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Socially Driven HVAC Optimization Federal Building and US Courthouse Phoenix, Arizona

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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.

Disclaimer

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I. Executive Summary

A. Background

Under many circumstances in facilities management, keeping occupants comfortable and saving energy are diametrically opposed. To stay cool in summer and warm in winter requires energy to maintain indoor temperatures. If energy is saved by allowing indoor temperatures to get warmer in the summer or colder in winter, occupants' comfort levels decrease. There is great potential to reduce costs and maintain occupant comfort if a system existed that could break this diametric opposition.

The comfort of building occupants in today's facilities is controlled by maintaining a given space temperature through the use of a thermostat. These devices operate in a very simple manner in which they are set to maintain a certain constant space temperature range. If the occupant is too hot or cold, he or she writes a work order for facility maintenance staff to adjust the thermostat to a new constant temperature range. This feedback cycle is repeated as needed to avoid generating complaints of too hot/cold from the occupants.

This system has two areas in which it can be improved. First, there is the labor cost associated with a facilities maintenance person having to respond to each request when an occupant is uncomfortable. Person-hours are spent receiving the work order and adjusting space thermostats to a level that, hopefully, will allow the occupant to be comfortable.

Second, the space temperature is maintained within a constant range, with no effort being made to fine-tune the space temperature to a setting that conserves energy while maintaining occupant comfort. Occupant comfort is based upon many more factors than just the space temperature. When other factors are taken into account, there is potential to save energy while maintaining that comfort level.

B. Tech Overview

This study will evaluate a technology known as "Socially Driven HVAC Optimization." This technology is purported to address both shortcomings discussed in the previous section.

User-based control for the socially driven heating, ventilation, and air conditioning (HVAC) system is accessed through an application on each occupant's computer or handheld device. Through this application, occupants can indicate whether they are "too hot," "too cold," or "comfortable." This feedback is sent immediately to the building automation system (BAS), and the BAS automatically takes action to adjust the space conditions to maintain occupant comfort. A work order is not required, nor is a facility maintenance person required to take action to address a work order.

The socially driven HVAC system works to maintain occupant comfort while conserving energy by automatically adjusting the thermostat set point to a more energy-saving level. This is done "behind the scenes" within the BAS. When an occupant uses the application to indicate he/she is too hot/cold, the BAS triggers the HVAC system to provide an immediate large flow of conditioned air into the specific space. This flow of air is sensed by the occupant both audibly and tactilely, thereby providing immediate comfort. After a short period, airflow and temperature return to their previous energy-saving states, while waiting for the next feedback from the occupant. Over extended periods, the socially driven HVAC system "learns" through data trending how to keep occupants comfortable while saving energy, and also learns how to save energy by relaxing set points in unoccupied spaces.

C. Study Design and Objectives

The study was designed to measure whether space temperatures do, indeed, change to a more energy-saving point by logging space temperatures over extended periods, both before and after installation of the socially driven HVAC system. The study team also evaluated whether the technology provides the immediate large bursts of air based upon input from occupants' computer applications. This study, thus, was designed to determine whether the technology does, in fact, adjust space temperatures to energy-saving set points while providing the "bursts" that provide immediate comfort to occupants (see Table ES.1).

Where the socially driven HVAC technology demonstrated the ability to adjust thermostat set points to more energy-saving set points, the amount of change was documented. The amount of change was then applied in two different scenarios using standard energy models of three building types in 16 cities in various climate zones (96 total combinations) to determine the potential energy savings of this technology. Local utility rates from each city were applied to determine the economic viability of the socially driven HVAC technology.

The study was designed to measure occupant satisfaction through an extensive network of surveys and interviews, details of which are described in later paragraphs.

Table ES.1. Performance Objectives

Quantitative Objectives	Metrics and Data		
Reduce Energy Use	Does the space temperature adjust over time to a point that saves energy? The amount of change in space temperature will then be applied using standard building energy modeling practices to determine potential energy savings.	Documenting the space temperature during a baseline and test period will provide the answer. A visible change in temperature will indicate success.	The socially driven HVAC technology demonstrated a 2-degree rise in average cooling set point.
Reduce Costs	Local utility costs will be applied to the energy savings learned in the above step to determine cost savings. Labor costs will also be tracked to determine whether savings are achieved.	A reduction in energy and labor costs will determine success.	The socially driven HVAC technology demonstrated the ability to reduce energy costs by widening HVAC deadbands. While labor hours were lowered by the socially driven HVAC system, the available labor was used to address other issues in the building. There is some debate whether this would constitute a true "labor savings."

Table ES.1. Performance Objectives (continued)

Quantitative Objectives	Metrics and Data Requirements	Success Criteria	M&V Results
Increase Comfort	Extensive surveys were used to determine whether comfort level was maintained or increased.	Survey results would show whether success was achieved.	Results were generally positive. 83% of occupants reported being more thermally comfortable with the socially driven HVAC technology than with the incumbent system.
Qualitative Objectives			
Easy Installation	Documentation of issues during installation, such as information technology (IT) security issues, would determine whether this was “easy.”	Installation can be completed without an excessive number of labor hours, which would make the technology economically unviable.	GSA internal IT security reviews were more extensive than originally anticipated but should provide enough information to streamline reviews for potential future installations.
Reduced Maintenance	Records of hot/cold calls sent to maintenance were kept for both the baseline period and the test period.	Reduced number of calls during the test period would indicate success.	Hot and cold calls were reduced by 59%.
Increased Occupant Satisfaction	Extensive surveys were used to determine whether comfort level was maintained or increased.	Survey results would show whether success was achieved.	Results were generally positive. 89% of users reported satisfaction with ease of use.

Reductions in greenhouse gas emissions were also calculated based on the energy savings (Table ES-2).

Table ES-2. 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
Phoenix, AZ	0.181	0.189
Seattle, WA	0.068	0.099
Los Angeles, CA	0.114	0.230

Note: Greenhouse gas (GHG) figures were 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 2°F setback year-round. GHG per kilowatt-hour savings found in the US Environmental Protection Agency’s eGrid, 9th ed., Version 1.0, Year 2010 Summary Tables.

D. Project Results/Findings

The socially driven HVAC technology did show that it has the ability to provide the immediate burst of conditioned air to address occupants’ short-term complaints of being too hot or too cold.

It also showed that it has the ability to adjust space temperatures over time to a set point, which will save energy. At the Phoenix facility, the technology adjusted the thermostats from normal heating/cooling settings of 70/75°F to 68/77°F. These findings can be interpreted in two ways. First, the findings show that the technology allows occupants to be comfortable, while shifting the temperature set points 2°F from the former settings to which they were accustomed. Second, the findings show that the technology allows customers to be comfortable at 68/77°F, regardless of the initial temperature settings. Both interpretations are explored in further depth within this study.

Occupant surveys showed that the system generally maintains occupant comfort over time. Details are included in the body and appendices of this report.

E. Conclusions

While the socially driven HVAC technology showed itself to have the ability to keep occupants comfortable, while automatically making adjustments that will save energy, this report cannot make a conclusion that this technology is cost-effective at this time. Break-even technology subscription costs are included in Section V, "Results."

Overall, the socially driven HVAC optimization technology should be considered for facilities where thermal comfort is a priority. The socially driven HVAC technology will be most cost-effective in facilities with high energy costs, narrow deadbands, and a significant portion of space that is only intermittently occupied.

II. Introduction

A. Problem Statement

The US General Services Administration (GSA) is a leader among federal agencies in aggressively pursuing energy efficiency opportunities for its facilities and installing renewable energy systems to provide heating and cooling and to power those facilities. On average, GSA buildings are 39% more efficient than commercial buildings within the United States. The GSA Public Buildings Service has jurisdiction, custody, and control over more than 9,600 assets and is responsible for managing an inventory of diverse federal buildings totaling more than 354 million ft^2 of building stock. This includes about 400 buildings listed in or eligible for listing in the National Register of Historic Places and more than 800 buildings that are more than 50 years old. GSA has an abiding interest in examining the technical performance and cost-effectiveness of different energy-efficient technologies in its existing building portfolio, as well as in those buildings currently proposed for construction. Identifying appropriate energy-efficient solutions has been a high priority for GSA, as well as for other federal agencies. Based on the sheer size of the federal building portfolio, there is a huge opportunity for potential energy savings.

The buildings sector accounts for almost 41% of the total annual energy consumption in the United States. About 37% of this "building energy" is used by the heating, ventilation, and air conditioning (HVAC) systems to heat and cool the facilities.[1] A key element in every HVAC system is the thermostat. The thermostat is an adjustable device that is typically located on the wall of an occupied space. Occupants of that space adjust the thermostat to a specific temperature (or the occupant calls for a maintenance technician to make the adjustment), and the HVAC system works to maintain that temperature through the introduction of cold or warm air into the space. Thermostats have worked this way for decades within the HVAC industry.

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[1]Avdelidis, Nicholas P., and Kauppinen, Timo K. 2008. "Thermography as a Tool for Building Applications and Diagnostics," in Proceedings of SPIE, v. 6939, Thermosense XXX, March 18–20, 2008, Orlando, Florida.

Using thermostats in this fashion is advantageous: the devices are straightforward, the vast majority of building occupants understand how thermostats work, and thermostats control building temperature reliably.

There is, however, a major disadvantage to thermostats. Thermostats control the condition of a space to a given *temperature*, but temperature setting does not necessarily translate to occupant comfort. The temperature at which even a single individual is comfortable varies according to conditions such as humidity level, airflow, sunlight, heat from office equipment, and drafts, as well as according to the individual's activity level. Therefore, thermostats can over- or under-heat or cool a space, resulting in wasted energy (particularly when occupants use individual fans and heaters) and occupant discomfort and reduced productivity.

Also, many buildings with large HVAC systems do not have thermostats that individual occupants can adjust at will. If an occupant in one of these buildings is uncomfortable, he or she will have to contact the building maintenance staff, initiate a work order, and wait for the maintenance staff to make adjustments in what can be a labor-intensive process. All during this time, the occupant is uncomfortable and irritated at the condition.

Socially Driven HVAC Optimization is a technology that is purported to improve occupant comfort while saving energy. With this technology, an algorithm operates within the building's HVAC management system to move the thermal space condition gradually to a more energy-saving setting. The condition is then controlled by occupant feedback based on comfort level. With socially driven HVAC, occupants have the ability to enter their comfort levels into a program on their computers or smartphones. The program feeds into the building HVAC management system, which then provides an immediate burst of warm or cool air to address the occupant's discomfort. The algorithm tracks the input of each occupant and executes settings that will maintain each occupant's comfort level while optimizing to a more energy-saving temperature setting.

The socially driven HVAC technology was installed in the Federal Building and US Courthouse in Phoenix, Arizona, and became operational on March 24, 2014. The building has eight floors, comprising 289,000 ft^2, and about 350 occupants.

This technology is TRL 7 (i.e., Technical Readiness Level 7), as defined by the US Department of Energy. It is a system prototype that is being demonstrated in an operational environment.

The anticipated benefits are improved energy savings and greater occupant satisfaction due to the ability to control their individual environments.

The major limitation of the socially driven HVAC technology is that it is primarily designed to be installed in buildings that use a variable air volume (VAV) HVAC system controlled by a digital energy management system. While it can be installed in facilities with other HVAC systems, its effectiveness has not yet been proven in these environments.

B. Opportunity

Within the portfolio of buildings under the jurisdiction, custody, or control of GSA, about 50% have HVAC systems that are VAV and controlled by a digital energy management system. Within this number are most of the large buildings in the inventory. These buildings are under the same energy conservation mandates as all federal facilities. Also, based on anecdotal observations, about the same percentage of commercial office space is controlled by similar HVAC systems. In other words, about half the available office space in the country, and most of the large buildings, is eligible to use this technology. The socially driven HVAC technology is most effective in facilities that use VAV systems, though it also has been used in other facilities.

Within the domestic commercial building sector, space heating, cooling, and ventilation account for 3.75 quads[2] of energy consumption per year. This is roughly equal to the energy found in 135,000,000 tons of coal.

Using rough figures, if 50% of commercial buildings could have their thermostats automatically reset to a more energy-saving position while maintaining occupant comfort, and save just 5% per year on HVAC energy, about 0.0938 quads (93.8 x 10^{12} Btu) could be saved per year. This is roughly equal to the energy found in 3,380,000 tons of coal.

The socially driven HVAC technology is purported to have the ability to adjust thermostats, maintain occupant comfort, and deliver energy savings.

A literature search showed that this technology is proprietary and currently available from only one vendor.

There is a minor risk in implementing this technology. Should a facility install the socially driven HVAC technology and it does not perform as advertised, it would potentially take time to remove the software and algorithms from the building automation system (BAS) and restore it to its previous condition. However, there is virtually no risk of the technology causing an "incident" that damages the facility.

One barrier to deploying this technology is the fact that it operates directly within the respective building's HVAC control system. This system is typically on the secure side of the facility's information technology (IT) firewall. As such, the technology requires heavy scrutiny by GSA's IT security team. This extra time must be accounted for when planning to install the technology. Also, it is possible that some facilities might have tenants with security restrictions that do not permit this technology to be installed.

III. Methodology

A. Technology Description

The socially driven HVAC technology adjusts the interior thermal conditions using building tenant input rather than conventional thermostats with temperature settings. The technology consists of a website that individual building occupants can access through their office computers or mobile devices. On this website, which is an Ethernet connection to the building management system, occupants specify their location in the building. They can then indicate whether they want to "Cool My Space," "Warm My Space," or do nothing ("I am Comfortable"). When occupants indicate they are either too warm/hot or too cool/cold, a blast of cool or warm air streams into their designated spaces within seconds. When the space is occupied by more than one person (i.e., a workspace that has cubicles), the control system can be set up so that this process requires at least one other person sharing the space to second the request.

Over time, the website gathers input from occupants and uses an algorithm to adjust and optimize thermal conditions within their spaces. When space conditions are optimized based on occupant thermal comfort,

[2] US Department of Energy, Energy Efficiency & Renewable Energy: http://buildingsdatabook.eren.doe.gov/TableView.aspx?table=3.1.4
One quad = 10^{15} Btu or 1,000,000,000,000,000 Btu.

the algorithm works to minimize energy use while maintaining thermal comfort. Also, because the occupants' inputs are going directly to the algorithm and the BAS, no labor is required by the building's maintenance staff, thereby freeing them up to address other work orders.

Over time, the technology also learns to identify commonly unoccupied spaces, and is purported to save energy by relaxing set points in those areas.

The effectiveness of socially driven HVAC technology was evaluated at the Federal Building and US Courthouse in Phoenix, Arizona. Oak Ridge National Laboratory (ORNL) staff led the evaluation and analysis, with support from the vendor and GSA personnel at the local, regional, and national levels.

B. Technical Objectives

The overarching objective of this study was to conduct a thorough evaluation of the socially driven HVAC technology's performance by evaluating its performance against predetermined performance expectations in an objective fashion.

There were three technical objectives of this evaluation.

- Does socially driven HVAC have the ability to adjust space thermostats to a more energy-saving set point based upon individuals inputting their comfort levels instead of setting thermostats to a specific temperature number?

- Are occupants more satisfied with space conditions when they are given the ability to instantly control their own space conditions?

- Does socially driven HVAC do the above two tasks in a cost-effective fashion based upon (A) energy savings and (B) labor savings for hot/cold calls?

The measurement and verification (M&V) objectives were as follows.

- Verify the short burst of air that is provided immediately upon an occupant indicating he or she is too hot/cold.

- Measure space temperature changes that occur due to socially driven HVAC establishing a thermostat set point that saves energy while maintaining occupant comfort.

- Based upon observed changes in space temperatures, model potential energy savings in buildings if these set point changes occur in different climate zones around the country.

- Measure and verify occupant comfort and satisfaction with the system among building occupants, facility managers, operations staff, and cybersecurity and IT managers. (A more thorough discussion of this objective follows.)

Evaluating the socially driven HVAC technology from the "human" perspective encompasses multiple perspectives. Beyond the vendor, there are three categories of key players who are critical to the success of the socially driven HVAC technology. They are the Phoenix Courthouse occupants, the facility's management and operations staff (hereafter referred to as M&O), and GSA cybersecurity and IT staff. Each of these groups of key players has distinctive roles and responsibilities and, therefore, interacts with the socially driven HVAC technology in different ways and at different times. What constitutes success varies among these groups. Occupants, for example, may emphasize the technology's ease of use, speed of responsiveness, and similar attributes. M&O staff members may focus on a reduction of their workloads. While both M&O and IT/cybersecurity staff may gauge success in terms of compliance with GSA rules, the two groups care about divergent sets of rules—energy-related for the former group and cybersecurity and IT reliability for the latter group.

Thus the success of a technology is multidimensional. Success also is conditional. Usability and satisfaction are inherently subjective, context-dependent, and subject to change over time. For example, usability can change with familiarity and learning. Satisfaction is also variable rather than fixed over time. And, judgments of overall satisfaction within any single group may reflect an asymmetry wherein negative experiences outweigh positive experiences. An asymmetry also may be evident when considering the three sets of key players. While satisfaction within any single category of key players may be insufficient to determine the success of the socially driven HVAC technology, a single group's strong dissatisfaction could be sufficient to influence decisions about whether to deploy (or continue deploying) the socially driven HVAC technology.

In our evaluation of the socially driven HVAC technology, we gathered qualitative and quantitative data to gauge usability from the different perspectives of the key players defined above. We addressed two main questions: (1) to what extent is the socially driven HVAC technology usable, primarily by occupants? and (2) to what extent do the key players find the socially driven HVAC technology satisfactory? Part of our evaluation identified the attributes of satisfaction relevant to each of the three groups. (Table 1 shows examples of the constituents by group.) Satisfaction is a context-dependent, multifaceted condition that can vary over time. Therefore, we will emphasize the attributes that occupants, M&O staff, and cybersecurity staff identify as affecting their satisfaction more than their levels of satisfaction, per se.

Table 1. Attributes of Satisfaction by Group

Group	Attributes
Occupants	• Technical responsiveness and timeliness of response • Temperature • Air movement • Ease of use • Vendor responsiveness to complaints • Does the socially driven HVAC technology complicate or improve their lives?
Management and Operations	• Time expenditures • Technical effectiveness • Compliance with GSA rules
Cybersecurity/Information Technology	• Sufficient system documentation • Compliance with GSA rules • Time expenditures

Neither the technical functionality nor the use of a technology automatically equates to usability or usefulness of the technology. Similarly, the frequency of use does not strictly imply either satisfaction or dissatisfaction. The success of a technology is affected, but not necessarily determined by, its technological effectiveness. The issue is not just about what a technology can do (e.g., lower the building set points) but how it functions and is experienced in practice. How it works and is experienced in practice depend on multiple variables, including, in this case of the socially driven HVAC technology, how the vendor/helpdesk acts (customer service and responsiveness). Additionally, for this technology, a key feature of its design is nontechnical; specifically, the voting/consensus procedures for shared spaces/ducts. Satisfaction with that aspect of the socially driven HVAC technology may influence occupants' opinions about usability/satisfaction tremendously. If there is dissatisfaction with that aspect alone, occupants may report dissatisfaction with the overall technology or say it does not work.

C. Demonstration Project Location

The vendor's technology was evaluated at the Federal Office Building and Bankruptcy Courthouse in Phoenix, Arizona. The building has eight floors, comprising 289,000 ft^2, and about 350 occupants. The selected building is ideal for testing socially driven HVAC due to several characteristics. First, the building has a VAV HVAC system that is controlled by a digital control system. The socially driven HVAC technology was designed to work with this type of system as it can be very responsive to space conditions within individual zones, and its framework allows the socially driven HVAC software to work within the control system.

Second, the building has a robust BAS system that monitors nearly all the points that are needed for the evaluation. By using the existing BAS system, very few new M&V instruments will be needed for the evaluation, which will allow the project to be conducted in a more cost-effective fashion.

Third, the building has a variety of tenant spaces (e.g., individual offices, cubicles, conference rooms, and courtrooms). This variety allowed a thorough evaluation of the technology's effectiveness within tenant spaces that are representative of those found in GSA buildings across the country.

The socially driven HVAC technology evaluation was conducted as a standalone project. It was not incorporated into a large renovation or change in occupancy. Because the building's operating conditions remained consistent throughout the evaluation, with only the socially driven HVAC system being changed, it made for an excellent opportunity to evaluate the technology's performance.

IV. M&V Evaluation Plan

A. Facility Description

The federal courthouse's HVAC system consists of more than 250 separate zones. Each is served by a VAV "box" that regulates airflow and temperature to the space. VAV boxes serving exterior zones have a hot water coil that gives them the ability to heat space, as needed, during winter months. Interior zones have VAV boxes that only provide cooling but can reduce airflow during periods when minimal cooling is needed.

All the VAV boxes are controlled through a central BAS. It is on the BAS that the socially driven HVAC software was applied. It should be noted that the socially driven HVAC technology is principally a software product. There is not a physical piece of equipment (e.g., chiller, light fixture, or window glazing) that is installed somewhere within the building.

The facility has a robust BAS system, which gave the team the ability to track space temperatures along with many other parameters. Because of the system's strength, no additional meters were required to be installed.

The facility is also very well run. It already is exercising energy-saving control strategies such as an occupied/unoccupied setback schedule. The M&O staff were also very enthused about implementing the socially driven HVAC technology and were cooperative in every way during this project.

B. Technology Specification

The socially driven HVAC technology consists principally of two items.

First is the user interface, which allows building occupants to communicate with the technology regarding their comfort levels. The interface is available on users' individual workstations. It can also be downloaded as an app to a smartphone or similar device.

The user interface is very straightforward. It allows users to express one of three opinions about their space conditions: "I'm too hot," "I'm too cold," or "I am comfortable." These opinions are then routed to the second component of the socially driven HVAC technology, the software controls package.

The software controls package works within the facility's BAS system. When an occupant sends an "I'm too hot/cold" message to the package, it immediately adjusts the VAV box serving that area to provide a burst of airflow to mitigate the discomfort. This burst is designed to do two things for the occupant. First, it is large enough that the flow can be heard through the HVAC diffusers, which provides audible feedback that the occupant's space conditions are being adjusted to suit his/her desires. Second, the burst does change the space temperature to make it more comfortable for the occupant.

After the burst of air, the software controls package continues adjusting the HVAC system in ways that save energy. This includes reducing the airflow after the burst and continuously monitoring and adjusting space conditions to a more energy-conserving state. This process continues until it receives another message from the user interface, at which time it adjusts the HVAC system again to balance occupant comfort and save energy.

If the occupant is located within an area where one VAV box serves multiple people, the controls package can be set so that it monitors feedback from every person in the space. It then adjusts the HVAC system based upon a "vote" rather than adjusting after every individual feedback from a user. This allows the controls package to provide comfort to a wide variety of people while still saving energy.

This technology is proprietary and was still in its beta development stage at the time of the GSA Green Proving Ground program (GPG) evaluation.

C. Technology Deployment

The incumbent technology at the Federal Building and US Courthouse in Phoenix was a conventional VAV HVAC system controlled by a robust BAS system. Occupants who were uncomfortable had to complete a work order, submit it to building operations personnel, and wait for them to adjust the space thermostat manually. There was no technology that was comparable to the socially driven HVAC technology.

The socially driven HVAC technology was installed by the vendor to interact with the BAS. Before installation, extensive security checks were required. These included having the vendor personnel pass GSA security clearances to obtain access to the BAS. Also, the software package had to meet GSA IT security standards.

D. Test Plan

The M&V plan for the socially driven HVAC technology consisted of three major parts. The first part consisted of making sure that the technology provided a consistent burst of air in response to input from an occupant. The second was to determine whether the technology did indeed have the ability to track customer comfort over a longer period and reset thermostat settings to a more energy-saving set point. The third was to survey occupants and determine whether their comfort levels were maintained and to gauge their overall satisfaction with the technology.

Measuring the socially driven HVAC's ability to provide an instantaneous burst of air was a very straightforward process. After commissioning the system on March 24, 2014, the vendor was accompanied by GSA and ORNL team members into 20 different randomly selected spaces. In each space, a user interface was used to communicate a message to the socially driven HVAC system that would indicate discomfort by space occupants. If the technology was working effectively, all team members would notice an immediate burst of cool air into the space. This burst would be noticed both tactilely (by air on the skin) and audibly (by a rushing noise as airflow increased through the respective space's HVAC diffuser). Results were documented for incorporation in the findings.

Measuring whether the technology could adjust space temperatures to an energy-saving setting while maintaining comfort was accomplished through the building's BAS system. As mentioned previously, the site's BAS system is very robust and includes the ability to track space temperatures over time. This data point was tracked in 5-minute intervals from August 2013 to July 2014 for every HVAC zone within the building. The socially driven HVAC technology went active on March 24, 2014. All measurements prior to that date reflected the building's "baseline" temperatures. All measurements after the technology went active reflected changes due to the technology being implemented.

The technology's ability to move the space temperature to a more energy-saving point would be measured by graphing the space temperatures and looking for a noticeable change after March 24, 2014. Given that this month is part of the cooling season in Phoenix, it was expected that space temperatures would begin to rise to a point where less cooling energy was required. If no such rise was noticed, this would be evidence that the system was not saving energy as purported.

M&V FOR OCCUPANT COMFORT AND SATISFACTION

BASELINE and SOCIALLY DRIVEN HVAC TECHNOLOGY SURVEYS

Two online occupant surveys were conducted. The baseline survey opened on March 5, 2014, and closed on Friday, March 21, before the socially driven HVAC technology's launch on March 24th. The purpose was to collect baseline data on the thermal comfort of the tenants of the Federal Building and US Courthouse in Phoenix. The GSA assistant property manager distributed an email to tenant agency department heads, who were asked to forward the email to their staff members. A link to the survey was provided in the email. The survey consisted of a total of 20 questions (see Appendix B). The survey was kept to a length of five computer-screen pages, as requested by GSA, so that its length did not overwhelm potential respondents and reduce their willingness to complete the survey. It should be noted that not all people answered all questions. We did not require answers to each question as this requirement has been suggested to potentially increase respondents' abandonment of surveys.[3,4,5,6]

The socially driven HVAC technology survey was open for 3 weeks from September 4, 2014, through September 26, 2014. This online survey was conducted after the socially driven HVAC technology had been deployed in the building for about 5 months. The purpose was to evaluate the socially driven HVAC technology from the building occupants' perspectives. As with the baseline survey, the building's GSA assistant property manager distributed an email to the agency department heads, who were asked to forward the message to their staff members. A link to the survey was provided in the email. The survey consisted of a total of 32 questions (see Appendix C). As with the baseline survey, the survey length was five pages and did not require answers to each question.

There were three categories of questions common to both the baseline and the socially driven HVAC technology surveys: Background, Personal Workspace Location and Description, and Thermal Comfort in Your Workspace. The questions within these categories were the same in both surveys (see Table 2). A fourth category of questions was added to the socially driven HVAC technology survey. Table 3 shows the types of information requested for this fourth category, which was entitled "Your Use of The Socially Driven HVAC Technology."

Table 2. Information Requested by Survey: Question Categories Common to Baseline and Socially Driven HVAC Technology Surveys

Question Category	Type of Information Requested
Background	Occupant characterization • Tenure in the building and workspace • Hours spent in workspace (weekly) • Type of work • Age • Gender

Personal Workspace Location and Description	• Location (N, S, E, or W) of
	  ▪ Workspace
	  ▪ Closest windows
	• Distance from exterior walls and windows
	• Floor in building
	• Office type (e.g., private, cubicle)

[3] Sue, Valerie M., & Ritter, Lois A. 2012. *Conducting Online Surveys* (2nd ed.). Thousand Oaks, CA: Sage.
[4] Lynn, Peter, editor, 2009. *Methodology of Longitudinal Surveys*. United Kingdom: John Wiley & Sons, Ltd.
[5] Stieger, Stefan, Relps, Ulf-Dietrich, & Voracek, Martin. 2007. Forced-Response in Online Surveys: Bias from Reactance and an Increase in Sex-Specific Dropout. *Journal of the American Society for Information Science and Technology*, 58(11): 1653-1660.
[6] Schonlau, Mathias, Fricker, Ronald D. Jr., & Elliott, Marc N. 2002. *Conducting Research Surveys via E-mail and the Web*. Santa Monica, CA: RAND.

Table 2 (continued)

Question Category	Type of Information Requested
Thermal Comfort in Your Workspace	• General satisfaction with temperature: ▪ In warm/hot and cool/cold weather ▪ By time of day • Sources of thermal discomfort (choices provided) • Adjustments made (e.g., blinds, fans, personal heaters) when not satisfied with temperature [choices were provided][a]

[a]In the baseline survey, one of the final questions in the third category asked respondents to identify what they personally adjust (e.g., fans, blinds, vents) when they are not satisfied with the thermal comfort in their workspace. For the socially driven HVAC technology survey, this question was moved from the "Thermal Comfort" category to the "Your Use of the Socially Driven HVAC Technology" category to ascertain what those adjustments were in conjunction with the socially driven HVAC technology.

Table 3. Information Requested by Survey: "Your Use of the Socially Driven HVAC Technology" Question Category

Question Category	Type of Information Requested
Your Use of Socially Driven HVAC Technology	• How often • Purpose (to cool or warm workspace, or to indicate comfort with current conditions) • For whom • Likes and dislikes about the socially driven HVAC technology • Satisfaction with ○ Ease of use ○ Access ○ Technical support ○ Change in thermal comfort of workspace ○ Responsiveness to request for change of temperature ○ Voting zones • When, during the day, is the socially driven HVAC technology used to ○ Cool the space ○ Warm the space • If and how often service calls are made to facilities manager in conjunction with use of the socially driven HVAC technology • Adjustments made (e.g., blinds, fans, personal heaters) when not satisfied with temperature [choices were provided]

E. Instrumentation Plan

As discussed previously, the building's BAS system is very robust and has the ability to track myriad data points within the space. For purposes of this study, the following points were recorded at 5-minute intervals during the evaluation period.

- Supply air temperatures (degrees Fahrenheit) for each air handler unit.
- Supply airflow rate (cfm) for each VAV box.

- Thermostat setting for each VAV box.
- Space temperature for the zone served by each VAV box.
- Supply air temperature for each VAV box that has a reheat coil.
- The valve position for the reheat coil valve for each VAV box that has one.

The principal data point analyzed for this report was the space temperature for each zone. The other points were tracked to provide correlating data, as needed, during the analysis.

V. Results

For reference, the following paragraph is quoted from Section IV.D. of this report. It outlines the three tests that were conducted to evaluate the performance of the socially driven HVAC system.

> *The M&V plan for the socially driven HVAC technology consisted of three major parts. The first part consisted of making sure that the technology provided a consistent burst of air in response to input from an occupant. The second was to determine whether the technology did indeed have the ability to track customer comfort over a longer period and reset thermostat settings to a more energy-saving set point. The third was to survey occupants and determine whether their comfort levels were maintained and to gauge their overall satisfaction with the technology.*

Testing the first part was very straightforward. After commissioning the socially driven HVAC system on March 21, 2014, GSA and ORNL team members accompanied the vendor into 20 different randomly selected spaces. In each space, a user interface was used to communicate a message to the socially driven HVAC that would indicate discomfort by space occupants. If the technology was working effectively, all team members would notice an immediate burst of cool air into the space.

In each of the 20 spaces, when the message was entered into the user interface, team members noticed the sound of rushing air as the set VAV box adjusted to its full-open position. In spaces where the ceiling was low enough, team members also tactilely detected a slight breeze.

The audible and tactile sensing of the immediate extra airflow is a positive indication that the socially driven HVAC technology does, in fact, have the ability to provide a burst of air to immediately address a hot or cold complaint by an occupant.

Evaluating the socially driven HVAC technology's ability to keep track of an occupant's comfort level and adjust the thermostat to a more energy-saving set point was accomplished by documenting interior space temperatures and how they changed from the baseline to the test period. If the socially driven HVAC technology was operating as purported, space temperatures would show a change to a more energy-saving position after installation of the technology.

Figure 1 shows the initial results from a typical zone within the building.

The graph shows the space temperature within this zone for the 3-month period surrounding installation of the socially driven HVAC system. In this graph, the temperatures show a very clear rise that began when the system was installed. This graph is similar to what was found in other zones within the building. On average, space temperature rose about 2°F within the building. This gave strong indication that the socially driven

HVAC technology was, in fact, working as promised to reset the space temperature to a point that would save more energy.

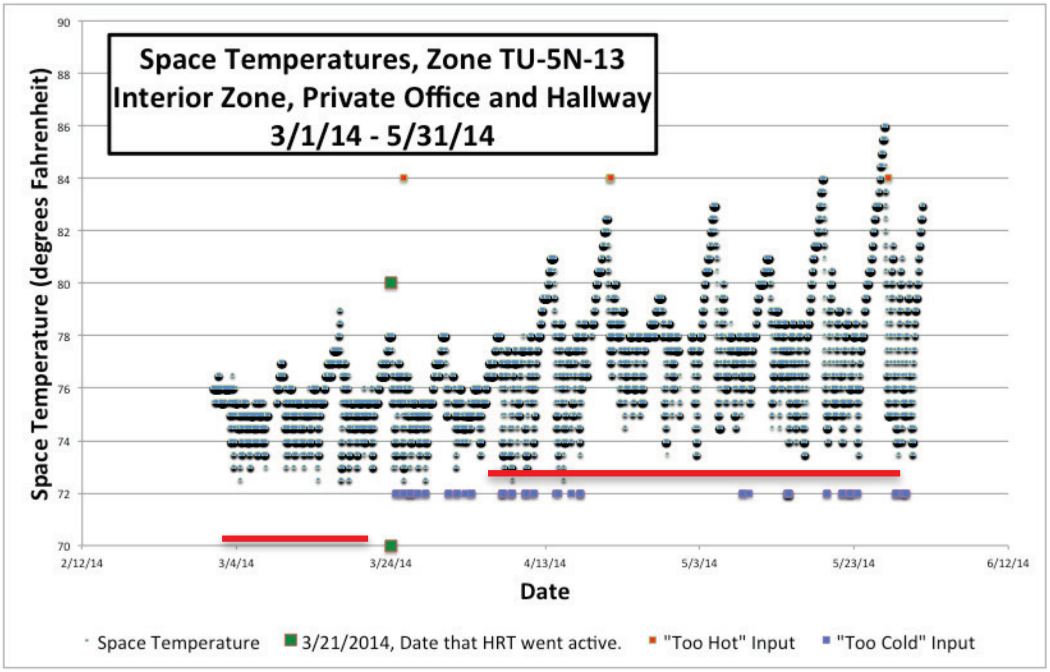

Figure 1. Initial results for zone TU-5N-13.

Figure 2 is the same zone for the extended period of November 2013–July 2014.

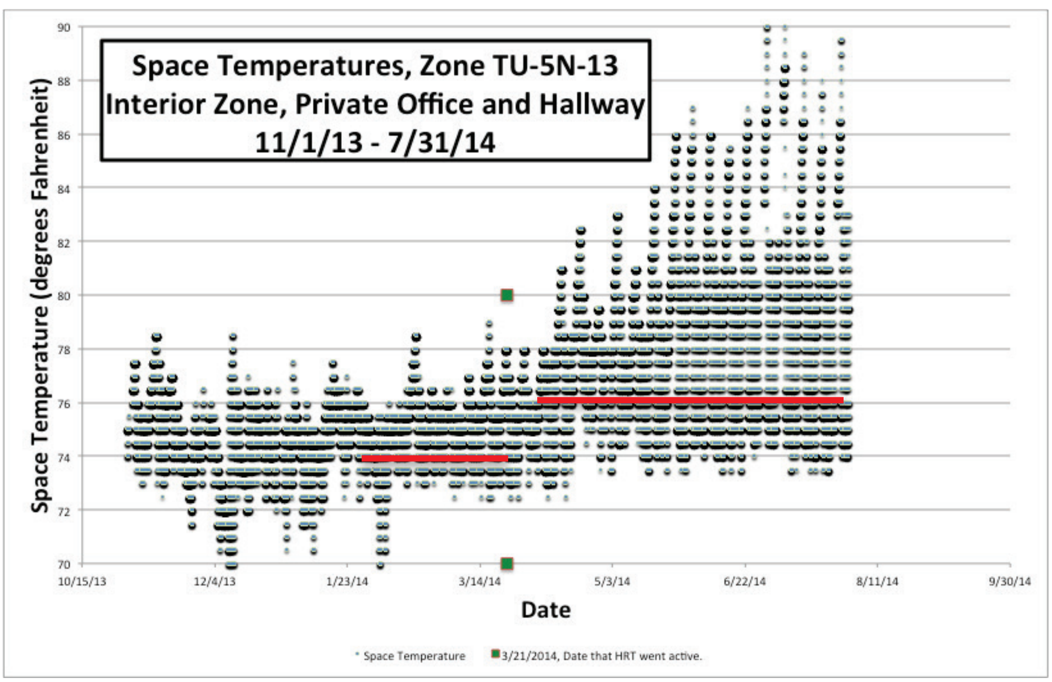

Figure 2. Results for zone TU-5N-13 for the extended period of November 2013–July 2014.

Data within the graph clearly show that the space temperatures during the day changed when the socially driven HVAC system was installed, and this change was maintained going forward throughout the test period. Overall, the average change in space temperature within the facility was 2°F.[8] Daytime temperatures in the space made a noticeable move at the time of installation and remained that way for the duration of the summer. This indicates clearly that the socially driven HVAC technology has the ability to move the space's temperature setting to a more energy-saving position while maintaining space comfort based on feedback.

Because of time and budget limitations, the socially driven HVAC technology was tested only during the cooling season at the facility in Phoenix, Arizona. As discussed previously, this site documented an energy-saving 2°F shift in space temperature. It was not possible to test this technology in other climate zones or seasons. While discussing the findings and limitations of the test and how to apply them to a broader range of sites than just Phoenix, two possible conclusions were reached.

The first possible conclusion is that, in any given facility, the socially driven HVAC technology would allow the occupants to be comfortable while at the same time the site's thermostats were shifted by 2°F to a more energy-saving set point. For example, the Phoenix facility had normal set points of 70°F for heating and 75°F for cooling. With the technology installed, the set points would be allowed to shift to 68°F and 77°F.

The second possible conclusion is that, in any given facility, the technology would allow the occupants to be comfortable when the heating and cooling set points were 68°F and 77°F, regardless of what the initial thermostat set points were. This potential conclusion is based on findings that most facilities in the GSA inventory have thermostat set points of 70°F and 73°F, rather than 70°F and 75°F as with Phoenix. Given this fact, if the technology would allow occupants to be comfortable at 68°F and 77°F, then there is potential that a facility with the 70/73°F set points would experience greater energy savings than one which began at 70/75°F.

To convert energy-saving shifts in room temperature to economic savings for both scenarios, energy modeling techniques were applied. 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 the Pacific Northwest National Laboratory and are used as a standard in many types of energy comparative analyses. Descriptions of the models are as follows.

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

Figure 3 is a map of the 16 climate zones in which the three building types were modeled.

[8] Please note that the high temperatures recorded from roughly May 1 going forward reflect the nighttime temperatures within the space. The test facility was operating its HVAC such that it was functionally turned off during hours when the building was unoccupied. Due to high ambient temperatures in Phoenix, the space temperatures rose during these night and weekend hours when the HVAC system was turned off to save energy. The focus of this study was the density of data points between 74°F and 76°F. These reflect the space temperatures during periods when the building was occupied.

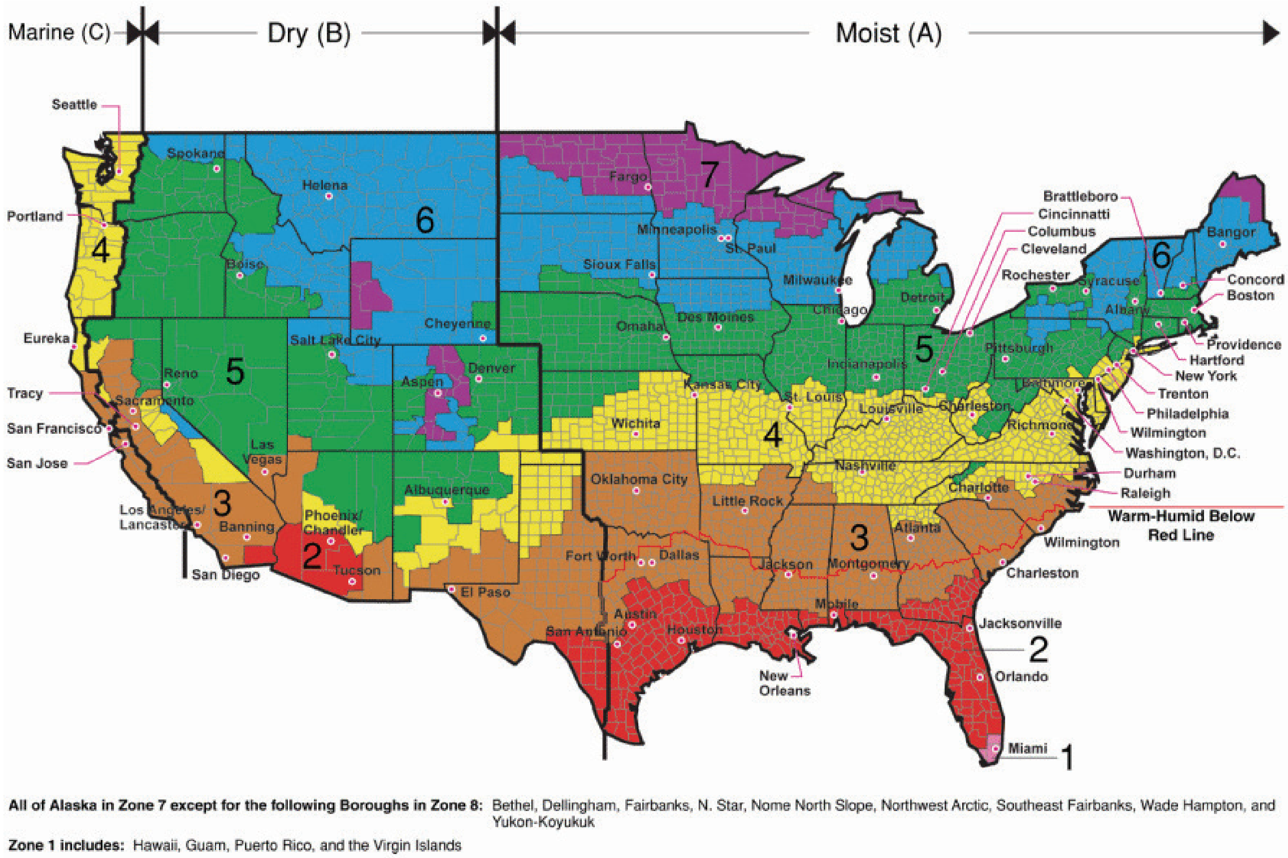

Figure 3. Climate zones in the United States.

Energy models were run for each of the three buildings within the climates of 16 different cities that represent areas around the country. To replicate the first possible conclusion, the models first were run using standard conditions where the heating set point was 70°F and the cooling set point 75°F.[9] They were then run with the space temperature set point being changed by 2°F to a more energy-saving point, 68°F for heating and 77°F for cooling. The change in energy consumption was calculated. Local utility rates were applied to the energy saved to determine total potential energy saving at each location. Results are tabulated in Tables 4, 5, and 6.

[9] GSA PBS-100 "Facilities Standards for the Public Building Service, 5.1 Mechanical Performance Requirements" allows for significant variation in thermostat setting depending upon the performance standards being attained by the building. Thermostat settings can vary as low as 65°F for heating and 80°F for cooling.

Table 4. Total Potential Energy Savings for Small Office Buildings in Each of the 16 Climate Zones for 70°F–75°F Set Point with 68°F–77°F Setback

Data for "Small Office Buildings" (based on 70-75dF setpoint with 68-77dF setback)			Annual Electricity Savings (kwh/year)	Unit Cost of Electricity ($/kwh)	Annual Electricity Cost Savings ($/year)	Annual Heat Energy Saved (1000 btu/year)	Unit Cost of Natural Gas ($/MCF)	Annual Natural Gas Cost Savings ($/year)	Total Annual Energy Cost Savings ($/year)	Subscription Cost "Break Even" Point ($/sf/yr)
Climate Zone #	City									
1A	Miami	FL	12,731	$0.0992	$1,263	384	$11.04	$4	$1,267	$0.230
2A	Houston	TX	9,920	$0.0813	$807	9,824	$7.24	$71	$878	$0.160
2B	Phoenix	AZ	9,370	$0.1008	$944	7,768	$8.43	$65	$1,010	$0.184
3A	Atlanta	GA	7,828	$0.1042	$816	17,160	$9.37	$161	$976	$0.178
3B-coast	Los Angeles	CA	7,359	$0.1535	$1,130	9,605	$7.05	$68	$1,197	$0.218
3B	Las Vegas	NV	8,077	$0.0947	$765	13,615	$6.61	$90	$855	$0.155
3C	San Francisco	CA	4,946	$0.1535	$759	27,138	$7.05	$191	$951	$0.173
4A	Baltimore	MD	5,478	$0.1137	$623	23,854	$10.00	$239	$861	$0.157
4B	Albuquerque	NM	5,378	$0.1043	$561	20,894	$6.69	$140	$701	$0.127
4C	Seattle	WA	4,548	$0.0793	$361	27,774	$9.82	$273	$633	$0.115
5A	Chicago	IL	3,984	$0.0873	$348	29,205	$7.77	$227	$575	$0.104
5B	Boulder	CO	3,840	$0.1030	$395	24,984	$7.26	$181	$577	$0.105
6A	Minneapolis	MN	3,457	$0.0974	$337	30,483	$6.82	$208	$545	$0.099
6B	Helena	MT	2,832	$0.0950	$269	30,213	$8.13	$246	$515	$0.094
7	Duluth	MN	2,467	$0.0974	$240	35,966	$6.82	$245	$486	$0.088
8	Fairbanks	AK	1,497	$0.1719	$257	43,550	$8.41	$366	$624	$0.113

Table 5. Total Potential Energy Savings for Medium Office Buildings in Each of the 16 Climate Zones for 70°F–75°F Set Point with 68°F–77°F Setback

Data for "Medium Office Buildings" (based on 70-75dF setpoint with 68-77dF setback)			Annual Electricity Savings (kwh/year)	Unit Cost of Electricity ($/kwh)	Annual Electricity Cost Savings ($/year)	Annual Heat Energy Saved (1000 btu/year)	Unit Cost of Natural Gas ($/MCF)	Annual Natural Gas Cost Savings ($/year)	Total Annual Energy Cost Savings ($/year)	Subscription Cost "Break Even" Point ($/sf/yr)
Climate Zone #	City									
1A	Miami	FL	61,164	$0.0992	$6,068	118,887	$11.04	$1,313	$7,380	$0.138
2A	Houston	TX	46,774	$0.0813	$3,803	199,528	$7.24	$1,445	$5,247	$0.098
2B	Phoenix	AZ	42,356	$0.1008	$4,270	252,927	$8.43	$2,132	$6,402	$0.119
3A	Atlanta	GA	38,720	$0.1042	$4,035	253,745	$9.37	$2,378	$6,412	$0.120
3B-coast	Los Angeles	CA	34,204	$0.1535	$5,250	401,591	$7.05	$2,831	$8,081	$0.151
3B	Las Vegas	NV	34,082	$0.0947	$3,228	276,660	$6.61	$1,829	$5,056	$0.094
3C	San Francisco	CA	15,865	$0.1535	$2,435	479,893	$7.05	$3,383	$5,819	$0.108
4A	Baltimore	MD	32,564	$0.1137	$3,703	260,118	$10.00	$2,601	$6,304	$0.118
4B	Albuquerque	NM	22,993	$0.1043	$2,398	261,769	$6.69	$1,751	$4,149	$0.077
4C	Seattle	WA	12,630	$0.0793	$1,002	428,242	$9.82	$4,205	$5,207	$0.097
5A	Chicago	IL	17,602	$0.0873	$1,537	277,863	$7.77	$2,159	$3,696	$0.069
5B	Boulder	CO	16,456	$0.1030	$1,695	272,101	$7.26	$1,975	$3,670	$0.068
6A	Minneapolis	MN	15,346	$0.0974	$1,495	261,760	$6.82	$1,785	$3,280	$0.061
6B	Helena	MT	11,646	$0.0950	$1,106	296,491	$8.13	$2,410	$3,517	$0.066
7	Duluth	MN	10,153	$0.0974	$989	331,143	$6.82	$2,258	$3,247	$0.061
8	Fairbanks	AK	8,557	$0.1719	$1,471	389,396	$8.41	$3,275	$4,746	$0.088

Table 6. Total Potential Energy Savings for Large Office Buildings in Each of the 16 Climate Zones for 70°F–75°F Set Point with 68°F–77°F Setback

Data for "Large Office Buildings" (based on 70-75dF setpoint with 68-77dF setback)			Annual Electricity Savings (kwh/year)	Unit Cost of Electricity ($/kwh)	Annual Electricity Cost Savings ($/year)	Annual Heat Energy Saved (1000 btu/year)	Unit Cost of Natural Gas ($/MCF)	Annual Natural Gas Cost Savings ($/year)	Total Annual Energy Cost Savings ($/year)	Subscription Cost "Break Even" Point ($/sf/yr)
Climate Zone #	City									
1A	Miami	FL	225,009	$0.0992	$22,321	612,047	$11.04	$6,757	$29,078	$0.058
2A	Houston	TX	221,590	$0.0813	$18,015	1,843,553	$7.24	$13,347	$31,363	$0.063
2B	Phoenix	AZ	167,013	$0.1008	$16,835	2,041,113	$8.43	$17,207	$34,042	$0.068
3A	Atlanta	GA	189,592	$0.1042	$19,755	2,329,885	$9.37	$21,831	$41,587	$0.083
3B-coast	Los Angeles	CA	203,309	$0.1535	$31,208	3,323,038	$7.05	$23,427	$54,635	$0.110
3B	Las Vegas	NV	135,710	$0.0947	$12,852	2,450,581	$6.61	$16,198	$29,050	$0.058
3C	San Francisco	CA	107,125	$0.1535	$16,444	4,335,425	$7.05	$30,565	$47,008	$0.094
4A	Baltimore	MD	170,806	$0.1137	$19,421	2,483,834	$10.00	$24,838	$44,259	$0.089
4B	Albuquerque	NM	100,244	$0.1043	$10,455	2,484,086	$6.69	$16,619	$27,074	$0.054
4C	Seattle	WA	87,694	$0.0793	$6,954	4,087,492	$9.82	$40,139	$47,093	$0.094
5A	Chicago	IL	95,822	$0.0873	$8,365	2,712,159	$7.77	$21,073	$29,439	$0.059
5B	Boulder	CO	83,526	$0.1030	$8,603	2,661,630	$7.26	$19,323	$27,927	$0.056
6A	Minneapolis	MN	89,192	$0.0974	$8,687	2,592,568	$6.82	$17,681	$26,369	$0.053
6B	Helena	MT	69,019	$0.0950	$6,557	2,940,190	$8.13	$23,904	$30,461	$0.061
7	Duluth	MN	66,764	$0.0974	$6,503	3,359,435	$6.82	$22,911	$29,414	$0.059
8	Fairbanks	AK	57,295	$0.1719	$9,849	3,941,922	$8.41	$33,152	$43,001	$0.086

To model the potential energy savings from the second possible conclusion, the same energy modeling was conducted, except this time the base thermostat settings were 70°F and 73°F, which were then shifted to 68°F and 77°F. The results are captured in Tables 7, 8, and 9.

Table 7. Total Potential Energy Savings for Small Office Buildings in Each of the 16 Climate Zones for 70°F–73°F Set Point with 68°F–77°F Setback

Data for "Small Office Buildings" (based on 70-73dF setpoint with 68-77dF setback)			Annual Electricity Savings (kwh/year)	Unit Cost of Electricity ($/kwh)	Annual Electricity Cost Savings ($/year)	Annual Heat Energy Saved (1000 btu/year)	Unit Cost of Natural Gas ($/MCF)	Annual Natural Gas Cost Savings ($/year)	Total Annual Energy Cost Savings ($/year)	Subscription Cost "Break Even" Point ($/sf/yr)
Climate Zone #	City									
1A	Miami	FL	26,730	$0.0992	$2,652	309	$11.04	$3	$2,655	$0.483
2A	Houston	TX	21,219	$0.0813	$1,725	7,226	$7.24	$52	$1,777	$0.323
2B	Phoenix	AZ	20,277	$0.1008	$2,044	5,679	$8.43	$48	$2,092	$0.380
3A	Atlanta	GA	17,430	$0.1042	$1,816	11,840	$9.37	$111	$1,927	$0.350
3B-coast	Los Angeles	CA	17,547	$0.1535	$2,694	9,604	$7.05	$68	$2,761	$0.502
3B	Las Vegas	NV	16,540	$0.0947	$1,566	7,991	$6.61	$53	$1,619	$0.294
3C	San Francisco	CA	11,126	$0.1535	$1,708	21,645	$7.05	$153	$1,860	$0.338
4A	Baltimore	MD	12,940	$0.1137	$1,471	16,123	$10.00	$161	$1,632	$0.297
4B	Albuquerque	NM	13,433	$0.1043	$1,401	15,033	$6.69	$101	$1,502	$0.273
4C	Seattle	WA	10,269	$0.0793	$814	18,484	$9.82	$182	$996	$0.181
5A	Chicago	IL	9,096	$0.0873	$794	25,437	$7.77	$198	$992	$0.180
5B	Boulder	CO	8,771	$0.1030	$903	22,623	$7.26	$164	$1,068	$0.194
6A	Minneapolis	MN	8,151	$0.0974	$794	27,463	$6.82	$187	$981	$0.178
6B	Helena	MT	6,528	$0.0950	$620	27,901	$8.13	$227	$847	$0.154
7	Duluth	MN	5,927	$0.0974	$577	32,619	$6.82	$222	$800	$0.145
8	Fairbanks	AK	4,048	$0.1719	$696	40,198	$8.41	$338	$1,034	$0.188

Table 8. Total Potential Energy Savings for Medium Office Buildings in Each of the 16 Climate Zones for 70°F–73°F Set Point with 68°F–77°F Setback

Data for "Medium Office Buildings" (based on 70-73dF setpoint with 68-77dF setback)			Annual Electricity Savings (kwh/year)	Unit Cost of Electricity ($/kwh)	Annual Electricity Cost Savings ($/year)	Annual Heat Energy Saved (1000 btu/year)	Unit Cost of Natural Gas ($/MCF)	Annual Natural Gas Cost Savings ($/year)	Total Annual Energy Cost Savings ($/year)	Subscription Cost "Break Even" Point ($/sf/yr)
Climate Zone #	City									
1A	Miami	FL	127,596	$0.0992	$12,658	263,445	$11.04	$2,908	$15,566	$0.290
2A	Houston	TX	97,984	$0.0813	$7,966	349,755	$7.24	$2,532	$10,498	$0.196
2B	Phoenix	AZ	90,408	$0.1008	$9,113	425,832	$8.43	$3,590	$12,703	$0.237
3A	Atlanta	GA	79,534	$0.1042	$8,287	409,891	$9.37	$3,841	$12,128	$0.226
3B-coast	Los Angeles	CA	73,880	$0.1535	$11,341	444,215	$7.05	$3,132	$14,472	$0.270
3B	Las Vegas	NV	73,815	$0.0947	$6,990	667,880	$6.61	$4,415	$11,405	$0.213
3C	San Francisco	CA	33,260	$0.1535	$5,105	732,372	$7.05	$5,163	$10,269	$0.191
4A	Baltimore	MD	67,404	$0.1137	$7,664	404,104	$10.00	$4,041	$11,705	$0.218
4B	Albuquerque	NM	50,621	$0.1043	$5,280	422,542	$6.69	$2,827	$8,107	$0.151
4C	Seattle	WA	28,167	$0.0793	$2,234	663,920	$9.82	$6,520	$8,753	$0.163
5A	Chicago	IL	39,236	$0.0873	$3,425	409,655	$7.77	$3,183	$6,608	$0.123
5B	Boulder	CO	37,049	$0.1030	$3,816	418,377	$7.26	$3,037	$6,853	$0.128
6A	Minneapolis	MN	34,397	$0.0974	$3,350	375,702	$6.82	$2,562	$5,913	$0.110
6B	Helena	MT	26,178	$0.0950	$2,487	427,545	$8.13	$3,476	$5,963	$0.111
7	Duluth	MN	22,659	$0.0974	$2,207	462,282	$6.82	$3,153	$5,360	$0.100
8	Fairbanks	AK	18,739	$0.1719	$3,221	529,872	$8.41	$4,456	$7,677	$0.143

Table 9. Total Potential Energy Savings for Large Office Buildings in Each of the 16 Climate Zones for 70°F–73°F Set Point with 68°F–77°F Setback

Data for "Large Office Buildings" (based on 70-73dF setpoint with 68-77dF setback)			Annual Electricity Savings (kwh/year)	Unit Cost of Electricity ($/kwh)	Annual Electricity Cost Savings ($/year)	Annual Heat Energy Saved (1000 btu/year)	Unit Cost of Natural Gas ($/MCF)	Annual Natural Gas Cost Savings ($/year)	Total Annual Energy Cost Savings ($/year)	Subscription Cost "Break Even" Point ($/sf/yr)
Climate Zone #	City									
1A	Miami	FL	454,615	$0.0992	$45,098	1,540,993	$11.04	$17,013	$62,110	$0.125
2A	Houston	TX	439,371	$0.0813	$35,721	3,241,843	$7.24	$23,471	$59,192	$0.119
2B	Phoenix	AZ	333,608	$0.1008	$33,628	3,480,194	$8.43	$29,338	$62,966	$0.126
3A	Atlanta	GA	370,830	$0.1042	$38,641	3,872,576	$9.37	$36,286	$74,927	$0.150
3B-coast	Los Angeles	CA	284,958	$0.1535	$43,741	3,985,406	$7.05	$28,097	$71,838	$0.144
3B	Las Vegas	NV	389,716	$0.0947	$36,906	5,573,394	$6.61	$36,840	$73,746	$0.148
3C	San Francisco	CA	208,695	$0.1535	$32,035	6,826,792	$7.05	$48,129	$80,164	$0.161
4A	Baltimore	MD	355,682	$0.1137	$40,441	4,040,905	$10.00	$40,409	$80,850	$0.162
4B	Albuquerque	NM	212,734	$0.1043	$22,188	4,127,688	$6.69	$27,614	$49,802	$0.100
4C	Seattle	WA	173,546	$0.0793	$13,762	6,472,373	$9.82	$63,559	$77,321	$0.155
5A	Chicago	IL	201,021	$0.0873	$17,549	4,242,695	$7.77	$32,966	$50,515	$0.101
5B	Boulder	CO	178,685	$0.1030	$18,405	4,357,726	$7.26	$31,637	$50,042	$0.100
6A	Minneapolis	MN	187,777	$0.0974	$18,290	4,019,453	$6.82	$27,413	$45,702	$0.092
6B	Helena	MT	146,391	$0.0950	$13,907	4,638,239	$8.13	$37,709	$51,616	$0.104
7	Duluth	MN	141,269	$0.0974	$13,760	5,062,448	$6.82	$34,526	$48,286	$0.097
8	Fairbanks	AK	57,295	$0.1719	$9,849	5,838,957	$8.41	$49,106	$58,955	$0.118

As discussed in previous paragraphs, the evaluation documented a 2°F shift in space temperatures during the summer season in Phoenix. There are different ways that this can be interpreted. There are also many factors that could potentially influence this shift in other climate zones and seasons. The following lists some of those potential factors, but by no means is it meant to be an all-inclusive list.

- Normal variations in outside air conditions.
- Normal amounts of clothing worn by residents of that climate zone.
- Tolerance to temperature changes experienced by residents of that climate zone.
- Enforcement of “no personal heaters or fans” policy by building management.
- Initial thermostat set points at the facility.
- The facility’s limitations as to the extent the set points are allowed to drift. For example, is the facility a data center or other critical space? Are there policies in place that restrict widening of HVAC set points?
- Building occupancy patterns.

Because of potential variations, each site considering the use of this technology is encouraged to work closely with the vendor to determine potential energy and energy cost savings for the particular facility.

ECONOMIC ANALYSIS

Under normal circumstances, a GPG project would look at the installed cost of the new technology being evaluated and determine whether the energy savings potential and operating costs can justify the first cost over the life of the product. In this case, at the time of this report, the socially driven HVAC technology is a subscription-based service, and therefore a typical payback calculation would not be a relevant means of evaluation.

Because of the complexity and uncertainty involved in this process, this report will not attempt a detailed life-cycle cost analysis of the socially driven HVAC technology. However, the energy saving tables shown above have a column on the far right side titled “Subscription Cost ‘Break Even’ Point ($/sf/yr)." This cost reflects the annual energy cost savings divided by the total square footage of the building that was modeled. If a building manager is considering this technology, and the vendor proposes a subscription cost that is less than the amount shown in this column, the technology should pay for itself on a rolling basis. If the vendor proposes a cost that is more than this column’s amount, simply divide the proposed cost by the figure in this column to determine the simple payback period. At the time of evaluation, the vendor provided a subscription cost range of $0.12–$0.60/sf/yr, depending on the size, complexity, and duration of the service.

Another factor considered in life-cycle cost analyses is maintenance cost and whether there is any change in cost (reduction or addition) associated with the new technology. At the Phoenix facility, maintenance staff did document a reduced number of hot/cold calls after the socially driven HVAC technology was installed. This is attributable to the occupants’ ability to directly enter their comfort levels into the technology’s interface and not having to contact the site’s O&M personnel. The O&M contractor estimates that 23.5 person-hours were saved by fewer hot/cold calls or about $882 in labor. However, building management noted that the current structure of the O&M contract prohibits GSA from having its annual bill reduced by this amount. Therefore, any labor savings are not truly seen by GSA.

Also, during the test period, the O&M contractor felt that it needed to manually verify the set points within each room to make sure that the equipment was reporting accurately. This activity took about

1.5 hours/week. This activity is not something that would be expected at every installation that uses the new technology. However, it is included here as a reference point.

Building O&M personnel estimate, using their own method, that about $7,800 in net labor and energy savings was attributable to the technology during the evaluation period. This is less than what is shown in energy modeling efforts for two reasons. First, the test period was only for 3 months, whereas the modeling exercise looked at 12 months of projected energy savings. Second, the Phoenix building has only 289,000 ft^2 of space, whereas the "large office building" model has 498,500 ft^2. Given these factors, the authors believe that the estimated savings from the O&M contractor are consistent with what the energy modeling exercise forecasts for probable annual energy savings.

The report authors hope that this column [Subscription Cost "Break Even" Point ($/sf/yr)] will give facility managers a straightforward way to determine the economic viability of the socially driven HVAC optimization in their particular set of circumstances.

SUMMARY OF RESULTS FROM OCCUPANT SURVEYS

To evaluate how building occupants, maintenance staff, and GSA management perceived the socially driven HVAC optimization technology, ORNL used extensive baseline and post-installation surveys and interviews. Data were gathered across the project's entire duration in multiple ways. The results and detailed analysis of these data are included in the appendices.

As a very high level summary, it can be concluded that building personnel were generally pleased with the technology's results (Figure 4). In post-installation surveys of customer satisfaction, occupants were asked "To what extent has your satisfaction with the thermal comfort of your workspace changed as a result of the socially driven HVAC technology?" Figure 4 shows that 83% of occupants responding to the survey indicated that the technology increased their comfort levels.

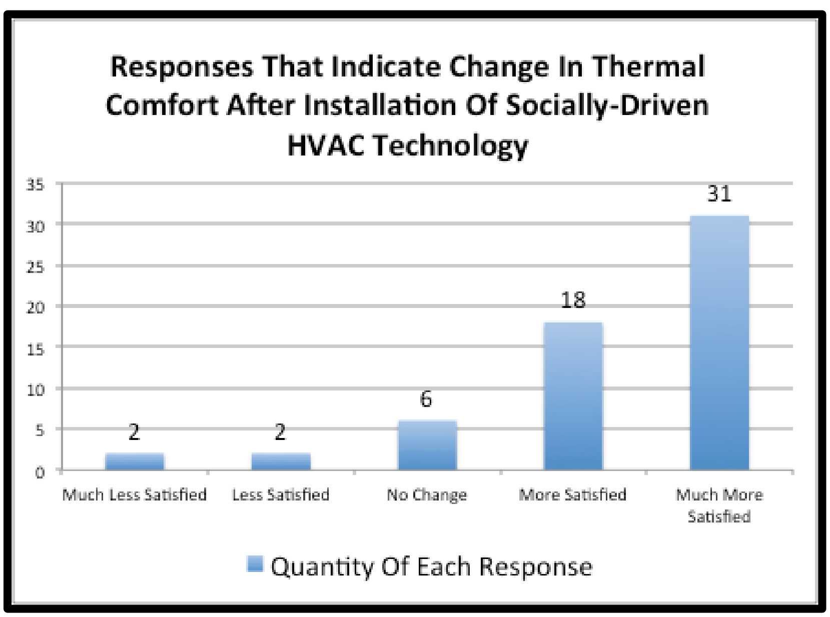

Figure 4. Summary of results from occupant surveys.

Figure 5 shows the results when users were asked to rate their satisfaction with the technology in terms of Ease of Use, Access to the Socially Driven HVAC System, and Technical Support. This graph is typical of what was observed with regard to many of the questions.

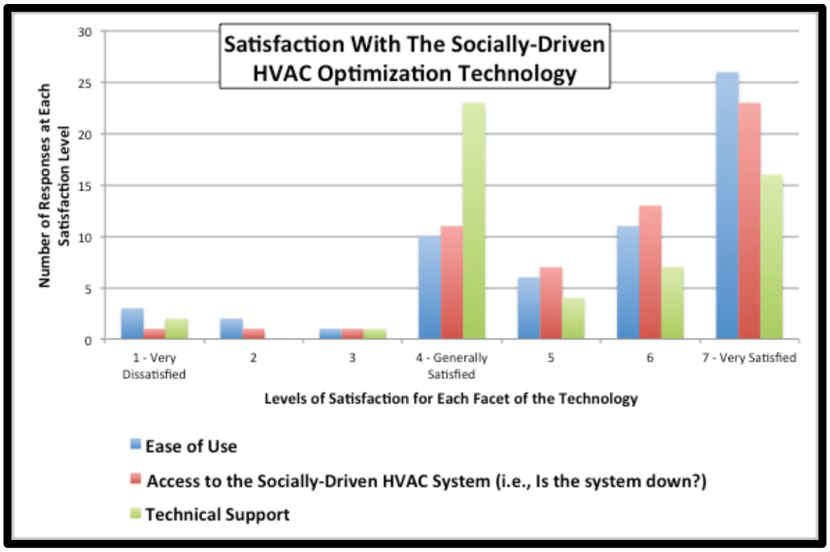

Figure 5. Results of user satisfaction survey.

According to vendor data, the user count for the socially driven HVAC technology in May 2014 was 156; in August 2015, the user count was 272. While this does not necessarily indicate increasing satisfaction with the technology, it does suggest sustained levels of employee acceptance and adoption.

Readers are encouraged to read through Appendix A for a full discussion of the detailed results.

VI. Summary Findings and Conclusions

A. Overall Technology Assessment at Demonstration Facility

The socially driven HVAC technology did show that it had the ability to address the shortcomings of conventional HVAC thermostats. The number of hot and cold calls to maintenance was reduced because individual occupants had the ability to adjust the thermostat through their personal computers and receive an immediate response to mitigate their discomfort. This immediate feeling of comfort was provided by the technology supplying an immediate burst of conditioned air to address occupants' short-term complaints of being too hot or too cold.

It also showed that it has the ability to adjust individual space temperatures over time to a set point that will save energy and keep occupants comfortable. Set points in the individual spaces were based upon feedback from occupants and were tuned to what allowed the occupants to be comfortable while saving energy. This is different than conventional thermostats, which set a certain temperature and maintain it constant for large areas or for the entire facility.

The technology also showed the ability to address the opposing relationship discussed in the opening paragraphs in which energy savings and occupant comfort tend to work against each other. With the socially driven HVAC technology, occupants are comfortable while energy consumption is reduced.

Occupant surveys showed that the system generally maintains occupant comfort over time. Details are in the body of this report.

The economic viability of this technology is undetermined. Costs are expected to stabilize as the technology and market become more established. For the present time, economic guidelines are provided for facility managers who might be considering this technology for their buildings.

Overall, the socially driven HVAC optimization technology should be considered for facilities where thermal comfort is a priority. The socially driven HVAC technology will be most cost-effective in facilities with high energy costs, narrow deadbands, and a significant portion of space that is only intermittently occupied.

B. Best Practice

This technology is substantially different than existing HVAC control technologies, and it is nearly impossible to compare it to an existing standard of any sort. It does have the potential to provide energy savings while maintaining comfort in ways that have not been available before.

If the pricing structure stabilizes in an economically viable fashion, this technology has the potential to be a new best practice for both federal and commercial clients.

C. Barriers and Enablers to Adoption

One major barrier to adoption of this technology is the inability of this study to establish the technology’s economic viability. When installation and subscription costs stabilize, its full potential within the federal and commercial marketplace can be analyzed.

Parallel to the economic viability barrier, it was time consuming to get this technology approved by GSA IT experts for use on the facility’s BAS. This exercise purports to be a one-time approval that will not have to be repeated with the same level of scrutiny, but it should be assumed that every installation will require some level of IT review and sign-off.

A third barrier that might be present in a facility would be re operation with very tight limitations on thermostat set points. This barrier is influenced heavily by GSA's facilities standards in PBS-P100, which establishes the parameters within which GSA facility thermostats must operate. Also, set point limitations could be set by the contract between GSA and the occupant agency if a facility were operated 24/7 and needed to be maintained at tighter conditions than a normal office.

This technology creates energy saving by maintaining comfort while resetting the set point to a point where less HVAC energy is consumed. If there were reasons why a facility’s temperature had to be more tightly controlled (e.g., in a data center), then the technology would not be able to accomplish this task.

A fourth barrier would be that this technology can only be implemented in a facility that has a functioning direct digital control system operating on a VAV system. If a facility has an older all-pneumatic system, this technology would not be able to operate on it without wireless pneumatic technology or a full system retrofit.

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

Because this technology relies so heavily on occupant input, it is recommended that a thorough in-brief be held with management and staff at any facility that has it installed.

Also, facility O&M staff must be properly trained to work with this system and not inadvertently override any inputs from occupants.

VII. Appendices

A. Results of Human Perspectives Evaluation and Occupant and Staff Survey[10]

Human Perspectives Evaluation

The socially driven heating, ventilation, and air conditioning (HVAC) technology was evaluated from the human perspective based on several sources of data.

- Online surveys of building occupants
  - Baseline survey
  - The socially driven HVAC technology survey

- Conference calls
  - Phoenix management and operations staff
  - GSA cybersecurity and information technology (IT) staff

- Phoenix records of hot/cold calls

- The socially driven HVAC technology use data provided by the vendor

Each of these sources is presented individually.

Baseline Survey

The baseline survey opened on March 5, 2014, and closed on Friday, March 21, before the socially driven HVAC technology's launch on March 24. The survey consisted of a total of 20 questions. The purpose was to evaluate the thermal comfort of the tenants of the Federal Building and US Courthouse in Phoenix. One hundred and one people responded to the survey. Based on an estimated building occupancy of 350 (GSA assistant property manager, Phoenix), this number constitutes a 29% response rate. A sample of 101 from a population of 350 corresponds to 95% certainty of ± 8.24% accuracy.[11] It should be noted that not all people answered all questions. For the reasons stated above, we did not require answers to each question. The answers to each question can be found in Appendix B.

The first battery of six questions was asked to characterize building occupants. Answers revealed the following.

- More than 63% of respondents had worked in the building for 5 or more years.

- Seventy-seven percent had been in their current workspaces more than 1 year.

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[10] Many survey questions included space for respondents to write in comments as an "other" response in conjunction with other structured responses to these questions. At the request of GSA, these "other" comments were redacted from this final report. However, some questions were asked open-ended in which every response was a comment directly from the respondent. In these cases, the responses were left in the appendices.

[11] A population of 350 requires a sample size of 183 to have 95% certainty of ± 5% accuracy.

- More than 75% worked more than 30 hours in a typical workweek.
- About 40% categorized themselves as "professionals," followed by 31% "administrative support."
- Nine percent were under 30 years of age, 46% were 31–50, and 45% were over 50.
- Seventy-one percent were female.

The second battery of questions concerned location of workspace and windows. Ninety-three occupants responded to these questions. Thirty occupants located their workspaces in the east area of the building, 27 in the west, 11 in the north, and 9 in the south; 1 did not know the area of his/her workspace. Forty-three people located the nearest windows to their workspace to be facing east and 33 facing west. Ten were not near windows; the remainder of answers were split between north, south, and "don't know." About 60% answered that they were within 15 ft of an exterior wall, and about 63% within 15 ft of a window. Table A.1 shows the distribution of responding occupants' workspace location by floor. An equal number, 27%, were located on the 2nd and 4th floors. Seventeen respondents were on the 1st floor. It should be noted that courtrooms are located on the 1st, 3rd, 6th, and 7th floors. Almost 65% identified their workspaces as enclosed, private offices. Cubicles with high partitions followed at 17.2%.

Table A.1. Respondent Locations by Floor

Floor	Response Count
Basement	0
First	17
Second	26
Third	6
Fourth	26
Fifth	7
Sixth	6
Seventh	5
TOTAL	**93**

The final battery of questions asked general questions about the thermal comfort of occupants' workspaces. Forty-seven of 81 respondents (58%) were "Generally Satisfied" to "Very Satisfied" with the temperatures in their workspaces. Forty-two percent were less than "Generally Satisfied." The average score for this question was 3.63, which is less than "Generally Satisfied."[12]

[12] There were seven answer choices for this question: *Very Dissatisfied* (score = 1), two more choices between *Very Dissatisfied* and *Generally Satisfied* (with scores of 2 and 3, respectively), *Generally Satisfied* (score = 4), two choices between *Generally Satisfied* and *Very Satisfied* (with scores of 5 and 6, respectively), and *Very Satisfied* (score = 7). Weighting each score by the number of people who chose it, and dividing by the total number of responses for that category, provided the rating average. This method applies to all questions with scored answers.

Table A.2 shows the results of two questions: one that asked about workspace temperature when the weather is warm/hot and the second with respect to cool/cold weather. It should be noted that respondents were allowed to choose more than one answer. The largest proportion of people was "Generally Comfortable" in either type of weather, with a few more choosing that answer in cool/cold weather. The total number of answers for being sometimes-to-often too cold in cool/cold weather is the same as the number of answers for being sometimes-to-often too hot in warm/hot weather. So, the type of discomfort coincides with the weather type.

Table A.2. Workspace Discomfort by Weather Type

Answers	In warm/hot weather		In cool/cold weather	
	Count	Percent of Respondents[a]	Count	Percent of Respondents[a]
Often too cold	7	7.6	16	17.4
Sometimes too cold	21	22.8	27	29.3
Generally comfortable	31	33.7	36	39.1
Sometimes too hot	27	29.3	16	17.4
Often too hot	16	17.4	4	4.3
Respondents	92		92	
Responses	102		99	

[a]Percent does not add to 100% because respondents were asked to choose all choices that applied. So, a respondent could choose more than one answer.

Two questions asked about times of the day when workspace temperature is too warm/hot or too cool/cold, respectively. Figure A.1 shows these results. [Note that the "I am not….." on the far left side of the horizontal axis is either "I am not too cool/cold in my workspace," or "I am not too warm/hot in my workspace."] An almost equal number of respondents were not too cold or too hot (24 and 23, respectively). The peak time for being too warm was in the 2–5 PM period, while the peak time for being too cold (with an equal number of respondents) was before 11 AM. During the 11 AM to 2 PM period, an equal number of respondents chose too cold or too warm. Only six respondents reported being too warm after 5 PM, and none reported being too cold; these numbers could be a result of the majority of people having exited the building by 5:00 pm.

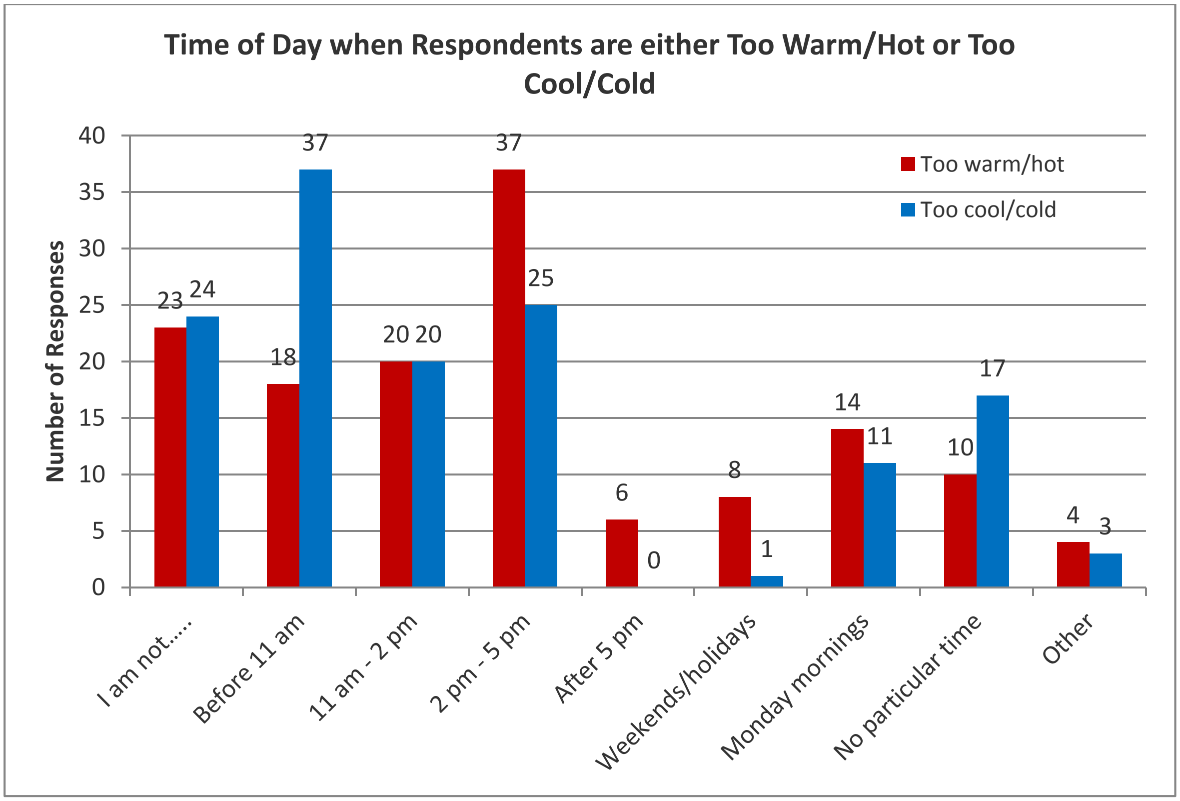

Figure A.1. Thermal discomfort by time of day.

When asked what the source of their thermal discomfort was (choices were provided), the majority said there was too little air movement. This response was followed by thermostat issues (e.g., inaccessible, adjusted by other people, or system does not respond quickly enough to the thermostat) and air movement being too great. Table A.3 shows the responses by answer options.

Table A.3. Answers to Question about the Source of Thermal Discomfort in the Workspace

Answer Options	Response Percent	Response Count
Humidity too high (damp)	4.5	4
Humidity too low (dry)	5.6	5
Air movement too great	20.2	18
Air movement too little	39.3	35
Incoming sun	16.9	15
Hot/cold floor surfaces	1.1	1
Hot/cold ceiling surfaces	2.2	2
Hot/cold wall surfaces	2.2	2
Hot/cold window surfaces	11.2	10
Heat from office equipment	1.1	1
Drafts from windows	7.9	7

Table A.3 (continued)

Answer Options	Response Percent	Response Count
Drafts from vents	15.7	14
Drafts falling from the ceiling	10.1	9
Thermostat is inaccessible	22.5	20
Thermostat is adjusted by other people	21.3	19
Heating/cooling system does not respond quickly enough to the thermostat	20.2	18
Clothing policy is not flexible	4.5	4
Other (please specify)	14.6	13

When respondents are not happy with the temperatures in their workspaces, they most frequently use portable fans, followed by adjusting the window blinds or shades, and portable heaters (Table A.4).

Table A.4. Answers to the question "When you are not satisfied with the thermal comfort in your workspace, which of the following do you personally adjust or control in your workspace and how often?" (check all that apply)

Answer Options	Cannot adjust/control	Never	Rarely	Sometimes	Frequently	Response Count
Window blinds or shades	22	14	9	21	13	79
Operable window	55	17	0	0	0	72
Thermostat	39	14	3	17	8	81
Portable heater	22	44	0	4	11	81
Permanent heater	31	40	0	0	0	71
Room air-conditioning unit	34	38	0	2	2	76
Portable fan	13	23	6	11	30	83
Ceiling fan	29	38	0	0	0	67
Adjustable air vent in wall or ceiling	39	31	1	0	2	73
Adjustable floor air vent (diffuser)	38	33	0	0	0	71
Door to interior space	19	35	4	11	4	73
Door to exterior space	29	37	1	2	0	69
Other	9	16	0	2	1	28
Please specify Other						9
					answered question	**89**
					skipped question	**12**

The final question of the baseline survey asked for a description of other issues that were related to being either too warm or too cold in the workspace. Twenty-three answers were provided. The full list can be found in Q20 of Appendix B. In general, the comments echoed the responses to various questions discussed above; for example, too hot in summer, too cold in winter, too little air movement, too much air movement, and unresponsive thermostats.

The Socially Driven HVAC Technology Survey

The "Socially Driven HVAC Technology in Phoenix Bankruptcy Building" survey was open for 3 weeks from September 4, 2014, through September 26, 2014. This online survey was conducted after the technology had been deployed in the building for about 5 months. The purpose was to evaluate the socially driven HVAC technology from the building occupants' perspectives. The survey consisted of a total of 32 questions. The questions and their answers can be found in AppendixC. Sixty-two building occupants responded to the survey. Based on an estimated building occupancy of 350 (GSA assistant property manager, Phoenix), this number constitutes almost an 18% response rate. A sample size of 62 from a population of 350 corresponds to 95% certainty of ± 11.31% accuracy. We have no way of knowing whether the 62 respondents of the technology survey were among the 101 respondents of the baseline survey. Therefore, it should be noted that a direct comparison cannot be made between the results of this survey and the baseline survey.

The answers to the six background questions designed to characterize the occupants of the building revealed that, at the time of the survey, 70.3% of the respondents had worked in the building at least 5 years and, therefore, had a long-term experience with the building's thermal conditions. Almost 63% had been in their workspaces more than 1 year; thus, they had been in their current workspaces for at least 6 or 7 months prior to the socially driven HVAC technology's deployment. The vast majority of respondents (more than 82%) reported spending more than 30 hours per week in the building, translating to a good representation of occupancy over the course of a day. Almost 40% of the respondents reported their work type as "professional," with "administrative support" in second place at more than 25%. Less than 7% of respondents reported their age as 30 or under; 63% were over age 50. Almost 68% of the respondents were female.

The next battery of questions asked about the respondents' workspace locations and descriptions. These were the same questions asked in the baseline survey. Fifty-three percent of respondents identified their workspaces to be in the east area of the building, followed by 23% in the west area. More than 57% of respondents stated that they were in workspaces where the closest windows faced east, with 31% identifying the nearest windows to be west facing. Seventy-seven percent of respondents said they were within 15 ft of an exterior wall, and almost 80% were within 15 ft of a window. Table A.5 shows the distribution of occupants' workspaces by floor. The majority of respondents were on either the first or second floors.

Table A.5. Respondent Locations by Floor

Floor	1st	2nd	3rd	4th	5th	6th	7th
Number of respondents	18	14	6	6	2	9	7

When asked to describe their workspaces (choices were provided for the answers), 77% of respondents said they were in an enclosed, private office. Almost 13% were in cubicles with high partitions (Q12 in Appendix C).

The next battery of questions, which were the same for the baseline survey, asked general questions about the thermal comfort of the respondents' workspaces. Sixty-five percent of respondents were "Generally

Satisfied” to “Very Satisfied” with the temperatures in their workspaces. The average score for this question was 3.87.[13] Respondents reported greater dissatisfaction with the temperatures in their workspaces in times of warm/hot weather than in cool/cold weather, as shown in Table A.6. In warm/hot weather, the majority of respondents (respondents were allowed to choose all answer options that applied) indicated that workspace temperature was sometimes-to-often too hot. Fifteen respondents indicated that they were generally comfortable, and only eight chose sometimes-to-often too cold. There is a stark contrast in the answers to the question in cool/cold weather. In that case, about 69% of respondents reported being generally comfortable in cool/cold weather, while 25% were sometimes-to-often too cold, but only four respondents indicated being too hot in colder weather.

Table A.6. Workspace Discomfort by Weather Type

Answers	In warm/hot weather		In cool/cold weather	
	Count	Percent of Respondents[a]	Count	Percent of Respondents[a]
Often too cold	3	4.9	3	5.2
Sometimes too cold	5	8.2	12	20.7
Generally comfortable	15	24.6	42	72.4
Sometimes too hot	27	44.3	3	5.2
Often too hot	16	26.2	1	1.7
Respondents	61		58	
Responses	66		61	

[a]Percent does not add to 100% because respondents were asked to choose all choices that applied. So, a respondent could choose more than one answer.

Two survey questions asked what times of the day (choices provided) the workspace temperature was either too warm/hot or too cool/cold, respectively. Respondents were allowed to choose more than one answer. Figure A.2 shows the results of both questions. The responses show that being too warm is more often a problem than being too cool. Occupants were generally too warm throughout the workday, with a slight dip midday. Monday mornings were also described as too warm. With respect to workspace temperatures being too cool, the largest number of respondents said their workspace was not too cool/cold. Throughout the workday, the too cool workspace temperatures peaked in the morning, dropping midday, and rose slightly in the afternoon.

[13] There were seven choices for this question: *Very Dissatisfied* (score = 1), two more choices between *Very Dissatisfied* and *Generally Satisfied* (with scores of 2 and 3, respectively), *Generally Satisfied* (score = 4), two choices between *Generally Satisfied* and *Very Satisfied* (with scores of 5 and 6, respectively), and *Very Satisfied* (score = 7). Weighting each score by the number of people who chose it provides the average score. This method is used with all questions that asked occupants to rank their satisfaction.

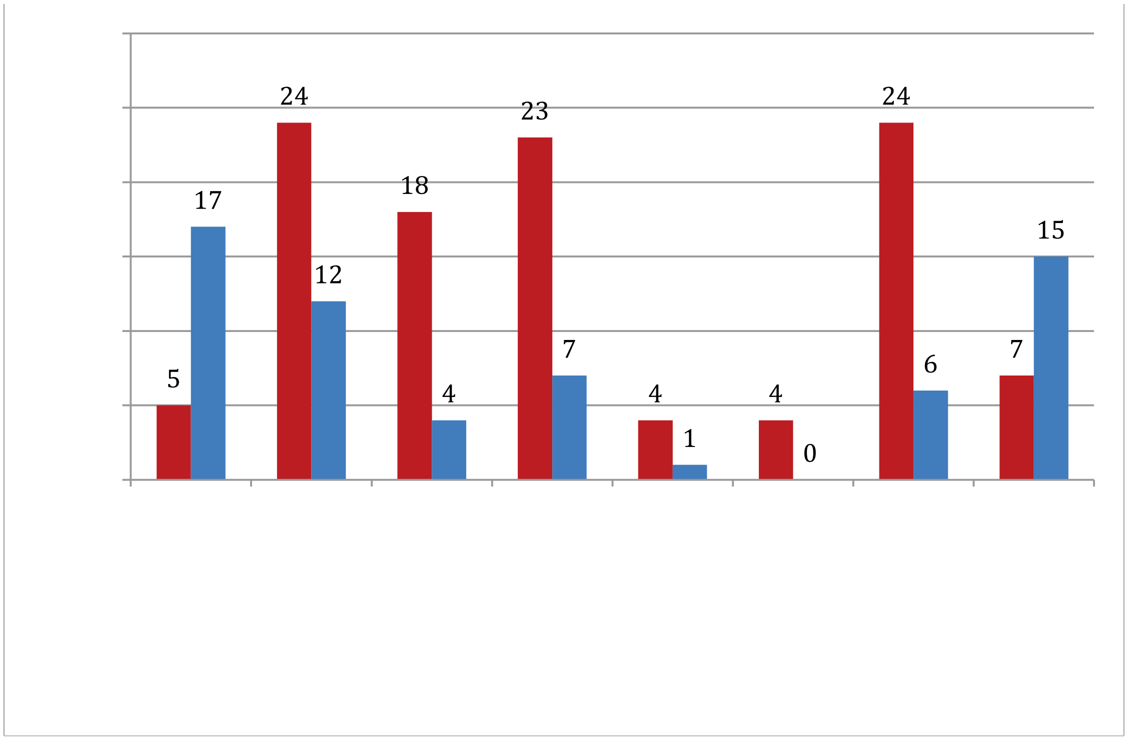

Figure A.2. Thermal discomfort in the workspace by time of day.

This battery of questions ended with a question asking respondents to identify the sources of their thermal discomfort (either too warm or too cold) from a list of choices; respondents were allowed to identify more than one source. The answers are in Table A.7. The largest number of respondents identified “Air movement too little” as the source of discomfort. The same number of respondents identified the source of discomfort as “Humidity too high (damp)” as did those who chose “Incoming sun.” These were followed by “Heating/cooling system does not respond quickly enough to the thermostat.” The responses supplied for “Other,” shown in Appendix C (see Q18), center on thermostat issues and workspace being very warm in the morning before the system comes on.

Table A.7. Answers to Question about the Source of Thermal Discomfort in the Workspace

Answer Options	Response (%)	Response Count
Humidity too high (damp)	23.7	14
Humidity too low (dry)	1.7	1
Air movement too great	13.6	8
Air movement too little	62.7	37
Incoming sun	23.7	14
Hot/cold floor surfaces	0.0	0
Hot/cold ceiling surfaces	0.0	0
Hot/cold wall surfaces	1.7	1
Hot/cold window surfaces	16.9	10

Table A.7 (continued)

Answer Options	Response (%)	Response Count
Heat from office equipment	3.4	2
Drafts from windows	10.2	6
Drafts from vents	8.5	5
Drafts falling from the ceiling	5.1	3
Thermostat is inaccessible	15.3	9
Thermostat is adjusted by other people	15.3	9
Heating/cooling system does not respond quickly enough to the thermostat	18.6	11
Clothing policy is not flexible	0.0	0
Other (please specify)	18.6	11

The fourth battery of questions (Q19–Q32 in Appendix C) is specific to the use of the socially driven HVAC technology. Table A.8 shows the frequency with which respondents use the technology either to raise or lower the temperature in their workspaces. One can see from the data that the socially driven HVAC technology was used more frequently by survey respondents to cool their workspaces than to warm them during the demonstration period (late March through early October). This finding is consistent with the fact that a larger number of respondents reported being too warm in their spaces than being too cool. This result would also be expected because of the fact that the technology trial period covered spring and the very hot months of summer.

Table A.8. Frequency of Socially Driven HVAC Technology Use

Frequency of Use	Cool My Space	Warm My Space
Never registered	1	7
Registered, but have not used	4	26
Rarely (only used once or twice)	3	14
Sometimes (a few times in the last five months)	8	6
Occasionally (a couple of times per month)	8	0
Frequently (a couple of times per week)	15	3
Often (several times per week)	22	2
Number of Responses[a]	**61**	**58**
Number of Respondents	**59**	**55**

[a]Some respondents chose more than one answer. Thus, the total number of responses does not equal the number of respondents.

Respondents were asked on whose behalf they used the socially driven HVAC technology, with the choices being just themselves, themselves and others, or just others. No one indicated that they used the technology just for others. Sixty percent of respondents reported using the socially driven HVAC technology only for themselves and the remainder (40%) for themselves and others. Respondents were asked to specify who “others” were, and the responses included judges, courtrooms, conference rooms, training rooms, and a boss (for the complete list, see Q21 in Appendix C).

When respondents were asked to list what they liked about the socially driven HVAC technology (up to three choices), the answers of the 46 respondents fell into the following general categories.

- Control (17 answers)
- Quick response (13 answers)
- Ease of use (7 answers)
- Accessibility (6 answers)
- Other (3)

Based on these responses, control was what respondents liked most about the socially driven HVAC technology: being able to control the temperature in their workspaces by requesting the technology to make adjustments to the temperature. One person explicitly mentioned not having to go through local maintenance for adjustments. Respondents wrote about "quick," "immediate," and "prompt" responses from the socially driven HVAC technology within the category with the second highest number of answers. Ease of use and accessibility were also features the respondents reported liking about the technology.

Thirty-seven respondents answered the request to list no more than three things they liked the least about the socially driven HVAC technology. The answers fell into the following three general categories.

- Temperature change takes too long or is not sustained (12 answers)
- Conflicting temperature preferences (6 answers)
- Other (17 answers)

Although 13 respondents indicated liking the quick response of the socially driven HVAC technology (above), there were 12 respondents who felt that a temperature change resulting from a the socially driven HVAC technology request response took too long, was not sustained, or had to be requested multiple times. One person wrote that when the socially driven HVAC technology says that it thinks the space is comfortable, he (she) is "sitting here sweating and it won't let you send another request for 10 minutes." All six responses in the category of conflicting temperature spaces had to do with shared zones in which occupants had differing temperature preferences.

As noted in Table 3 in the main body of this report, respondents were asked to rate their satisfaction with the socially driven HVAC technology with respect to the following

1. Ease of use
2. Access
3. Technical support
4. Change in thermal comfort of workspace
5. Responsiveness to request for change of temperature
6. Voting zones

Based on answers from 59 respondents, satisfaction with the first three aspects of the socially driven HVAC technology was above "Generally Satisfied" (see Table A.9). Access to the socially driven HVAC technology received the highest satisfaction. The following four comments were provided by respondents.

- Have not contacted customer service.
- When the system did not work as advertised, there was a lot of work required to get it fixed.

- I go onto the website and get no connection.
- I don't know who to call for help.

Table A.9. Level of Satisfaction with the Socially Driven HVAC Technology Aspects

Answer Options	Very dissatisfied			Generally satisfied			Very satisfied	Rating Average	Response Count
Ease of use	3	2	1	10	6	11	26	5.56	59
Access to the socially driven HVAC technology (i.e., is the system down?)	1	1	1	11	7	13	23	5.68	57
Technical support	2	0	1	23	4	7	16	5.11	53
Comments									4

Respondents were asked about the extent to which they were satisfied with the change in the thermal comfort of their workspaces as a result of the socially driven HVAC technology (4 above). There were five choices from “Much Less Satisfied” (score = 1) to “Much More Satisfied” (score = 5). The average score of the 59 responses was 4.25, which is between “More Satisfied” and “Much More Satisfied.” One respondent noted that, before the socially driven HVAC technology, he (she) was not able to get his (her) office “to cool down at all.”

Reported levels of satisfaction with the socially driven HVAC technology’s response for a temperature change (5 above) are shown in Table A.10. The vast majority (almost 81%) of the 57 building occupants who responded to this question said they were “Generally Satisfied” to “Always Satisfied.” No one answered “Not at all satisfied.” About 19% pointed out that they had to make several “requests” to the socially driven HVAC technology.

Table A.10. Satisfaction with the Socially Driven HVAC Technology’s Responsiveness to a Request for Temperature Change

Answer Options	Response Percent	Response Count
Not at all	0.0	0
I have to make several requests	19.3	11
Generally satisfied	21.1	12
Almost always satisfied	33.3	19
Always satisfied	26.3	15

The sixth category of satisfaction related to voting zones (6 above). The question was posed to those who were in a voting zone. Thirty-three respondents answered the question. The results, in Table A.11, indicate that the process of voting was rated as being more satisfactory than the outcome of voting on thermal comfort. On a seven-point scale, satisfaction with each aspect of voting rated higher than “Generally Satisfied,” with the exception of the effect of voting on thermal comfort, which scored just under “Generally Satisfied.” The ease of voting ranked the highest, followed by the ease of finding others to vote. The time required to reach a consensus did not appear to overly burden the respondents, nor did finding others to vote.

Table A.11. Level of Satisfaction with the Socially Driven HVAC Technology Voting

Answer Options	Have Never Voted	Very dissatisfied			Generally satisfied			Very satisfied	Rating Average	Response Count
Requirement to vote	20	0	0	1	8	0	2	2	4.46	33
Ease of my voting	17	1	0	1	6	0	2	4	4.64	31
Ease of finding others to vote	18	0	0	1	7	0	2	2	4.50	30
Time involved in reaching consensus	18	1	0	1	6	0	2	2	4.25	30
Effect of voting on my thermal comfort	18	1	0	2	6	0	2	2	3.92	31
Comments										5

Figure A.3 shows the times of day when respondents reported using the socially driven HVAC technology most often to cool or warm their workspaces. It is clear that survey respondents used the socially driven HVAC technology more often to cool spaces than to warm them. Figure A.3 shows that, while the peak time respondents reported using the socially driven HVAC technology to cool their spaces was Monday morning, they consistently sought to cool their spaces from midmornings through much of the afternoon. During the workday hours, the socially driven HVAC technology was used most frequently to warm a space before 11 AM.

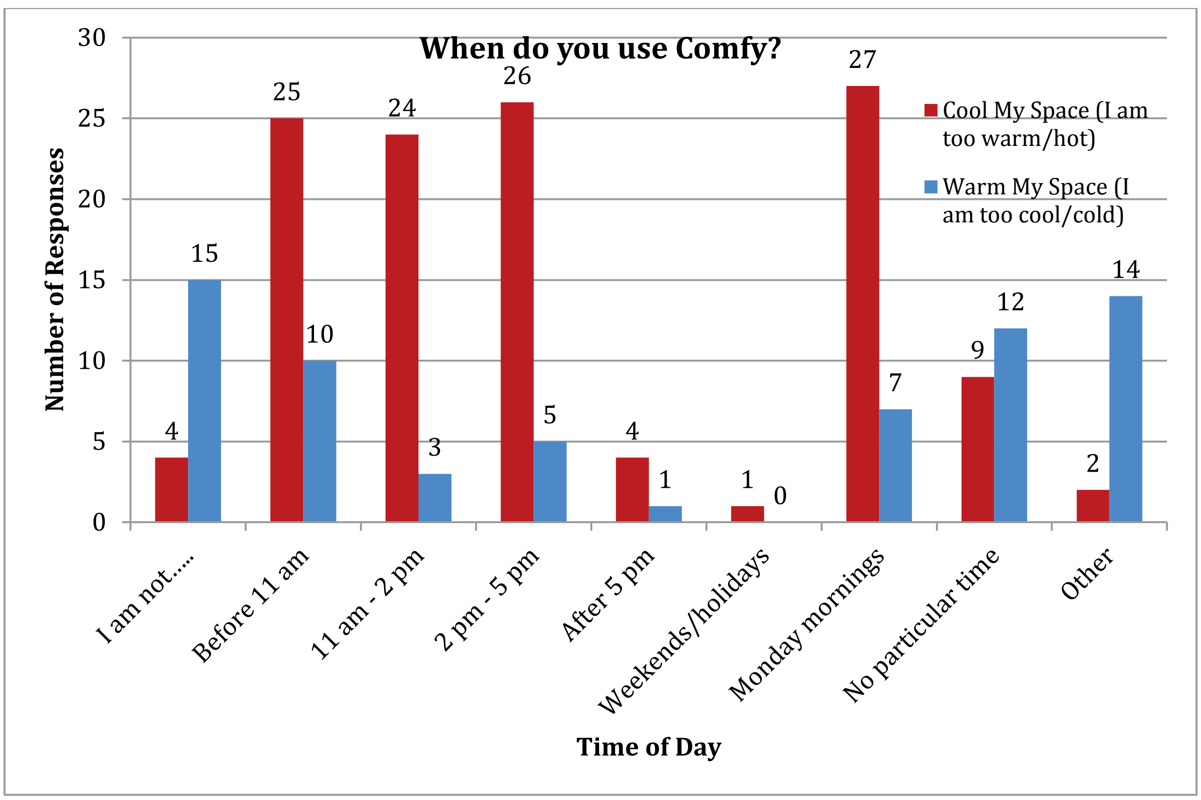

Figure A.3. Times of day the socially driven HVAC technology is used.

Figure A.4 shows an overlay of Figure A.2 (when occupants are uncomfortable) with Figure A.3 (when occupants use the socially driven HVAC technology). Requests to use the socially driven HVAC technology are shown by the dotted lines, and the solid lines represent the responses to the question about what times of the day occupants were either too warm or too cool. The patterns of the socially driven HVAC technology use, by types, generally follow the patterns of when respondents said they were either too cool or too warm.

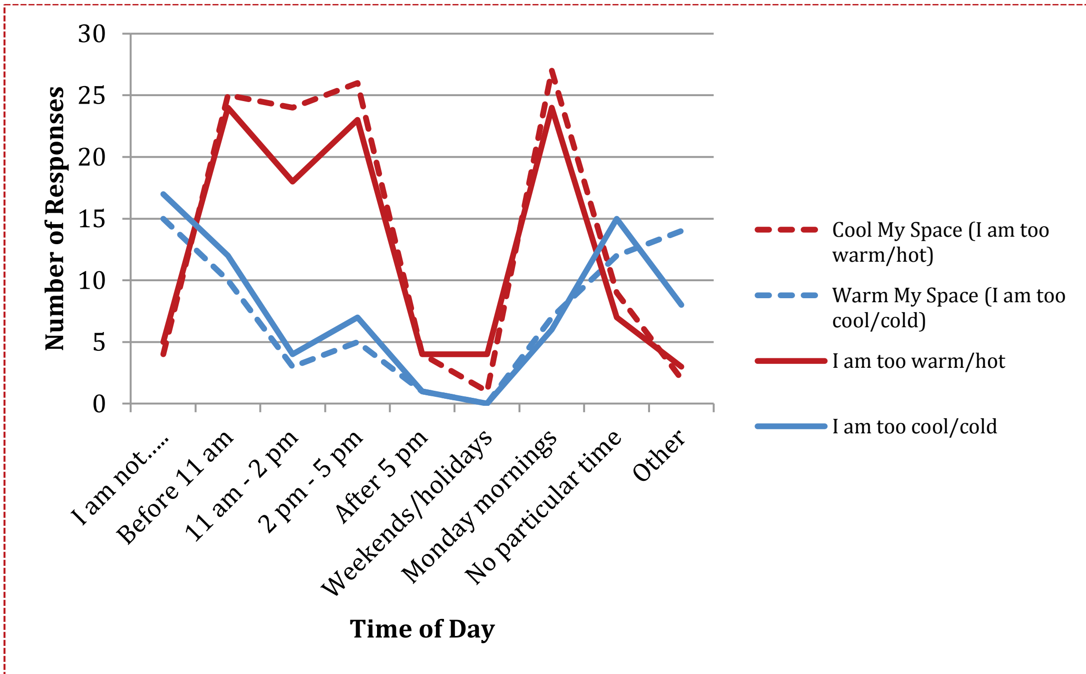

Figure A.4. Times of day when occupants are uncomfortable and when they use the socially driven HVAC technology.

Respondents were asked how often, if they were using the socially driven HVAC technology, they also made hot or cold calls to the facilities manager. Of the 55 respondents who answered the question, almost 71% said they never made hot/cold calls in addition to their use of the socially driven HVAC technology. Only 2% make frequent (several times per week) hot/cold calls. The comments provided on this question can be found in Appendix C (Q30).

Another survey question asked respondents to identify what measures they took to make themselves more comfortable, in addition to using the socially driven HVAC technology to adjust temperature. The answers are shown in Table A.12. Measures frequently used were adjusting window shades or blinds and using portable fans. Adding/removing clothing and drinking hot/cold beverages were also used frequently.

Finally, the socially driven HVAC technology survey asked respondents to provide any other comments related to their use of the socially driven HVAC technology. All comments can be found in Q32 in Appendix C. Seventeen respondents answered the question. Sixteen of the seventeen comments were positive (e.g., “a benefit,” “ideal,” “thank you for providing the socially driven HVAC technology,” “like it very much,” “I wish it were permanent”). The only negative comment stated: “Total waste of money. Set it at the government norm, whatever that is, and leave it alone.”

Table A.12. When you use the socially driven HVAC technology to adjust the temperature in your workspace, do you also use any of the following to make yourself more comfortable (please check all that apply)?

Answer Options	Cannot adjust/control	Never	Rarely	Sometimes	Frequently	Response Count
Window blinds or shades	10	5	5	11	21	52
Operable window	39	8	0	0	1	48
Thermostat	28	9	4	3	5	49
Portable heater	15	24	5	4	4	52
Permanent heater	17	26	1	0	2	46
Room air-conditioning unit	19	26	0	0	1	46
Portable fan	10	10	6	5	21	52
Ceiling fan	19	26	0	0	1	46
Adjustable air vent in wall or ceiling	20	17	5	1	3	46
Adjustable floor air vent (diffuser)	24	20	1	0	1	46
Door to interior space	9	24	3	7	3	46
Door to exterior space	13	22	2	5	3	45
Clothing	2	9	6	22	12	51
Drink hot/cold beverages	1	6	7	25	13	52
Other	5	7	1	0	2	15
Please specify Other						2
					answered question	**56**
					skipped question	**6**

Phoenix Management and Operations

On October 29, 2014, the Oak Ridge National Laboratory (ORNL) team conducted a conference call with five management and operations (M&O) staff members at Phoenix (from this point forward, "staff" refers to those five individuals), eliciting information using an open-ended, semi-structured interview protocol. That is, the call adhered to a predetermined outline of topics, but the order and wording of primary and follow-up questions followed the flow of conversation rather than a precisely worded script. This section summarizes statements made by the staff during the call.

Overall, the staff had both positive and negative comments about the socially driven HVAC technology. Interviewees stated that the concept for the technology was great, but that it needed some technical and operational improvements.[14] The staff expressed confidence that these improvements could be made as the technology matures. The staff said that the vendor should engineer the product more and really focus on customer service.

[14] "Technical" and "operational" are not always distinctly different categories, as described by staff.

Positives Noted

All staff described benefit from the socially driven HVAC technology. Among the main positives that staff identified was tenant satisfaction. All staff commented on the importance of, and value associated with customer (i.e., tenant) satisfaction. One interviewee estimated that the majority (about 75%–80%) of tenants are happy with the socially driven HVAC technology. Additionally, staff reported that, based on weekly walk-throughs of the building, the use of personal space heaters and fans—devices that a number of tenants use although they are not authorized—seemed to have decreased since the socially driven HVAC technology deployment.

Problems Noted

Despite reporting this level of tenant satisfaction, staff identified tenant complaints about and rejection of the socially driven HVAC technology as problematic. Staff reported receiving a number of complaints about the socially driven HVAC technology from tenants occupying certain zones in the building. Staff described how the socially driven HVAC technology was turned off in one particular zone because a single tenant was never happy with the socially driven HVAC technology results, although the vendor repeatedly endeavored to respond to the concerns raised. Staff noted that this particular individual was often dissatisfied with the thermal comfort in his workspace before the socially driven HVAC technology deployment. Additionally, staff reported there may have been several agencies that had stopped using the socially driven HVAC technology (the socially driven HVAC technology was not turned off in these cases) because the building occupants in those zones thought the socially driven HVAC technology helpdesk took too long to address user issues. Staff stated that, by the time the socially driven HVAC technology helpdesk would respond—sometimes in a day or two—the situation would have changed such that the helpdesk response was moot.

In response to this finding regarding the responsiveness of the vendor's helpdesk services, the vendor made the following statement: "The vendor reviewed all helpdesk ticket response times for GSA zones and did not find any situations that match this observation that helpdesk took too long. For all zones that (sic) where usage dropped off, the vendor's Help Desk responed (sic) every time to user tickets in less than a day, and averaged under 4 hours. Furthermore, overall, the vendor's helpdesk had a median first response time of 0.9 hours and a median resolution time of just 25.8 hours for all tickets at the Phoenix Courthouse." [15]

Staff also stated that they did not perceive the socially driven HVAC technology addressed differing temperature requests within a voting zone.

Another problem that staff perceived was lack of accessibility to the socially driven HVAC technology in conference rooms by nonemployees. Because nonemployees did not have access to the socially driven HVAC technology controls, staff described occasions when M&O personnel went into the building automation system (BAS) to lower the conference room temperature before a meeting only to have the socially driven HVAC technology reset the temperature to the default value about an hour later. This automated response by the socially driven HVAC technology required maintenance personnel to go back into the BAS to lower the temperature again.

[15] In accordance with GSA policy, any time the vendor mentioned its trade names within its responses (quoted in this report), the report authors changed the wording to a neutral term, such as "the vendor." Other than that, the quotation is shared directly as received from the vendor.

In response to this observation, the vendor provided the following comment: "Regarding the use of the technology in conference rooms. The system was on and should have worked for all eligible users in conference rooms, we did not receive any communications on this issue stating anything to the contrary."

Staff perceived that the "black box" in the building crashed about four or five times during the course of the pilot period. Each crash required M&O to spend 20 minutes to fix it. M&O learned of these black box crashes from tenants who were unable to access the socially driven HVAC technology system and, therefore, could not contact the socially driven HVAC technology helpdesk. In such cases, M&O had to contact the vendor, who told M&O how to respond.

In response to this observation, the vendor provided this comment: "According to our logs, the technology service only went down twice during operating hours. We would welcome records that show otherwise. Also, we would like to claify (sic) that in both circumstances, the service went down due to the GSA IT outages/maintenance (sic), not the vendor's system. As part of the technology's service, we monitor uptime closely and have maintained an overall uptime of 99.86%."

Staff expressed concerns that the socially driven HVAC technology sometimes reduces the set point temperature to 1°F–2°F below the GSA allowable 74°F set point because of tenant requests. In turn, M&O staff spent an extra 1.5 hours/week to check the set point on all floors.

Hot/Cold Calls

Staff said the number of hot/cold calls to M&O staff was reduced from 61 calls in March through September of 2013 to 25 calls over the same period in 2014. While notable in quantity, M&O staff stated that this difference did not have a "significant" or "dramatic" impact on M&O contract costs.

Estimated Savings

Energy management staff estimated the annual energy cost savings attributable to the socially driven HVAC technology to be about $6,700. This figure is based on "occupied time" in the building—11 hours per weekday, excluding nights, weekends, and holidays. This savings calculation was based on the industry standard of 3% for every one degree change in temperature. So, a two degree change in the set point would produce a 6% savings. Staff said that amount of cost savings was significant, but not enough to justify the future annual costs of the socially driven HVAC technology system.[16] Staff described a broad spectrum of noneconomic and economic value considerations, such as comfort and control for tenants, and energy costs. However, the decreased use of personal space heaters and fans that staff observed was not a component of these calculated energy savings. Staff described the value versus energy cost at that time as "a night and day difference," and said that the energy savings did not justify the price the vendor then was asking for the system. Staff said that the building was meeting its energy requirements before the socially driven HVAC technology and that the socially driven HVAC technology could be considered one tool in the suite of the building's energy savings programs that could become more valuable as energy goal requirements become greater in the future.

[16] Note that at the time of the conference call, M&O staff was deciding whether to proceed with a contract to continue use of the socially driven HVAC technology. The price the vendor was charging at that point in time was different from—and higher than—the price both entities later agreed to use. At the time of the M&O conference call, staff said they would not recommend proceeding with the socially driven HVAC technology because the cost savings were insufficient to justify the annual cost of the technology.

Estimated Costs

Staff talked about labor costs they incurred due to the extra 1.5 hours per week needed to check set points on each floor because the socially driven HVAC technology sometimes lowered set points below the GSA allowable 74°F. They said that this additional checking resulted in more time spent than was saved by reduced hot/cold service calls. Staff also noted that the estimated energy savings from higher set points ($6,700) might be offset by the costs of increased energy use associated with the lowered set points.

In response to these observations, the vendor provided the following comment: “The vendor can confirm that the technology’s cooling set points did go below 74 in 6 zones (out of 250). This occurred for less than 1.3% of total operating hours and the variance was never more than 2 degrees cooler. This occured (sic) due to the fact that these zones’ controller logic was different from the rest of zones.

“Regarding the 1.5 hours of M&O time spent to check set points: we were dismayed to hear that this time was spent without our knowledge, and certainly would have been happy to remedy this, had we known. We would advocate for this being reported within that context.”

It should be noted that this extra time spent checking set points is not anticipated to be a typical requirement for this technology and that this issue has since been addressed between the vendor and building staff at Phoenix.

GSA Cybersecurity and IT

The human perspective associated with the socially driven HVAC technology’s deployment and operation necessarily involves cybersecurity and IT personnel. The socially driven HVAC technology is designed to link occupants directly with the BAS through an internet interface. By design, the socially driven HVAC technology links two kinds of networks that GSA typically takes pains to separate. Thus, GSA cybersecurity and IT staff are critical players identifying issues, checking equipment and systems, and ensuring that the two systems are compliant with cybersecurity rules and protocols. To evaluate the socially driven HVAC technology from cybersecurity and IT perspectives, ORNL conducted a conference call on January 26, 2015, with four relevant GSA staff members. These four individuals work in multiple IT program areas across the country and not in close geographic proximity to Phoenix.

GSA cybersecurity and IT staff have different roles and are responsible for different cybersecurity and IT components associated with the socially driven HVAC technology. The GSA cybersecurity group is responsible for protecting GSA operational and business computer networks. The group encompasses five divisions, each of which has a distinct role that came into play at different stages of the socially driven HVAC technology demonstration. Interviewees noted that coordinating among these divisions within the necessary timeframes created challenges during the socially driven HVAC technology demonstration project. GSA IT roles include setting up, configuring, installing and hardening the servers (that is, making sure they are working well) through which the socially driven HVAC technology box operated. The socially driven HVAC technology demonstration also involved a GSA networking team.

There is a segregation of duties. The staff we interviewed had different roles with respect to the socially driven HVAC technology. A manager within GSA’s Public Buildings Service who focuses on building technologies with respect to standards and implementations was the interface between Phoenix and the vendor during the socially driven HVAC technology demonstration. With respect to the IT implementation aspect of the socially driven HVAC technology, his role was to determine what was needed on the business side and the cybersecurity side and bridge the two. Another interviewee was a part of the IT security team during the initial phase of the socially driven HVAC technology implementation. His role was to ensure that the socially driven HVAC technology met GSA's policies, standards, and procedures because the building and the structure are operated by GSA, not by the users of the socially driven HVAC technology, and because the servers operate within the GSA environment but were accessed outside the firewall. The cybersecurity interviewee is part of the GSA Information Security Office for the general support system. That office provides operational support for production systems. Responsibilities include operating system (OS) patching, mid-tier software standardization, overseeing the lifecycle of the software with defined change system, and offering contingency and backup solutions to problems that arise. Another IT staff interviewee was responsible for getting all pieces to play together from a technical standpoint. He worked with the vendor to integrate the socially driven HVAC technology into the GSA network. Some building controls and integration between the vendor and the building's BAS were needed. The interviewee noted that, once achieved, this integration had to be managed over time.

Different cybersecurity and IT issues came up at different stages of the socially driven HVAC technology's deployment. For instance, there was a period of intense activity before installation to ensure that cybersecurity criteria were met and the socially driven HVAC technology was scanned. Additionally, procedures were developed and initiated to authenticate which people can or cannot use the socially driven HVAC technology. In Phoenix, this user authentication had to enable individuals working for different federal agencies within the building to be recognized as allowed users but prevent others from accessing the system (e.g., citizens who appeared in one of the building's courtrooms).

Interviewees said that everything GSA does in terms of its computer systems is standardized to the extent possible, as a cost-management strategy. For example, GSA currently supports a Windows platform. The socially driven HVAC technology, however, was developed on a Linux platform. Before deployment, the vendor had to change the socially driven HVAC technology from a Linux to Windows platform and to recode the web portion for Windows. More generally, interviewees said that developers of technologies like the socially driven HVAC technology should not be rigid, and the technology should have the ability to plug and play in multiple environments. Further, interviewees said that if the vendor offered multiple deployment options (one being Windows), then that would have saved GSA staff about 20 hours. Other modifications the vendor had make prior to deployment included changing to Secure Sockets Layer to ensure the privacy of the interaction that building tenants had with the socially driven HVAC technology and some Apache configuration changes. According to interviewees, these sorts of modifications are fairly standard.

Interviewees also commented on the vendor's reliance on Java in developing the socially driven HVAC technology. They noted that the vendor was a bit antiquated with regard to security issues in that Java and similar programs have known cybersecurity problems. These interviewees pointed out that it is easy to check on National Institute of Standards and Technology standards and that vendors—especially those that are newer—need to be attuned to security matters. More generally, interviewees said that vendors should have the ability to adapt their technologies to larger institutions' standard environments.

Staff said there has been an ongoing IT/cybersecurity role since the socially driven HVAC technology was approved to install and set up. The GSA technical operations team regularly patches and updates the server. Additionally, the staff member who was responsible for working to integrate the socially driven HVAC technology into the GSA network said he will have involvement in the day-to-day operation of the socially driven HVAC technology for as long as it is being used in Phoenix. It was pointed out that, in the routine monitoring of the socially driven HVAC technology, the discovery of a significant flaw could cause a significant finding that could potentially cause staff to pull the socially driven HVAC technology off the internet.

After deployment, GSA migrated from one data server to another (this migration was independent of the socially driven HVAC technology), and there were some associated adjustment issues. However, there were no server issues since that time.

Cybersecurity and IT staff noted that their procedures were different for the socially driven HVAC technology as a time-limited demonstration project than they would be if the socially driven HVAC technology were to be fully deployed. Because the socially driven HVAC technology was under a GSA Green Proving Ground program pilot, the socially driven HVAC technology did not go through the full assessment process that is typically required of a new technology. If the socially driven HVAC technology were extended beyond the pilot period, GSA cybersecurity and IT staff would have to do further assessment. Likewise, GSA staff would have to engage in another assessment and authorization phase if a different black box was needed or if the socially driven HVAC technology was upgraded. Staff stated that a pilot program is a good start for a new technology assessment because cybersecurity and IT become familiar with the technology. However, a pilot can create more confusion if the technology changes when it goes to a full stand-up. These assessments take time and, therefore, money. Interviewees estimated that, together, they spent about 300 to 400 hours in total for the socially driven HVAC technology demonstration. They said the funding for their work on the socially driven HVAC technology came under the umbrella of their overall work. It was not funded separately. If the socially driven HVAC technology were fully deployed, further assessment would be needed, and it is not clear who would pay for that time or how that cost would or would not be included in economic evaluations of technologies like the socially driven HVAC technology. They noted that a full cybersecurity assessment can take 200 hours. These interviewees pointed out that if the socially driven HVAC technology really does reduce energy use in the building and the social aspects of the socially driven HVAC technology work, then the security investment is more valuable, particularly on a savings per square foot basis.

Additionally, if the socially driven HVAC technology is viable and funded beyond the pilot, interviewees stated that GSA will need full documentation (which was not required of the socially driven HVAC technology as a pilot). This documentation includes full configuration, step-by-step information on how the technology is deployed and the interconnections so that GSA could reconstitute the system if the technology failed. These steps would be no different from what GSA requires of other technologies. The amount of time needed for that process typically depends on the contract and the developer, who generally does most of the documentation. ,

Note that the cybersecurity and IT human perspectives described in this section have virtually nothing to do with energy costs or cost savings in the building or with occupants' thermal comfort. Interviewees said that cybersecurity and IT staff are agnostic to end users, whose needs are handled by application support personnel. Cybersecurity and IT are responsible for OS issues. Who the building tenants are is irrelevant to them, other than ensuring that the users are authorized. A user is authorized independent of the agency for which he or she works. The agencies occupying GSA buildings do not influence GSA systems. However, the reverse could be true.

In summary, the interviewees identified and discussed elements that are important to the deployment and operation of technologies like the socially driven HVAC technology (and that these elements might otherwise be overlooked). Much, but not all, of the work that cybersecurity and IT staff do occurs before deployment. Because these staff members interact with the vendor, they were able to work to ensure that the system "works" from a GSA cybersecurity and IT perspective. There are issues of who pays for the time it would take for full evaluation and how those costs are integrated into cost-benefit calculations. And there are ways in which the efforts to ensure success from cybersecurity and IT perspectives could be made smoother (and quicker and less expensive) by developers of technologies (e.g., a technology's interoperability with multiple platforms, attention to cybersecurity standards, and provideing full documentation).

Phoenix M&O Hot/Cold Service Calls

Pre-Retrofit Service Calls to Phoenix Maintenance

Records of hot/cold service calls for June 20, 2012, through June 20, 2013, were provided to ORNL by the building's GSA assistant property manager. There were 124 hot/cold service calls over this period. "Too hot" service calls accounted for 75% of total calls. The majority of hot calls (59%) were for office spaces, with the remaining hot calls for courtrooms and conference rooms. There were 29 cold calls, all of which were for office spaces. The average time spent resolving the calls was 0.51 hours/call, regardless of call type (hot or cold). Therefore, about 62 hours were required to address all of the calls during the year. Records show that the majority of the calls were handled by either adjusting the set point or the air flow.

The number and types of calls varied throughout the year and seemed to follow seasonal patterns (see Figure A.5; note that June 2012 and June 2013 are not complete months). January marked the highest number of cold calls. It was the only month in which cold calls exceeded hot calls. And, there were no cold calls from June through September 2012. More hot calls were made during the warmer months than cooler months, with the greatest number occurring in July 2012. The month with the highest number of calls was November, with a total of 16. While almost 63% of those incidents consisted of hot calls, the second highest number of cold calls was also in November. One possible explanation for these figures is that November is a month when the seasons are transitioning, and the building's space conditioning is moving from air conditioning to heat, resulting in thermal comfort issues for building occupants.

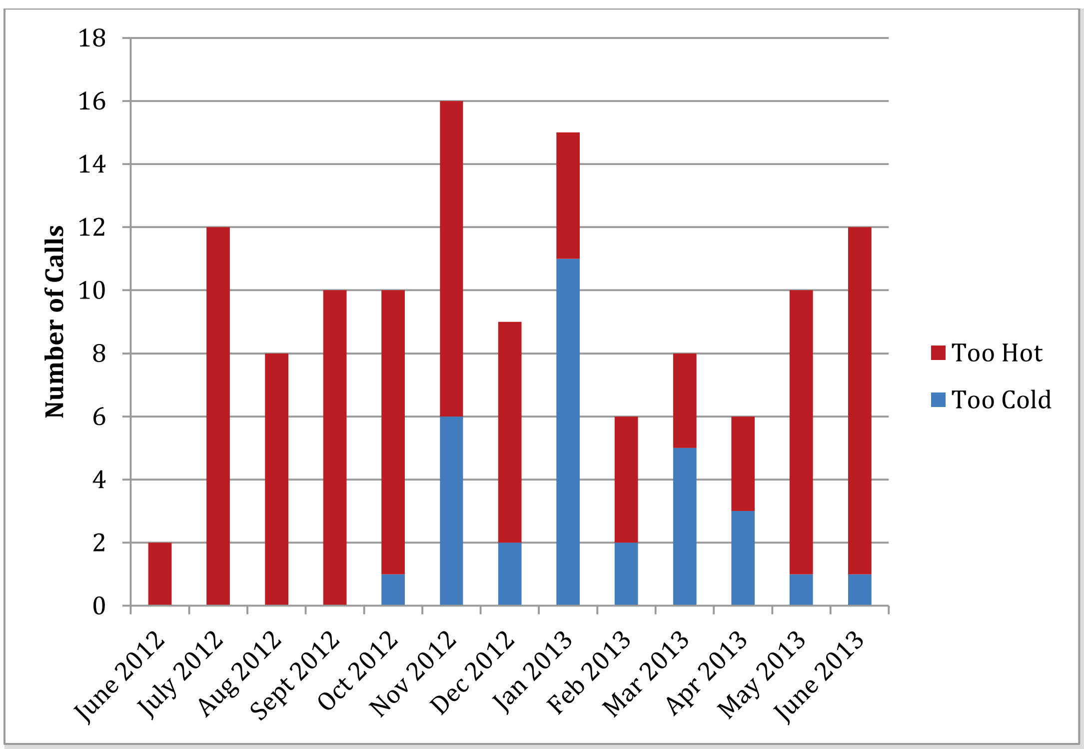

Figure A.5. Number of hot/cold calls by month.

The distribution of calls by time of day, shown in Figure A.6, is quite different for cold versus hot calls. There are two obvious daily peaks for cold calls, first at 9 AM and a higher peak at noon. In contrast, hot calls peak at 9 AM and stay relatively high until they drop substantially toward the end of the workday (4 PM).

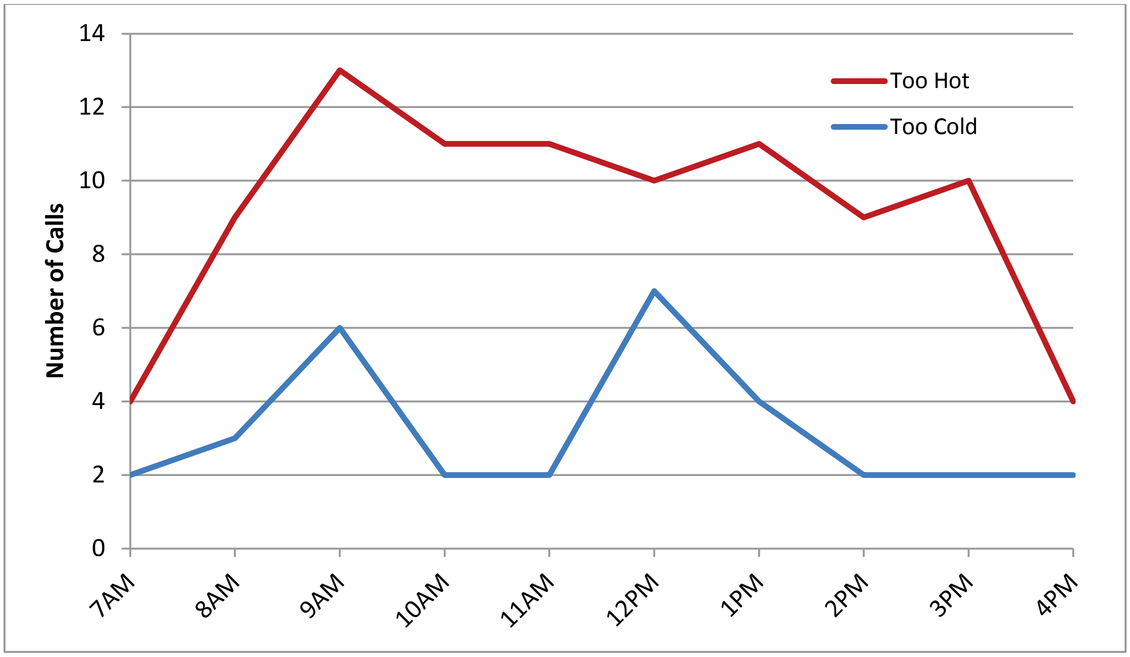

Figure A.6. Number of hot/cold calls by time of day.

Finally, as shown in Table A.13, the floors with courtrooms (1st, 3rd, 6th, and 7th) generated almost 60% of total calls. Of the calls on those floors, 72% were hot calls.

Table A.13. Type of Calls by Floor

Floor	Number of Hot Calls	Number of Cold Calls
Basement	0	1
1	8	7
2	19	6
3	10	5
4	15	3
5	5	0
6	20	4
7	15	5
8 (Elevator room)	1	0
TOTAL	**93**	**31**

Post-Retrofit Service Calls to Phoenix Maintenance

The hot/cold service call log shows a total of 23 calls between the date he socially driven HVAC technology was deployed and October 28, 2014 (Table A.14). If we assume the same average time resolving a call as in the pre-retrofit period, 23 calls results in 11.5 hours for M&O staff. The numbers of calls are too few to discern any seasonal patterns. There were no service calls for the first several weeks after the socially driven HVAC technology was deployed on March 24th. The first service call following the socially driven HVAC technology's deployment occurred on May 6. Almost 83% of all calls were too warm/hot calls versus 75% of pre-retrofit calls being hot calls.

Table A.14. Service Calls Following the Socially Driven HVAC Technology Deployment

Month	Number of Too Warm/Hot Calls	Number of Too Cool/Cold Calls
March (from March 24)	0	0
April	0	0
May	4	2
June	3	0
July	2	0
August	1	0
September	5	2
October	4	0
TOTAL	**19**	**4**

Comparing the number of calls during the same months pre- and post-retrofit shows a reduction of 47 total calls (from 70 to 23), or 23.5 hours for M&O staff. Figures A.7 and A.8 show the number of calls pre- and post-retrofit for too hot and too cold, respectively. Note that March for post-retrofit is only for March 24–31, 2014. The June number of calls for pre-retrofit is the sum of June 20–30, 2012, and June 1–20, 2013. In the case of hot calls, the numbers for pre-retrofit exceeded those of post-retrofit calls for May through October, when there were post-retrofit calls. The only 2 months with post-retrofit cold calls were May and September.

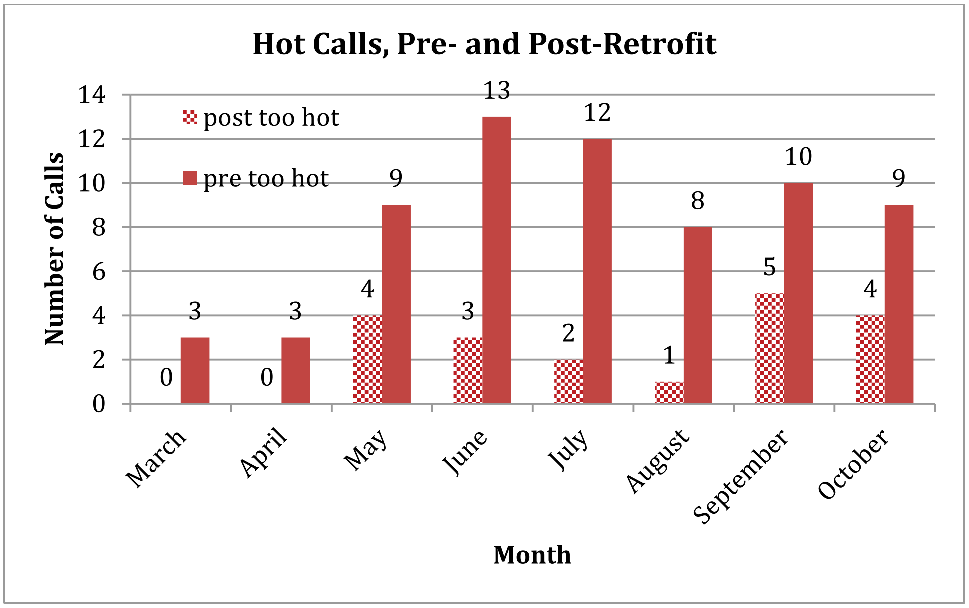

Figure A.7. Hot calls to M&O pre- and post-retrofit.

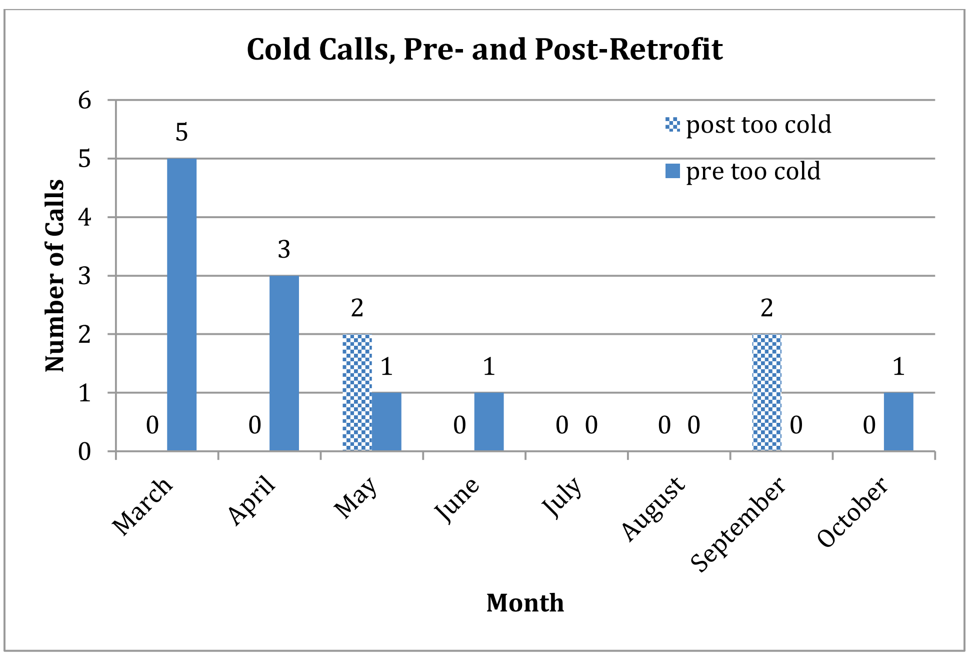

Figure A.8. Cold calls to M&O pre- and post-retrofit.

The Socially Driven HVAC Technology Use Data

The vendor provided its records of the socially driven HVAC calls and users to ORNL from the March 24, 2014, date of deployment through October 7, 2014. "Calls" consist of interactions with the socially driven HVAC technology system in which users signal that they are comfortable or seek to make their workspaces warmer or cooler. The same individuals could, and often did, interact with the socially driven HVAC technology system multiple times in a day. Analysis of the data revealed that there were 224 unique socially driven HVAC technology users (out of an estimated 350 total building occupants) who made a total of 15,756 calls during that time period. The vast majority of calls (12,964) were to "Cool My Space" (see Figure A.9). The following list characterizes the calls.

- 112 unique users of "I Am Comfortable"
  - Total number of calls was 666
  - Number of calls/user ranges from 1 to 75
  - 101 users (90%) made ≤ 10 calls each, accounting for 42% of total calls
  - 11% of users accounted for 58% of calls

- 115 unique users of "Warm My Space"
  - Total number of calls was 2,126
  - Number of calls/user ranges from 1 to 315
  - 111 users (96.5%) accounted for 59% of calls
  - Four users accounted for 41% of calls. The socially driven HVAC technology was eventually turned off for the users in this zone.

- 199 unique users of "Cool My Space"
  - Total number of calls was 12,964
  - Number of calls/user ranges from 1 to 997
  - 161 users (81%) made ≤ 100 calls each, accounting for 33% of total calls
  - 37 users (19%) made >100 and ≤ 409 calls, accounting for 60% of total calls
  - One user who made 997 calls accounted for almost 8% of total calls

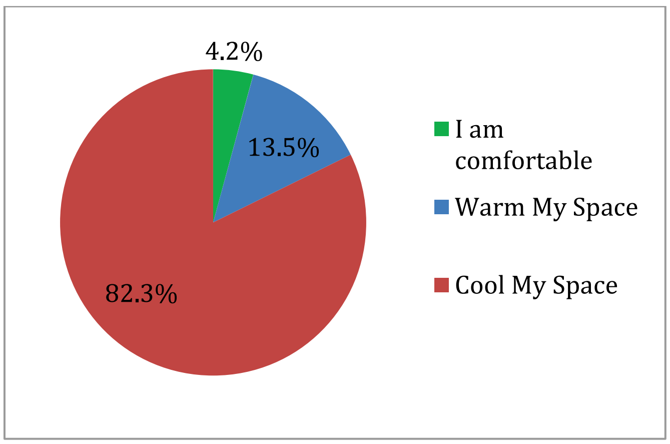

Figure A.9. The socially driven HVAC calls by type of call.

The total number of calls per month is found in Table A.15. Those monthly calls, by type of call, are shown in Figure A.10. Note that the March calls are only for March 24–March 31, and the October calls are only for October 1–7. These calls show a seasonal pattern as the total number of calls was highest in the summer months of July through September. Figure A.10 shows the number of "Cool My Space" calls increased each month from April through the peak in July, with a slight dip in August, and rose in September to just under the July number.

Table A.15. Total Number of Socially Driven HVAC Calls by Month

Month	Total Calls
March (beginning March 24)	447
April	1,990
May	2,078
June	2,224
July	2,865
August	2,745
September	2,904
October (through October 7)	503
TOTAL	**15,756**

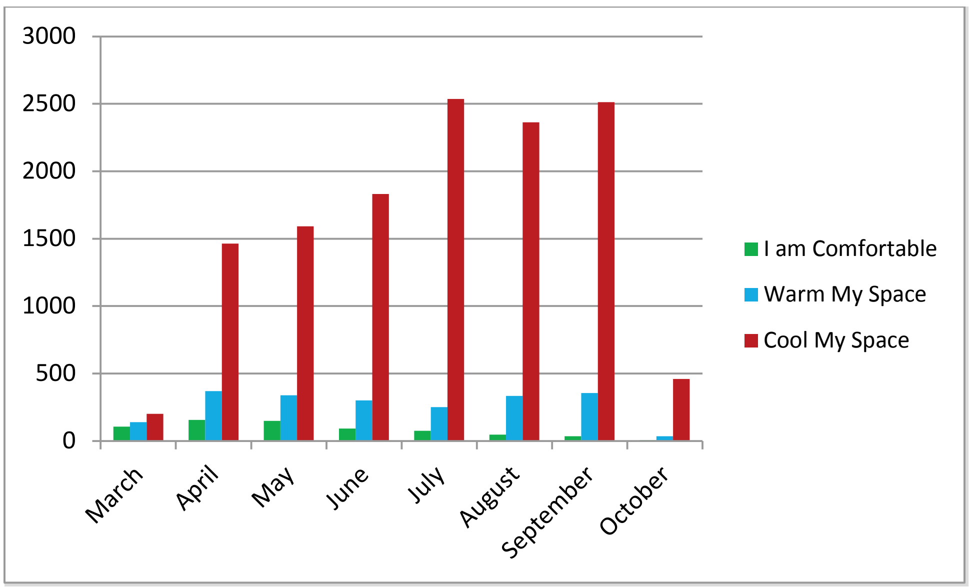

Figure A.10. Socially driven HVAC calls by month and type of call.

We also analyzed the types of socially driven HVAC calls by time of day. The calls to "Warm My Space" are shown in Figure A.11, along with the number of unique users for the time period. [Note that a time period of 7 AM covers all calls made from 7:00:00 AM through 7:59:59 AM]. Requests to "Warm My Space" peaked midday, with most calls at 1 PM, followed closely by noon.

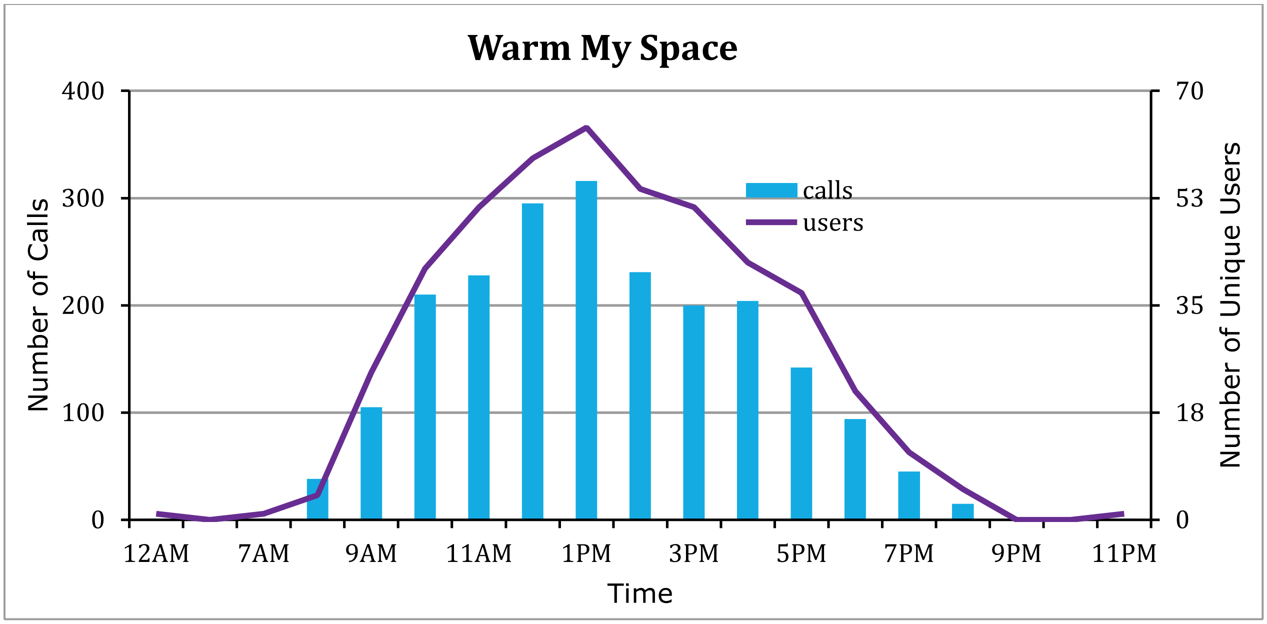

Figure A.11. "Warm My Space" calls by time of day.

Daily "Cool My Space" use patterns exhibited two peaks, though at different afternoon times compared with pre-retrofit data. We provide two views of post-retrofit "Cool My Space" data because of the individual who made 997 (8%) of the "Cool My Space" calls. Figure A.12 shows those calls, including this outlier's calls, and Figure A.13 excludes the outlier's calls. The overall pattern of morning and afternoon peaks is evident in both figures, but the afternoon peak is more pronounced when the individual's calls are included. In both cases, the peak number of calls occurs at 4 PM, and the morning peak occurs at 10 AM.

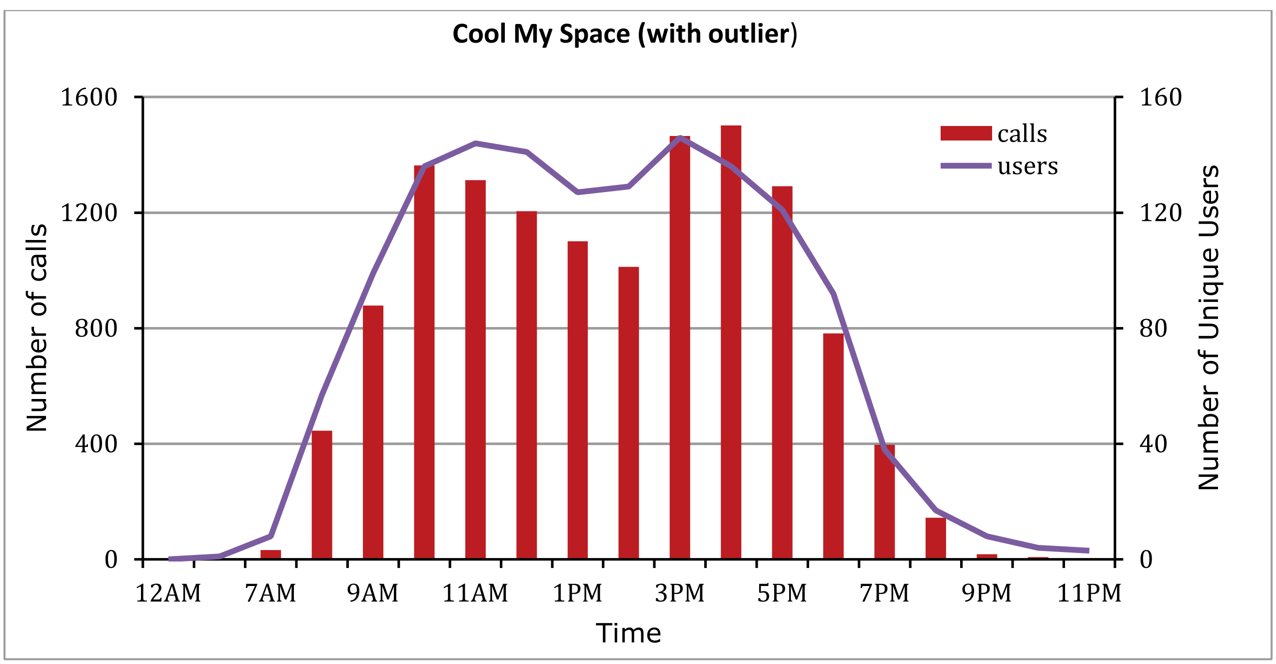

Figure A.12. "Cool My Space" calls by time of day, including outlier.

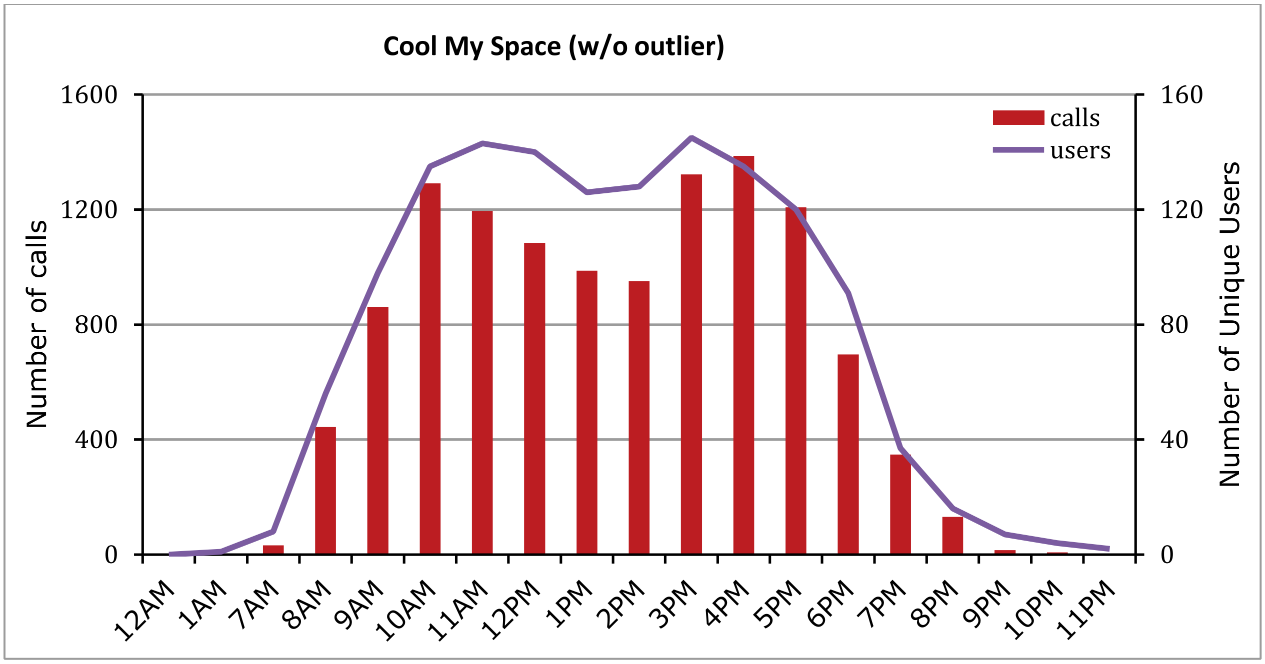

Figure A.13. "Cool My Space" calls by time of day, excluding outlier.

Vendor data identified the user's zone within the building. Thus, we were able to use the zones in conjunction with the building floor plans to determine which zones were along the east- and west-facing sides of the building, excluding interior zones (Table A.16 and Figure A.14). It should be noted that the office space of the outlier described above is in an interior zone, as are courtrooms and conference rooms. The calls to "Cool My Space" were split fairly evenly between the east and west sides of the building. However, we do not know the distribution of tenants. Given the warm to hot weather during the socially driven HVAC technology pilot period, one might expect there to be a larger number of "Cool My Space" calls from the west side. On the other hand, calls to "Warm My Space" on the east side outnumbered calls on the west side almost four to one.

Table A.16. Number of Hot/Cold Calls by Side of Building

Type of Call	East-Facing Offices	West-Facing Offices	Total (east + west)
Cool My Space	3,750	3,652	7402
Warm My Space	983	266	1249
TOTAL	**4,733**	**3,918**	**8651**

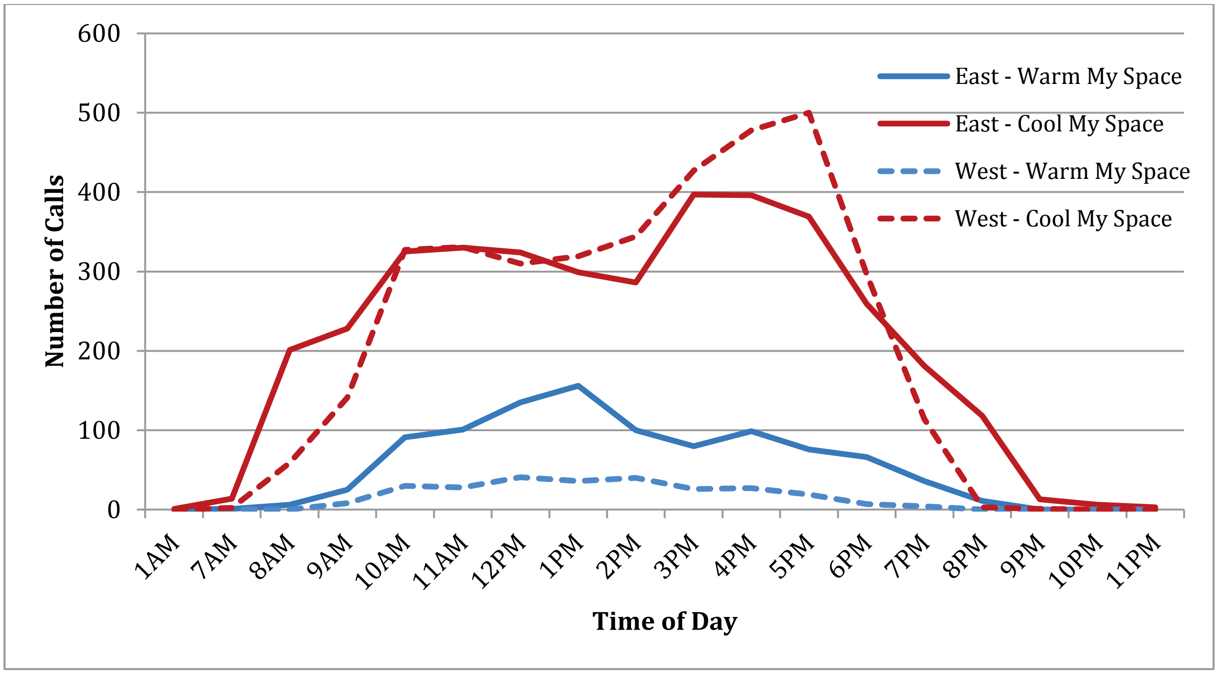

Figure A.14. "Hot" and "cold" calls for east- and west-facing zones.

B. Baseline Survey Questions and Answers

Summary of Baseline Survey

The baseline survey opened on March 5, 2014, and closed on Friday, March 21, 2014, before the socially driven HVAC technology's launch on March 24. The survey sought to collect data on the thermal comfort of the tenants of the Federal Building and US Courthouse in Phoenix. The GSA building assistant property manager distributed an email to the department heads of the customer agencies in the building and requested that they forward it to their staff members. A link to the survey was provided in the email.

The survey consisted of 20 questions. The survey was kept to five computer-screen pages, as requested by GSA. A total of 101 people responded to the survey. Based on an estimated building occupancy of 350 (GSA assistant property manager, Phoenix), this number constitutes a 29% response rate. A sample of 101 from a population of 350 corresponds to 95% certainty of ± 8.24% accuracy.[18]

It should be noted that not all people answered all questions. We did not require answers to each question as this requirement has been suggested to result in some respondents abandoning surveys.[19,20,21,22] A summary of responses to each question is found below.

[18] A population of 350 requires a sample size of 183 to have 95% certainty of ± 5% accuracy.
[19] Sue, Valerie M., and Ritter, Lois A. (2012), *Conducting Online Surveys* (2nd ed.). Thousand Oaks, CA: Sage.
[20] Lynn, Peter, editor (2009), *Methodology of Longitudinal Surveys*. United Kingdom: John Wiley & Sons, Ltd.
[21] Stieger, Stefan, Relps, Ulf-Dietrich, and Voracek, Martin (2007). Forced-Response in Online Surveys: Bias from Reactance and an Increase in Sex-Specific Dropout. *Journal of the American Society for Information Science and Technology*, 58(11): 1653–1660.
[22] Schonlau, Mathias, Fricker, Ronald D. Jr., and Elliott, Marc N. (2002). *Conducting Research Surveys via E-mail and the Web*. Santa Monica, CA: RAND.

Q1: How many years have you worked in this building?		
Answer Options	**Response (%)**	**Response Count**
Less than 1 year	5.9	6
1-2 years	12.9	13
3-5 years	17.8	18
More than 5 years	63.4	64
	answered question	101
	skipped question	0

Q2: How long have you been working at your present workspace?		
Answer Options	**Response (%)**	**Response Count**
Less than 3 months	5.0	5
4-6 months	10.0	10
7-12 months	8.0	8
More than 1 year	77.0	77
	answered question	100
	skipped question	1

Q3: In a typical week, how many hours do you spend in your workspace?		
Answer Options	**Response (%)**	**Response Count**
10 or less	5.0	5
11-30	19.8	20
More than 30	75.2	76
	answered question	101
	skipped question	0

Q4: How would you describe the work that you do?		
Answer Options	**Response (%)**	**Response Count**
Administrative Support	30.7	31
Technical	6.9	7
Professional	39.6	40
Managerial/Supervisory	12.9	13
Operations and Maintenance	3.0	3
Other (please specify)	6.9	7
	answered question	101
	skipped question	0

Q5: What is your age?		
Answer Options	**Response (%)**	**Response Count**
30 or under	9.0	9
31-50	46.0	46
Over 50	45.0	45
	answered question	100
	skipped question	1

Q6: What is your gender?		
Answer Options	**Response (%)**	**Response Count**
Female	71.3	72
Male	28.7	29
	answered question	101
	skipped question	0

Q7 and Q8 were prefaced with the following: When answering Questions 7 and 8, please note that the front of the building, on N. 1st Avenue, faces east. The W. Van Buren Street side of the building faces north. The W. Monroe Street side faces south.

Q7: In which area of the building is your workspace located?							
Area							
Options	North	East	South	West	Core	Don't know	Response Count
Location	11	30	9	27	15	1	93
							Question Totals
						answered question	93
						skipped question	8

Q8: Which direction do the windows closest to your workspace face?							
Options	North	East	South	West	No Windows	Don't know	Response Count
Direction	2	43	2	33	10	3	93
							Question Totals
						answered question	93
						skipped question	8

Q9: Is your workspace within 15 feet of an exterior wall (noting that the exterior walls of the East and West sides of the building have large continuous panes of glass)?		
Answer Options	Response (%)	Response Count
Yes	60.2	56
No	39.8	37
	answered question	93
	skipped question	8

Q10: Is your workspace near a window (within 15 feet)?		
Answer Options	Response (%)	Response Count
Yes	63.4	59
No	36.6	34
	answered question	93
	skipped question	8

Q11: On which floor is your workspace located?									
Floor	Basement	1st	2nd	3rd	4th	5th	6th	7th	Response Count
Count	0	17	26	6	26	7	6	5	93
								answered question	93
								skipped question	8

Q12: Which of the following best describes your workspace?		
Answer Options	Response (%)	Response Count
Enclosed office, private	64.5	60
Enclosed office, shared with one or more other people	5.4	5
Cubicle with high partitions (about five or more feet high)	17.2	16
Cubicle with low partitions (lower than five feet high)	8.6	8
Workspace in open office with no partitions (just desks)	2.2	2
Other (please specify)	2.2	2
	answered question	93
	skipped question	8

There were seven choices for **Q13**: *Very Dissatisfied* (score = 1), two more choices between *Very Dissatisfied* and *Generally Satisfied* (with scores of 2 and 3, respectively), *Generally Satisfied* (score = 4), two choices between *Generally Satisfied* and *Very Satisfied* (with scores of 5 and 6, respectively), and *Very Satisfied* (score = 7). Forty-three percent of the people who answered the question were generally satisfied (35 of 81). Weighting each score by the number of people who chose it, the average score is 3.63 or slightly under *Generally Satisfied*.

Q13: How satisfied are you with the temperature in your workspace?									
Options	Very Dissatisfied			Generally Satisfied			Very Satisfied	Rating Average	Response Count
	4	13	17	35	2	7	3	3.63	81
								answered question	81
								skipped question	20

For **Q14,** regarding thermal comfort in warm/hot weather, people were allowed to choose more than one answer; the total number of responses was 102 for the 92 people who answered the question. Overall, the most common response was *Generally Comfortable*, followed by *Sometimes too hot* and *Sometimes too cold*. In addition, 17.4% of the responses were *Often too hot*, while only 7.6% were *Often too cold*.

Q14: In warm/hot weather, the temperature in my workspace is: (check all that apply)		
Answer Options	Response (%)	Response Count
Often too cold	7.6	7
Sometimes too cold	22.8	21
Generally comfortable	33.7	31
Sometimes too hot	29.3	27
Often too hot	17.4	16
	answered question	92
	skipped question	9

Q15: The total number of responses was 99 for the 92 respondents. A higher percentage of people responded *Generally Comfortable* in cool/cold weather vs. warm/hot. This response is followed by 29.3% being *Sometimes too cold*. Interestingly, there were equal numbers of votes for *Often too cold* and *Sometimes too hot*. Only 4.3% responded *Often too hot* in the cool/cold weather.

Q15: In cool/cold weather, the temperature in my workspace is: (check all that apply)		
Answer Options	Response (%)	Response Count
Often too cold	17.4	16
Sometimes too cold	29.3	27
Generally comfortable	39.1	36
Sometimes too hot	17.4	16
Often too hot	4.3	4
	answered question	92
	skipped question	9

Q16: Ninety-three people provided 140 responses. Almost 25% of the responses indicated that people are not too hot in their workspace. Of those who are too warm/hot in the workspace, 19.4% are too warm in the morning before 11:00 AM; this figure rises to 21.5% by midday; almost 40% of the responses indicate that people are too warm/hot in the midafternoon (2:00 PM–5:00 PM). There were only six responses indicating too warm after 5:00 PM; the number of responses would imply that the vast majority of people have exited the building by 5:00 PM. Another 10.8% are too warm regardless of the time of day.

Q16: When the temperature in my workspace is too warm/hot, it is most often a problem... (check all that apply)		
Answer Options	**Response (%)**	**Response Count**
I am not too warm/hot in my workspace	24.7	23
Morning (before 11am)	19.4	18
Mid-day (11am - 2pm)	21.5	20
Afternoon (2pm - 5pm)	39.8	37
Evening (after 5pm)	6.5	6
Weekends/holidays	8.6	8
Monday mornings	15.1	14
No particular time	10.8	10
Other (please specify)	4.3	4
	answered question	93
	skipped question	8

Q17 mirrors Q16 for when the workspace is too cool/cold. There were 138 responses from 93 people. Of those, 25.8% of the responses were that the tenant is not too cool/cold in the workspace; 39.8% of responses were the space is too cold in the morning up to 11:00 AM, contrasted with the same percentage too warm in their space (Q16) in the midafternoon (2–5 PM). The number of too cool/cold drops from 11 AM to 2 PM, but rises slightly from 2 to 5 PM. There were no votes for after 5 PM—possibly because people left the building or because the chillers turned off at 5.

Q17: When the temperature in my workspace is too cool/cold, it is most often a problem... (check all that apply)		
Answer Options	**Response (%)**	**Response Count**
I am not too cool/cold in my workspace	25.8	24
Morning (before 11 am)	39.8	37
Mid-day (11 am-2 pm)	21.5	20
Afternoon (2 pm-5 pm)	26.9	25
Evening (after 5 pm)	0.0	0
Weekends/holidays	1.1	1
Monday mornings	11.8	11
No particular time	18.3	17
Other (please specify)	3.2	3
	answered question	93
	skipped question	8

Q18: This question shows all the choices for what the tenants reported as the sources of their thermal discomfort (either too hot or too cold). There were 197 responses from 89 respondents. Almost 40% of the responses (35) indicated that there was too little air movement in the workspace. The most popular response was “Thermostat is inaccessible” (22.5%), followed by ”Thermostat is adjusted by other people” (21.3%), and an equal number of respondents (18, or 20.2%) selected “Air movement too great” and “Heating/cooling system does not respond quickly.”

Q18: How would you best describe the source of thermal discomfort (either too cold or too hot) in your workspace? (check all that apply)		
Answer Options	**Response (%)**	**Response Count**
Humidity too high (damp)	4.5	4
Humidity too low (dry)	5.6	5
Air movement too great	20.2	18
Air movement too little	39.3	35
Incoming sun	16.9	15
Hot/cold floor surfaces	1.1	1
Hot/cold ceiling surfaces	2.2	2
Hot/cold wall surfaces	2.2	2
Hot/cold window surfaces	11.2	10
Heat from office equipment	1.1	1
Drafts from windows	7.9	7
Drafts from vents	15.7	14
Drafts falling from the ceiling	10.1	9
Thermostat is inaccessible	22.5	20
Thermostat is adjusted by other people	21.3	19
Heating/cooling system does not respond quickly enough to the thermostat	20.2	18
Clothing policy is not flexible	4.5	4
Other (please specify)	14.6	13
	answered question	89
	skipped question	12

Q19: When you are not satisfied with the thermal comfort in your workspace, which of the following do you personally adjust or control in your workspace and how often? (check all that apply)						
Answer Options	Cannot adjust/control	Never	Rarely	Sometimes	Frequently	Response Count
Window blinds or shades	22	14	9	21	13	79
Operable window	55	17	0	0	0	72
Thermostat	39	14	3	17	8	81
Portable heater	22	44	0	4	11	81
Permanent heater	31	40	0	0	0	71
Room air-conditioning unit	34	38	0	2	2	76
Portable fan	13	23	6	11	30	83
Ceiling fan	29	38	0	0	0	67
Adjustable air vent in wall or ceiling	39	31	1	0	2	73
Adjustable floor air vent (diffuser)	38	33	0	0	0	71
Door to interior space	19	35	4	11	4	73
Door to exterior space	29	37	1	2	0	69
Other	9	16	0	2	1	28
Please specify Other						9
					answered question	89
					skipped question	12

Q20: Please describe any other issues related to being too hot or too cold in your workspace.	
Answer Options	Response Count
[No answer options provided]	23
answered question	23
skipped question	78

The following were among the issues reported in response to **Q20**.

- In my area it gets very cold but only for a little while and then it seems to adjust. Probably two to three times a week.
- I just need continuous flowing cold/cool air in my office throughout the year. The air can't be stagnant,
- Just too hot in the summer. Not enough air movement. Not cool enough temp when the little air does move.
- Some floors of the building are colder than others. So when I know I have to go to the other floors, I make sure I bring a sweater. For the most part, I am comfortable in my work space.
- Building heating system very poorly designed. Concept of heating the building perimeter and circulating that air to heat the interior works only if left on 24/7.

- I ALWAYS have my fan running in my office. But then there are other offices where it is REALLY cold.
- Windows are single pane plexiglass; usually too cold in winter months on Monday mornings; air is extremely DRY and NO air flow.
- It's usually more cold than hot in my area (under the desk/work station—feels like a draft).
- At this point, I do not want to close any of my vents since I am not sure what the temperature will be in my office in the middle of summer.
- Feels like no air—no air movement—suffocating feeling.
- The Courtrooms are sometimes too warm because there is no air moving.
- Aside from keeping my workspace cold, the vent that blows almost continuously is very noisy and disruptive to my work.
- I can get hot in my office fairly easy, but a coworker always complains about being cool. We share the same thermostat.
- Thermostat on wall in my one-person office, but it does not seem to do anything.
- It often feels very stuffy and airless, as well as being too warm
- My workspace in a hall area, others have control over hot/cold. Never too hot in my area, I am not near any windows, and if air is turned up to accommodate the hot offices then my area stays cool. I use a sweater if it gets too cool. Rather be cool than hot. Office is cold, on Monday morning, only after a really cold weekend; not a problem this year.
- During the winter fan is on and it’s cold. During summer it is warm in the afternoon.
- The temperature varies upon where you are in the office. I’m closer to the central part of the office, and it may feel warm here, but the main office entrance, which is closer to the northern side of the building, tends to be cold like the air hits there first and warms up before it gets to our section.

C. Socially Driven HVAC Technology Survey Questions and Answers

Socially Driven HVAC Technology Survey Results

The “Socially Driven HVAC Technology in Phoenix Bankruptcy Building” survey was open for 3 weeks from September 4, 2014, through September 26, 2014. This online survey was conducted after the socially driven HVAC technology had been deployed in the building for about 5 months. The purpose was to evaluate the socially driven HVAC technology from building occupants’ perspectives. As with the baseline survey, the building’s GSA assistant property manager distributed an email to the department heads of the customer agencies in the building and requested that they forward the message to their staff members. A link to the survey was provided in the email.

The survey consisted of 32 questions. The survey was kept to five computer-screen pages, as requested by GSA. Sixty-two building occupants responded to the survey. As with the baseline survey, we did not require answers to each question. Based on an estimated building occupancy of 350 (GSA assistant property manager, Phoenix), this number constitutes a roughly 18% response rate. A sample size of 62 from a population of 350 corresponds to 95% certainty of ± 11.31% accuracy.

A summary of responses to each question follows.

Q1: How many years have you worked in this building?		
Answer Options	**Response (%)**	**Response Count**
Less than 1 year	6.3	4
1-2 years	9.4	6
3-5 years	14.1	9
More than 5 years	70.3	45
	answered question	62
	skipped question	0

Q2: How long have you been working at your present workspace?		
Answer Options	**Response (%)**	**Response Count**
Less than 3 months	12.5	8
4-6 months	9.4	6
7-12 months	15.6	10
More than 1 year	62.5	40
	answered question	62
	skipped question	0

Q3: In a typical week, how many hours do you spend in your workspace?		
Answer Options	**Response (%)**	**Response Count**
10 or less	3.2	2
11-30	12.7	8
More than 30	84.1	53
	answered question	62
	skipped question	0

Q4: How would you describe the work that you do?		
Answer Options	**Response (%)**	**Response Count**
Administrative Support	25.4	16
Technical	7.9	5
Professional	39.7	25
Managerial/Supervisory	17.5	11
Operations and Maintenance	3.2	2
Other (please specify)	6.3	4
	answered question	62
	skipped question	0

Q5: What is your age?		
Answer Options	**Response (%)**	**Response Count**
30 or under	6.5	4
31-50	30.6	19
Over 50	62.9	39
	answered question	62
	skipped question	0

Q6: What is your gender?		
Answer Options	**Response (%)**	**Response Count**
Female	67.7	42
Male	32.3	20
	answered question	62
	skipped question	0

Questions 7 and 8 were prefaced with the following: When answering Questions 7 and 8, please note that the front of the building, on N. 1st Avenue, faces east. The W. Van Buren Street side of the building faces north. The W. Monroe Street side faces south.

Fifty-three percent of respondents identified their workspace to be on the east side of the building, and more than 57% were in workspaces where the closest windows faced east. Seventy-seven percent of respondents said they were within 15 ft of an exterior wall, and almost 80% were within 15 ft of a window. Of the 62 responses to Question 11, 29% were on the first floor of the building and 23% on the second floor.

In the answers to Question 12, 48 of the 62 (48%) respondents said they were in an enclosed, private office. Eight respondents (almost 13%) were in cubicles with high partitions.

Q7: In which area of the building is your workspace located?							
Options	North	East	South	West	Core	Don't know	Response Count
Answer	5	33	4	14	5	1	62
						answered question	62
						skipped question	0

Q8: Which direction do the windows closest to your workspace face?							
Options	North	East	South	West	No Windows	Don't know	Response Count
Answers	1	35	0	19	6	0	61
						answered question	61
						skipped question	1

Q9: Is your workspace within 15 feet of an exterior wall (noting that the exterior walls of the East and West sides of the building have large continuous panes of glass)?		
Answer Options	Response (%)	Response Count
Yes	77.4	48
No	22.6	14
	answered question	62
	skipped question	0

Q10: Is your workspace near a window (within 15 feet)?		
Answer Options	Response (%)	Response Count
Yes	79.7	47
No	20.3	12
	answered question	59
	skipped question	3

Q11: On which floor is your workspace located?									
Options	Basement	1st Floor	2nd Floor	3rd Floor	4th Floor	5th Floor	6th Floor	7th Floor	Response Count
Answers	0	18	14	6	6	2	9	7	62
								answered question	62
								skipped question	0

Q12: Which of the following best describes your workspace?		
Answer Options	Response (%)	Response Count
Enclosed office, private	77.4	48
Enclosed office, shared with one or more other people	4.8	3
Cubicle with high partitions (about five or more feet high)	12.9	8
Cubicle with low partitions (lower than five feet high)	3.2	2
Workspace in open office with no partitions (just desks)	1.6	1
Other (please specify)	0.0	0
	answered question	62
	skipped question	0

With respect to **Q13**: There were seven answer choices for this question: *Very Dissatisfied* (score = 1), two more choices between *Very Dissatisfied* and *Generally Satisfied* (with scores of 2 and 3, respectively), *Generally Satisfied* (score = 4), two choices between *Generally Satisfied* and *Very Satisfied* (with scores of 5 and 6, respectively), and *Very Satisfied* (score = 7). Weighting each score by the number of people who chose it, and dividing by the total number of responses for that category, provided the "Rating Average." This method applies to all questions with scored answers.

Q13: How satisfied are you with the temperature in your workspace?									
Answer Options		Very Dissatisfied		Generally Satisfied			Very Satisfied	Rating Average	Response Count
	6	4	11	25	3	7	4	3.87	60
								answered question	60
								skipped question	2

Q14: In warm/hot weather, the temperature in my workspace is (check all that apply):		
Answer Options	**Response (%)**	**Response Count**
Often too cold	4.9	3
Sometimes too cold	8.2	5
Generally comfortable	24.6	15
Sometimes too hot	44.3	27
Often too hot	26.2	16
	answered question	61
	skipped question	1

Q15: In cool/cold weather, the temperature in my workspace is (check all that apply):		
Answer Options	**Response (%)**	**Response Count**
Often too cold	5.2	3
Sometimes too cold	20.7	12
Generally comfortable	72.4	42
Sometimes too hot	5.2	3
Often too hot	1.7	1
	answered question	58
	skipped question	4

Q16: When the temperature in my workspace is too warm/hot, it is most often a problem... (check all that apply)		
Answer Options	**Response (%)**	**Response Count**
My workspace is not too warm/hot	8.3	5
Morning (before 11 am)	40.0	24
Midday (11 am-2 pm)	30.0	18
Afternoon (2 pm-5 pm)	38.3	23
Evening (after 5 pm)	6.7	4
Weekends/holidays	6.7	4
Monday mornings	40.0	24
No particular time	11.7	7
Other (please specify)	5.0	3
	answered question	60
	skipped question	2

Q17: When the temperature in my workspace is too cool/cold, it is most often a problem... (check all that apply)		
Answer Options	**Response (%)**	**Response Count**
My workspace is not too cool/cold	29.3	17
Morning (before 11 am)	20.7	12
Midday (11 am-2 pm)	6.9	4
Afternoon (2 pm-5 pm)	12.1	7
Evening (after 5 pm)	1.7	1
Weekends/holidays	0.0	0
Monday mornings	10.3	6
No particular time	25.9	15
Other (please specify)	13.8	8
	answered question	58
	skipped question	4

Q18: How would you best describe the source of thermal discomfort (either too cold or too hot) in your workspace? (check all that apply)		
Answer Options	**Response (%)**	**Response Count**
Humidity too high (damp)	23.7	14
Humidity too low (dry)	1.7	1
Air movement too great	13.6	8
Air movement too little	62.7	37
Incoming sun	23.7	14
Hot/cold floor surfaces	0.0	0
Hot/cold ceiling surfaces	0.0	0
Hot/cold wall surfaces	1.7	1
Hot/cold window surfaces	16.9	10
Heat from office equipment	3.4	2
Drafts from windows	10.2	6
Drafts from vents	8.5	5
Drafts falling from the ceiling	5.1	3
Thermostat is inaccessible	15.3	9
Thermostat is adjusted by other people	15.3	9
Heating/cooling system does not respond quickly enough to the thermostat	18.6	11
Clothing policy is not flexible	0.0	0
Other (please specify)	18.6	11
	answered question	59
	skipped question	3

Q19 through Q31 are specific to the socially driven HVAC technology.

Q19: How often have you used the socially driven HVAC technology to "Cool My Space?"		
Answer Options	**Response (%)**	**Response Count**
Never registered	1.7	1
Registered, but have not used	6.8	4
Rarely (only used once or twice)	5.1	3
Sometimes (a few times in the last five months)	13.6	8
Occasionally (a couple of times per month)	13.6	8
Frequently (a couple of times per week)	25.4	15
Often (several times per week)	37.3	22
Comments		12
	answered question	59
	skipped question	3

Q20: How often have you used the socially driven HVAC technology to "Warm My Space?"		
Answer Options	**Response (%)**	**Response Count**
Never registered	12.7	7
Registered, but have not used	47.3	26
Rarely (only used once or twice)	25.5	14
Sometimes (a few times in the last five months)	10.9	6
Occasionally (a couple of times per month)	0.0	0
Frequently (a couple of times per week)	5.5	3
Often (several times per week)	3.6	2
Comments		8
	answered question	55
	skipped question	7

Q21: On whose behalf do you use the socially driven HVAC technology?		
Answer Options	**Response (%)**	**Response Count**
Just myself	59.7	37
Myself and others	40.3	25
Just others	0.0	0
Please specify for whom you use the socially driven HVAC technology other than yourself (e.g., people who use conference rooms or courtrooms, people in my voting area		18
	answered question	58
	skipped question	6

Q22: What do you like most about the socially driven HVAC technology? Please list no more than three.	
Answer Options	Response Count
[No answer options were provided]	46
answered question	46
skipped question	16

Answers, arranged loosely by topic, were as follows.

Quick response

- Works quickly.
- That the response is pretty quick.
- Quick Response.
- Seems pretty responsive.
- Immediate response.
- It kicks in right away; it's nice to have some control.
- Immediate response.
- Response is immediate.
- Very responsive and effective in cooling my areas. I would highly recommend the system.
- Quick response.
- I like the prompt results.
- Can get air moving quickly.

Control

- Being able to cool my space without having to suffer through it or email someone to turn the air down.
- Ability to adjust room temp without having to email our local maintenance list, who then contact GSA.
- I like that I can start it on my own as soon as get into the office. By the time around 11:00 am comes, the office is starting to feel comfortable.
- Being able to adjust the temperature when needed.
- I can let the system know if it's too hot or too cold.
- I like the control I have & I don't have to worry about anyone else's comfort.
- I control the temperature of my space.
- I think it's great a system was designed to adjust my own temperature in my office.
- Just that I'm able to help control the temperature and it's so easy.
- I am in control of the temperature at all times.

- Accessibility to control temp. Being able to control my own space temp.
- Response is immediate.
- Control.
- Online access and ability to control climate.
- I can control my office temp.

Ease of Use

- It is easy to use and I am able to control the temperature in my workspace.
- It is fairly easy!
- Easy to make requests.
- Easy to use.
- Easy to use.
- Convenient, easy to access.
- Easy to use.

Accessibility

- Accessibility.
- I can access from my phone.
- Easily accessed.
- It is accessible from anywhere. Once it starts working, it works well.
- Online access and ability to control climate.
- That you can access it when you want . . . whenever you feel a need.

Other

- I can't say. If the GSA temperature ranges were consistently met, then the socially driven HVAC technology wouldn’t be necessary in my mind.
- Nothing. It is completely pointless if you have more than one person being able to change the temperature within one work station, simply because different people have different comfort levels. The person in the office next to me prefers a temperature of about 68, while I prefer a temperature of about 74. Long term this cannot work, and I am considering changing offices, despite the fact I have been in my current office for 10 years.
- I think it’s great a system was designed to adjust my own temperature in my office.
- It does cool location down. But have to request over and over again.
- The ability to get cooler air.
- That I can ask for cool air most anytime.

Q23: What do you like least about the socially driven HVAC technology? Please list no more than three.	
Answer Options	Response Count
[No answer options were provided]	37
answered question	37
skipped question	25

Answers, arranged loosely by topic, were as follows.

Conflicting temperature preferences

- Shared zones sometimes cause an issue if their comfort levels differ.
- It is completely pointless if you have more than one person being able to change the temperature within one work station, simply because different people have different comfort levels. The person in the office next to me prefers a temperature of about 68, while I prefer a temperature of about 74. Long term this cannot work, and I am considering changing offices, despite the fact I have been in my current office for 10 years.
- Needs to be more specific to area that needs heat. The front of this office is too warm for the people who work here. When they make requests at the same time, we negate each other. The back of this office is freezing and the front is ordering it to be cooler.
- My office is connected to two more offices in my socially driven HVAC technology area so if I adjust the temperature, it effects the other two offices (only one office is being used at this time). Therefore, I only use the socially driven HVAC technology when the coworker isn’t in the office.
- Having to share with other workers in my shared space.
- Sharing it with someone else who has a different comfort than I do.

Temperature change takes too long or is not sustained

- That the office is always way too hot first thing in the morning and it takes several hours to cool it down.
- Often inaccessible, link doesn't always work. Coolness isn't sustained requiring multiple contacts.
- Doesn't last. Only provides temporary relief.
- It shuts off too soon (i.e., before area is sufficiently cooled—I have to keep hitting the temperature controls).
- Once the stream is over I usually need to cool my space one to three times.
- It doesn’t seem to work quickly enough, especially in the morning.
- Having to request over and over again.
- Responses to requests take a while.

- It takes a long time for it to cool down. I wish I could set a specific temperature and then leave it alone instead of continually hitting it.
- When it says “we think your space is comfortable” yet I'm sitting here sweating and it won’t let you send another request for 10 minutes. Thank goodness I have a fan in my cubicle.
- Only cools for a short time . . . would like it to last a little longer.
- On days that temperatures are hotter than normal, I have to keep the socially driven HVAC technology up on my desktop because I am accessing it several times a day.

Other

- Nothing; I love having it.
- It did not work as advertised for the first 4 months.
- No complaints (3 answers).
- N/A (2 responses).
- Had to struggle with getting the settings correct.
- When it’s on snooze.
- Not sure how long it will take to cool/warm the space once I click on the button.
- I don’t have it readily available as a desktop icon.
- The fact that user must wait 10 minutes to continue use. Conference rooms do not have a way to access control other than on computer.
- Response doesn't last. The socially driven HVAC technology trying to tell me I’m comfortable when I am not.
- No app for iPad (would be handy when in a meeting in different space than my office).
- Cannot appropriately cool Courtroom 601.
- Does not noticeably work. Need to do it every 10 minutes. Poorly designed system.
- (1) I can’t (don’t know how) to control the “common areas” of our office space. (2) You can really feel how hot it is in the hallways of the building.
- That it’s needed.
- I don’t feel the “cooling” effect that it suggests from the picture when I ask it to cool down my space. I don’t feel any “breeze.”

Q24: Check your level of satisfaction with the socially driven HVAC technology regarding the following:									
Answer Options	**Very dissatisfied**			**Generally satisfied**			**Very satisfied**	**Rating Average**	**Response Count**
Ease of use	3	2	1	10	6	11	26	5.56	59
Access to the socially driven HVAC technology (i.e., is the system down?)	1	1	1	11	7	13	23	5.68	57
Technical support	2	0	1	23	4	7	16	5.11	53
Comments									4
								answered question	59
								skipped question	3

Q25: To what extent has your satisfaction with the thermal comfort of your workspace changed as a result of the socially driven HVAC technology?							
Answer Options	**Much less satisfied**	**Less Satisfied**	**No change**	**More Satisfied**	**Much more satisfied**	**Rating Average[a]**	**Response Count**
	2	2	6	18	31	4.25	59
Comments							3
						answered question	59
						skipped question	3

[a]There were five answer choices: *Much Less Satisfied* (score = 1), *Less Satisfied* (score = 2), *No Change* (score = 3), *More Satisfied* (score = 4), and *Much More Satisfied* (score = 5).

Q26: To what extent are you satisfied with the socially driven HVAC technology's responsiveness to your request for a temperature change?		
Answer Options	**Response (%)**	**Response Count**
Not at all	0.0	0
I have to make several requests	19.3	11
Generally satisfied	21.1	12
Almost always satisfied	33.3	19
Always satisfied	26.3	15
Comments		7
	answered question	57
	skipped question	5

Q27: If you are in a the socially driven HVAC technology voting zone, please rate your satisfaction with the following:										
Answer Options	Have never voted	Very dissatisfied			Generally satisfied			Very satisfied	Rating Average	Response Count
Requirement to vote	20	0	0	1	8	0	2	2	4.46	33
Ease of my voting	17	1	0	1	6	0	2	4	4.64	31
Ease of finding others to vote	18	0	0	1	7	0	2	2	4.50	30
Time involved in reaching consensus	18	1	0	1	6	0	2	2	4.25	30
Effect of voting on my thermal comfort	18	1	0	2	6	0	2	2	3.92	31
Comments										5
									answered question	33
									skipped question	29

Q28: When you use the socially driven HVAC technology to “Cool My Space,” it most often occurs (check all that apply):		
Answer Options	Response (%)	Response Count
I am not too warm/hot in my workspace	6.9	4
Morning (before 11 am)	43.1	25
Midday (11 am-2 pm)	41.4	24
Afternoon (2 pm-5 pm)	44.8	26
Evening (after 5 pm)	6.9	4
Weekends/holidays	1.7	1
Monday mornings	46.6	27
No particular time	15.5	9
Other (please specify)	3.4	2
	answered question	58
	skipped question	4

Q29: When you use the socially driven HVAC technology to “Warm My Space,” it most often occurs (check all that apply):		
Answer Options	**Response (%)**	**Response Count**
I am not too warm/hot in my workspace	27.3	15
Morning (before 11 am)	18.2	10
Mid-day (11 am-2 pm)	5.5	3
Afternoon (2 pm-5 pm)	9.1	5
Evening (after 5 pm)	1.8	1
Weekends/holidays	0.0	0
Monday mornings	12.7	7
No particular time	21.8	12
Other (please specify)	25.5	14
	answered question	**55**
	skipped question	**7**

Q30: If you use the socially driven HVAC technology to adjust the temperature in your workspace, how often do you also make cold/hot calls that are routed to the Facilities manager? Please explain why in the comment box.		
Answer Options	**Response (%)**	**Response Count**
Never	70.9	39
Rarely (1-2 times per month)	18.2	10
Occasionally (1-2 times per month)	9.1	5
Frequently (several times per week)	1.8	1
Comments		12
	answered question	**55**
	skipped question	**7**

Q31: When you use the socially driven HVAC technology to adjust the temperature in your workspace, do you also use any of the following to make yourself more comfortable (please check all that apply)?						
Answer Options	Cannot adjust/control	Never	Rarely	Sometimes	Frequently	Response Count
Window blinds or shades	10	5	5	11	21	52
Operable window	39	8	0	0	1	48
Thermostat	28	9	4	3	5	49
Portable heater	15	24	5	4	4	52
Permanent heater	17	26	1	0	2	46
Room air-conditioning unit	19	26	0	0	1	46
Portable fan	10	10	6	5	21	52
Ceiling fan	19	26	0	0	1	46
Adjustable air vent in wall or ceiling	20	17	5	1	3	46
Adjustable floor air vent (diffuser)	24	20	1	0	1	46
Door to interior space	9	24	3	7	3	46
Door to exterior space	13	22	2	5	3	45
Clothing	2	9	6	22	12	51
Drink hot/cold beverages	1	6	7	25	13	52
Other	5	7	1	0	2	15
Please specify Other						2
					answered question	56
					skipped question	6

Q32: Please provide any other comments related to your use of the socially driven HVAC technology.	
Answer Options	Response Count
[No answer options were provided]	17
answered question	17
skipped question	45

Answers to **Q32** were as follows.

- I think it was one of the better devices installed in this building...
- Total waste of money. Set it at the government norm, whatever that is, and leave it alone.
- My office used to be a storage room so it is always too warm. I start adjusting the socially driven HVAC technology at 6:30 am and the room doesn’t get comfortable until around 10–11 in the morning. I have a fan that goes 24/7 to keep the air circulating in the room. Between the fan and the socially driven HVAC technology, I finally have a comfortable office to work in. Before the socially driven HVAC technology, I never could get the thermostat to work and by about 1:00 pm, I was dying from the heat in the office.

- The socially driven HVAC technology pilot has been ideal!!!
- In general, I like the system very much! I wish it was permanent.
- I am very cold most of the time.
- Mostly, I've found it to be a benefit. I would note that many times when in the courtrooms, they will get warm. Rarely, cool.
- I recently moved to a new office. In the old office the socially driven HVAC technology did not fix the problem between three office workers until we called facilities.
- Thank you for providing the socially driven HVAC technology to employees to adjust their own temperature; I think it was a wonderful idea. The only issue is since my controls are connected to other offices, I rarely am able to use it; I don't want to make others uncomfortable. Thank you for your concerns regarding the use of the socially driven HVAC technology.
- I like it and glad it’s available.
- Have enjoyed the socially driven HVAC technology.
- If ceiling fans were installed in offices it would help with air flow. Individual offices should have ceiling fan access.
- It’s a wonderful climate tailoring tool.
- Overall I like it.
- I like it! I would like to know how to use it for our conference room in our office space & how to use it for the common areas too.
- The theory behind the socially driven HVAC technology is good. The set temps do not take into account dead air spaces, sharing space, and air pressure.
- Would like to know how we can get the socially driven HVAC technology access for our 3rd floor break room. It is very warm in that room and almost too uncomfortable to eat lunch in there. I don't have access to that area through the socially driven HVAC technology.