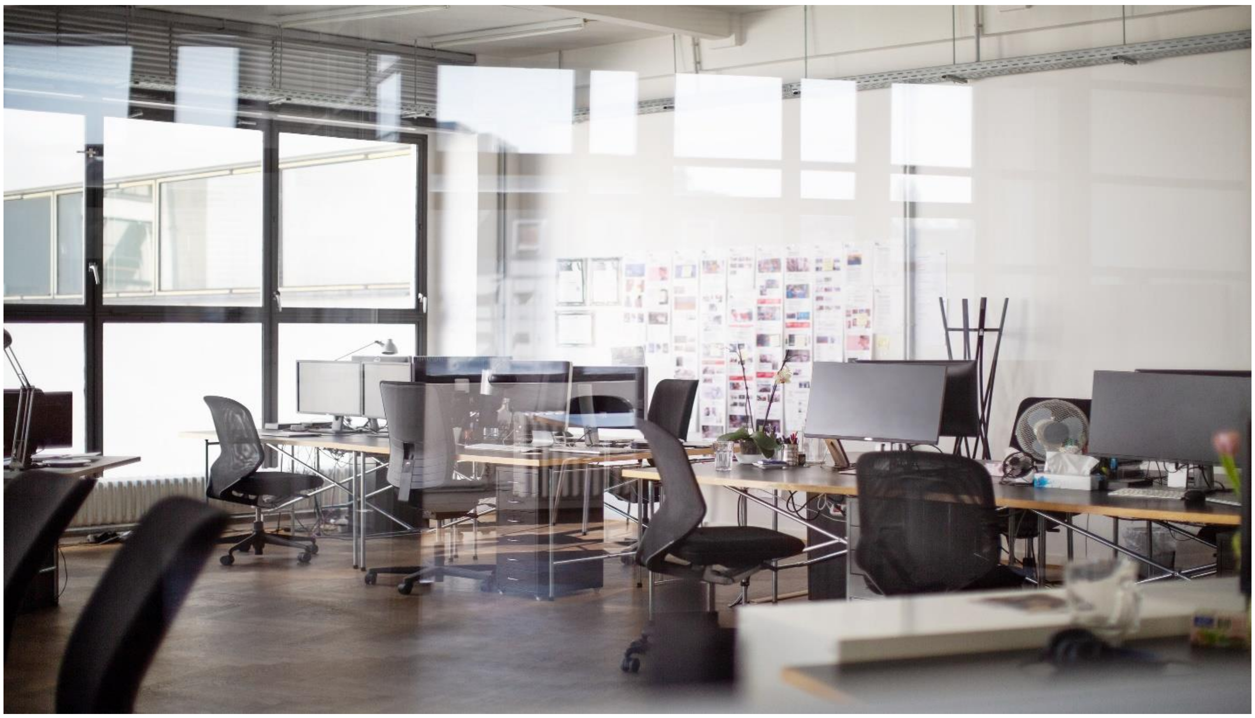
Occupancy-based Thermostat Control for Commercial Offices

Final Report

ET22SWE0023



Prepared by:

Akane Karasawa ASK Energy, Inc.

Amber Zepeda ASK Energy, Inc.

February 15, 2023

Disclaimer

Executive Summary

A field demonstration of occupancy-based control (OBC) for thermostats with remote occupancy sensors was conducted at two offices in San Diego County to evaluate the savings potential of the technology. This is a follow-up to the previous field study performed on the technology (Karasawa & Corradini, 2021), which demonstrated annual estimated savings of 9.5%. The study was performed to update the savings because the office occupancy pattern had changed greatly since the COVID-19 pandemic. Based on the online survey conducted as part of this study, 80% of offices reported a reduction in office occupancy and operated in hybrid work schedule. In addition, a nationwide survey revealed employees now work from offices three days a week on average (AEC Advisors, 2022).

In this field test, programmable thermostats were replaced with thermostats with OBC, an emerging technology consisting of a smart thermostat and wirelessly connected PIR occupancy sensors. The technology can decide whether to turn on/off a single-zone HVAC unit by gathering occupancy information from occupancy sensors placed in each individual space in its zone. The offices were separated into a control group with existing programmable thermostats and a treatment group with emerging technology. The energy consumptions of single-zone HVAC units in each group were monitored from September 2022 to November 2022.

The study found that the occupancy-based thermostat the treatment group consumed less energy and expected to save 15% to 34% annually, as summarized in the table below.

	Site 1	Site 2
Baseline Total	21,900 kWh	1,060 kWh
Weekday Savings	6,500 kWh	108 kWh
Holiday Savings	990 kWh	45 kWh
Total Savings	7,490 kWh	153 kWh
Precent Savings	34%	15%
Electric GHG Savings[1]	1.55 tons CO_2	0.03 tons CO_2
Savings per Ton	178 kWh/ton	31 kWh/ton
Cost Savings[2]	$2,700	$50
Total ET Cost[3]	$9,000	$900

[1] The Climate Registry May 2021 (Table 3.1, Page 43) WECC California 2019 Default Factors for Emission Rates by eGRID

[2] Cost savings based on the office suite's blended rate of $0.357 per kWh, inclusive of both winter and summer rates

[3] Total ET cost includes the cost of equipment (thermostat, remote occupancy sensors, and a gateway) as well as installation labor cost

Simple Payback	3.3 years	18 years

The results confirmed that the change in occupancy patterns post COVID-19 pandemic shutdown increased the saving potential of this technology. However, the magnitude of savings largely depended on the variability of office occupancy as well as baseline operation of HVAC equipment at each facility. Additionally, the technology still lacks capabilities necessary to be implemented in office environment because the technology was developed for and still targeted to hospitality applications. Therefore, it is recommended to work with manufacturers to develop features that are specific to office uses.

Abbreviations and Acronyms

Acronym	Meaning
AC	Air Conditioner
AI	Artificial Intelligence
Amps	Amperes
ASHRAE	American Society of Heating, Refrigeration, and Air Conditioning Engineers
BMS	Building Management System
CEC	California Energy Commission
CPUC	California Public Utilities Commission
CT	Current Transformer
CZ	Climate Zone
DCV	Demand Control Ventilation
DDC	Direct Digital Control
EER	Energy Efficiency Ratio
EMS	Energy Management System
EPA	Environmental Protection Agency
ET	Emerging Technology
HP	Heat Pump
HVAC	Heating Ventilation and Air Conditioning
IPMVP	International Performance Measurement and Verification Protocol
kW	Kilowatts
kWh	Kilowatt-hours

Acronym	Meaning
M&V	Measurement and Verification
OAT	Outside Air Temperature
OBC	Occupancy-Based Control
PIR	Passive Infrared
PF	Power Factor
RFID	Radio Frequency Identification
RH	Relative Humidity
T/RH	Temperature/Relative Humidity
TWh	Terawatt hour
VRF	Variable Refrigerant Flow

Table of Contents

List of Tables

List of Figures

Introduction

Many small to medium-sized offices are conditioned by a single-zone, constant-volume heating ventilation and air conditioning (HVAC) unit serving multiple spaces. These HVAC units conventionally operate on a fixed schedule, temperature setpoint, and ventilation rate for the duration of building operating hours and more. This continuous fan operation, required by the Title 24, guarantees adequate ventilation, temperature control, and personal comfort for occupants, particularly when there are multiple spaces within a single zone. However, when the entire zone is vacant, these single-zone units could save energy if they used occupancy status as the basis to reduce temperature setpoints or to turn-off the unit.

Occupancy is an especially important variable now as workers return to offices after the COVID-19 pandemic shutdowns. Office occupancy has changed for most commercial businesses since the implementation of COVID-19 quarantine precautions beginning in March of 2020. During the pandemic, many offices went remote company wide. After the pandemic, many businesses recognized the value of face-to-face interactions and collaborative spaces and embraced a hybrid work model, where employees work part-time at home and part-time at the office. With the flexibility of hybrid employment, offices are now experiencing unpredictable and dynamic occupancies. However, office operating hours and HVAC operations have not adapted to meet these changing demands.

This change in office occupancy patterns is expected to increase the energy savings potential that occupancy-based control (OBC) can bring to HVAC systems in offices. OBC responds in real time to zone occupancy status' and reduces or eliminates the delivery of heating, cooling, and ventilation to the zone when the zone is unoccupied. Depending on the accuracy of a system's sensors to determine the occupancy of a space, occupant-centric building control strategies have found savings potential up to 42% in dynamically occupied spaces (Naylor, Gillott, & Lau, 2018).

OBC is already common in spaces where the zone consists of a single room with variable occupancy, such as in hotels, motels, and occasionally in educational settings. These systems have a one-to-one relationship between the thermostat and the space, utilizing a single sensor. However, in commercial office spaces, a single zone often consists of multiple spaces. Such a space requires multiple occupancy sensors that can all communicate with a single thermostat controlling the zone.

In this study, a field test was conducted in two buildings to evaluate the applicability and energy saving potential of a thermostat with OBC with remote passive infrared (PIR) occupancy sensors in a small to medium sized commercial office. The studied thermostats can connect to multiple wireless occupancy sensors and collect occupancy information from the spaces served by the HVAC unit. The technology responds to the zone occupancy by modifying thermostat settings, setting back temperature setpoints, or turning off the HVAC unit completely if the zone is deemed unoccupied. OBC is becoming an increasingly common feature of commercially available thermostats, but multi-sensor capabilities are the keystone for office applications. The interest for this study is the compatibility of single-zone HVAC units with this technology, the accuracy with which the system can determine the space is occupied, the energy savings potential of this technology with the post-pandemic office occupancy, and the cost effectiveness of retrofitting this technology in a commercial office.

Background

This study is a follow-up to our previous study (Karasawa & Corradini, 2021) which explored the application of a thermostat with integrated and remote occupancy sensors in a small office setting. In that study, a single-zone heat pump unit provided air conditioning to a conference room and three private offices. One remote occupancy sensor was added to each space and when all four spaces were found unoccupied, the unit was shut off. The study estimated that the occupancy-based thermostat could save 9.5% annually when compared to baseline energy consumption. Most of the energy savings were attributed to reduced operating hours during shoulder hours (e.g., Friday afternoon) and holidays that were not recognized by the building management system's (BMS) schedule. The study also found that the HVAC equipment ran approximately 10% less hours than the baseline, suggesting non-energy benefits of lower long-term maintenance and a greater lifespan of the HVAC equipment.

Several other studies have explored the application of occupancy-based thermostat control technology and have found a range of savings. One study that performed energy simulations of thermostats with OBC in small commercial office buildings found that the buildings used 21% less cooling energy with DX systems and 15% less with heat pumps when compared to programmable thermostats (Nikdel, Janoyan, Bird, & Powers, 2017). Supplementarily, field experiments found an energy-saving potential of 21–31% for open office and 24–34% for private office zones when applying camera-based OBCs to a variable air volume system serving multiple zones and testing various levels of ventilation and temperature setbacks (Anand, Sekhar, Cheong, Santamouris, & Kondepudi, 2019). Furthermore, an experimental study conducted at the Total Indoor Environmental Quality (TIEQ) Lab in Syracuse University found a weekly averaged energy saving between 17 and 24% (Kong, Dong, Zhang, & O'Neill, 2022). The study fabricated two identical open-plan offices with ten occupants. HVAC in one office operated on a fixed schedule with fixed temperature setpoints (control) while the temperature setpoint and ventilation rate were adjusted based on the occupancy status in the other office (treatment). In all studies, the most influential factors were space type and sensor accuracy. Spaces with variable use levels saw a more significant reduction in energy usage, as expected, when HVAC control accounted for real-time occupancy.

Incumbent Technology

According to the California Commercial Saturation Survey (CPUC, 2014), 46% of packaged and split single-zone HVAC units in commercial buildings are controlled manually, 36% are controlled by programmable thermostats, and only 5% use any kind of energy management system (EMS). When controlled manually, the HVAC system generally runs continuously with a fixed setpoint while the programmable thermostats are used to program the HVAC system to run on a set schedule with or without night setback (e.g., 7 AM to 7 PM, Monday through Friday).

All new single-zone air conditioner and heat pump control devices are required to comply with the California Title 24 Sections 110.2(c) and 110.12(a) as well as 110.12(b), if equipped with direct digital controls (DDC) to the zone level. Thermostats need to be capable of demand responsive controls and programmable so that occupants can program the temperature setpoints for at least four periods within 24 hours. The minimum ventilation is always required when the space is usually occupied, unless the ventilation system serving the zone is controlled by a demand control ventilation (DCV) device or by an occupancy sensor control device.

When the ventilation is controlled by an occupancy sensing device, the mechanical ventilation can be shut off during the "occupied-standby" mode per Title 24 section 120.1(d). The occupancy sensor is required in every room served by the HVAC unit and the zone is not considered vacant until all the rooms in the zone are vacant, which is defined as 20 minutes or less of inactivity. The system is put into occupied-standby mode when all rooms in the zone are determined vacant during the scheduled occupied hours. In five minutes or less after entering the occupied-standby mode, the code requires mechanical ventilation to the zone to shut off and zone setpoints to reset until the zone becomes occupied or until ventilation is needed to provide space heating or conditioning. The pre-occupancy purge one hour prior to expected occupancy is still required. However, the system can be put back into occupied-standby mode if the zone is vacant, until occupants are detected.

The Emerging Technology and Product Details

The emerging technology (ET) assessed in this study is an advanced thermostat with an integrated PIR occupancy sensor that can be linked to multiple remote and wireless PIR occupancy sensors. The occupancy sensors are located in each distinctive space within a single HVAC zone while the thermostat resides in one of these spaces. PIR sensor detects both body temperature and motion to determine the occupancy in a space. This ET directly replaces an existing programmable or smart thermostat and is compatible with most unitary HVAC systems such as packaged terminal air conditioners, fan coils, heat pumps, and split systems including variable refrigerant flow (VRF) systems. The retrofit does not require any modifications to the HVAC system itself: It only replaces the existing thermostat and adds wireless occupancy sensors to each individual space in the zone. The occupancy sensors are battery powered and are expected to last for approximately two years per the manufacturer. Some occupancy sensor models include temperature sensing capability.

The field demonstration of this study examined two models of this technology. The first is a smart thermostat with an onboard PIR occupancy sensor that can be linked to multiple remote PIR occupancy sensors wirelessly. The thermostat and occupancy sensor combo communicates the occupancy information in each space to the thermostat via ZigBee protocol and can also integrate Bluetooth devices. The thermostat itself connects to the manufacturer's integration server via Wi-Fi. This allows users to view and configure thermostat settings remotely through a mobile app and/or cloud-based software.

The thermostat can be configured to turn off equipment, both supply fan and compressor, or setback temperature setpoints when associated spaces in a zone are detected to be unoccupied for a preset amount of time. Although occupant access to most of the configurable settings is locked at the local thermostat, occupants can still turn on/off the unit, change the fan setting, and change setpoints within the pre-programmed limits.

The second example of this technology is also a thermostat with an onboard occupancy sensor connected to remote and wireless PIR occupancy sensors. The thermostat works in much the same way as the first technology using wireless PIR occupancy sensors to determine occupancy in each space and adjusts the thermostat settings accordingly. However, this thermostat requires a separate gateway to view and configure thermostat remotely. The advantage of this feature is that it allows the user to view and access all thermostats and change thermostat settings from one place, like EMS as shown in Figure 1. It is a notable feature for small to medium offices where EMS is not common and there is no visibility to the thermostat settings and HVAC unit operations because the thermostat settings are often "set and forget." The thermostats may initially be set correctly but their settings are changed overtime by an occupant and/or due to power outage, which causes the thermostat to reset. Without periodical checkups, the HVAC could run on a wrong setting and schedule for a long time, unknowingly to the building manager or HVAC operator.

Figure 1: An example of thermostat data accessible from the thermostat EMS

Source: Manufacturer's EMS dashboard.

Assessment Objectives

The goal of this ET assessment is to identify the potential energy savings and operational benefits of an occupancy-based control (OBC) for thermostats in a small to medium commercial office building setting through market study and field assessment.

This assessment report consists of two parts: First section of this report details the results of market study, which includes the results of literature research and survey. The second section details the specifics and the results of field assessments conducted at two test sites. Specific goals related to each portion of the study are detailed in respective sections.

This report can serve as a case study for future upgrade opportunities and develop recommendations for measure development through deemed pathways and strategies to overcome discovered market barriers.

Market Study

Objectives

Understanding the market is a critical first step to assess the potential opportunity of any ET. The following objectives were established in conducting the market study:

- Size the total market of offices with single-zone air conditioners serving multiple spaces.
- Identify workplace occupancy trends to evaluate workplace occupancy and return to work trends in California or nationally.
- Identify the currently available communicating occupancy sensors that can be leveraged in commercial retrofit scenarios.
- Identify current marketplace opportunities and barriers of the ET.

Methodology and Approach

Due to the effect the 2019 COVID pandemic has had on the market, this study attempted to only leverage studies and literatures published after March 2022, especially in regard to workplace occupancy trends and current available technology. Furthermore, California data was utilized over national data when available. This market study will be used in developing the site selection criteria for the two field tests.

Primary market research was conducted using engineering experience and an online survey to provide direct data about office spaces variables, HVAC scheduling, and office occupancy trends. Surveying of businesses with single-zone HVAC systems and their adjustments to post-pandemic office environments was also performed to bridge the assumptions from the previous study (Karasawa & Corradini, 2021). The survey results were reinforced by the information found within the secondary market research. Secondary market research included a study of journals, articles, peer reviewed studies, and catalogs as were publicly available.

Results

Market Share and Energy Use

This ET in review is focused on single-zone HVAC systems, typically found in small to medium commercial office buildings. In California, offices use roughly 16.4-terawatt hour (TWh) of electricity annually (CPUC, 2006) and approximately 33% of their total energy usage is consumed by the HVAC system (EIA, 2022). As shown in Figure 2, Over 70% of small to mid-sized commercial offices in California utilize packaged single-zone and split single-zone HVAC systems and these systems typically use either a manual or pre-programmed thermostats; 38% and 46%, respectively (CPUC, 2014). In total, single-zone HVAC systems in commercial offices account for about 3.2 TWh of annual energy consumption in California.

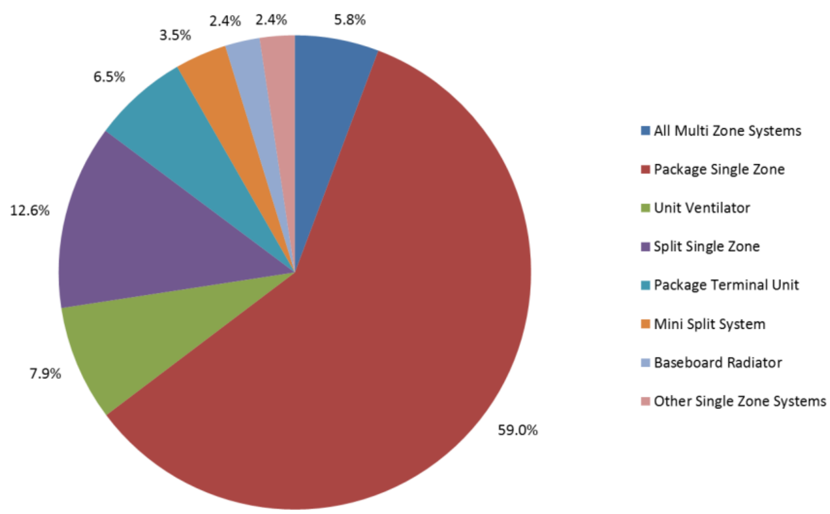


Figure 2: Distribution of HVAC units by system type

Source: (CPUC, 2014).

One can expect energy savings of 10-15% by replacing programmable thermostats with smart thermostats alone (Energy Efficient Smart Thermostats, 2022) while energy savings up to 24% have been reported when OBCs are coupled with smart thermostats. This translates to a potential energy savings capacity of 320-765 GWh annually by installing ET in commercial office spaces in California.

Workplace Occupancy Trends

Many businesses were forced to close in-person operations either partially or completely during the COVID-19 pandemic in 2020. Commercial offices were no exception and work-from-home became the norm for those who could perform work remotely. Some companies embraced the work-from-home work model and remained completely remote to this day. Others have adopted the more flexible hybrid work model, where in-office and remote work are combined. One survey found approximately two-thirds of pandemic affected workers would prefer not to return to the office full-time (Cifuentes, 2022). Another survey found 20-65% of employees preferred a hybrid work model, coming into the office only one to three days a week (Seabrook, 2021) (Li, 2020)

Figure 3: The shift in percentage of office occupancy since January 2020

Source: (Kastle, 2022).

The return to office adaptation has been slow, as illustrated in Figure 3 above. Based on the data collected from over 2,600 buildings in 138 cities over two years, only 47.7% of the workforce had returned to offices as of October 2022 (Kastle, 2022). Another survey reported that only 40% of firms had made the decision to require employees to return to the office. On average, firms expect employees to come into the office three days a week, with only 10% of firms expecting the employees to work in the office every day (AEC Advisors, 2022).

To better understand the change in occupancy patterns and HVAC operations in small to medium offices after the COVID-19 pandemic in 2020, an online survey was conducted in September 2022. The survey consisted of twenty brief questions about the office size, space composition, occupancy, HVAC type and its operations. A total of 15 survey responses were collected.

The surveyed office size ranged from 1,000 sq. ft. to 60,000 sq. ft., with an average of 36,000 sq. ft. Most were single-story buildings, but five of them were two-story buildings and a couple had three stories or more. Of all offices that participated in the survey, 87% described their spaces as a mix of open and closed/private offices while the rest solely had open offices. The office space type composition differed with each surveyed office, but all included private offices and 87% had conference rooms as well as lobby/front desk area.

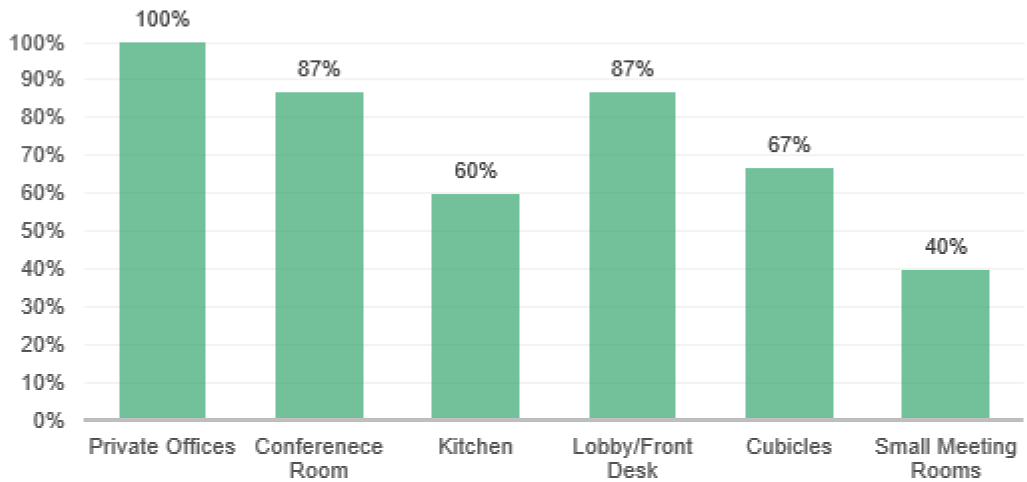


Figure 4: Office space type compositions

Source: Project Team.

The number of total employees varied from fewer than five to more than fifty, depending on the size of the building. 80% of survey participants reported that there had been a reduction in office occupancy since returning to offices. As shown in Figure 5, majority of offices now have their employees on a hybrid work schedule with some offices having all their employees on a hybrid work schedule.

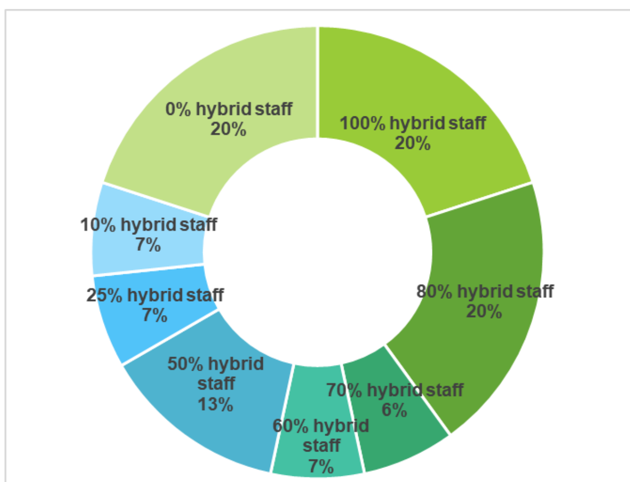


Figure 5: Percent of workers that are on hybrid work schedule

Source: Project Team.

While occupancy patterns and the degree of reductions in occupancy varied from office to office, as illustrated in Figure 6, survey results found an average of 27% occupancy reduction for all weekdays. Fridays saw the most reduction, with 34% reduction on average as shown in Figure 7,. The survey findings are consistent with other studies, one of which reported nearly a 50% average reduction in occupancy on Fridays (Kastle, 2022).

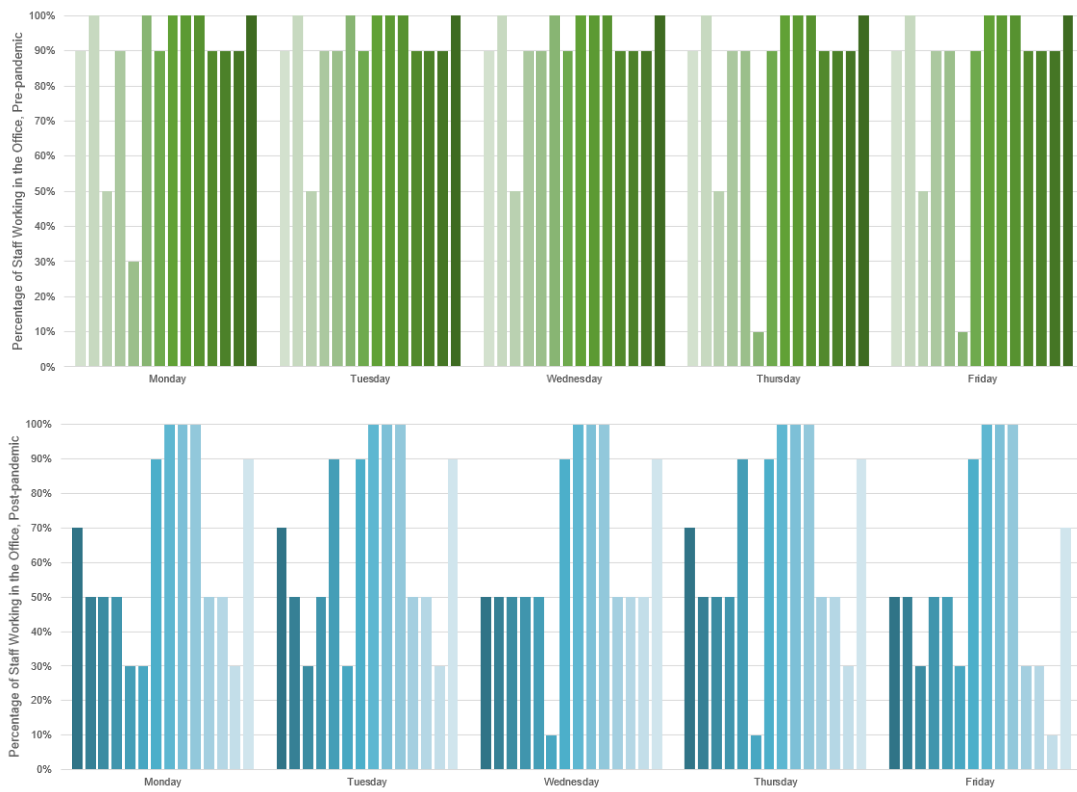
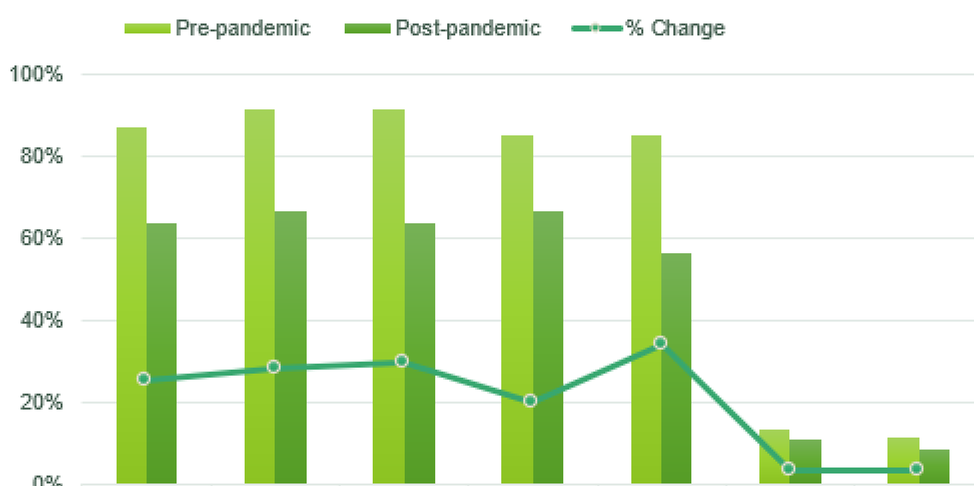


Figure 6: Survey results on office occupancy as the percentage of staff working in the office before the pandemic shutdown in March 2020 (top) and after (bottom). Each bar represents one office.

Source: Project Team.

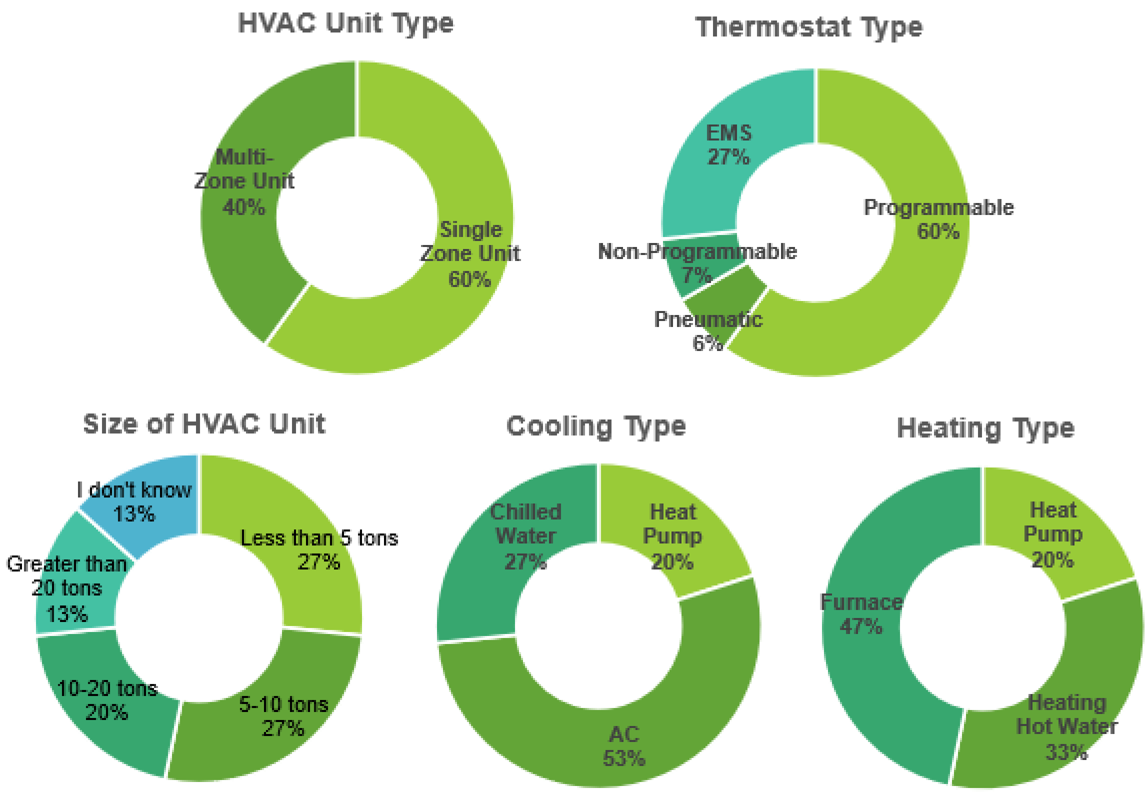


	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Pre-pandemic	87%	91%	91%	85%	85%	14%	11%
Post-pandemic	64%	66%	64%	66%	56%	11%	9%
% Change	25%	28%	30%	20%	34%	3%	3%

Figure 7: The change in office occupancy before and since the pandemic shutdown offices in March 2020

Source: Project Team.

Figure 8 below summarizes the type and size of HVAC systems utilized in the surveyed offices. Approximately 60% of offices surveyed are air-conditioned by single-zone HVAC units controlled by programmable thermostats. Over half of these units are less than five tons in size. Most are packaged air conditioners with furnace for heating, but some are heat pumps. Prior to the COVID-19 pandemic, 13% of offices ran their HVAC units 24/7 without a setback, 20% ran 24/7 with a night setback, and 67% operated with a set schedule (Monday through Friday from 7 AM to 6 PM, for example). The HVAC operations have not changed since the pandemic shutdown in March of 2020 for most offices except for a couple offices that adjusted their programming from 24/7 operation to scheduled operation. None of the offices whose thermostats were already scheduled adjusted their HVAC operations even though the office occupancy changed due to the COVID-19 pandemic.



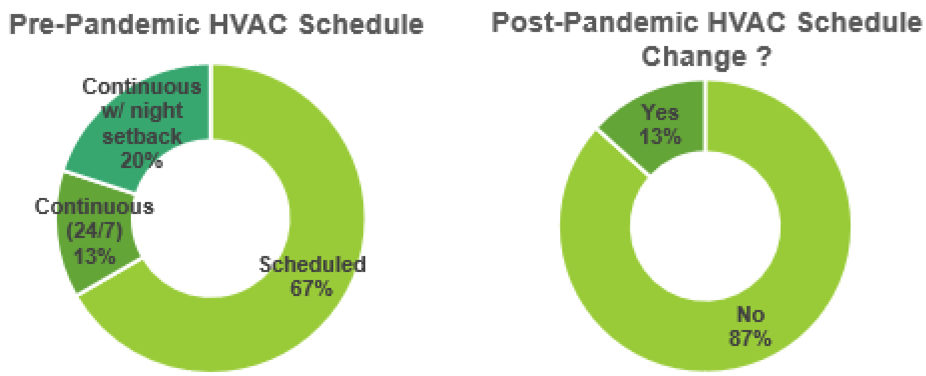


Figure 8: Survey Results

Source: Project Team.

The survey results confirmed the changes in office occupancy as a result of the COVID-19 pandemic in small to medium offices, as summarized below:

- The office occupancy has declined with the hybrid working style becoming the mainstream.
- Fridays have the greatest likelihood for office vacancies, however, the average office occupancy decreased on all days of the week.
- Regardless of the change in occupancy, the HVAC operations remained the same before and after the pandemic.
- Most single-zone HVAC units are controlled by programmable thermostats, which are used to schedule the HVAC unit to operate one to two hours before and after when the office occupancy is expected.

Currently Available Technology

The Environmental Protection Agency (EPA) estimates that Americans spend 87% of their time inside buildings, but their movements are dynamic and unpredictable (Klepeis, et al., 2001). Occupancy sensors give the ability to control their lighting and HVAC systems based on actual usage, functioning only as needed and reducing wasteful processes when spaces are vacant. Thermostats with OBC have been available for single-zone single-space applications, such as hotels rooms, for some time. However, with growing interest in energy efficiency, opportunities for optimization, and accessibility to smart technologies, thermostats with OBC are becoming available for more complex applications like residential homes and commercial buildings. Some smart thermostats even employ artificial intelligence (AI) to follow and learn users' occupancy trends and comfort preferences over time, dynamically adjusting settings to make spaces more comfortable.

Prior to 2020, OBC had been slow to integrate into HVAC systems due to their high costs, uncertainties with installation, and little need for this technology outside spaces such as hotels and motels. However, these costs have been decreasing as both savings and demand for these systems increased. As a result of the COVID-19 pandemic, the occupancy sensors demand increased because they were used to monitor and control occupancy density in public spaces. The demand for occupancy sensors is expected to continue: Between 2019 and 2024, the occupancy analytics market is estimated to increase from $2.17B to $5.73B and sensor and control technologies are predicted to contribute $18B in annual energy savings by 2030 (Kong, Dong, Zhang, & O'Neill, 2022).

Occupancy sensors can be classified into four categories: image-based sensors, motion sensors, radio-based sensors, and threshold and mechanical sensor (Kong, Dong, Zhang, & O'Neill, 2022). Image-based sensors are cameras that synthesize occupant data from video or images to determine both presence and count. There are several lighting and resolution options with these sensors, and they generally provide the most accurate occupancy information. They are also usually the most expensive sensor option, but their processes may sometimes be paired with security systems, such as an entryway security camera as a supplementary sensor taking in occupant count data. However, unless image-sensors were placed in each room of a space, an overly complex and expensive endeavor, the system would necessitate the pairing of other occupancy sensors to comply with Title 24 requirements for OBCs that control multiple spaces. There are also some privacy concerns related to these types of sensors. Depending on the specific sensor system, they either provide assurances that the captured images are anonymized or that the system does not have storage capabilities but merely uses the face or body detection to advance or retract the occupancy counter within the system (SenSource, 2021) (Mannino A., 2019).

Motion sensors define a range of sensors that can include radio sensors. It commonly refers to sensors which employ either ultrasonic or electromagnetic (EM) waves that reflect off objects and bounce back to the original emission point (Tholen, 2021). These are active systems that detect occupancy when a moving object disrupts the sensor's wave output. Motions sensors are generally inexpensive but have low accuracy, only detecting significantly moving entities. Some advanced motion sensors have excellent resolution and occupancy accuracy, but they can be expensive (Wireless World, 2012).

Threshold and mechanical sensors generally refer to sensors that monitor entryways and workspaces and can include radio wave sensors. These can be radio frequency identification (RFID) response systems, Bluetooth or Wi-Fi user counters, depth sensors, or pressure sensors. These systems can be expensive and complex to implement. They also require occupants to use the spaces as anticipated (i.e., having their phones or RFID tags on person, sitting at desks to activate pressure sensors in chairs, entering premises one person at a time). Even so, they are exceedingly accurate systems and can provide count data along with vacancy status.

The ET employed in this study used PIR sensors to detect occupancy. A PIR sensor works similarly to an ultrasonic sensor but measures infrared light radiating from objects in view. The PIR sensor's detection mechanism uses a multi-faceted lens that defines its coverage area as a series of discrete fan-shaped zones. Most PIR sensors are sensitive to full body movement up to about 40 ft., but only up to 15 ft for more discrete hand movement (Dilouie, 2017). PIR sensors are very efficient to run because they are passive, and the thermal aspect of their readings improves the accuracy over ultrasonic sensors. However, the accuracy of PIR sensors alone can still be a concern. To provide adequate occupancy accuracy readings, spaces should be relatively small in size (it is recommended for a maximum 15'x12' square foot area), such as single-person offices or individual cubicles (Naylor, Gillott, & Lau, 2018). PIR sensors have the added benefits of being comparatively lower in price, easy to integrate, and can often be paired with occupancy detection for lighting systems (Agarwal, et al., 2010).

The ET has become increasingly smart and connected in recent years as smart thermostats have become more prevalent in the market. Although a stand-alone solution is possible, this option is often tied with other systems in the building such as lighting and plug loads. While this option is highly customizable and works with most HVAC systems, the technology cost becomes significantly higher than the thermostat retrofit option. Therefore, finding affordable thermostat systems with multi-sensor capabilities is critical to the success of this technology in commercial settings.

Table 1 below lists the type and cost of ET sensors that are commercially available. The list only includes thermostats that can communicate with remote occupancy sensors wirelessly. While there are more thermostat options available with wired occupancy sensors, the installation of such systems increases the cost to a prohibitive level unless installed as part of a major renovation or as a new construction project. Wireless sensors and a smart thermostat combination generally has fewer capabilities, but they are suitable for small to medium office applications as they are much easier to install and can be managed remotely.

Table 1: Costs of Commercially Available Smart Thermostats with Occupancy Sensor Options

Manufacturer	Product	Type	Cost[4]
A	Smart Thermostat	Wired or Wireless: onboard PIR and Humidity sensors	$250
	Sensor	Wireless: PIR	$65
B	Smart Thermostat	Wireless: onboard Radar Occupancy and Air Quality sensor (1 PIR sensor included)	$250
	Sensor	Wireless: Temperature and PIR	$100
C	Smart Thermostat	Wired or Wireless: onboard Temperature, Humidity, and CO2	$300
	Sensor	Wired or Wireless: Temperature, Humidity, and CO2	$110
D	EMS Thermostat[5]	Wired or Wireless: onboard Temperature	$290
	Sensor	Wireless: Temperature and PIR	$77

Source: Project Team.

[4] The costs do not include installation and labor.

[5] The EMS thermostat may require an additional gateway to remotely access the thermostat.

Market Potential and Barriers

Given the market size, the change in occupancy patterns, and the advancement in technology in recent years, the ET has significant potential to reduce energy consumption in small to medium commercial offices. Additionally, the technology has the potential to reduce demand and energy during peak hours between 4pm and 8pm on weekdays, if the OBC could power off the HVAC equipment earlier than scheduled time due to unoccupancy. Based on the survey and past study results, offices are likely to be able to reduce peak loads on Fridays when the chance of the office being unoccupied is the greatest after 4pm.

There are a few barriers to this ET. The first one is a lack of out of the box technology solution that is ready to be used in a commercial office with a single-zone unit serving multiple spaces. Most commercial thermostat manufacturers have at least one thermostat model with an optional onboard PIR occupancy sensor. However, these thermostats often lack the option to gather occupancy information from multiple sensors in remote spaces. Wired occupancy sensor options are more common among those with remote sensor compatibility, but it significantly increases the installation costs to run the wires and requires customized configurations.

Presently available occupancy sensing thermostats are designed to work mainly in a single space, such as a hotel room or a classroom. Furthermore, they may not provide robust programming options, such as differentiating weekday vs. weekend schedules since this detail is not important for hotels whom the product was developed for initially. Although possible with custom configurations, it can be difficult to ensure that the thermostat control will meet the needs of a commercial space. To our knowledge, there is no thermostat with OBC that is ready for single-zone multiple-space applications right out of the box currently.

Another barrier is technology cost. The costs for smart thermostat have come down in recent years as market demand has increased, but they are still an investment. While many smart thermostats claim high energy savings, the upfront cost of the product and installation is still a strong deterrent for many. Depending on existing electrical wiring, the brand of the smart thermostat, and installation labor, the total cost ranges between $200 to $500 (Cutrona, 2022). With occupancy sensors, the total cost can double or more, depending on the sensor type, the quantity of sensors required, and installation.

Although not common in small to medium offices, HVAC systems in some offices are controlled by building management system (BMS). The technology has made its advancement in connectivity and compatibility with IoT devices in recent years. Some can be integrated with BMS using BACnet communication protocols. However, the technology may still not be compatible, depending on the age of an existing BMS. Additionally, working with the existing BMS program and architecture can be costly.

Lastly, the type of occupancy sensor and its placement should be considered carefully because the potential savings of this technology are entirely dependent on the accurate occupancy readings provided by the sensors. In a 2022 study, the accuracy of various occupancy sensors was found to range from 5%-100% (Kong, Dong, Zhang, & O'Neill, 2022). Combining multiple types of sensors provides the highest levels of accuracy. For PIR sensors on their own, a single detector placed near the entryway of single-entrance spaces is typically sufficient for accurate occupancy readings of offices (Naylor, Gillott, & Lau, 2018). It is recommended that PIR sensors are placed high in corners of rooms so that their array (~120°) has maximum coverage and placed near chokepoints so that they are responsive to traffic areas. They should not be placed above heat sources, near windows, or in bathrooms because the temperature and humidity from these spaces can either reduce sensitivity or trip sensors in unoccupied spaces (Boundary, 2021). Therefore, proper selection and installation of occupancy sensors is crucial for the success of this technology.

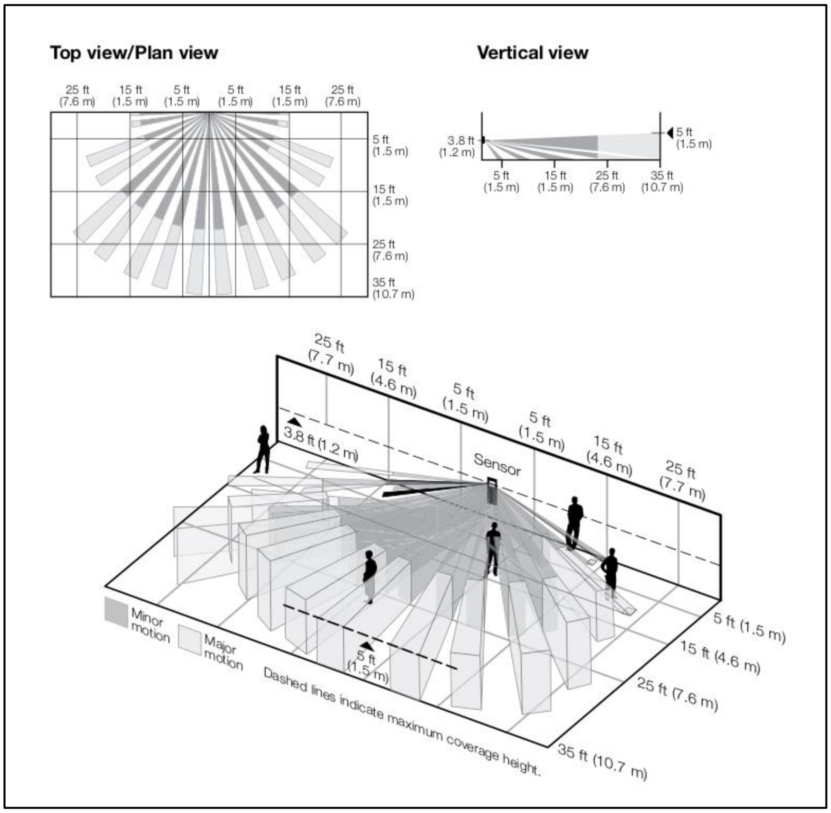


Figure 9: PIR Coverage

Source: (ThreePhaseEel, 2019).

Field Assessment

Objectives

The goal of this field assessment is to identify the energy savings and operational benefits of OBC for thermostats in commercial office settings. Several objectives were established:

- Evaluate existing HVAC unit energy usage to establish a baseline case
- Monitor HVAC unit energy usage after the technology is installed to establish a post-installation case
- Quantify potential energy savings resulting from the technology
- Conduct surveys to understand occupancy patterns, comfort, workplace schedules, and to return to work practices at the test site.
- Generate an assessment report that can be used as a case study for future upgrade opportunities, deemed workpaper development, and utility incentive program design.

To accomplish these objectives, a test plan that adheres to IPMVP principles was created. The test plan is outlined in the following sections and was designed to directly measure energy effects, as well as relevant factors and performance characteristics.

Methodology and Approach

The following sections details the methodology and approach used for the field assessment.

Test Sites

A field assessment of the ET was conducted at two customer sites, both located in CZ7. The first site is a manufacturing facility in Vista, CA. The building is 125,000 sq. ft. and consists of a large manufacturing area and an adjacent two-story office area on the north side of the building, which was used for testing. The first floor consists of private offices, a small area with cubicles, and a kitchen. The second floor consists of private offices, an open office with cubicles, common area, and a large conference room. At this site, 60% of employees are on a hybrid schedule and the typical office occupancy has decreased as much as 50% after the COVID-19 pandemic.

Table 2: Site 1 characteristics

Characteristics	Vista Site
Building Type	Manufacturing
Building Area [ft^2]	125,000
Year Built	1999
Office Occupied Hours (Typical)	Mon – Fri, 8am – 5pm
Test Area Type	Private offices, open offices with cubicles, a kitchen, and a large conference room

Characteristics	Vista Site
Test Area [ft^2]	25,000
Typical Number of Occupants	20
CA Climate Zone	7

Source: Project Team.

Figure 10: Office layout (upstairs above and downstairs below) and the location of thermostats at Vista site
Source: Thermostat locations added to the office map provided by the site 1 facility manager.

The offices are conditioned by nine packaged rooftop air conditioners (ACs). The ACs are scheduled to operate from Monday through Friday, 6am to 7pm. The unit characteristics are listed in Table 3 below. None of the units have economizers.

Table 3: AC specifications at Site 1

Unit	Make	Model	Size (tons)	Efficiency (SEER/AFUE)
AC1	York	PCG4B601003X1A	5	14/81%
AC2	Daikin	D6NZ036N05606NXA	3	13/81%
AC3	York	PCG4B601003X2B	5	14/81%
AC4	Daikin	DCG0721403VXXXAA	6	11.3/80%
AC5	Daikin	DCG0721403BXXXAB	6	11.3/80%
AC6	Daikin	DP14GM6108043AA	5	14/81%
AC8	Carrier	48GSN060090501	5	10/81%
AC9	Carrier	48GSN060090501	5	10/81%
AC10	York	PCG4A240502X1A	2	14/81%

Source: Project Team.

Figure 11: Packaged rooftop air conditioners at Site 1

Source: Project Team.

The second test site is a 14,400 sq. ft. office building with two tenants in Carlsbad, CA. Each tenant space consists of private offices, a kitchen, a conference room, an IT/electrical room, and an open space. One site tenant uses the open space for customer exhibitions while the other tenant uses about half of the open space as an open office with some cubicles and the other half as a storage space. The test was conducted only in the office areas. In this office building, 80% of employees are on a hybrid schedule and the typical office occupancy has decreased as much as 40% since the COVID-19 pandemic.

Table 4: Site 2 characteristics

Characteristics	Carlsbad Site
Building Type	Warehouse
Building Area [ft^2]	14,400
Year Built	2004
Office Occupied Hours (Typical)	Mon – Fri, 8am – 5pm
Test Area Type	Private offices, open offices with cubicles, conference rooms, and storage
Test Area [ft^2]	12,000 (approximate)
Typical Number of Occupants	10
CA Climate Zone	7

Source: Project Team.

Figure 12: Office layout and the location of thermostats at Carlsbad site

Source: Thermostat locations added to the office map provided by the site contact.

The building is air conditioned by a total of eleven packaged rooftop heat pumps (HPs), but only seven of them were included in the study because one was dedicated to an isolated IT room and the rest was not actively used by the current occupants. The HPs are scheduled to operate from Monday through Friday, 8am to 6pm when the building is occupied. The unit characteristics are listed in Table 5 below. None of the HPs have economizers.

Table 5: Heat pump specifications at site 1

Unit	Make	Model	Size (tons)	Efficiency (SEER/HSPF)
HP1	ICP	PHF060H000E	5	10/6.8
HP2	YORK	B3HP060005A	5	13/7.7
HP3	Bryant	607CNXC2400	2	14.5/8.0
HP4	Bryant	655ANH624	2	12/6.9
HP5	ICP/CARRIER	PHD3600H	5	13.5/7.7
HP6	ICP/CARRIER	PHD3600H	5	13.5/7.7
HP7	ICP/CARRIER	PHD3600H	5	13.5/7.7

Source: Project Team.

Figure 13: Packaged rooftop HPs at Site 2

Source: Project team.

Test Plan

The test plan included a field testing of the ET at two offices. A field study was chosen over a laboratory study because the energy saving of this technology is dependent on the occupant behavior, which cannot be mimicked in a lab. Two thermostat models were tested.

A comparative testing method was used to evaluate technology energy savings. The comparative approach was used because the control group's occupancy data can be used to normalize the occupancy of the treatment group. At each site, ET was installed to replace all thermostats that served offices (test area). However, the technology's energy saving features were activated on thermostats that serve only 50% of the test area. These thermostats are designated as a treatment group where the ET was used to turn off the HVAC unit, both supply fan and compressor, when all the associated spaces in a zone are detected to be unoccupied for a preset amount of time. The rest of the thermostats that serves the other 50% of the test area remained untreated as the control group. In these spaces, occupancy was monitored but was not used to control the thermostats. The energy consumptions and occupancy patterns of the treatment group and control group were both monitored and compared to establish technology savings.

The data collection was performed following IPMVP Option A (Retrofit Isolation: Key Parameter Measurement). The key parameters and logging instrumentation used are listed in Table 6. The key parameters in the table were continuously monitored and logged on an interval basis. The HP power and current data were recorded at one-minute intervals to capture any compressor or fan cycling that may have occurred. A spot measurement of voltage and power factor was also performed. The ambient air temperature from nearby weather stations were also used to supplement outside air temperature data collected at each site.

Table 6: Logging instrumentation details

Data Point	Measurement	Instrument	Accuracy	Logging Interval
HP unit power	kW, kWh	Dent Power Meter	+/-1% of full scale	1 minute
HP unit current	Amps	HOBO Split-Core CTs	+/-1% of full scale	1 minute
Space temperature	T/RH	HOBO UX100	±0.63°F, ±2.5% RH	5 minutes
Space Occupancy	T/RH	HOBO UX90	102° (±51°) Horizontal; 92° (±46°) Vertical	5 minutes
Outside air temperature	T/RH	HOBO UX100	±0.63°F, ±2.5% RH	5 minutes

Source: Project Team.

The data was monitored for one month following the technology installation. In addition, all key parameters were monitored approximately for one month prior to the technology installation to establish baseline performance of the HVAC units. This data was used to normalize HVAC consumption data to weather.

Results

Site 1 Results

At site 1, the performance of RTUs was monitored from September 19, 2022, for about a month prior to installing the ET. The ET, a combination of an EMS thermostat and wirelessly connected remote occupancy sensors, was installed on October 24, 2022, to replace all nine existing programmable thermostats at the site. At this site, one thermostat model was used for all units. However, OBC was activated for thermostats for RTUs in the treatment group only (AC2, AC3, AC5, and AC9 serving the second floor). The thermostats for the RTUs in the control group (AC1, AC4, AC6, AC8, and AC10 serving the first floor) was programmed to operate from 5am to 7pm, consistent with the thermostat schedule prior to technology installation. Post-installation monitoring started on October 26, 2022, after all thermostats were configured until November 18, 2022.

The Figure 14 below compares the daily energy consumptions of RTUs serving the first floor (control group) and the second floor (treatment group) before and after the ET installation. In this chart, the energy consumption of RTUs were plotted against average OATs recorded during the scheduled operation, 5am to 7pm. As shown, there was no overlap in OAT between pre- and post-installation data due to the weather change that occurred right around the time when the ET was installed. When the pre-installation data was collected in September and October, the average daily OAT ranged between 65°F to 80°F. Therefore, the regression models developed for the pre-installation data is only applicable to that OAT range. Since the average daily OAT recorded during the post-installation period was mostly outside of this OAT range, the direct comparison between the two period using the regression models was not possible.

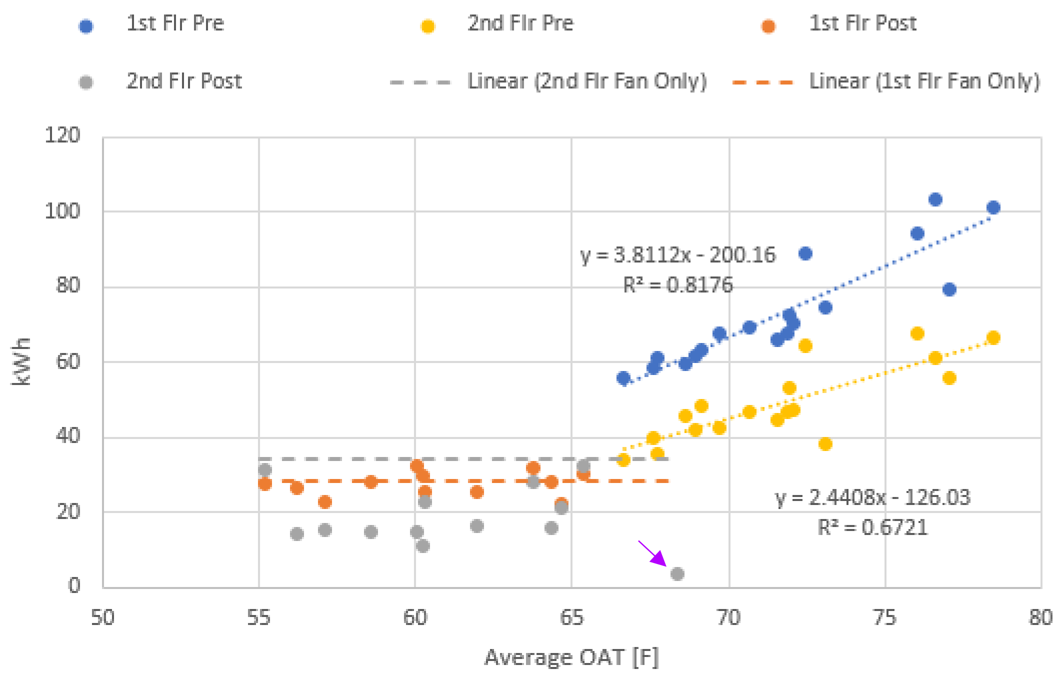


Figure 14: Daily energy consumptions of first-floor (control group) and second-floor (treatment group) RTUs plotted against daily average OAT.

Source: Created by the project team

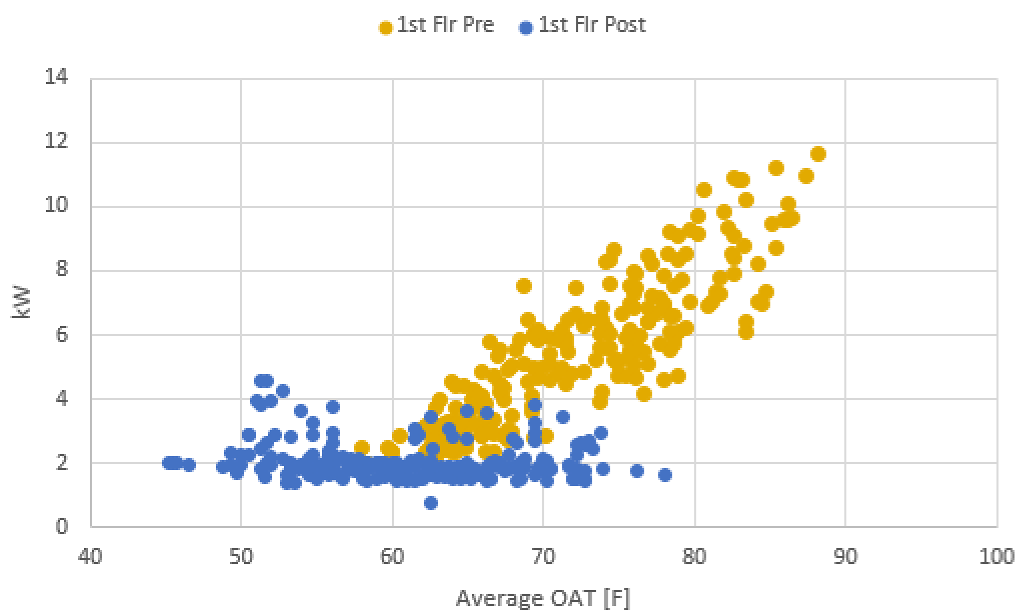
Looking at the post data, however, it is evident that ET saved energy consumptions of second-floor units. The horizontal dashed lines in the above figure represent the daily energy consumption of first-floor and second-floor RTUs with scheduled ventilation-only operations (i.e. supply fan operating for ventilation only from 5am-7pm). The daily energy consumption of ventilation-only operation was calculated as 28 kWh for the first-floor units and 34 kWh for the second-floor units. The post consumption of the first-floor RTUs (control group) matched the calculated value, indicating that the units were mostly operating in ventilation-only mode during the scheduled hours. On the other hand, the second-floor RTUs (treatment group) consistently consumed less than the ventilation-only value during the post period. This suggests that the ET was able to reduce the duration of supply fan operations by controlling the RTUs based on zone occupancy. During the post period, the second-floor units consumed 20 kWh per day on average, 41% less than the calculated baseline ventilation-only operation. The facility also had one holiday during the post-period, as indicated by an arrow in Figure 14. The ET saved approximately 37 kWh on this day.

Table 7: Comparison of Supply Fan Energy Savings

	Control Group	Treatment Group
Total Supply Fan Power	2.0 kW	2.4 kW
Total Supply Fan Power as Percent of System Peak Power	10.4%	10.9%
Ventilation-only Baseline (Calculated based on 14 hrs/day operation)	28 kWh	34 kWh
Post-install Average	28 kWh	20 kWh
Savings	-	41%

Source: Project Team.

Next, the hourly average demand of RTUs were compared before and after the ET installation. Similar to the daily energy consumption comparison above, the data overlap between the two was limited to OAT between 60°F to 75°F due to the seasonal change in weather. However, the figures clearly shows that the OBC occasionally reduced the hourly energy demand of the second-floor RTUs (as indicated by the area highlighted in purple) while the first-floor RTUs operated constantly during the scheduled hours.



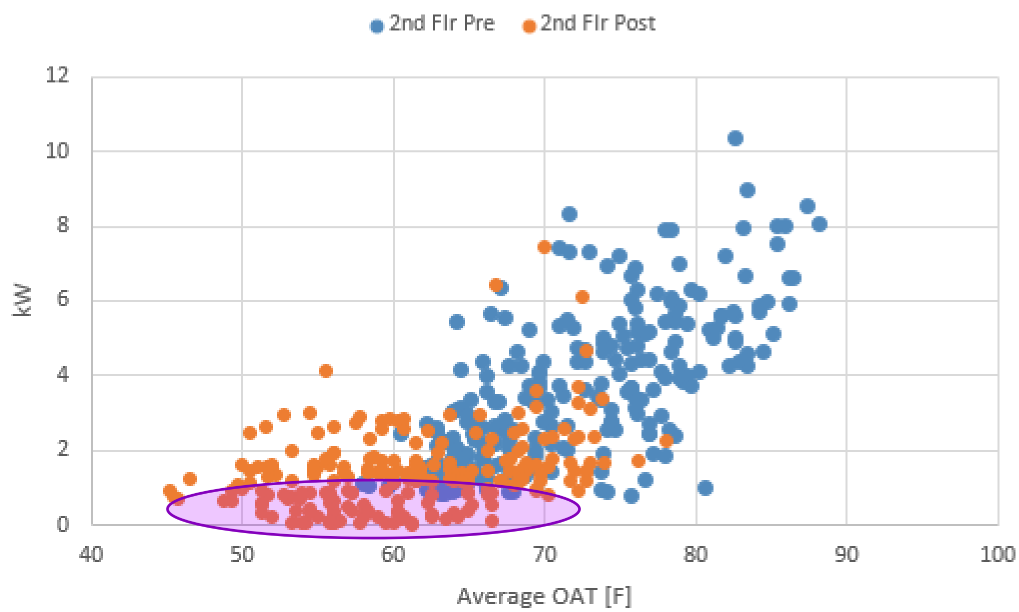


Figure 15: Hourly energy demand of RTUs in control group (above) and treatment group (below) before and after the ET installation.

Source: Project Team.

The performance of similarly sized and loaded RTUs were also evaluated. The comparison was made between AC8 in control group and AC9 in treatment group, both 5-ton unit. AC8's zone is located downstairs and consists of seven offices and one breakroom. AC9's zone is located directly above the AC8's zone and also consists of seven offices and a lab room. AC8 and AC9's operating profiles from November 7, 2022, to November 12, 2022 are shown in Figure 16. As shown, AC8, a unit in control group, operated from 5am to 7pm as scheduled while AC9, a unit in treatment group, operated only when there was occupancy in its zone. On all days during that week, AC9 started up later than 5am and shut off earlier than 7pm. During the week, AC8 consumed 60 kWh in total while AC9 consumed 36 kWh, a 40% difference. Note that the compressor cycled on twice for AC8 and none for AC9.

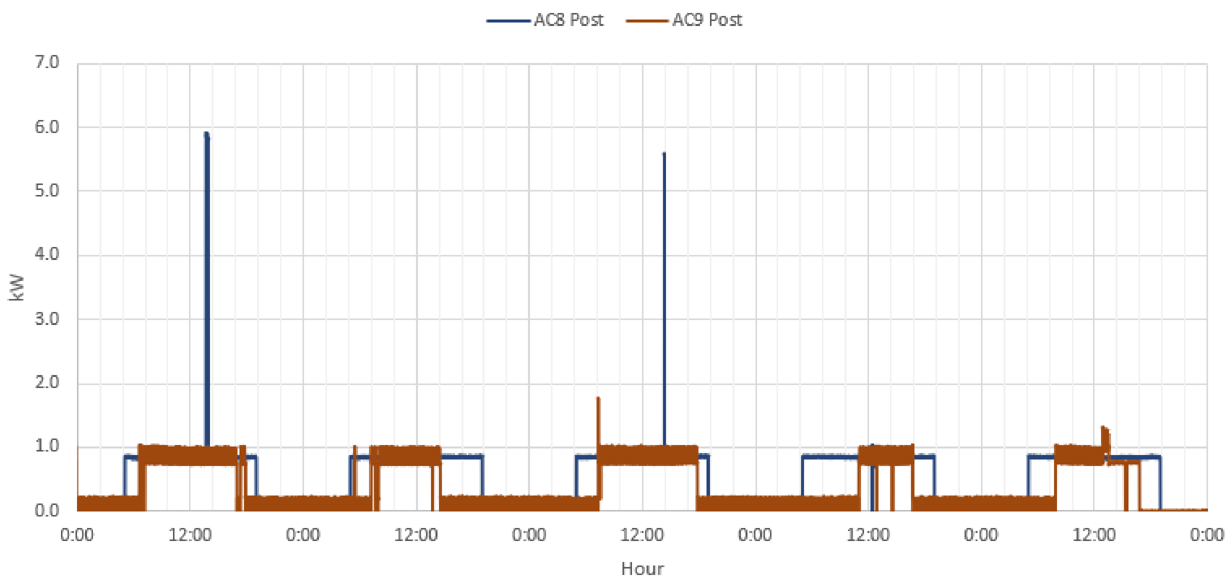


Figure 16: Operating profiles of AC8 in control group and AC9 in treatment group.

Source: Project Team.

Figure 17 below shows AC8 and AC9 operated similarly before the ET installation. After the ET was installed, the OBC installed on AC9 shut the unit off whenever there was no occupancy, resulting in approximately 41% less daily energy consumptions than AC8 during the entire post-installation period.

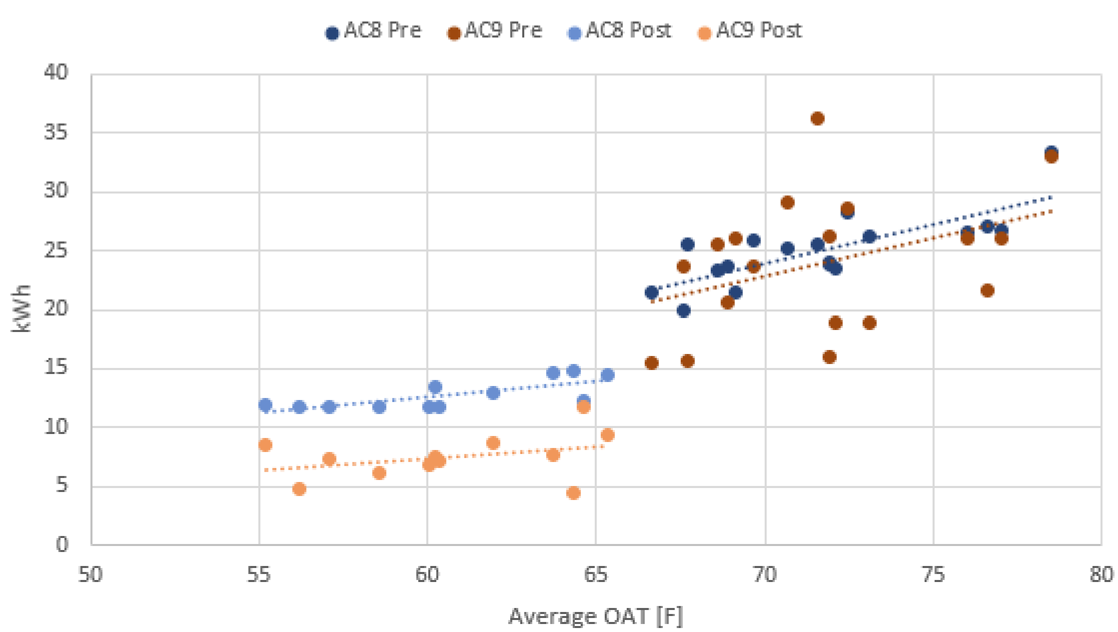


Figure 17: Daily energy consumption of AC8 and AC9 plotted against daily average OAT before (pre) and after (post) the ET installation.

Source: Project Team.

Due to lack of hot days during the test period, the most of energy savings was contributed to the fan not operating during the scheduled hours. Although small, some compressor energy savings were captured on October 27th, 2022 and October 28th, 2022, as shown in Figure 18. The figure shows AC6, a treatment group unit, operated until 7pm with compressor cycling on late in the afternoon. On the other hand, AC2 turned off around 4pm when the zone was vacated. Therefore, AC2 likely saved compressor energy in the late afternoon after the zone was vacated. On these two days, AC6 consumed the total of 4.2 kWh and with the max peak of 3.4 kW while AC2 consumed none during the peak period between 4pm and 9pm.

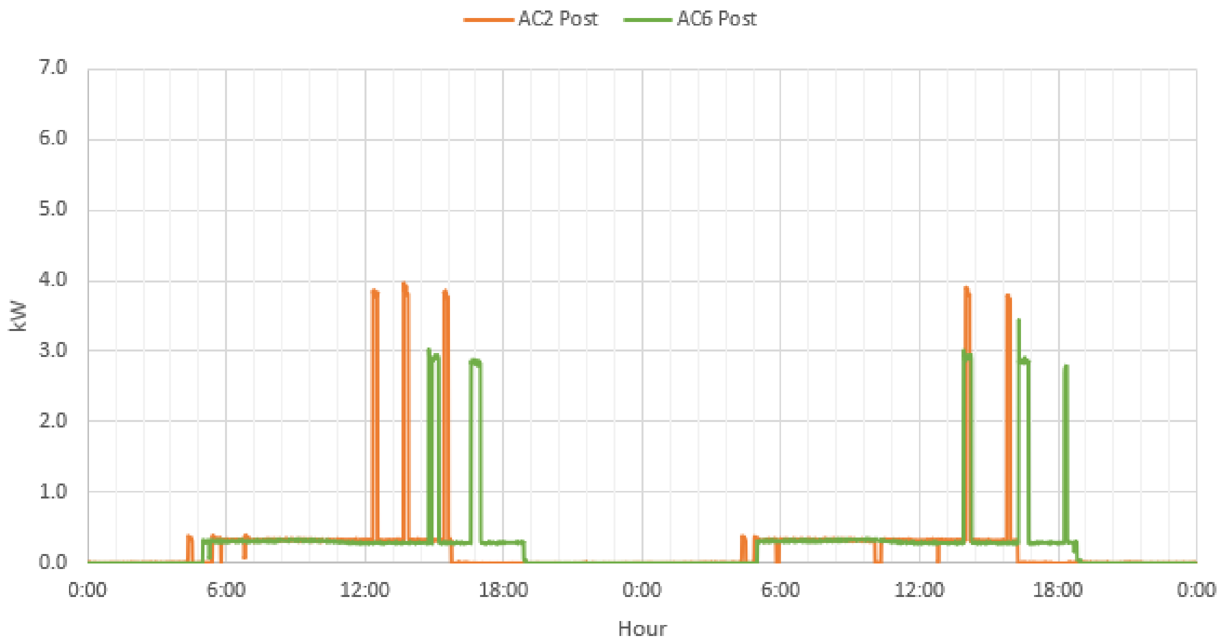


Figure 18: The operating profiles of AC2 and AC6 on relatively hot days.

Source: Project Team.

To estimate annual energy savings potential of the ET, a baseline regression model was created from the data collected prior to the ET installation. Daily energy consumptions of all nine RTUs were combined and regressed against average OATs recorded during the scheduled occupancy period, 5am to 7pm. The resulting model showed a good correlation with R^2 value of 0.81, as shown in Figure 19 below.

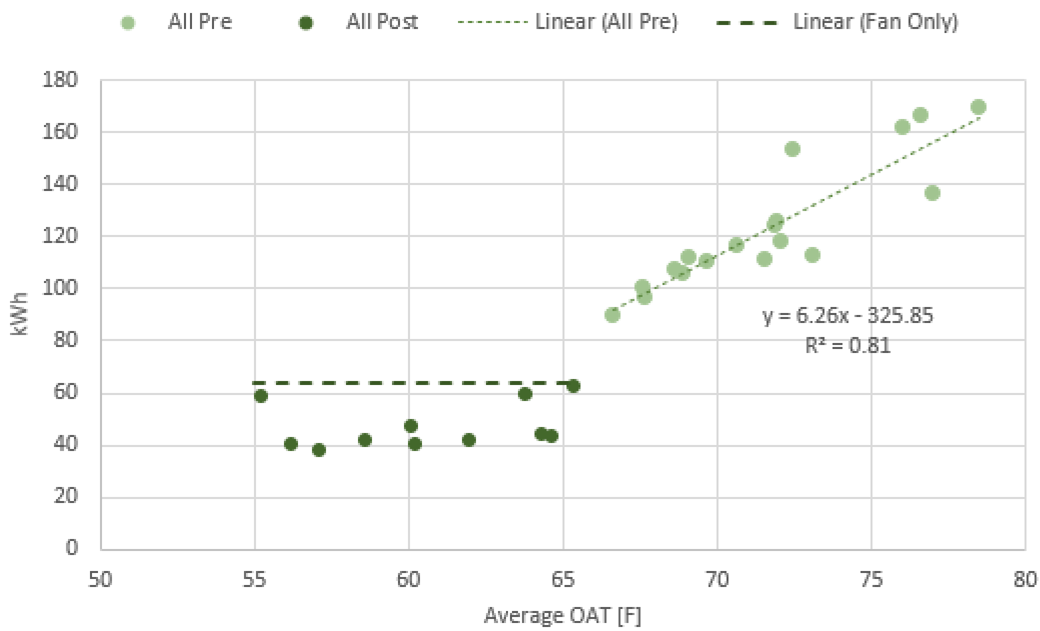


Figure 19: Daily energy consumptions of all nine RTUs combined before (pre) and after (post) the ET installation, plotted against daily average OAT.

Source: Project Team.

The horizontal dashed line in the above figure represents the daily energy consumption of RTUs if all of them operated supply fans only for ventilation during the scheduled operating hours, which was calculated as 64 kWh. With the baseline thermostat, the energy consumption would never fall below this line because the supply fans are left on during the scheduled hours. With the ET installed, the post data came in at or below this value, indicating that the ET reduced the operation of supply fans based on zone occupancy. Note that the savings implied by this chart do not represent the whole ET savings because the post data also includes control group units, where the supply fan operation was unchanged from the baseline.

Table 8 below summarizes the estimated annual savings of this technology. The baseline energy consumption was estimated using the regression model and CZ2022 weather data for CZ7. The annualized savings potential of the ET was calculated from the supply fan savings of 41% during the weekday based on the post data and daily savings for 11 federally observed holidays[6]. This results in a conservative estimate because it doesn't include compressor energy savings. As illustrated in the previous example, the compressor often cycles on to satisfy the occupied cooling setpoint even after the occupants have already left the office for the day (after 4pm in the example above). In such cases, the actual energy savings are greater than what was estimated because it would have included compressor savings in addition to supply fan savings.

[6] The federally observed holidays include New Year's Day, Birthday of Martin Luther King, Jr., Washington's Birthday, Memorial Day, Juneteenth National Independence Day, Independence Day, Labor Day, Columbus Day, Veterans Day, Thanksgiving Day, Christmas Day, and the day after Thanksgiving Day.

Table 8: Annualized Savings Summary for Site 1

	Site 1 Savings
Baseline Total	21,900 kWh
Weekday Savings	6,500 kWh
Holiday Savings	990 kWh
Total Savings	7,490 kWh
Precent Savings	34%
Electric GHG Savings[7]	1.55 tons CO_2
Savings per Ton	178 kWh/ton
Cost Savings[8]	$2,700
Total ET Cost[9]	$9,000
Cost per Ton	$214
Simple Payback	3.3 years

Source: Project Team.

Site 2 Results

At site 2, the baseline monitoring started on September 16, 2022 until the ET technology was installed. Two different models of ET were installed at this site. The first model, which is identical to the ones installed at site 1, was installed onto HP2, HP5, HP6, and HP7 on October 20th, 2020. The second model was installed onto HP4 on October 25th, 2020 but could not be configured properly until November 16, 2022. The initial results showed that ET operated according to zone occupancy and reduced the HP runtime. However, more data should be collected before drawing a conclusion.

A few other issues arose during the testing period at site 2. One of the units in the reception area (HP3, which was in control group) operated during the baseline but was disconnected during the post-installation period. Thus, this unit was removed from the analysis. Additionally, HP5, HP6, and HP7's post data showed that the units were often powered off and were not providing any ventilation unless there was a call for cooling or heating. The site does not have a facility manager and therefore the thermostats are controlled by the occupants in its respective zone. The occupants in the HP5,

[7] The Climate Registry May 2021 (Table 3.1, Page 43) WECC California 2019 Default Factors for Emission Rates by eGRID

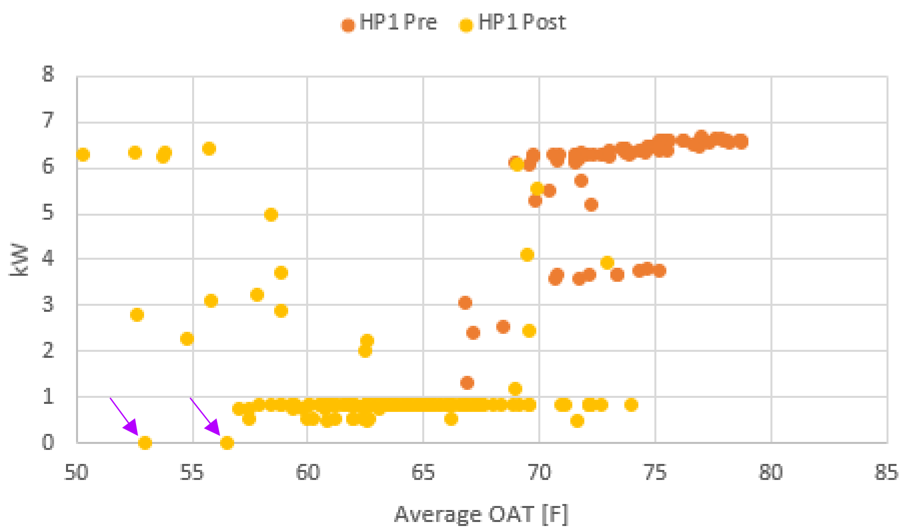
[8] Cost savings based on the office suite's blended rate of $0.357 per kWh, inclusive of both winter and summer rates

[9] Total ET cost includes the cost of equipment (thermostat, remote occupancy sensors, and a gateway) as well as installation labor cost

HP6, and HP7 zones were controlling the thermostats as they do at home, by tuning them on/off as needed. The lack of technology understanding as well as fundamental knowledge of HVAC operations led to the improper operations of the ET.

Given the constraints above, the data analysis was focused on HP1 (control) and HP2 (treatment).

First, the hourly average demands of HP1 and HP2 were compared before and after the ET installation. As with the case of site 1, the data overlap between the pre and post data was limited, ranging between 65°F to 75°F OAT due to the seasonal change in weather. However, it can be deduced that OBC on HP2 occasionally reduced the hourly energy demand in the post period, as indicated by the area highlighted in purple. On the other hand, HP1's supply fan operated constantly during the scheduled hours. It is noteworthy that the programmable thermostat controlling the HP1 did not recognize the time change that occurred during the post monitoring period. Therefore, HP1 operated one hour later than scheduled operating hours until the clock on the thermostat was manually corrected. The two data points with zero consumptions, marked by two arrows in the figure, signify the hours that HP1 was supposed to operate, but did not.



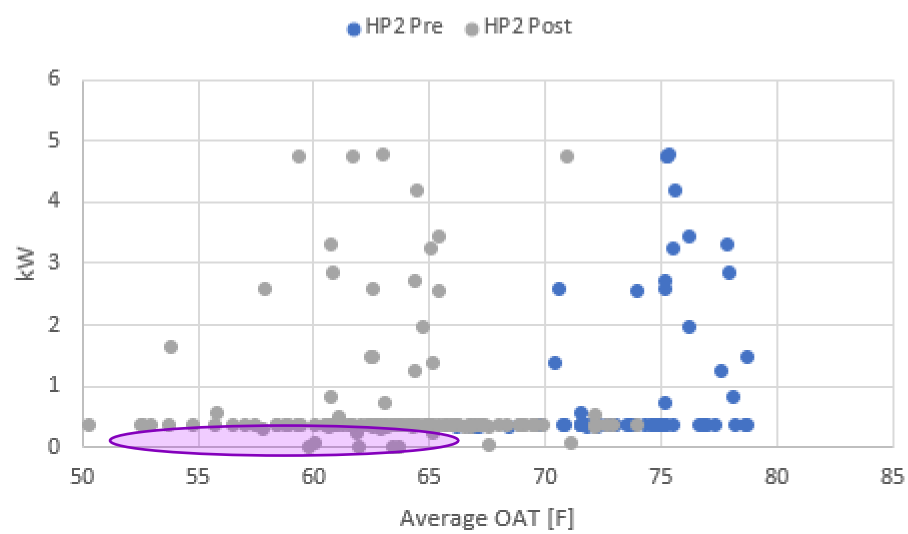


Figure 20: Hourly energy demand of HP1 (control) and HP2 (treatment) before and after the ET installation

Source: Project Team.

The typical operation of the two units during the week is show in Figure 21. As shown, HP1 operated from 8am to 5:30pm as scheduled while HP2 operated only when there was occupancy in its zone. On most days, HP1 and HP2 started up at around the same time, but HP2 shut off earlier than HP1. On some days, however, HP2 operated longer than HP1. On average, HP2 operated 8.8 hours per day during the week shown and 9.9 hours per day during the entire post-installation period. The HP2's operation exceeded the HP1, which was programmed to operate 9.5 hours per day (8am to 5:30pm). Consequently, the OBC did not result in energy savings at this site when compared to the control unit. However, the longer operation of HP2 with OBC indicates the mismatching of zone occupancy and scheduled operation of the control unit, given that the two zones have similar occupancy.

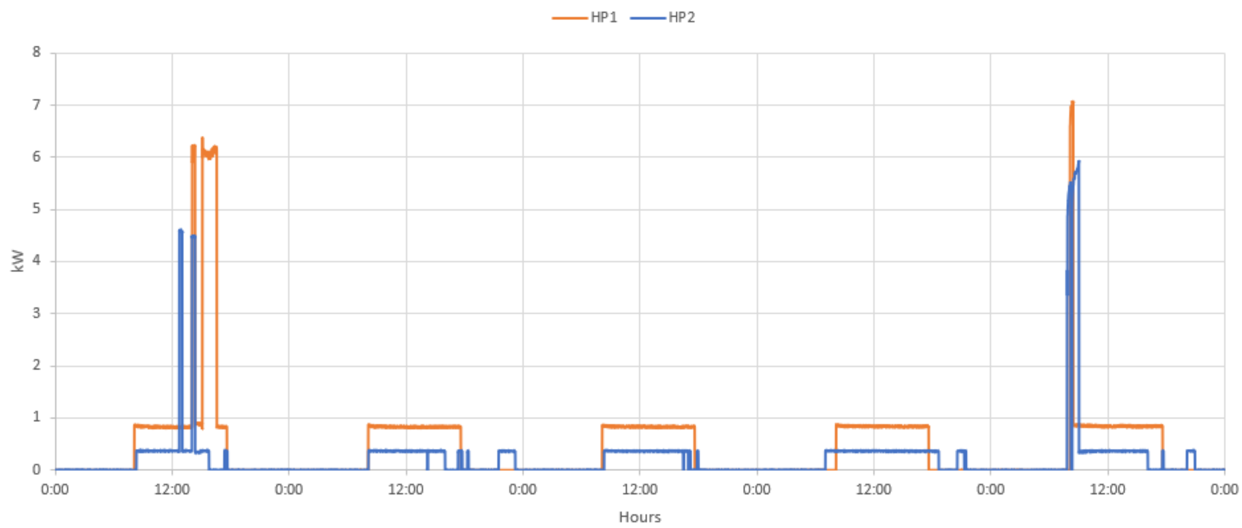


Figure 21: Operating profiles of HP1 and HP2 during the week of 10/31/2022

Source: Project Team.

Similar to the site 1, the energy savings mostly resulted from reduced operation of supply fan due to lack of hot days during the test period. However, some compressor energy savings were captured on October 31th, 2022, as shown in Figure 22. On this day, HP1 operated until 5:30pm as scheduled while the compressor cycled on at around 3pm and continued to operate until it cycled off at around 4:45pm. HP2 operated until at around 3:30pm and shut off as the zone became vacant. HP2 likely saved compressor energy in the late afternoon. On this day, HP1 consumed the total of 4.4 kWh and with the max peak of 6.2 kW while AC2 consumed 0.11 kWh with the max peak of 0.37 kW during the peak period between 4pm and 9pm.

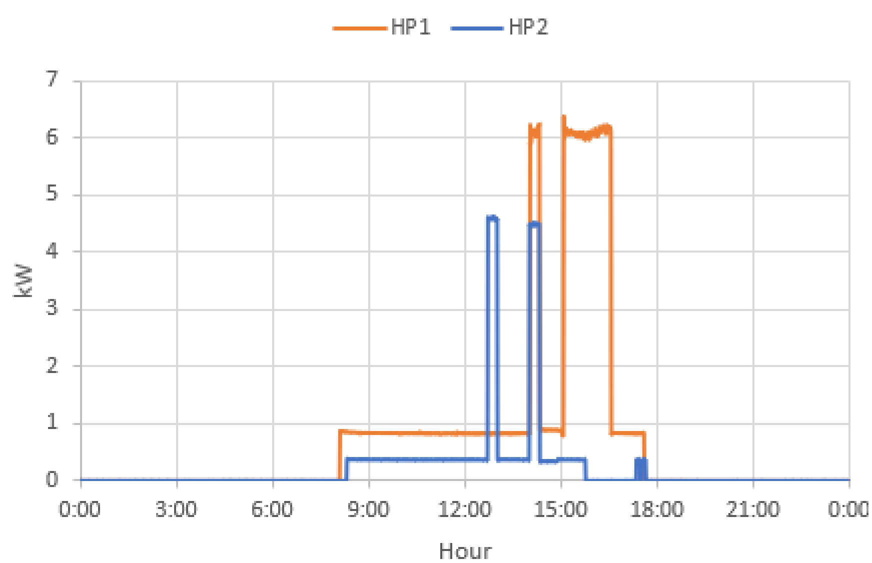


Figure 22: The operating profiles of HP1 and HP2 on a relatively hot day

Source: Project Team.

Although the field test resulted in no savings, the occupancy data collected showed that the spaces in the zone were typically occupied between 7:30am and 6:30pm or 11 hours per day. If this schedule was used as the baseline, the OBC would have saved at least 10% of supply fan energy during the post period. Table 9 below summarizes the estimated annual savings of this technology at Site 2. The annualized energy savings of HP2 was estimated using the 11-hour baseline, where HP2 is scheduled to operate from 7:30am to 6:30pm during the weekday. For this site, baseline consumption was estimated from supply fan energy consumption only because a good regression model could not be obtained for HP2 baseline due to lack of weather variations. Thus, the annualized savings potential of the ET was calculated solely from the supply fan savings. With 10% supply fan energy savings for weekdays and daily energy savings for 11 federally observed holidays[10], the ET is expected to save 15% annually at this site.

Table 9: Annualized Savings Summary for Site 2

Metric	Site 2 Savings
Baseline Total	1,060 kWh
Weekday Savings	108 kWh
Holiday Savings	45 kWh
Total Savings	153 kWh
Percent Savings	15%
Electric GHG Savings[11]	0.03 tons CO_2
Savings per Ton	31 kWh/ton
Cost Savings[12]	$50
Total ET Cost[13]	$900
Cost per Ton	$180
Simple Payback	18 years

Source: Project Team.

[10] The federally observed holidays include New Year's Day, Birthday of Martin Luther King, Jr., Washington's Birthday, Memorial Day, Juneteenth National Independence Day, Independence Day, Labor Day, Columbus Day, Veterans Day, Thanksgiving Day, Christmas Day, and the day after Thanksgiving Day.

[11] The Climate Registry May 2021 (Table 3.1, Page 43) WECC California 2019 Default Factors for Emission Rates by eGRID

[12] Cost savings based on the office suite's blended rate of $0.326 per kWh, inclusive of both winter and summer rates

[13] Total ET cost includes the cost of equipment (thermostat and remote occupancy sensors) as well as installation labor cost

Discussions & Conclusions

The market study found that office occupancy has changed greatly since the COVID-19 pandemic. Based on the online survey conducted with 15 small to medium offices, 80% of them reported a reduction in office occupancy and operated in hybrid work schedule. In addition, a nationwide survey revealed employees now work from offices three days a week on average (AEC Advisors, 2022). With over 70% of small to mid-sized commercial offices in California utilizing packaged single-zone and split single-zone HVAC systems, most of them likely serving multiple spaces, the documented reduction in office occupancy presents a great potential for the ET to save energy in offices.

The results from the field demonstrations revealed that the change in occupancy patterns post COVID-19 pandemic shutdown increased the saving potential of this technology, but the magnitude of savings largely depends on the variability of office occupancy as well as baseline operation of HVAC equipment.

At site one, the OBC achieved 41% savings during the post-installation period. Since the post-installation period coincided with cool weather days, most of the savings were attributed to supply fan not operating when no one was detected in its zone. In addition, the ET saved energy on a holiday when it detected no occupancy throughout the day. To project the savings annually, a regression model was developed using the data collected prior to the ET installation. For this site, the ET is expected to save 34% annually or 178 kWh per ton based on the regression model and CZ2020 weather data for CZ7. Note that the savings were calculated based solely on supply fan and holiday energy savings. The ET is expected to save even more during the summer months by cutting compressor power if the office vacancy occurs late in the afternoon when cooling is typically needed.

At site two, the OBC did not save energy because the unit with OBC operated longer than the counterpart with a programmable thermostat, which was scheduled to operate from 8am to 5:30pm, Monday through Friday. However, a mismatch between the programmed schedule and actual occupancy in the office was uncovered during the testing. According to the data collected during the testing, the office spaces are occupied anywhere from 7:30am to 6:30pm. Therefore, the units were not providing proper ventilation even when there was an occupancy in the zone and that the baseline schedule was not appropriate for the occupancy pattern of the zone. If the units were scheduled to operate to provide at least minimum ventilation when the zone is occupied, as required by the Title 24, the OBC would have saved at least 15% of supply fan energy.

The ET also showed a potential for demand and energy savings during the peak period, between 4pm and 9pm on weekdays. At both sites, there was at least one instance where the zone became vacant prior to 4pm and therefore OBC saved both supply fan and compressor energy during the peak. The peak demand reduction of kW was recorded at site one and kW at site two. While these number may not sound significant individually, the demand reduction from this technology can be substantial if aggregated over the entire market.

Simple payback of the ET was calculated as 3.3 years for Site 1 and 18 years for Site 2. The difference is due to the difference in the magnitude of savings, as described above. Note that the cost effectiveness of technology can increase with the size of installation. For example, one of the models tested required a gateway to be installed for the thermostats to be managed remotely. Site 1 required only one gateway for the entire site while two gateways would have been required for Site 2 because the building had two tenants with two separate internet connections. For the other model tested, however, the thermostats connected directly to the Wi-Fi network and did not require a separate gateway.

Although not explored in this study, the ET also has potential to save energy by eliminating the mismatching of zone occupancy and HVAC equipment operation. While visiting several offices during the site selection process, the team found many thermostats that were not configured properly and/or were off schedule. For example, some thermostats were scheduled to operate 24/7 when the zone was typically occupied 8am to 5pm or set to “fan auto” mode and therefore ventilation was only provided when cooling/heating was on despite the fact there was a constant occupancy in the zone. In another instance, a unit was found not operating on Monday at 10am even though the zone was occupied. The thermostat displayed showed it was Monday at 6am. The unit was not operating because 6am was still considered unoccupied based on the schedule set on the thermostat although it was actually 10am. In worst cases, the day and time on a thermostat were off by more than a day and the unit was not operating for the entire day thinking that it was a weekend when it was in fact a weekday. The programmable thermostats are often set once and not checked for a long time. However, the day/time on the thermostat can go astray in case of power loss and even with the time change. The ET can eliminate the issue of unit not operating during the occupied hours and/or operating during the unintended day or hours because it controls the unit to operate if there is an occupancy in the zone. It should also be noted that this is a none-issue for connected thermostats because the day and time are synchronized as long as it is connected to the server.

The ET presented additional non-energy benefits, which are summarized below:

- The ET could extend the life of the HVAC equipment from the reduced runtime. In this study, the HVAC equipment ran approximately 10% to 40% less than the baseline, and therefore the technology could potentially increase the life of HVAC equipment accordingly.
- The ET ensures that minimum ventilation is provided whenever there is an occupancy in the zone. With the increased awareness for the need of ventilation after the COVID-19 pandemic, the ET can act as a safety measure to deliver fresh air in the zone.
- The ET comes with an access to a simple energy management system (EMS), where the user can manage some settings on the thermostats. The EMS also allow the user to view and download current and past zone conditions, including zone temperature, humidity, occupancy status, and unit status (cooling/heating/ventilation). The facility managers at Site 1 really liked this feature because it allowed them to see the real-time status of all thermostats in one place remotely and helps them to respond to and diagnose issues reported.
- The EMS also has an alert feature, which was not explored during this study. However, the alerts may help diagnose and prevent the equipment operating unintentionally, especially for those sites without facility managers.

Recommendations

The field demonstrations of the ET in commercial office settings, where a single-zone system is conditioning multiple spaces within a zone, showed that the technology had potential not only to save energy but also improve air quality by ensuring ventilation is provided during zone occupancy. The market study also found that OBC technology has advanced since the last study in 2019, especially in the areas of IoT. It is our opinion, however, that the ET is still not ready for a large deployment as the technology needs to be fine-tuned for offices as it was originally designed for hospitality sector. Smart features are largely still in development as well. For example, a smartphone application that would allow remote connectivity and control of thermostat(s) is still in development for one manufacturer (deployment planned December of this year). Additionally, EMS dashboard is missing some features and need enhancements for better user experience. Following are next steps recommended for the adoption of this ET in an EE program:

- Work with manufacturers to customize the ET for office use
  - The title 24 requires the pre-occupancy purge one hour prior to the typically scheduled occupancy. Both thermostats do not have the off-the-shell capability to force the unit to operate when there is no occupancy in its zone.
  - Although both ET models came with EMS where users can view and configure thermostat settings, some of the key settings such as cooling/heating setpoints could not be changed remotely. For larger offices with facility manager(s), being able to change such settings is crucial.
  - Thermostat display should show cooling and heating setpoints separately. One of the models tested only showed the current temperature of the space on its display.
  - Both thermostat models tested did not have the ability to program a 7-day schedule because the thermostats are designed for hospitality applications where there is no difference between weekday vs. weekend operations.
  - Develop Training and best practices documentation to properly installing and configuring thermostats and occupancy sensors. The configuration is difficult without fundamental knowledge of HVAC operation, especially at offices without facility managers (which is the majority of facilities that have those type of HVAC systems). The proper positioning of occupancy sensors is also important as it can affect the unit operation.
- Recommend connected thermostats and/or EMS with OBC for small to medium offices
  - The study found existing programmable thermostats, currently required by the Title24 code, didn't work as intended and wasted energy if left unchecked. Connected thermostats and/or EMS should be considered for code implementation as they can sync time automatically, view real-time status, and remotely control thermostats, which would help avoid the thermostats to run unplanned hours. OBC in addition to these features greatly reduces the risk of thermostats running during unoccupied period.
  - Create a small retrocommissioning behavioral-type rebate to calibrate and check the schedule of thermostats once a year in order to avoid the mismatch of time and day of the week that was found in many thermostats surveyed.

References

AEC Advisors. (2022). 2022 CFO Summit State of the AEC Industry Update. *2022 CFO Summit* (p. 41). Virtual: AEC Advisors.

Agarwal, Y., Balaji, B., Gupta, R., Lyles, J., Wei, M., & Weng, T. (2010). Occupancy-driven energy management for smart building automation. *BuildSys '10: Proceedings of the 2nd ACM Workshop on Embedded Sensing Systems for Energy-Efficiency in Building*, 1-6.

Anand, P., Sekhar, C., Cheong, D., Santamouris, M., & Kondepudi, S. (2019). Occupancy-based zone-level VAV system control implications on thermal comfort, ventilation, indoor air quality and building energy efficiency. *Energy and Buildings, 204*, 109473.

Boundary. (2021, March 1). *PIR Motion Sensors: What they are & where to put them*. Retrieved from boundary: https://boundary.co.uk/blog/pir-sensors/

Cifuentes, K. (2022, April 07). *Office Occupancy Hits Pandemic High*. Retrieved from The Real Deal New York: https://therealdeal.com/2022/04/07/office-occupancy-hits-pandemic-high/

CPUC. (2006). *2006 California Commercial End-Use Survey (CEUS), Report # CEC-400-2006-005.* Sacramento, CA. Retrieved from http://capabilities.itron.com/CeusWeb/Default.aspx

CPUC. (2014). *California Commercial Saturation Survey Report.* Sacramento, CA. Retrieved from http://calmac.org/publications/California_Commercial_Saturation_Study_Report_Finalv2.pdf

Cutrona, S. (2022, June 22). *Learn how much it costs to Install a Smart Thermostat*. Retrieved from Home Advisor: https://www.homeadvisor.com/cost/heating-and-cooling/smart-thermostat-installation/

Dilouie, C. (2017, August 21). *All About Occupancy and Vacancy Sensors*. Retrieved from Lighting Controls Association: https://lightingcontrolsassociation.org/2017/08/21/all-about-occupancy-and-vacancy-sensors/

EIA. (2022, September 7). *Use of energy in commercial buildings in depth*. Retrieved from U.S. Energy Information Administration: https://www.eia.gov/energyexplained/use-of-energy/commercial-buildings-in-depth.php

Energy Efficient Smart Thermostats. (2022, October 4). Retrieved from Think Energy: https://www.thinkenergy.com/smart-thermostats-a-must-have-for-energy-efficiency-enthusiasts

Karasawa, A., & Corradini, A. (2021). Occupancy-based Thermostat for Commercial Offices. SDG&E. Retrieved from https://www.etcc-ca.com/reports/occupancy-based-thermostat-commercial-offices

Kastle. (2022, 10 11). *Getting America Back to Work*. Retrieved from Kestle: https://www.kastle.com/safety-wellness/getting-america-back-to-work/

Klepeis, N., Nelson, W., Robinson, J., Tsang, A., Switzer, P., Behar, J., . . . Engelmann, W. (2001). The National Human Activity Pattern Survey: a resource for assessing exposure to environmental pollutants. *Journal of Exposure Science & Environmental Epidemiology, 11*, 231-252.

Kong, M., Dong, B., Zhang, R., & O'Neill, Z. (2022). HVAC energy savings, thermal comfort, and air quality for occupant-centric control through a side-by-side experimental study. *Applied Energy, 306*, 117987.

Li, C. (2020, August 30). How the pandemic is changing office space. *The Straits Times*. Retrieved from Cushman & Wakefield, Singapore: https://www.cushmanwakefield.com/en/singapore/insights/blog/how-the-pandemic-is-changing-office-space

Mannino A., M. N. (2019). Office Building Occupancy Monitoring Through Image Recognition Sensors. *International Journal of Safety and Security, English*, 371-380.

Naylor, S., Gillott, M., & Lau, T. (2018). A Review of Occupant-Centric Building Control Strategies to Reduce Building Energy Use. *Renewable and Sustainable Energy Reviews, 96*, 1-10.

Naylor, S., Gillott, M., & Lau, T. (2018, November). A Review of Occupant-Centric Building Control Strategies to Reduce Building Energy Use. *Renewable and Sustainable Energy Reviews*, 1-10.

Nikdel, L., Janoyan, K., Bird, S., & Powers, S. (2017). Multiple Perspectives of the Value of Occupancy-based HVAC Control Systems. *Building and Environment*.

Seabrook, J. (2021, January 25). *Has the Pandemic Transformed the Office Forever?* Retrieved from The New Yorker: https://www.newyorker.com/magazine/2021/02/01/has-the-pandemic-transformed-the-office-forever

SenSource. (2021, April 15). *Addressing Privacy Concerns with People Counting Sensors*. Retrieved from sensourceinc.com: https://sensourceinc.com/blog/privacy-concerns-with-people-counting-sensors/

Tholen, C. (2021, June 10). *How Does a Motion Detector Work?* Retrieved from safewise: https://www.safewise.com/home-security-faq/how-motion-detectors-work/

ThreePhaseEel. (2019, April 30). *What is the typical vertical angle field of view for a PIR motion sensing light switch?* Retrieved from Home Improvement Stack Exchange: https://diy.stackexchange.com/questions/163870/what-is-the-typical-vertical-angle-field-of-view-for-a-pir-motion-sensing-light

Wireless World. (2012). *Difference between Radar motion sensor and PIR motion sensor*. Retrieved from RF Wireless World: https://www.rfwireless-world.com/Terminology/Difference-between-Radar-Motion-Sensor-and-PIR-Motion-Sensor.html