facility

The WPT technology proved itself capable of implementing energy-saving control strategies at facilities that are currently controlled by pneumatic control systems. The technology passed the performance test conducted in this evaluation.

It also shows indications that it would be economically viable in a wide variety of facilities around the country. Individual circumstances will have to be evaluated for each site that is considering this technology.

This technology should be recommended for implementation at facilities that currently are using conventional pneumatic control systems on their HVAC systems.

B. Best Practice

The WPT technology should be considered a best practice for facilities that currently use conventional pneumatic control systems with their HVAC systems. It represents an economically viable technology that can reduce HVAC energy consumption. This will result in lower energy costs and lower greenhouse gas emissions for the respective facilities.

Also, a best practice before installing the WPT technology would be to perform preinstallation tests to determine how well wireless signals can be transmitted through the building. Different construction types can interfere with signal transmission.

C. Barriers and Enablers to Adoption

There are no market barriers that would prevent the adoption of this technology. Based on this evaluation, it provides a valuable service by enabling energy-saving HVAC control strategies to be implemented on buildings that already have a properly functioning pneumatic system.

D. Recommendations for Installation, Commissioning, Training, and Change Management

This technology should have a useful service life of more than 10 years. This estimate is based upon the nature of the components used to manufacture the system and their historic service lives.

As with any new technology, a certain level of training would be required for facility operators to learn how to manage the technology. The vendor offers a training class that lasts 1 day.

VII. Appendices

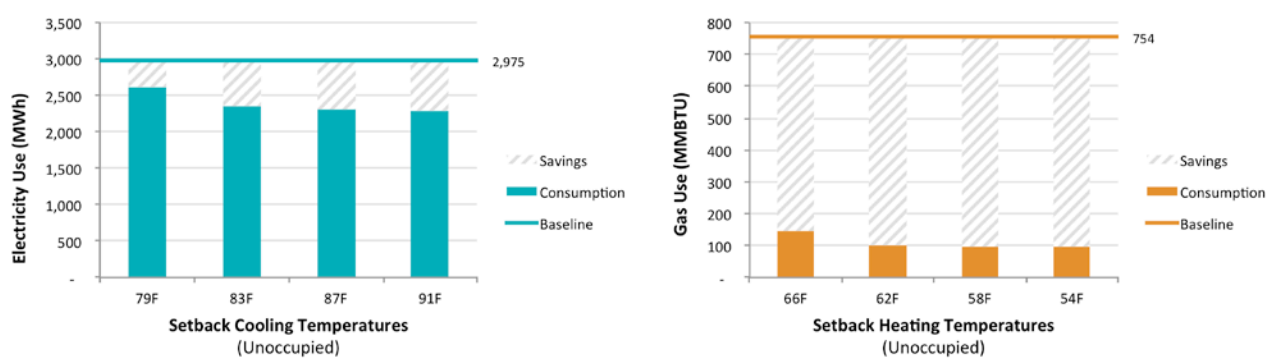
A. Detailed Technology Specification

Wherever possible, describe technology in terms of generic performance criteria, and refrain from providing vendor-specific images and proprietary data.

B. Research Details

This appendix has summary graphs that show the energy-saving results for each of the three modeled buildings (large office, medium office, and small office) within each of the 16 cities. Data from these graphs and tables can be used to estimate energy savings in the same fashion that was described in Section V.B., "Economic Performance Results."

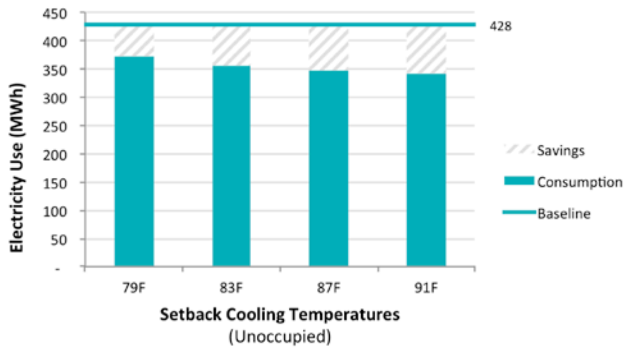
1A. Miami, FL. Large Office.

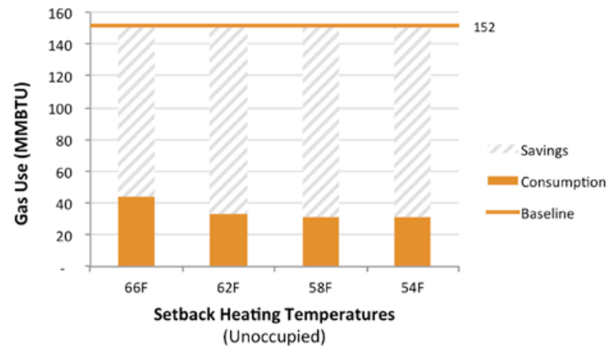


Annual Electricity Savings (kWh)			
Setback Cooling Temperatures (Unoccupied)	Consumption	Savings	Savings (%)
79F	2,602,717	371,809	12.5%
83F	2,358,775	615,750	20.7%
87F	2,302,939	671,586	22.6%
91F	2,278,111	696,414	23.4%
75F Baseline	2,974,525	-	-

Annual Gas Savings (kBTU)			
Setback Heating Temperatures (Unoccupied)	Consumption	Savings	Savings (%)
66F	147,815	605,929	80.4%
62F	102,242	651,502	86.4%
58F	97,699	656,045	87.0%
54F	96,891	656,854	87.1%
69F Baseline	753,744	-	-

1A. Miami, FL. Medium Office.

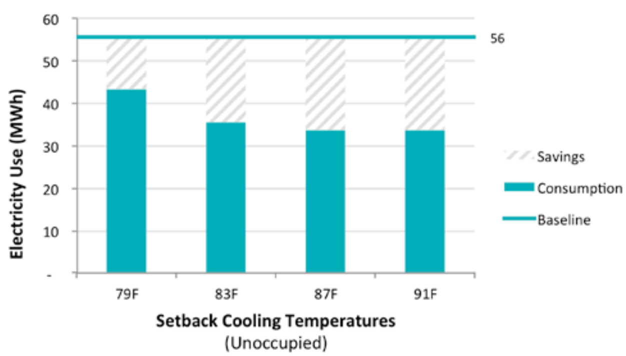


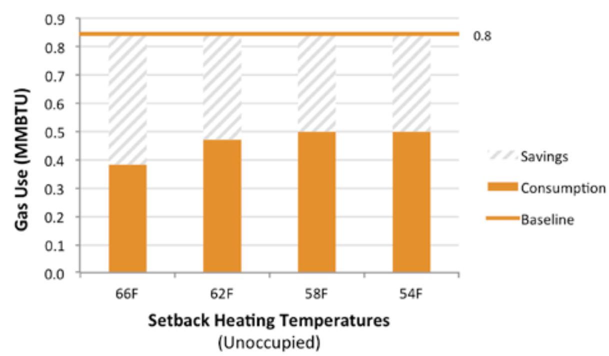


Annual Electricity Savings (kWh)			
Setback Cooling Temperatures (Unoccupied)	Consumption	Savings	Savings (%)
79F	373,334	54,763	12.8%
83F	354,707	73,391	17.1%
87F	347,476	80,622	18.8%
91F	341,931	86,167	20.1%
75F Baseline	428,098	-	-

Annual Gas Savings (kBTU)			
Setback Heating Temperatures (Unoccupied)	Consumption	Savings	Savings (%)
66F	43,589	107,963	71.2%
62F	33,281	118,271	78.0%
58F	31,463	120,089	79.2%
54F	30,963	120,589	79.6%
69F Baseline	151,552	-	-

1A. Miami, FL. Small Office.

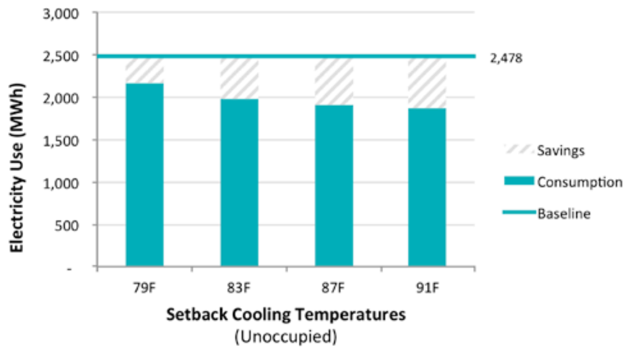


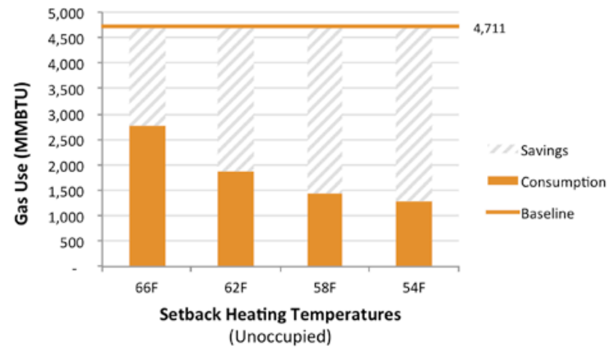


Annual Electricity Savings (kWh)			
Setback Cooling Temperatures (Unoccupied)	Consumption	Savings	Savings (%)
79F	43,245	12,287	22.1%
83F	35,518	20,014	36.0%
87F	33,604	21,928	39.5%
91F	33,506	22,026	39.7%
75F Baseline	55,532	-	-

Annual Gas Savings (kBTU)			
Setback Heating Temperatures (Unoccupied)	Consumption	Savings	Savings (%)
66F	382	460	54.7%
62F	469	374	44.3%
58F	498	344	40.8%
54F	499	343	40.7%
69F Baseline	842	-	-

2A. Houston, TX. Large Office.

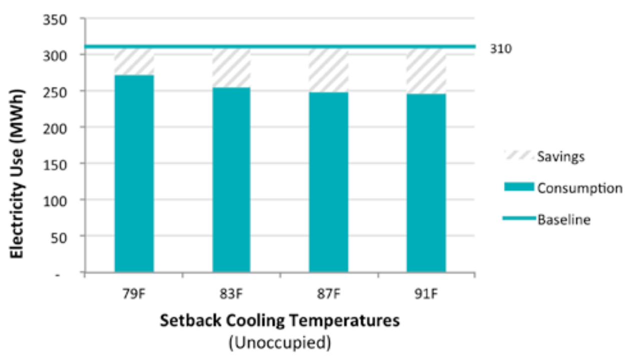


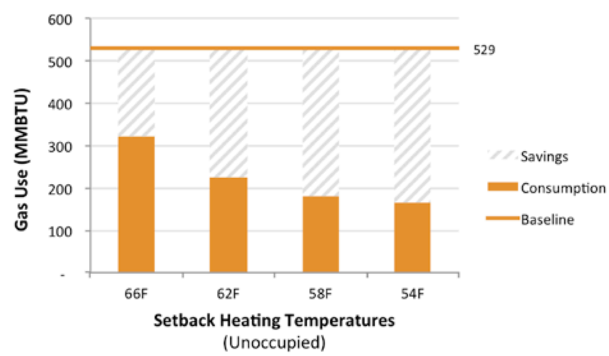


Annual Electricity Savings (kWh)			
Setback Cooling Temperatures (Unoccupied)	Consumption	Savings	Savings (%)
79F	2,172,267	305,890	12.3%
83F	1,975,371	502,786	20.3%
87F	1,895,749	582,408	23.5%
91F	1,859,672	618,485	25.0%
75F Baseline	2,478,157	-	-

Annual Gas Savings (kBTU)			
Setback Heating Temperatures (Unoccupied)	Consumption	Savings	Savings (%)
66F	2,764,461	1,946,796	41.3%
62F	1,882,568	2,828,689	60.0%
58F	1,435,155	3,276,102	69.5%
54F	1,276,578	3,434,679	72.9%
69F Baseline	4,711,257	-	-

2A. Houston, TX. Medium Office.

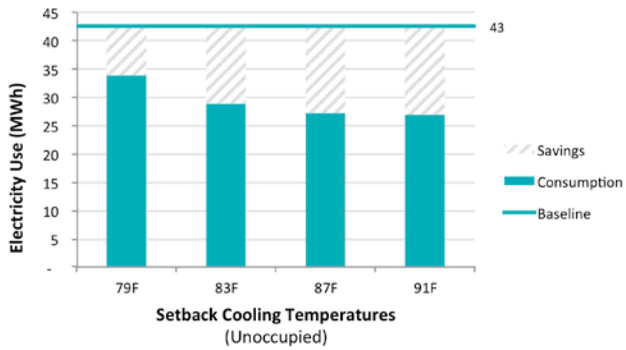


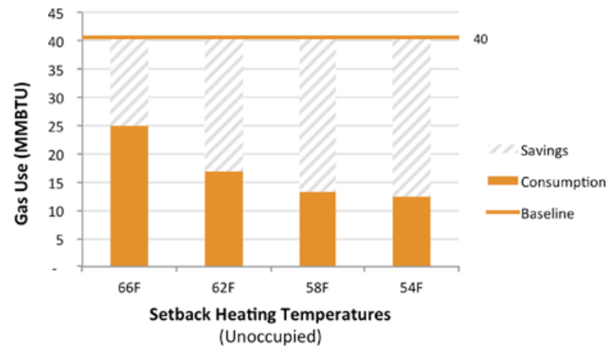


Annual Electricity Savings (kWh)			
Setback Cooling Temperatures (Unoccupied)	Consumption	Savings	Savings (%)
79F	272,037	37,888	12.2%
83F	255,608	54,318	17.5%
87F	248,651	61,275	19.8%
91F	245,770	64,156	20.7%
75F Baseline	309,926	-	-

Annual Gas Savings (kBTU)			
Setback Heating Temperatures (Unoccupied)	Consumption	Savings	Savings (%)
66F	322,220	206,881	39.1%
62F	223,333	305,767	57.8%
58F	178,530	350,571	66.3%
54F	163,927	365,174	69.0%
69F Baseline	529,101	-	-

2A. Houston, TX. Small Office.

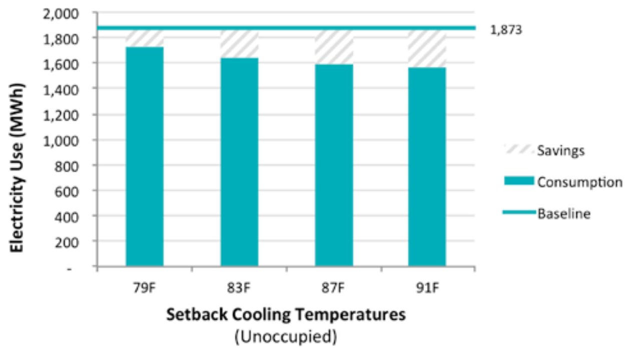


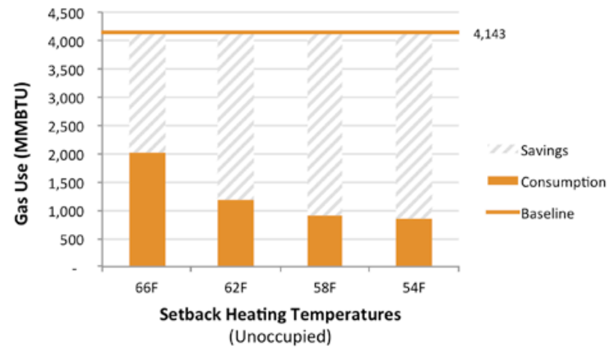


Annual Electricity Savings (kWh)			
Setback Cooling Temperatures (Unoccupied)	Consumption	Savings	Savings (%)
79F	33,986	8,537	20.1%
83F	28,878	13,645	32.1%
87F	27,224	15,299	36.0%
91F	26,919	15,604	36.7%
75F Baseline	42,523	-	-

Annual Gas Savings (kBTU)			
Setback Heating Temperatures (Unoccupied)	Consumption	Savings	Savings (%)
66F	25,012	15,488	38.2%
62F	16,847	23,653	58.4%
58F	13,279	27,221	67.2%
54F	12,314	28,186	69.6%
69F Baseline	40,500	-	-

2B. Phoenix, AZ. Large Office.

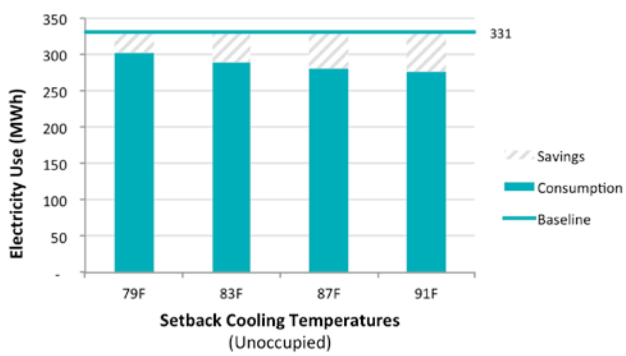


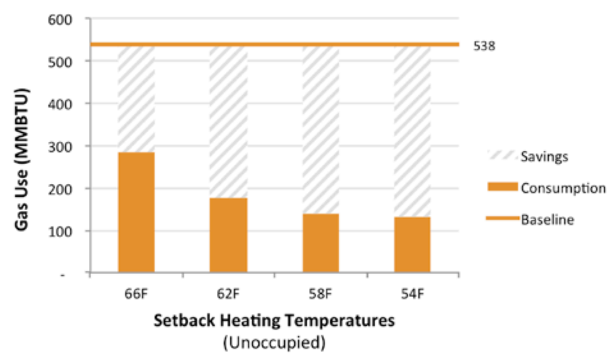


Annual Electricity Savings (kWh)			
Setback Cooling Temperatures (Unoccupied)	Consumption	Savings	Savings (%)
79F	1,726,065	147,048	7.9%
83F	1,637,734	235,378	12.6%
87F	1,591,963	281,149	15.0%
91F	1,567,789	305,323	16.3%
75F Baseline	1,873,112	-	-

Annual Gas Savings (kBTU)			
Setback Heating Temperatures (Unoccupied)	Consumption	Savings	Savings (%)
66F	2,017,952	2,124,607	51.3%
62F	1,181,650	2,960,910	71.5%
58F	901,083	3,241,476	78.2%
54F	852,822	3,289,737	79.4%
69F Baseline	4,142,559	-	-

2B. Phoenix, AZ. Medium Office.

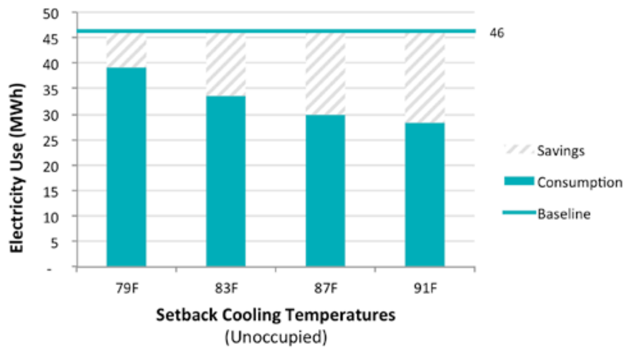


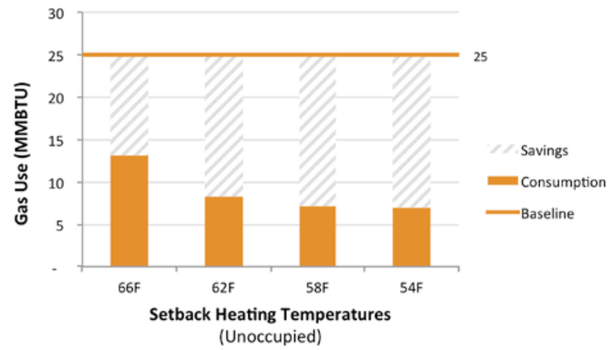


Annual Electricity Savings (kWh)			
Setback Cooling Temperatures (Unoccupied)	Consumption	Savings	Savings (%)
79F	302,587	28,177	8.5%
83F	288,886	41,878	12.7%
87F	281,443	49,321	14.9%
91F	277,202	53,561	16.2%
75F Baseline	330,763	-	-

Annual Gas Savings (kBTU)			
Setback Heating Temperatures (Unoccupied)	Consumption	Savings	Savings (%)
66F	283,704	254,337	47.3%
62F	174,996	363,045	67.5%
58F	139,807	398,234	74.0%
54F	133,461	404,579	75.2%
69F Baseline	538,041	-	-

2B. Phoenix, AZ. Small Office.

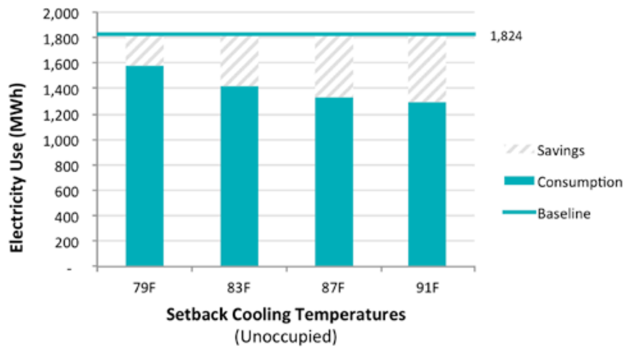


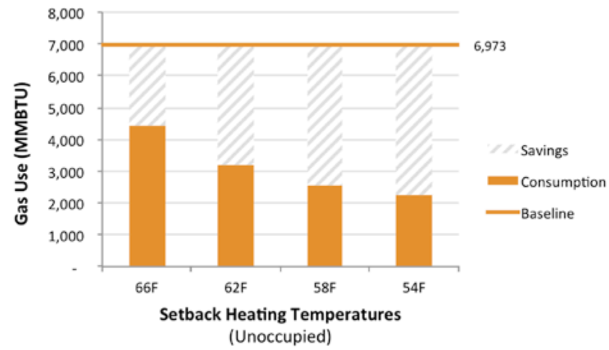


Annual Electricity Savings (kWh)			
Setback Cooling Temperatures (Unoccupied)	Consumption	Savings	Savings (%)
79F	39,087	7,124	15.4%
83F	33,442	12,769	27.6%
87F	29,785	16,426	35.5%
91F	28,380	17,831	38.6%
75F Baseline	46,211	-	-

Annual Gas Savings (kBTU)			
Setback Heating Temperatures (Unoccupied)	Consumption	Savings	Savings (%)
66F	13,088	11,833	47.5%
62F	8,238	16,683	66.9%
58F	7,125	17,796	71.4%
54F	7,007	17,914	71.9%
69F Baseline	24,921	-	-

3A. Atlanta, GA. Large Office.

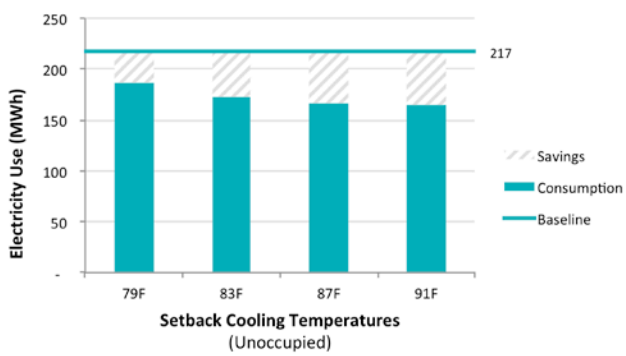


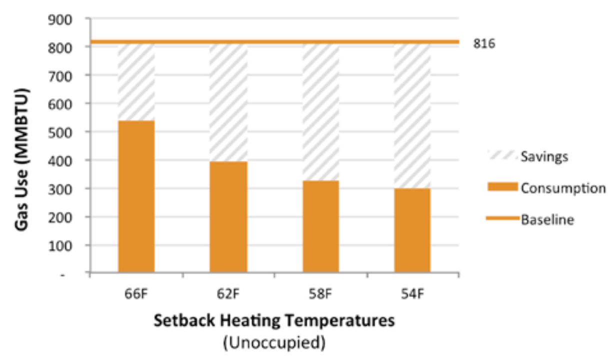


Annual Electricity Savings (kWh)			
Setback Cooling Temperatures (Unoccupied)	Consumption	Savings	Savings (%)
79F	1,574,040	249,971	13.7%
83F	1,419,507	404,503	22.2%
87F	1,334,799	489,211	26.8%
91F	1,299,216	524,794	28.8%
75F Baseline	1,824,010	-	-

Annual Gas Savings (kBTU)			
Setback Heating Temperatures (Unoccupied)	Consumption	Savings	Savings (%)
66F	4,452,897	2,520,191	36.1%
62F	3,190,650	3,782,439	54.2%
58F	2,535,830	4,437,259	63.6%
54F	2,254,528	4,718,561	67.7%
69F Baseline	6,973,089	-	-

3A. Atlanta, GA. Medium Office.

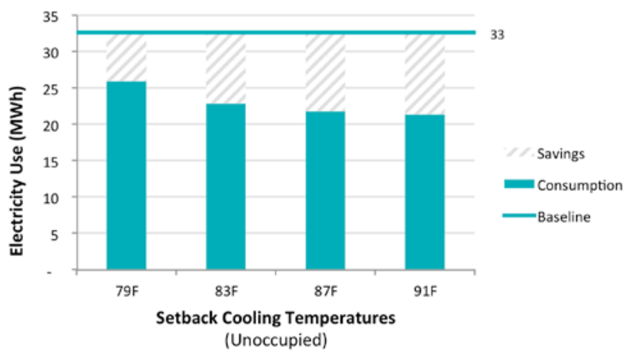


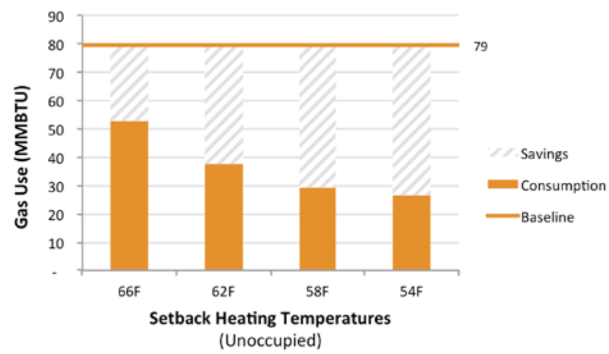


Annual Electricity Savings (kWh)			
Setback Cooling Temperatures (Unoccupied)	Consumption	Savings	Savings (%)
79F	186,124	30,725	14.2%
83F	172,411	44,438	20.5%
87F	166,181	50,668	23.4%
91F	164,102	52,747	24.3%
75F Baseline	216,849	-	-

Annual Gas Savings (kBTU)			
Setback Heating Temperatures (Unoccupied)	Consumption	Savings	Savings (%)
66F	538,569	276,957	34.0%
62F	392,757	422,769	51.8%
58F	323,643	491,883	60.3%
54F	296,888	518,638	63.6%
69F Baseline	815,526	-	-

3A. Atlanta, GA. Small Office.

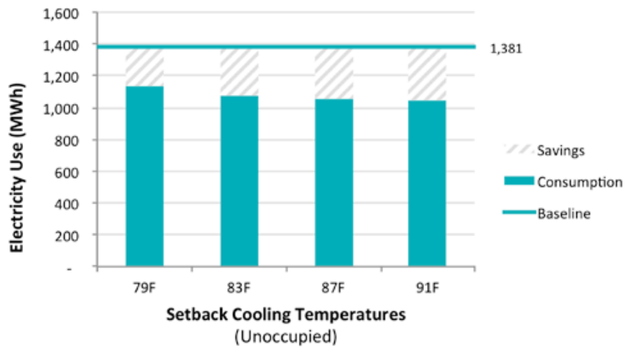


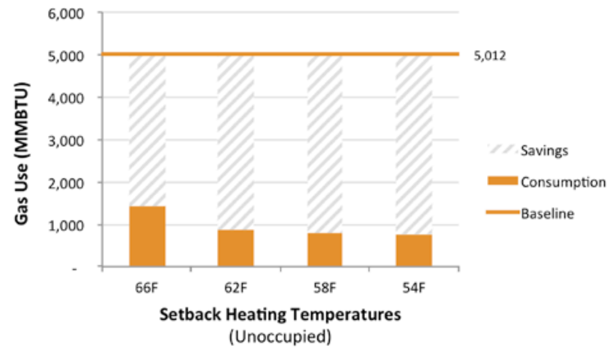


Annual Electricity Savings (kWh)			
Setback Cooling Temperatures (Unoccupied)	Consumption	Savings	Savings (%)
79F	26,002	6,522	20.1%
83F	22,862	9,661	29.7%
87F	21,756	10,768	33.1%
91F	21,377	11,146	34.3%
75F Baseline	32,524	-	-

Annual Gas Savings (kBTU)			
Setback Heating Temperatures (Unoccupied)	Consumption	Savings	Savings (%)
66F	52,833	26,633	33.5%
62F	37,505	41,961	52.8%
58F	29,395	50,072	63.0%
54F	26,234	53,233	67.0%
69F Baseline	79,467	-	-

3B-Coast. Los Angeles, CA. Large Office.

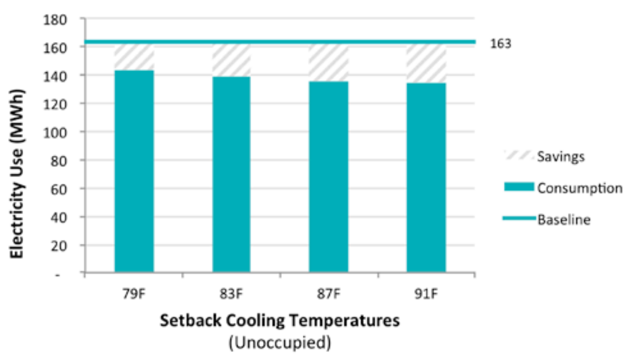


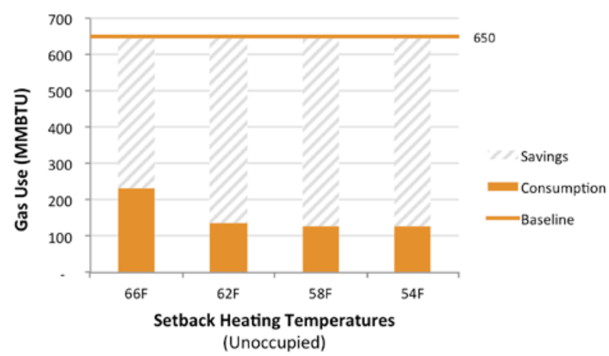


Annual Electricity Savings (kWh)			
Setback Cooling Temperatures (Unoccupied)	Consumption	Savings	Savings (%)
79F	1,129,388	251,495	18.2%
83F	1,075,372	305,511	22.1%
87F	1,053,633	327,250	23.7%
91F	1,042,857	338,026	24.5%
75F Baseline	1,380,883	-	-

Annual Gas Savings (kBTU)			
Setback Heating Temperatures (Unoccupied)	Consumption	Savings	Savings (%)
66F	1,446,609	3,565,657	71.1%
62F	853,977	4,158,290	83.0%
58F	781,733	4,230,534	84.4%
54F	772,957	4,239,310	84.6%
69F Baseline	5,012,267	-	-

3B-Coast. Los Angeles, CA. Medium Office.

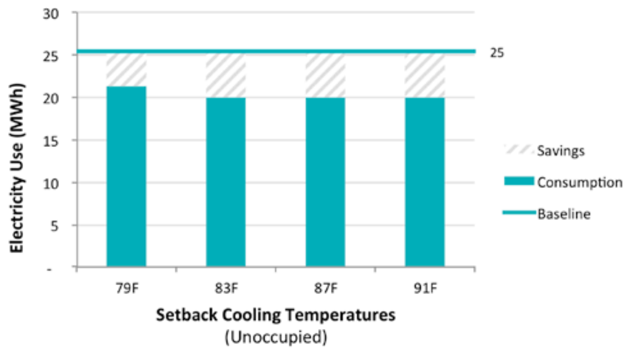


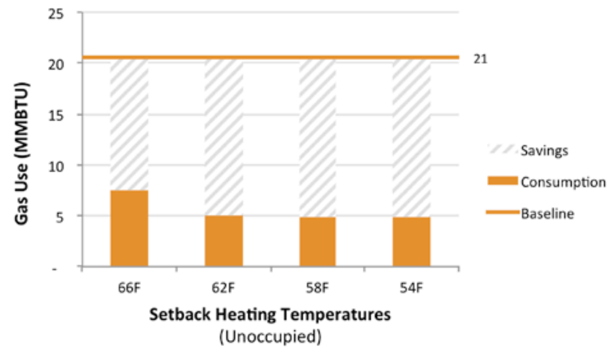


Annual Electricity Savings (kWh)			
Setback Cooling Temperatures (Unoccupied)	Consumption	Savings	Savings (%)
79F	143,241	19,949	12.2%
83F	138,430	24,761	15.2%
87F	135,888	27,303	16.7%
91F	134,712	28,479	17.5%
75F Baseline	163,191	-	-

Annual Gas Savings (kBTU)			
Setback Heating Temperatures (Unoccupied)	Consumption	Savings	Savings (%)
66F	230,223	419,318	64.6%
62F	136,954	512,587	78.9%
58F	127,348	522,193	80.4%
54F	126,503	523,038	80.5%
69F Baseline	649,541	-	-

3B-Coast. Los Angeles, CA. Small Office.

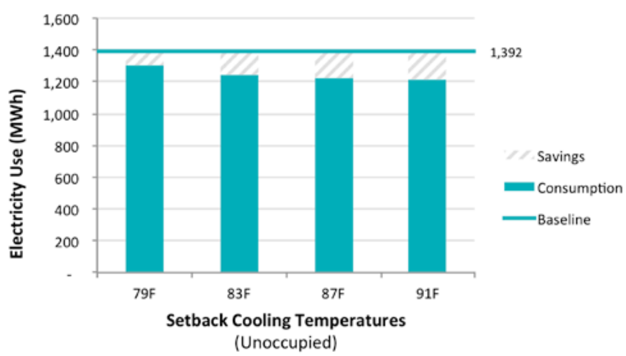


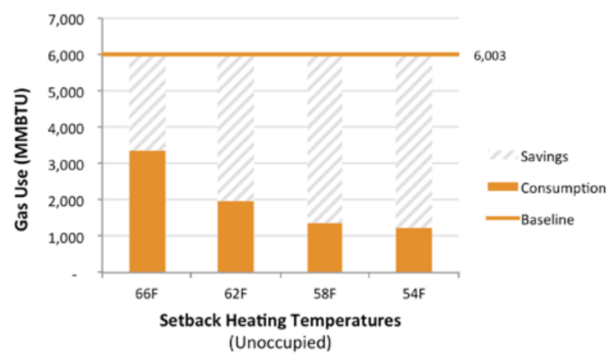


Annual Electricity Savings (kWh)			
Setback Cooling Temperatures (Unoccupied)	Consumption	Savings	Savings (%)
79F	21,177	4,222	16.6%
83F	20,030	5,368	21.1%
87F	19,886	5,512	21.7%
91F	19,875	5,523	21.7%
75F Baseline	25,398	-	-

Annual Gas Savings (kBTU)			
Setback Heating Temperatures (Unoccupied)	Consumption	Savings	Savings (%)
66F	7,482	13,079	63.6%
62F	4,984	15,577	75.8%
58F	4,904	15,657	76.2%
54F	4,904	15,657	76.2%
69F Baseline	20,561	-	-

3B. Las Vegas, NV. Large Office.

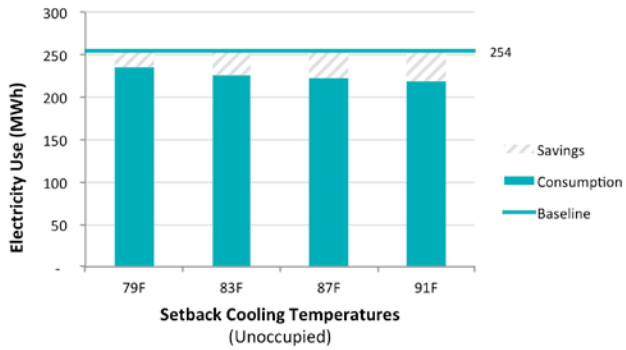


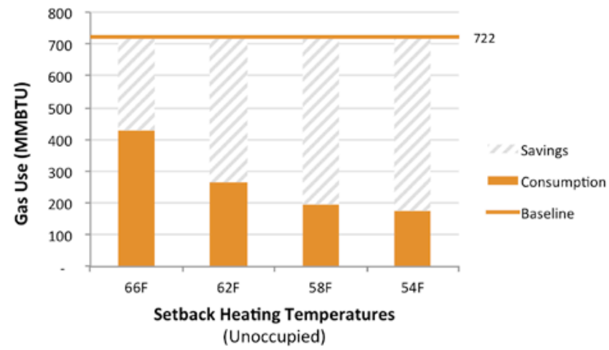


Annual Electricity Savings (kWh)			
Setback Cooling Temperatures (Unoccupied)	Consumption	Savings	Savings (%)
79F	1,299,676	92,621	6.7%
83F	1,246,626	145,671	10.5%
87F	1,222,859	169,438	12.2%
91F	1,211,090	181,206	13.0%
75F Baseline	1,392,297	-	-

Annual Gas Savings (kBTU)			
Setback Heating Temperatures (Unoccupied)	Consumption	Savings	Savings (%)
66F	3,371,210	2,631,602	43.8%
62F	1,992,330	4,010,482	66.8%
58F	1,378,045	4,624,767	77.0%
54F	1,238,382	4,764,430	79.4%
69F Baseline	6,002,812	-	-

3B. Las Vegas, NV. Medium Office.

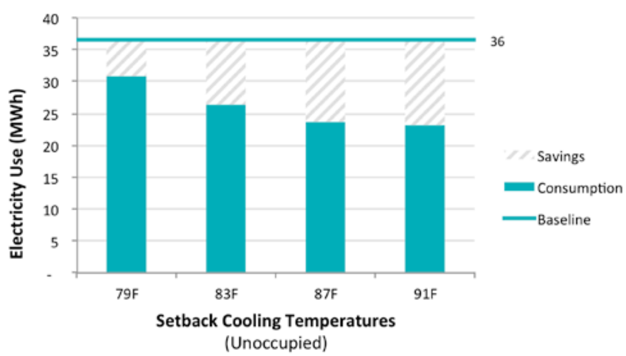


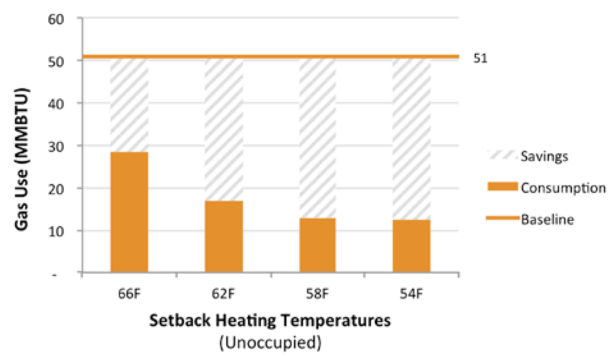


Annual Electricity Savings (kWh)			
Setback Cooling Temperatures (Unoccupied)	Consumption	Savings	Savings (%)
79F	234,770	19,409	7.6%
83F	226,395	27,783	10.9%
87F	221,352	32,826	12.9%
91F	218,529	35,650	14.0%
75F Baseline	254,178	-	-

Annual Gas Savings (kBTU)			
Setback Heating Temperatures (Unoccupied)	Consumption	Savings	Savings (%)
66F	426,155	296,276	41.0%
62F	264,622	457,809	63.4%
58F	193,180	529,251	73.3%
54F	176,469	545,962	75.6%
69F Baseline	722,431	-	-

3B. Las Vegas, NV. Small Office.

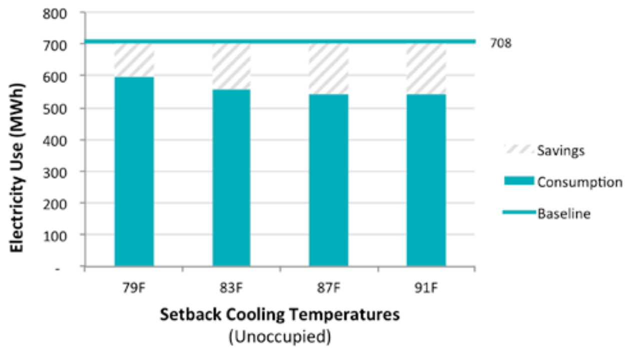


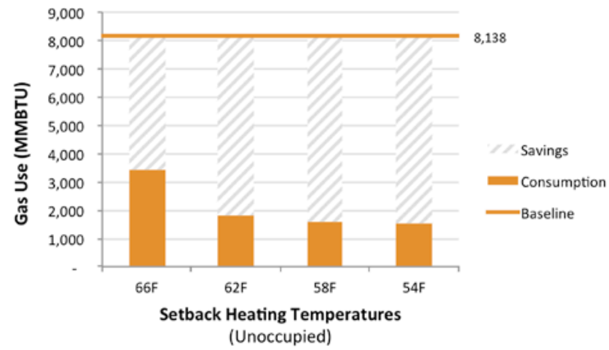


Annual Electricity Savings (kWh)			
Setback Cooling Temperatures (Unoccupied)	Consumption	Savings	Savings (%)
79F	30,764	5,711	15.7%
83F	26,384	10,091	27.7%
87F	23,775	12,700	34.8%
91F	23,098	13,377	36.7%
75F Baseline	36,474	-	-

Annual Gas Savings (kBTU)			
Setback Heating Temperatures (Unoccupied)	Consumption	Savings	Savings (%)
66F	28,322	22,518	44.3%
62F	16,956	33,884	66.6%
58F	12,832	38,008	74.8%
54F	12,432	38,408	75.5%
69F Baseline	50,840	-	-

3C. San Francisco, CA. Large Office.

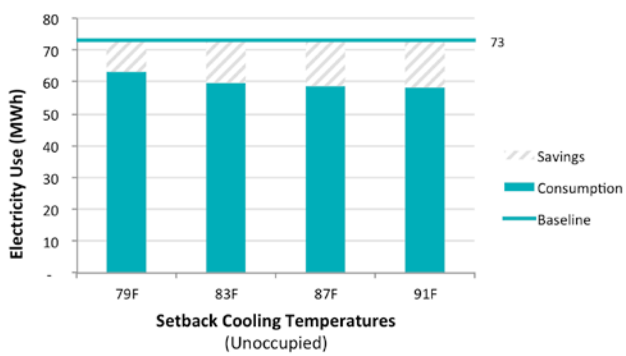


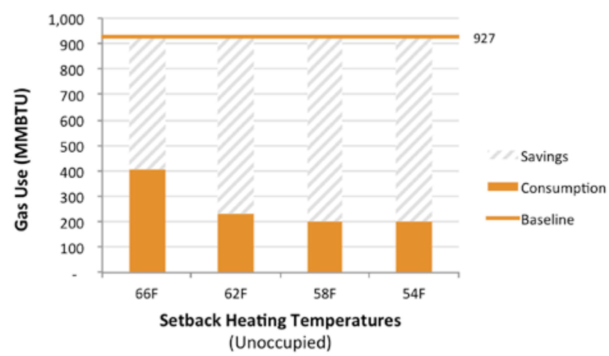


Annual Electricity Savings (kWh)			
Setback Cooling Temperatures (Unoccupied)	Consumption	Savings	Savings (%)
79F	597,305	110,888	15.7%
83F	555,421	152,772	21.6%
87F	542,811	165,382	23.4%
91F	540,760	167,433	23.6%
75F Baseline	708,193	-	-

Annual Gas Savings (kBTU)			
Setback Heating Temperatures (Unoccupied)	Consumption	Savings	Savings (%)
66F	3,413,336	4,725,141	58.1%
62F	1,824,576	6,313,901	77.6%
58F	1,573,389	6,565,088	80.7%
54F	1,535,136	6,603,341	81.1%
69F Baseline	8,138,477	-	-

3C. San Francisco, CA. Medium Office.

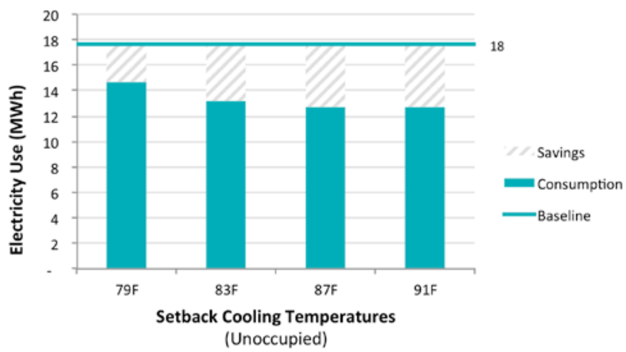


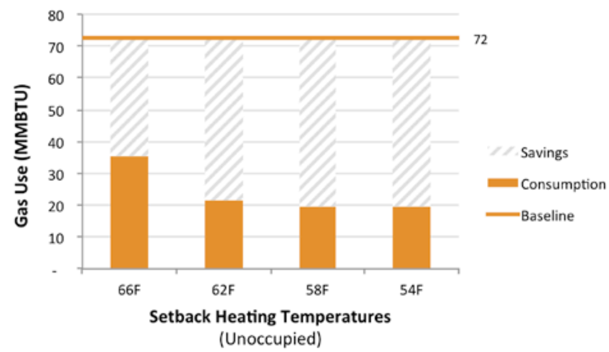


Annual Electricity Savings (kWh)			
Setback Cooling Temperatures (Unoccupied)	Consumption	Savings	Savings (%)
79F	63,394	9,424	12.9%
83F	59,493	13,324	18.3%
87F	58,561	14,257	19.6%
91F	58,396	14,422	19.8%
75F Baseline	72,818	-	-

Annual Gas Savings (kBTU)			
Setback Heating Temperatures (Unoccupied)	Consumption	Savings	Savings (%)
66F	407,078	519,861	56.1%
62F	231,807	695,133	75.0%
58F	203,980	722,959	78.0%
54F	200,270	726,669	78.4%
69F Baseline	926,939	-	-

3C. San Francisco, CA. Small Office.

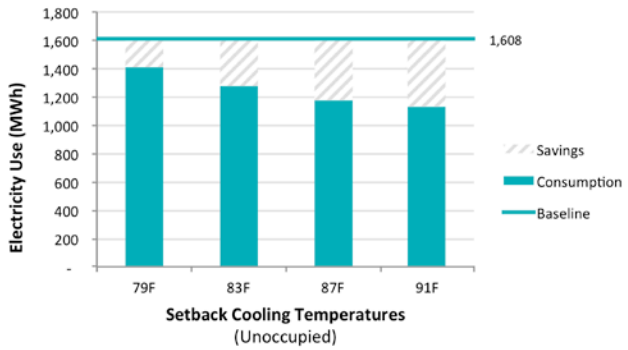


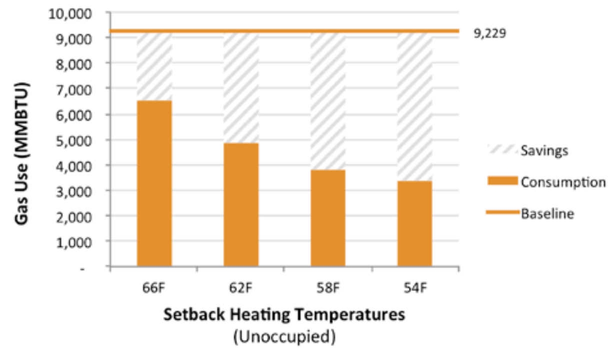


Annual Electricity Savings (kWh)			
Setback Cooling Temperatures (Unoccupied)	Consumption	Savings	Savings (%)
79F	14,691	2,908	16.5%
83F	13,151	4,448	25.3%
87F	12,716	4,883	27.7%
91F	12,677	4,921	28.0%
75F Baseline	17,599	-	-

Annual Gas Savings (kBTU)			
Setback Heating Temperatures (Unoccupied)	Consumption	Savings	Savings (%)
66F	35,331	37,144	51.3%
62F	21,786	50,690	69.9%
58F	19,577	52,899	73.0%
54F	19,349	53,126	73.3%
69F Baseline	72,475	-	-

4A. Baltimore, MD. Large Office.

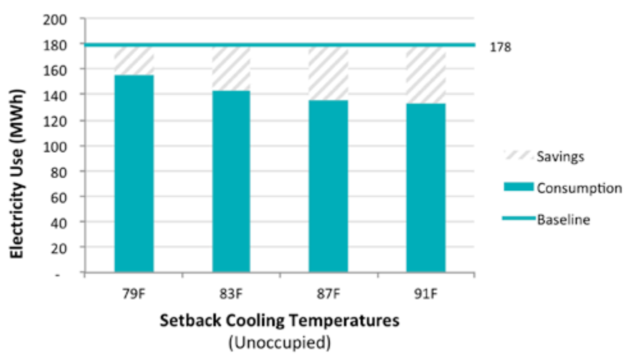


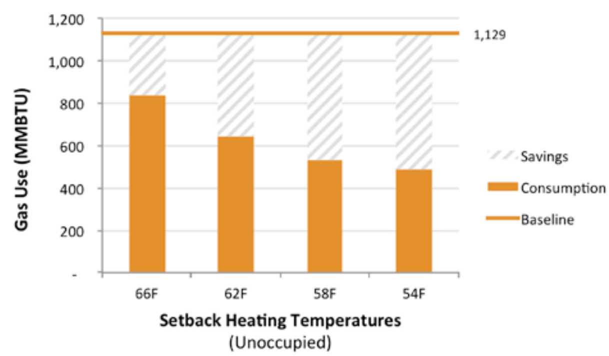


Annual Electricity Savings (kWh)			
Setback Cooling Temperatures (Unoccupied)	Consumption	Savings	Savings (%)
79F	1,404,906	203,413	12.6%
83F	1,276,115	332,204	20.7%
87F	1,175,391	432,927	26.9%
91F	1,134,185	474,134	29.5%
75F Baseline	1,608,319	-	-

Annual Gas Savings (kBTU)			
Setback Heating Temperatures (Unoccupied)	Consumption	Savings	Savings (%)
66F	6,501,766	2,727,237	29.6%
62F	4,869,017	4,359,986	47.2%
58F	3,805,648	5,423,355	58.8%
54F	3,381,257	5,847,746	63.4%
69F Baseline	9,229,003	-	-

4A. Baltimore, MD. Medium Office.

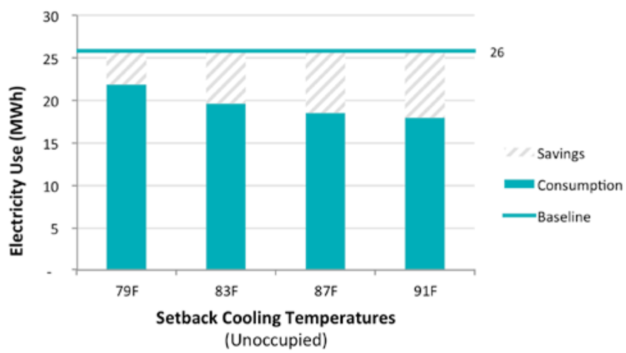


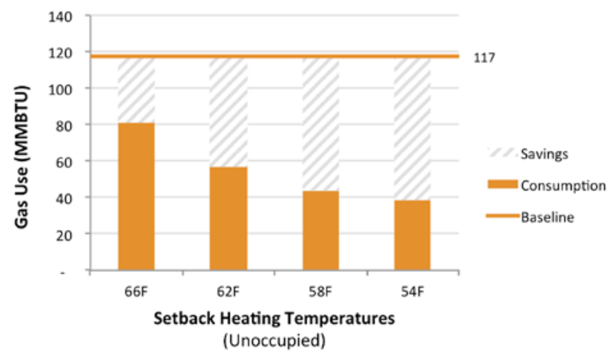


Annual Electricity Savings (kWh)			
Setback Cooling Temperatures (Unoccupied)	Consumption	Savings	Savings (%)
79F	154,837	23,638	13.2%
83F	142,663	35,813	20.1%
87F	135,444	43,032	24.1%
91F	132,970	45,506	25.5%
75F Baseline	178,476	-	-

Annual Gas Savings (kBTU)			
Setback Heating Temperatures (Unoccupied)	Consumption	Savings	Savings (%)
66F	832,747	296,058	26.2%
62F	645,464	483,341	42.8%
58F	532,869	595,937	52.8%
54F	484,702	644,103	57.1%
69F Baseline	1,128,805	-	-

4A. Baltimore, MD. Small Office.





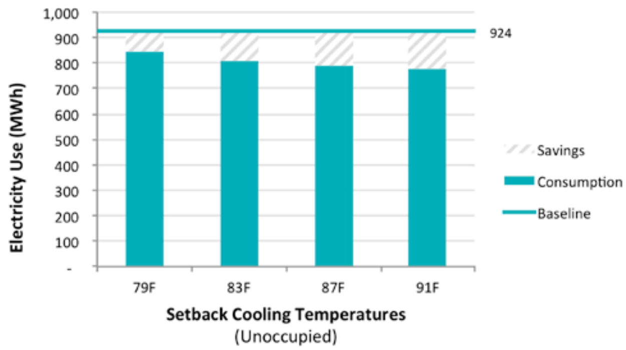
Annual Electricity Savings (kWh)

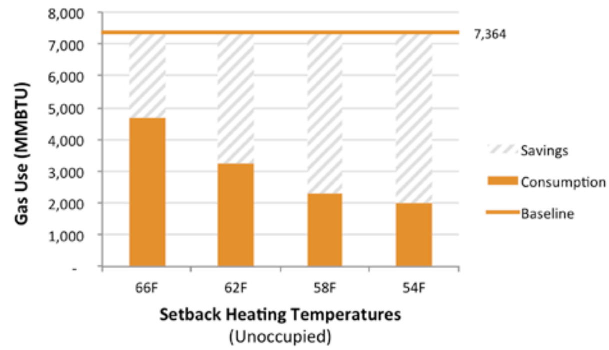
Setback Cooling Temperatures (Unoccupied)	Consumption	Savings	Savings (%)
79F	21,755	4,031	15.6%
83F	19,688	6,098	23.6%
87F	18,522	7,264	28.2%
91F	17,959	7,826	30.4%
75F Baseline	25,785	-	-

Annual Gas Savings (kBTU)

Setback Heating Temperatures (Unoccupied)	Consumption	Savings	Savings (%)
66F	81,247	36,193	30.8%
62F	56,736	60,704	51.7%
58F	43,488	73,951	63.0%
54F	38,388	79,051	67.3%
69F Baseline	117,440	-	-

4B. Albuquerque, NM. Large Office.

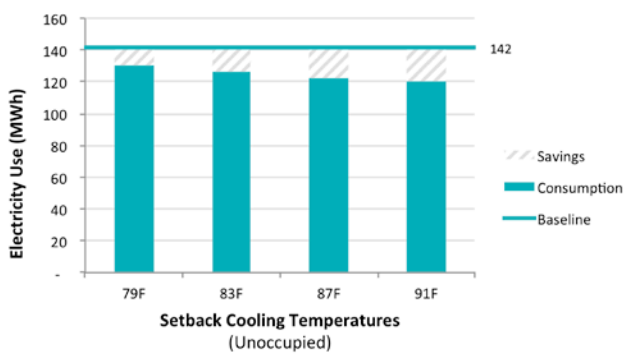


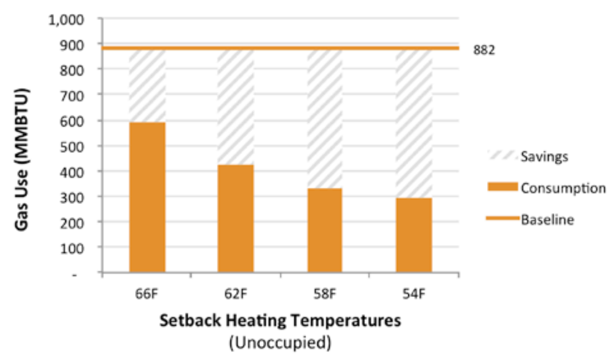


Annual Electricity Savings (kWh)			
Setback Cooling Temperatures (Unoccupied)	Consumption	Savings	Savings (%)
79F	843,775	80,150	8.7%
83F	807,704	116,220	12.6%
87F	787,717	136,207	14.7%
91F	777,525	146,400	15.8%
75F Baseline	923,925	-	-

Annual Gas Savings (kBTU)			
Setback Heating Temperatures (Unoccupied)	Consumption	Savings	Savings (%)
66F	4,698,766	2,665,434	36.2%
62F	3,226,446	4,137,753	56.2%
58F	2,319,323	5,044,877	68.5%
54F	1,993,458	5,370,742	72.9%
69F Baseline	7,364,199	-	-

4B. Albuquerque, NM. Medium Office.

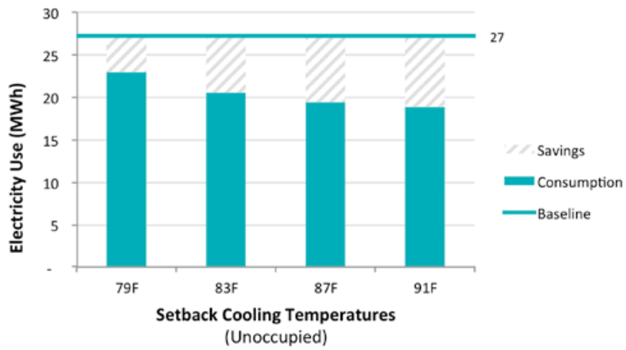


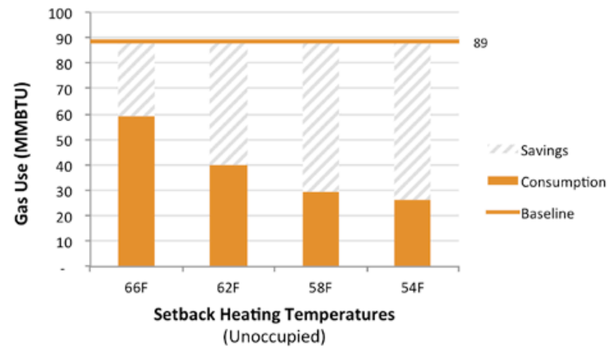


Annual Electricity Savings (kWh)			
Setback Cooling Temperatures (Unoccupied)	Consumption	Savings	Savings (%)
79F	130,547	11,021	7.8%
83F	125,912	15,656	11.1%
87F	122,396	19,172	13.5%
91F	120,621	20,948	14.8%
75F Baseline	141,569	-	-

Annual Gas Savings (kBTU)			
Setback Heating Temperatures (Unoccupied)	Consumption	Savings	Savings (%)
66F	593,994	287,809	32.6%
62F	426,278	455,525	51.7%
58F	330,279	551,524	62.5%
54F	294,313	587,490	66.6%
69F Baseline	881,803	-	-

4B. Albuquerque, NM. Small Office.





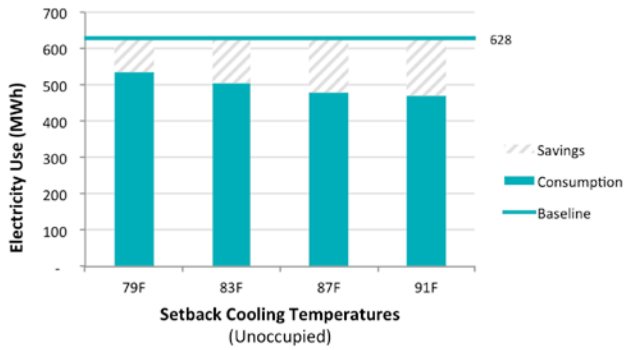
Annual Electricity Savings (kWh)

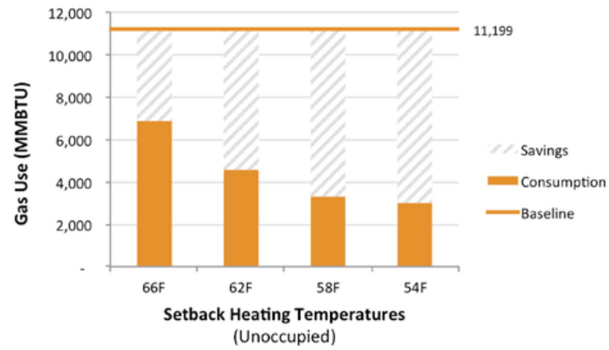
Setback Cooling Temperatures (Unoccupied)	Consumption	Savings	Savings (%)
79F	22,907	4,277	15.7%
83F	20,586	6,599	24.3%
87F	19,395	7,789	28.7%
91F	18,810	8,375	30.8%
75F Baseline	27,184	-	-

Annual Gas Savings (kBTU)

Setback Heating Temperatures (Unoccupied)	Consumption	Savings	Savings (%)
66F	58,878	29,642	33.5%
62F	40,075	48,446	54.7%
58F	29,477	59,043	66.7%
54F	26,465	62,055	70.1%
69F Baseline	88,520	-	-

4C. Seattle, WA. Large Office.

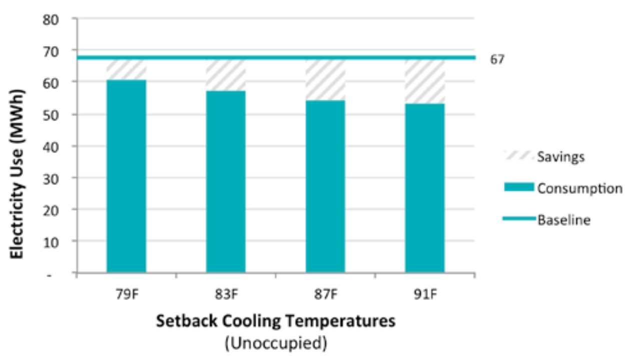


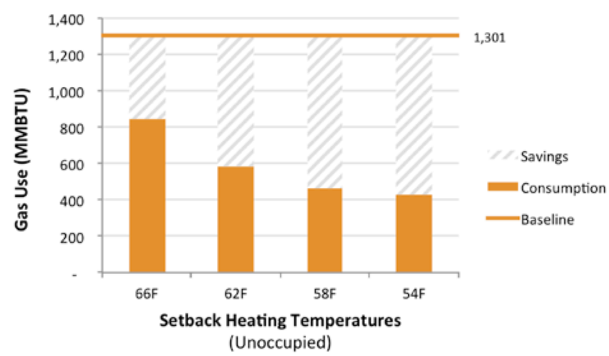


Annual Electricity Savings (kWh)			
Setback Cooling Temperatures (Unoccupied)	Consumption	Savings	Savings (%)
79F	533,411	94,938	15.1%
83F	503,337	125,012	19.9%
87F	477,817	150,532	24.0%
91F	468,581	159,768	25.4%
75F Baseline	628,349	-	-

Annual Gas Savings (kBTU)			
Setback Heating Temperatures (Unoccupied)	Consumption	Savings	Savings (%)
66F	6,863,323	4,335,671	38.7%
62F	4,573,967	6,625,027	59.2%
58F	3,293,341	7,905,652	70.6%
54F	3,037,874	8,161,119	72.9%
69F Baseline	11,198,993	-	-

4C. Seattle, WA. Medium Office.

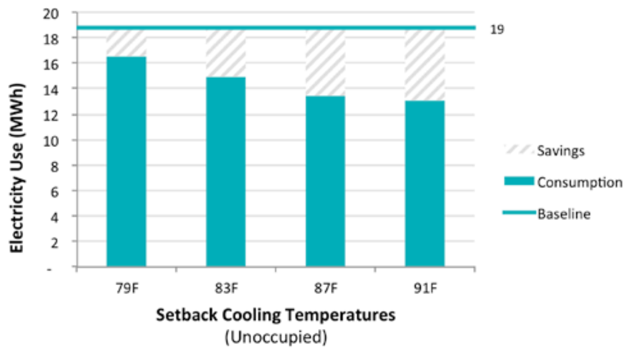


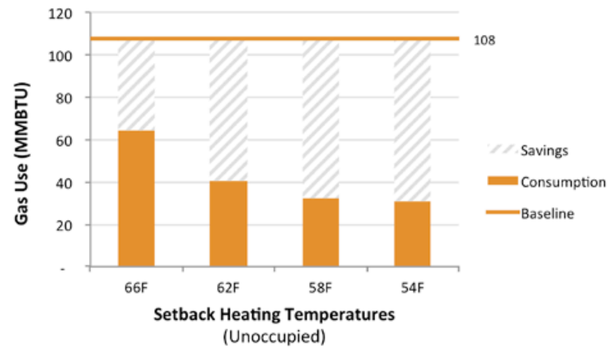


Annual Electricity Savings (kWh)			
Setback Cooling Temperatures (Unoccupied)	Consumption	Savings	Savings (%)
79F	60,649	6,850	10.1%
83F	57,185	10,314	15.3%
87F	54,221	13,277	19.7%
91F	53,074	14,425	21.4%
75F Baseline	67,498	-	-

Annual Gas Savings (kBTU)			
Setback Heating Temperatures (Unoccupied)	Consumption	Savings	Savings (%)
66F	845,098	455,506	35.0%
62F	584,568	716,035	55.1%
58F	460,703	839,900	64.6%
54F	429,733	870,870	67.0%
69F Baseline	1,300,603	-	-

4C. Seattle, WA. Small Office.

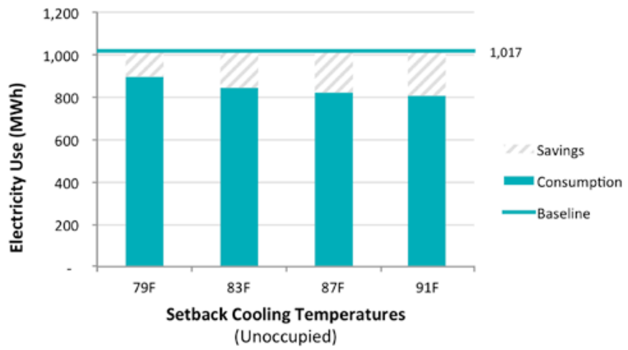


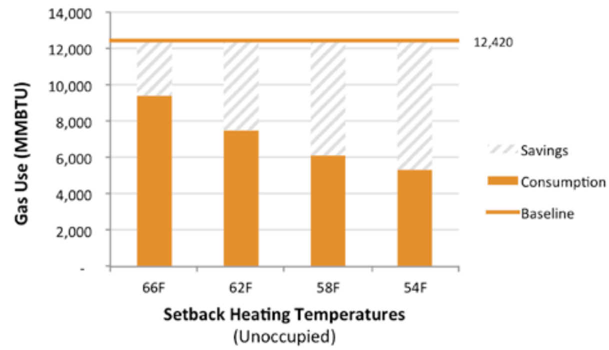


Annual Electricity Savings (kWh)			
Setback Cooling Temperatures (Unoccupied)	Consumption	Savings	Savings (%)
79F	16,490	2,292	12.2%
83F	14,943	3,839	20.4%
87F	13,474	5,309	28.3%
91F	13,105	5,678	30.2%
75F Baseline	18,782	-	-

Annual Gas Savings (kBTU)			
Setback Heating Temperatures (Unoccupied)	Consumption	Savings	Savings (%)
66F	64,227	43,303	40.3%
62F	40,707	66,823	62.1%
58F	32,079	75,452	70.2%
54F	31,118	76,412	71.1%
69F Baseline	107,530	-	-

5A. Chicago, IL. Large Office.

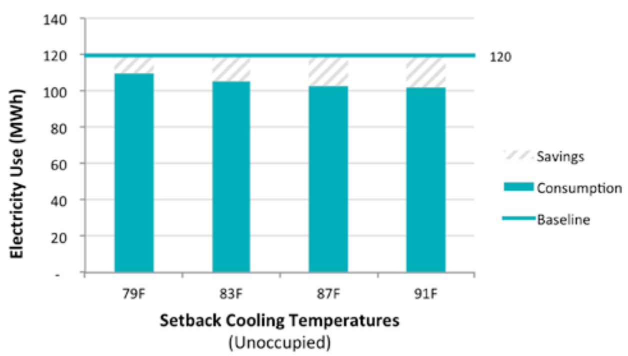


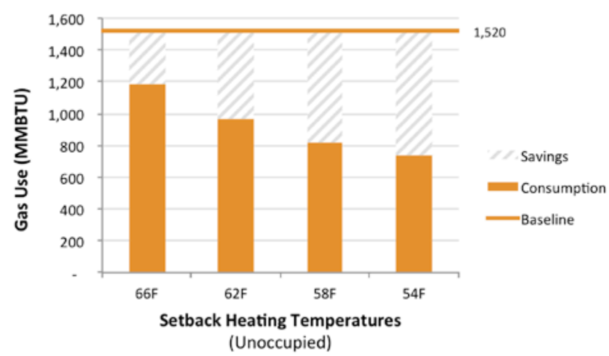


Annual Electricity Savings (kWh)			
Setback Cooling Temperatures (Unoccupied)	Consumption	Savings	Savings (%)
79F	894,425	122,688	12.1%
83F	846,138	170,974	16.8%
87F	822,031	195,082	19.2%
91F	808,902	208,210	20.5%
75F Baseline	1,017,113	-	-

Annual Gas Savings (kBTU)			
Setback Heating Temperatures (Unoccupied)	Consumption	Savings	Savings (%)
66F	9,369,667	3,050,210	24.6%
62F	7,495,806	4,924,071	39.6%
58F	6,082,757	6,337,120	51.0%
54F	5,348,738	7,071,139	56.9%
69F Baseline	12,419,877	-	-

5A. Chicago, IL. Medium Office.

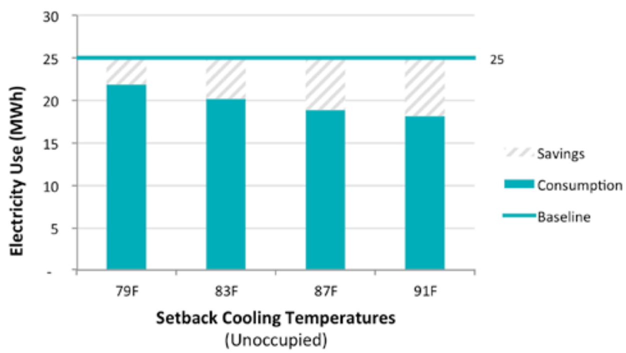


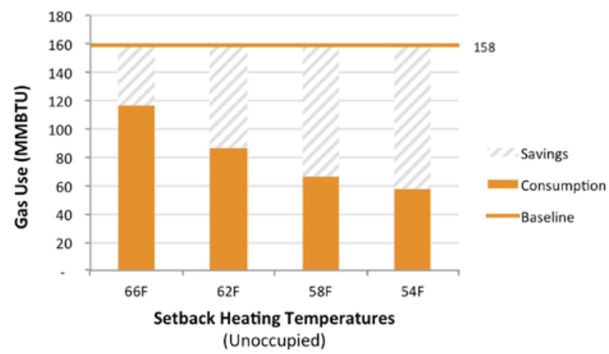


Annual Electricity Savings (kWh)			
Setback Cooling Temperatures (Unoccupied)	Consumption	Savings	Savings (%)
79F	109,325	10,232	8.6%
83F	105,357	14,201	11.9%
87F	102,920	16,638	13.9%
91F	101,561	17,997	15.1%
75F Baseline	119,558	-	-

Annual Gas Savings (kBTU)			
Setback Heating Temperatures (Unoccupied)	Consumption	Savings	Savings (%)
66F	1,187,736	332,028	21.8%
62F	968,227	551,537	36.3%
58F	819,117	700,646	46.1%
54F	742,782	776,981	51.1%
69F Baseline	1,519,763	-	-

5A. Chicago, IL. Small Office.





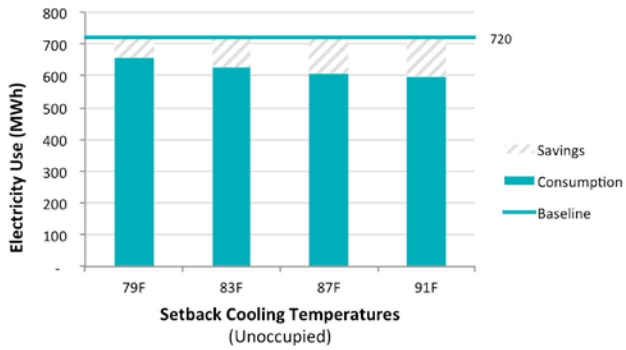
Annual Electricity Savings (kWh)

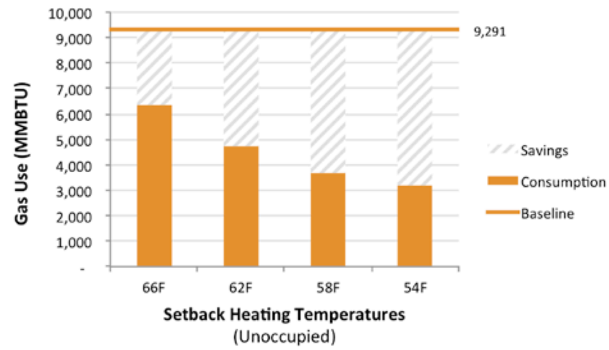
Setback Cooling Temperatures (Unoccupied)	Consumption	Savings	Savings (%)
79F	21,802	3,167	12.7%
83F	20,141	4,828	19.3%
87F	18,937	6,032	24.2%
91F	18,026	6,943	27.8%
75F Baseline	24,969	-	-

Annual Gas Savings (kBTU)

Setback Heating Temperatures (Unoccupied)	Consumption	Savings	Savings (%)
66F	116,942	41,533	26.2%
62F	86,253	72,223	45.6%
58F	65,914	92,561	58.4%
54F	57,234	101,241	63.9%
69F Baseline	158,475	-	-

5B. Boulder, CO. Large Office.

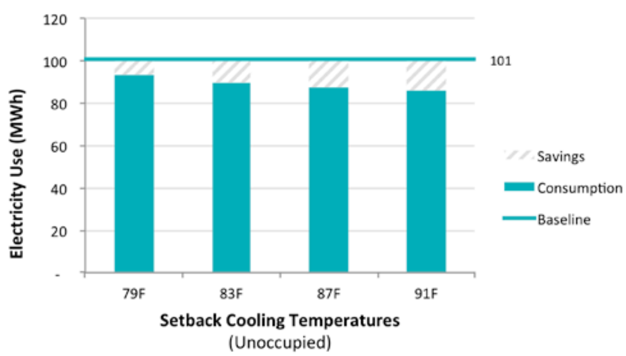


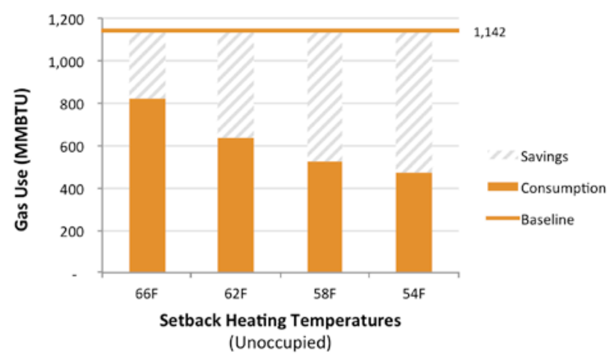


Annual Electricity Savings (kWh)			
Setback Cooling Temperatures (Unoccupied)	Consumption	Savings	Savings (%)
79F	656,374	64,050	8.9%
83F	626,773	93,652	13.0%
87F	607,036	113,388	15.7%
91F	597,664	122,761	17.0%
75F Baseline	720,425	-	-

Annual Gas Savings (kBTU)			
Setback Heating Temperatures (Unoccupied)	Consumption	Savings	Savings (%)
66F	6,360,778	2,930,468	31.5%
62F	4,721,895	4,569,352	49.2%
58F	3,665,834	5,625,412	60.5%
54F	3,213,762	6,077,485	65.4%
69F Baseline	9,291,246	-	-

5B. Boulder, CO. Medium Office.

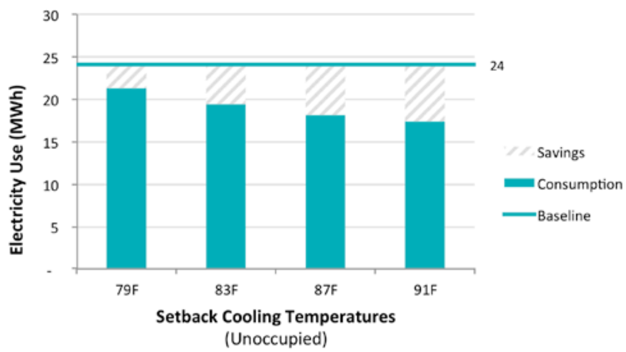


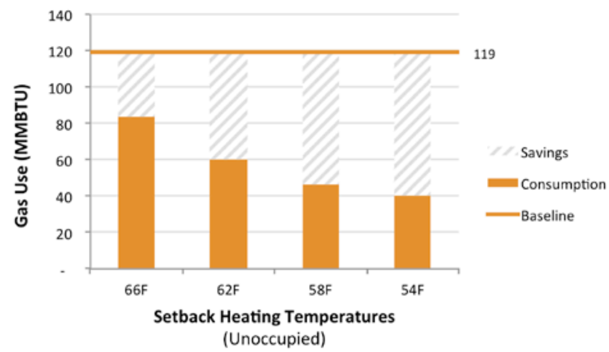


Annual Electricity Savings (kWh)			
Setback Cooling Temperatures (Unoccupied)	Consumption	Savings	Savings (%)
79F	93,525	7,094	7.1%
83F	89,841	10,778	10.7%
87F	87,160	13,460	13.4%
91F	85,889	14,731	14.6%
75F Baseline	100,620	-	-

Annual Gas Savings (kBTU)			
Setback Heating Temperatures (Unoccupied)	Consumption	Savings	Savings (%)
66F	823,966	317,638	27.8%
62F	634,329	507,275	44.4%
58F	523,131	618,473	54.2%
54F	474,167	667,437	58.5%
69F Baseline	1,141,604	-	-

5B. Boulder, CO. Small Office.

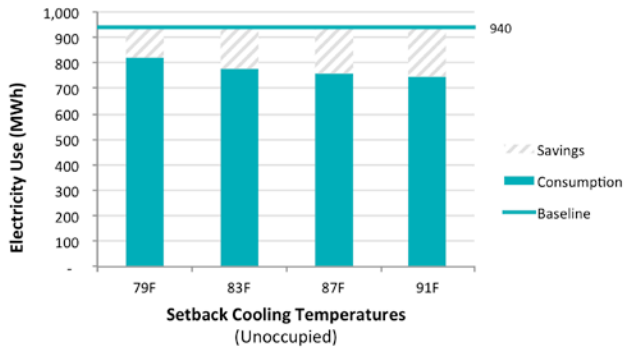


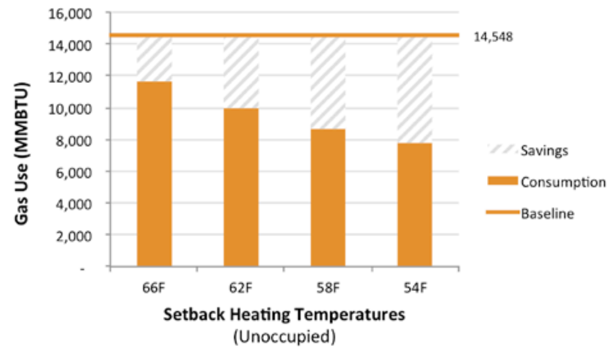


Annual Electricity Savings (kWh)			
Setback Cooling Temperatures (Unoccupied)	Consumption	Savings	Savings (%)
79F	21,186	2,893	12.0%
83F	19,407	4,672	19.4%
87F	18,196	5,884	24.4%
91F	17,450	6,629	27.5%
75F Baseline	24,079	-	-

Annual Gas Savings (kBTU)			
Setback Heating Temperatures (Unoccupied)	Consumption	Savings	Savings (%)
66F	83,687	35,208	29.6%
62F	60,483	58,412	49.1%
58F	46,256	72,639	61.1%
54F	40,615	78,280	65.8%
69F Baseline	118,895	-	-

6A. Minneapolis, MN. Large Office.

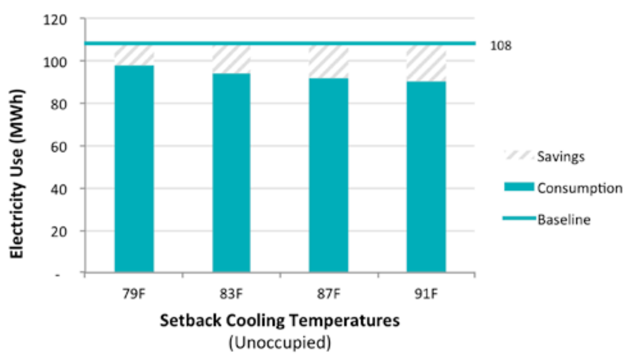


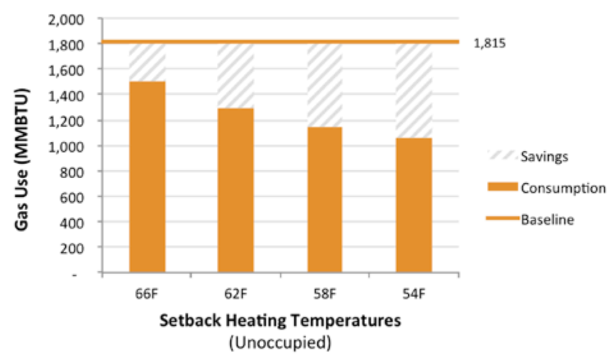


Annual Electricity Savings (kWh)			
Setback Cooling Temperatures (Unoccupied)	Consumption	Savings	Savings (%)
79F	823,183	116,620	12.4%
83F	779,185	160,618	17.1%
87F	758,004	181,799	19.3%
91F	743,235	196,568	20.9%
75F Baseline	939,803	-	-

Annual Gas Savings (kBTU)			
Setback Heating Temperatures (Unoccupied)	Consumption	Savings	Savings (%)
66F	11,681,436	2,866,957	19.7%
62F	9,980,678	4,567,715	31.4%
58F	8,676,074	5,872,319	40.4%
54F	7,808,672	6,739,720	46.3%
69F Baseline	14,548,393	-	-

6A. Minneapolis, MN. Medium Office.

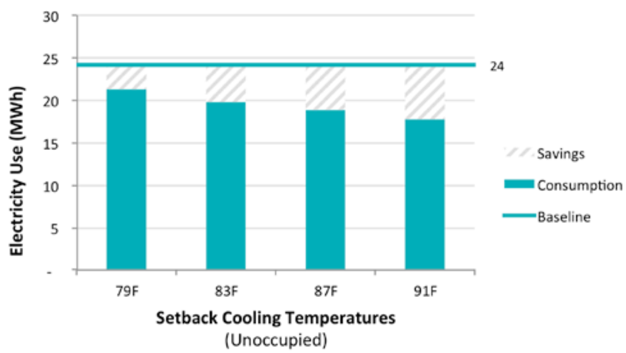


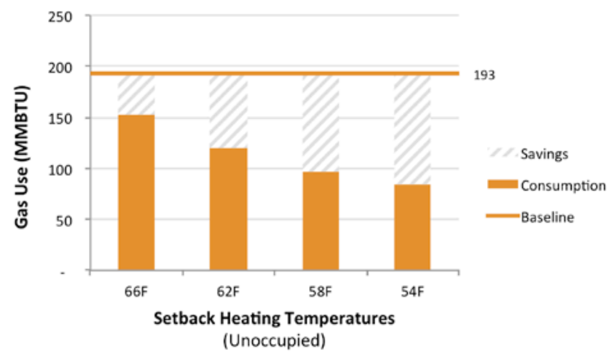


Annual Electricity Savings (kWh)			
Setback Cooling Temperatures (Unoccupied)	Consumption	Savings	Savings (%)
79F	98,024	9,809	9.1%
83F	94,184	13,649	12.7%
87F	91,813	16,021	14.9%
91F	90,410	17,423	16.2%
75F Baseline	107,833	-	-

Annual Gas Savings (kBTU)			
Setback Heating Temperatures (Unoccupied)	Consumption	Savings	Savings (%)
66F	1,502,652	312,364	17.2%
62F	1,298,893	516,123	28.4%
58F	1,149,680	665,336	36.7%
54F	1,057,096	757,920	41.8%
69F Baseline	1,815,016	-	-

6A. Minneapolis, MN. Small Office.





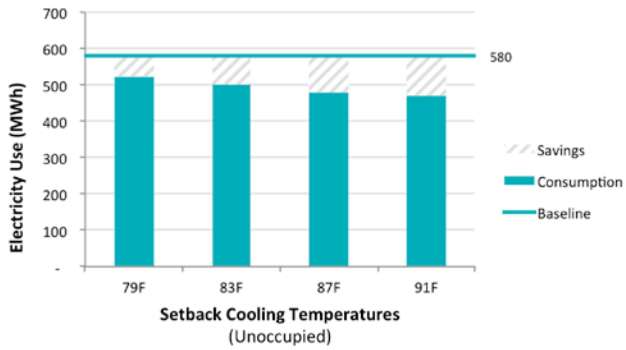
Annual Electricity Savings (kWh)

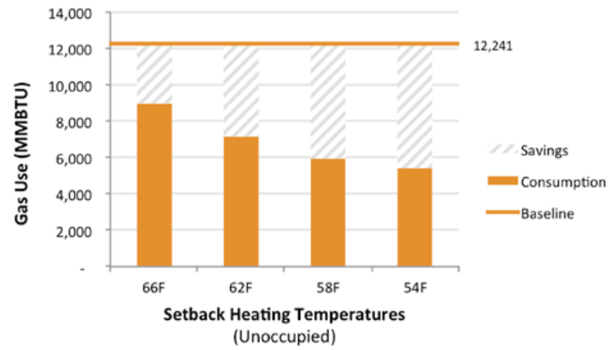
Setback Cooling Temperatures (Unoccupied)	Consumption	Savings	Savings (%)
79F	21,183	2,964	12.3%
83F	19,756	4,391	18.2%
87F	18,769	5,378	22.3%
91F	17,830	6,316	26.2%
75F Baseline	24,147	-	-

Annual Gas Savings (kBTU)

Setback Heating Temperatures (Unoccupied)	Consumption	Savings	Savings (%)
66F	151,750	41,191	21.3%
62F	119,995	72,946	37.8%
58F	96,908	96,033	49.8%
54F	84,204	108,737	56.4%
69F Baseline	192,941	-	-

6B. Helena, MT. Large Office.

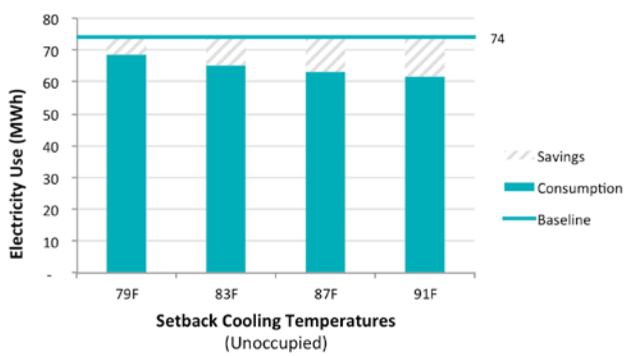


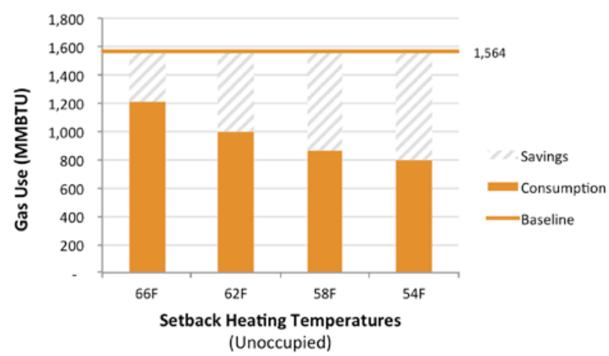


Annual Electricity Savings (kWh)			
Setback Cooling Temperatures (Unoccupied)	Consumption	Savings	Savings (%)
79F	524,155	55,900	9.6%
83F	498,687	81,368	14.0%
87F	480,309	99,745	17.2%
91F	471,644	108,411	18.7%
75F Baseline	580,055	-	-

Annual Gas Savings (kBTU)			
Setback Heating Temperatures (Unoccupied)	Consumption	Savings	Savings (%)
66F	8,956,623	3,283,997	26.8%
62F	7,155,166	5,085,454	41.5%
58F	5,932,490	6,308,131	51.5%
54F	5,396,959	6,843,662	55.9%
69F Baseline	12,240,620	-	-

6B. Helena, MT. Medium Office.

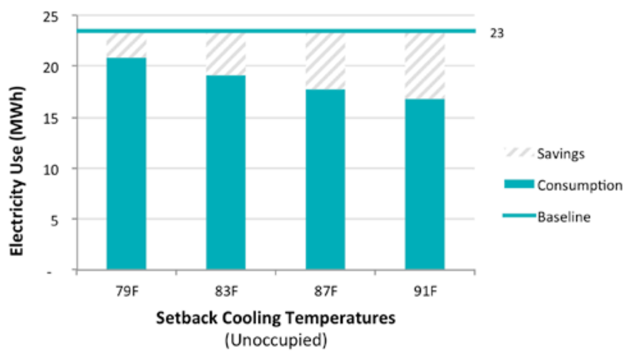


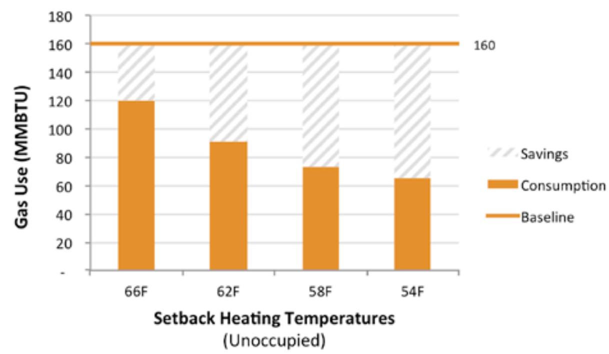


Annual Electricity Savings (kWh)			
Setback Cooling Temperatures (Unoccupied)	Consumption	Savings	Savings (%)
79F	68,364	5,585	7.6%
83F	65,289	8,660	11.7%
87F	63,000	10,949	14.8%
91F	61,736	12,212	16.5%
75F Baseline	73,949	-	-

Annual Gas Savings (kBTU)			
Setback Heating Temperatures (Unoccupied)	Consumption	Savings	Savings (%)
66F	1,209,577	354,835	22.7%
62F	992,261	572,151	36.6%
58F	858,553	705,859	45.1%
54F	794,331	770,081	49.2%
69F Baseline	1,564,412	-	-

6B. Helena, MT. Small Office.

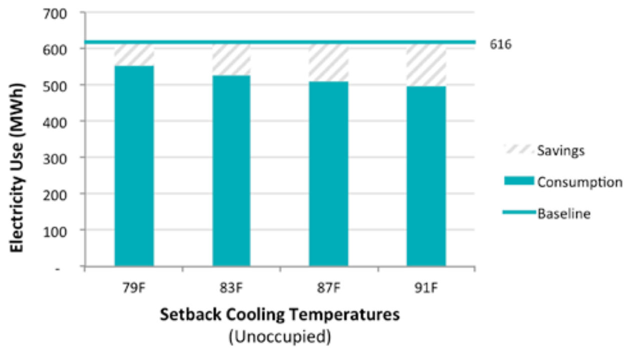


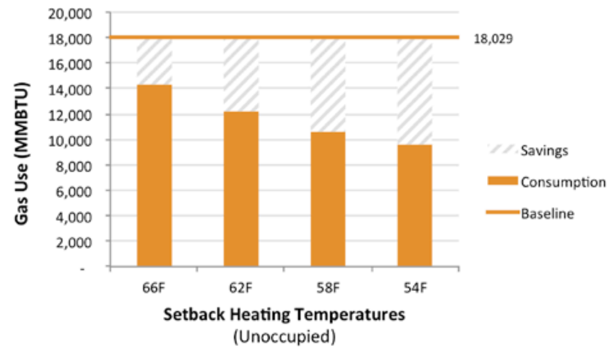


Annual Electricity Savings (kWh)			
Setback Cooling Temperatures (Unoccupied)	Consumption	Savings	Savings (%)
79F	20,815	2,571	11.0%
83F	19,075	4,311	18.4%
87F	17,727	5,658	24.2%
91F	16,800	6,586	28.2%
75F Baseline	23,386	-	-

Annual Gas Savings (kBTU)			
Setback Heating Temperatures (Unoccupied)	Consumption	Savings	Savings (%)
66F	119,596	40,259	25.2%
62F	91,040	68,815	43.0%
58F	72,924	86,930	54.4%
54F	65,446	94,409	59.1%
69F Baseline	159,855	-	-

7. Duluth, MN. Large Office.

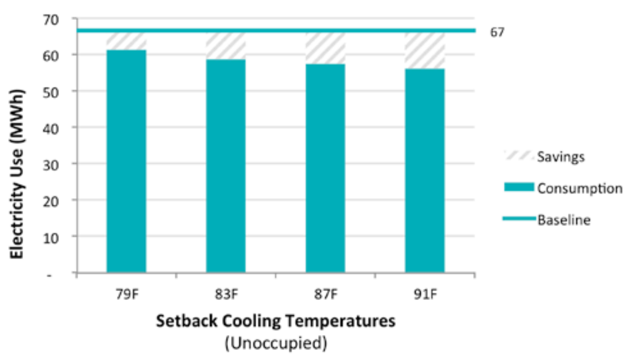


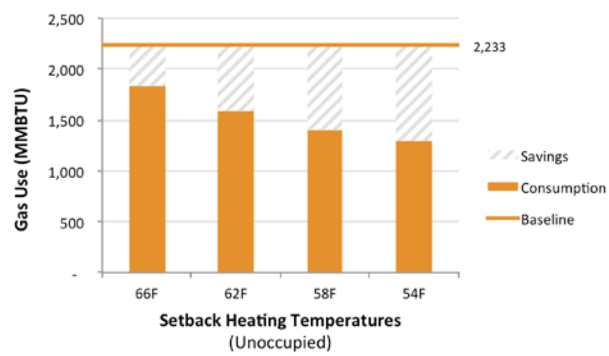


Annual Electricity Savings (kWh)			
Setback Cooling Temperatures (Unoccupied)	Consumption	Savings	Savings (%)
79F	551,620	64,105	10.4%
83F	527,243	88,482	14.4%
87F	510,919	104,806	17.0%
91F	498,318	117,407	19.1%
75F Baseline	615,725	-	-

Annual Gas Savings (kBTU)			
Setback Heating Temperatures (Unoccupied)	Consumption	Savings	Savings (%)
66F	14,316,595	3,712,562	20.6%
62F	12,153,673	5,875,484	32.6%
58F	10,606,377	7,422,780	41.2%
54F	9,546,459	8,482,698	47.0%
69F Baseline	18,029,157	-	-

7. Duluth, MN. Medium Office.

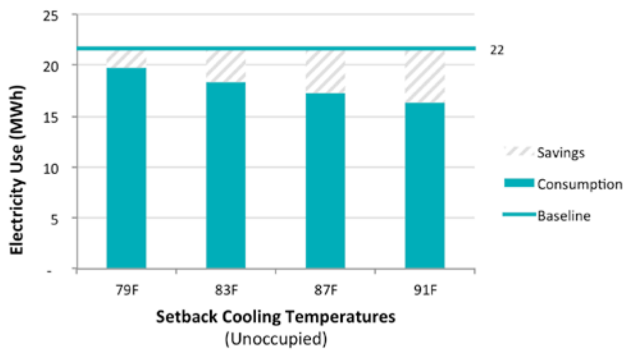


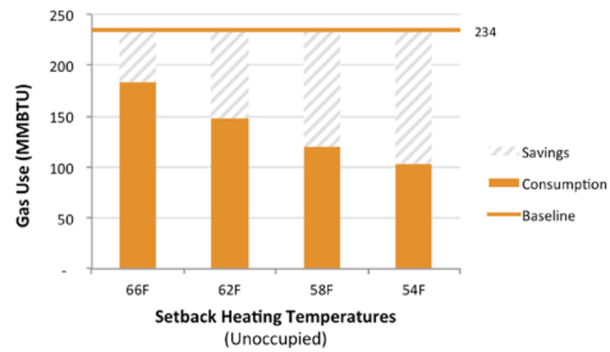


Annual Electricity Savings (kWh)			
Setback Cooling Temperatures (Unoccupied)	Consumption	Savings	Savings (%)
79F	61,419	5,193	7.8%
83F	58,917	7,695	11.6%
87F	57,231	9,381	14.1%
91F	55,922	10,690	16.0%
75F Baseline	66,612	-	-

Annual Gas Savings (kBTU)			
Setback Heating Temperatures (Unoccupied)	Consumption	Savings	Savings (%)
66F	1,836,200	396,338	17.8%
62F	1,583,545	648,993	29.1%
58F	1,408,271	824,267	36.9%
54F	1,295,394	937,144	42.0%
69F Baseline	2,232,538	-	-

7. Duluth, MN. Small Office.

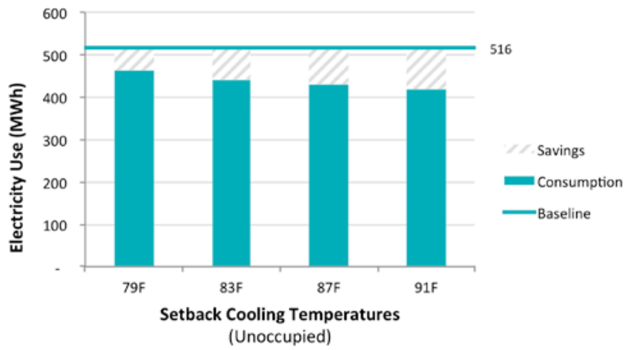


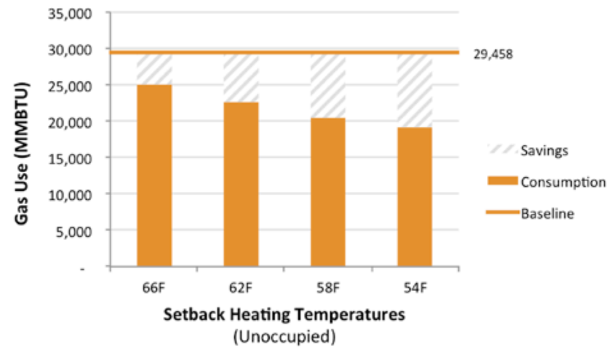


Annual Electricity Savings (kWh)			
Setback Cooling Temperatures (Unoccupied)	Consumption	Savings	Savings (%)
79F	19,737	1,905	8.8%
83F	18,407	3,235	14.9%
87F	17,331	4,311	19.9%
91F	16,394	5,248	24.2%
75F Baseline	21,642	-	-

Annual Gas Savings (kBTU)			
Setback Heating Temperatures (Unoccupied)	Consumption	Savings	Savings (%)
66F	183,993	49,824	21.3%
62F	147,427	86,390	36.9%
58F	120,165	113,651	48.6%
54F	103,435	130,382	55.8%
69F Baseline	233,817	-	-

8. Fairbanks, AK. Large Office.

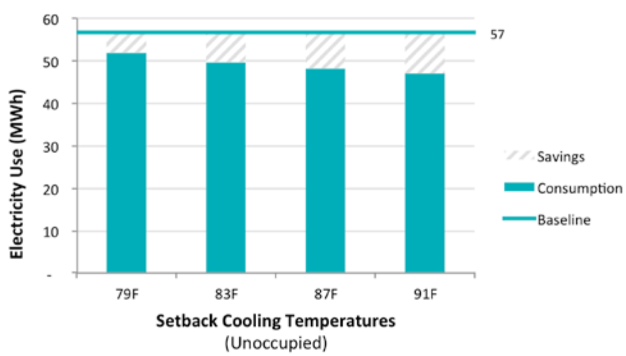


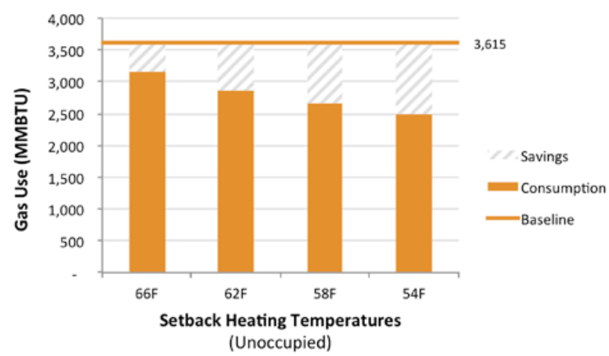


Annual Electricity Savings (kWh)			
Setback Cooling Temperatures (Unoccupied)	Consumption	Savings	Savings (%)
79F	461,585	54,366	10.5%
83F	442,062	73,889	14.3%
87F	428,709	87,242	16.9%
91F	418,232	97,719	18.9%
75F Baseline	**515,951**	-	-

Annual Gas Savings (kBTU)			
Setback Heating Temperatures (Unoccupied)	Consumption	Savings	Savings (%)
66F	25,090,931	4,366,791	14.8%
62F	22,537,167	6,920,554	23.5%
58F	20,582,215	8,875,507	30.1%
54F	19,118,446	10,339,275	35.1%
69F Baseline	**29,457,721**	-	-

8. Fairbanks, AK. Medium Office.

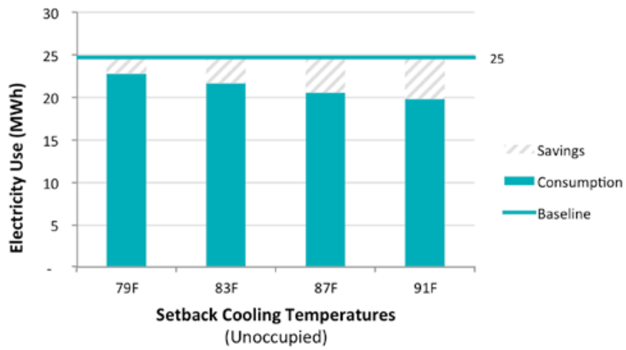


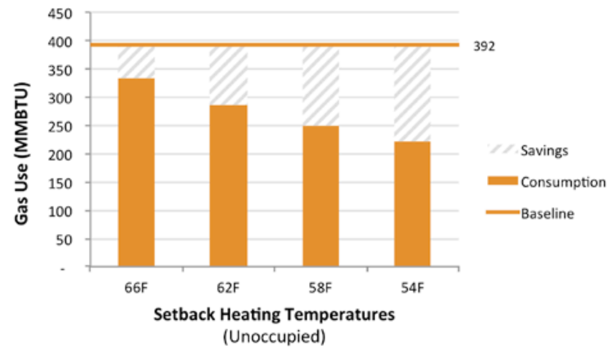


Annual Electricity Savings (kWh)			
Setback Cooling Temperatures (Unoccupied)	Consumption	Savings	Savings (%)
79F	51,933	4,606	8.1%
83F	49,654	6,884	12.2%
87F	48,089	8,449	14.9%
91F	47,121	9,417	16.7%
75F Baseline	56,538	-	-

Annual Gas Savings (kBTU)			
Setback Heating Temperatures (Unoccupied)	Consumption	Savings	Savings (%)
66F	3,163,177	452,139	12.5%
62F	2,869,875	745,442	20.6%
58F	2,650,886	964,431	26.7%
54F	2,495,127	1,120,190	31.0%
69F Baseline	3,615,317	-	-

8. Fairbanks, AK. Small Office.





Annual Electricity Savings (kWh)			
Setback Cooling Temperatures (Unoccupied)	Consumption	Savings	Savings (%)
79F	22,830	1,835	7.4%
83F	21,596	3,069	12.4%
87F	20,607	4,058	16.5%
91F	19,806	4,859	19.7%
75F Baseline	24,665	-	-

Annual Gas Savings (kBTU)			
Setback Heating Temperatures (Unoccupied)	Consumption	Savings	Savings (%)
66F	332,233	60,018	15.3%
62F	286,061	106,190	27.1%
58F	250,364	141,887	36.2%
54F	222,153	170,098	43.4%
69F Baseline	392,251	-	-