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Field Validation of a Building Operating System Platform

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GSA's GPG program and DOE's High Impact Technology (HIT) Catalyst program enable federal and commercial building owners and operators to make sound investment decisions in next generation building technologies based on their real-world performance.

Executive Summary

The U.S General Services Administration’s (GSA’s) Green Proving Ground program, in partnership with the National Renewable Energy Laboratory (NREL), completed a large pilot study of emerging technologies in the smart building field. The study focused on four different test bed facilities and the implementation of an energy management information system (EMIS) with automated system optimization (ASO). The study evaluated a technology provided by Prescriptive Data, a software-as-a-service called Nantum, to test building performance with the addition of EMIS with ASO. The software connects to building automation systems (BAS; or building management systems, BMS) to optimize operations. For this study, the EMIS with ASO aggregated historical data from the buildings and used machine learning and thermal modeling to optimize the buildings’ performance, specifically controlling air-side systems.

This field study evaluated EMIS with ASO at four different test bed facilities: (1) the Austin Courthouse in Austin, Texas; (2) the Terminal Annex Federal Building in Dallas, Texas; (3) the Harvey W. Wiley Federal Building in College Park, Maryland; and (4) the Bureau of Alcohol, Tobacco, Firearms (ATF), and Explosives Headquarters in Washington, D.C. Each facility met a specific set of site selection requirements, which are outlined in the report, including details such as, but not limited to, facility type, size, occupancy, and building control systems. Each facility has a unique set of attributes, but overall buy-in from the building facility staff was an important factor as well.

Quantitative and qualitative performance objectives for this EMIS with ASO field study were developed with input from the vendor and the building facility staff. Areas of focus for the quantitative performance objectives were energy savings, peak demand prediction, cost-effectiveness, and integration/platform functionality. The qualitative areas of focus consisted of an evaluation of the single pane of glass (SPOG)/portfolio view within the EMIS with ASO, ease of installation, and system operability. This portfolio view of building performance across multiple properties as well as the “cockpit view” of the performance of individual building systems within a single property is defined in this report as single pane of glass (SPOG) functionality. One final capability was also evaluated in the study: compatibility with GSALink, an internal GSA software system. The quantitative and qualitative performance objectives for the field studies, as well as results, are provided in Table 1 and Table 2, respectively.

Table 1: Quantitative Performance Objectives Results

Quantitative Objectives			
Objective	**Metric**	**Success Criteria**	**Final Results**
Energy savings	Modeled energy use intensity reduction	Whole-building energy savings >5%	- 11% modeled whole-building energy savings, Austin Courthouse - 5.1% modeled whole-building energy savings, Terminal Annex Federal Building
	Modeled kWh reduction	AHU fan energy savings >8%	- 8% modeled AHU fan energy savings, Harvey W. Wiley Federal Building
Peak demand prediction	Daily peak demand (kW)	Predicted electrical demand within 5% of measured electrical demand	- 97.5% accuracy, Terminal Annex Federal Building - 98.5% accuracy, Austin Courthouse - 95% accuracy, ATF Headquarters - 96.5% accuracy, Harvey W. Wiley Federal Building
Cost-effectiveness	Simple payback	Payback <5 years	Annual subscription costs exceed annual savings with the region's low utility costs at the Terminal Annex Federal Building ($0.066/kWh) and Austin Courthouse ($0.082/kWh) Austin Courthouse payback could be <5 years assuming the GSA average facility electricity rate of ($0.11/kWh) vs. the $0.082/kWh actual rate
Integration/ platform functionality	Third-party systems integration	Integration of two third-party application systems	Integration of multiple BAS, GSA AMI, density lidar sensor, FLIR sensor

Table 2: Qualitative Performance Objectives Results

Qualitative Objectives			
Objective	**Metric**	**Success Criteria**	**Final Results**
SPOG/portfolio view	Ability to review similar data across multiple buildings via multiple choice (1–5 Likert scale) survey and interview questions for GSA and operation-and-maintenance personnel	An Aggregate score above 3 for all factors	Aggregate score of 3.87 of 5 in focus group polling
Ease of installation	Time required to install and commission	Less than 12 weeks to install and commission the system	10-week installation at Terminal Annex Federal Building and Austin Courthouse 13-week installation at ATF Headquarters and 14 weeks at Harvey W. Wiley Federal Building due to complications outside the vendor's control, such as the COVID-19 pandemic
Operability	Multiple choice (1–5 Likert scale) survey and interview questions for GSA and operation-and-maintenance personnel	An Aggregate score above 3 for all factors	Aggregate score of 3.99 of 5 in focus group polling
Additional Capabilities			
Objective	**Metric**	**Success Criteria**	**Final Results**
GSALink compatibility	API integration from BOS API to GSALink	Successful API integration from BOS API to GSALink	Successful integration capability confirmed through BOS API

The EMIS with ASO was found to be effective in some performance objective metrics. In the modeled energy savings performance objective, the whole-building energy savings from the baseline ranged from 5% at the Terminal Annex Federal Building to 11% at the Austin Courthouse. For the Harvey W. Wiley building, the performance objective focused only on fan savings—11 air handling units (AHUs) of the 22 total in the building—which resulted in 8% savings when comparing the baseline to the model.

Peak demand prediction from the EMIS with ASO was found to predict kilowatt values with high accuracy. Results showed these predictions to be within 5% of the measured kilowatts. The collected and assessed predictions at all four test bed locations showed predictions within 1.5% at the Austin Courthouse, 2.5% at the Terminal Annex Federal Building, 3.5% at the Harvey W. Wiley Federal Building, and 5% at the ATF Headquarters.

The cost-effectiveness performance objective was evaluated and resulted in annual subscription costs exceeding the annual savings in utility costs for the Austin Courthouse and the Terminal Annex Federal Building whole-building modeling scenarios. These annual savings in dollars were low, likely due to the low utility costs at both facilities. The GSA average electricity rate of ($0.11/kWh) was higher than both test bed facilities involved in this performance objective, with a utility rate of ($0.082/kWh) at the Austin Courthouse and ($0.066/kWh) at the Terminal Annex Federal Building. When using the $0.11/kWh GSA average electric utility rate to calculate the payback, theoretically the Austin Courthouse could have a payback of less than 5 years.

The integration/platform functionality performance objective required the integration of at least two third-party systems into the EMIS with ASO. This performance objective resulted in successful third-party integrations, including multiple BAS, GSA advanced metering infrastructure (AMI), density light detection and ranging (lidar) sensors, and forward looking infrared (FLIR) sensors.

The success criteria of two qualitative performance objectives depended on Likert scale scores of 3/5 or higher in survey or focus group formats. For these, focus groups were conducted, which yielded scores of 3.87/5 for the SPOG/portfolio view performance objective and 3.99/5 for the operability performance objective. The SPOG capabilities successfully enabled key performance indicator (KPI) tracking of portfolio-wide energy usage trends, occupancy counting, peak demand alerts, monthly energy reporting, and trending of abnormal data anomalies. These views were noted to be easy to use and address several real-world problems with being able to remotely address building energy use and operational problems.

The ease of installation performance objective focused on the speed and ease of the installation of EMIS with ASO. The success criterion was defined as 12 weeks or less to install and commission the system. Two test bed facilities, the Austin Courthouse and the Terminal Annex Federal Building, successfully held installation and commissioning periods within the 12-week window; however, the ATF Headquarters and Harvey W. Wiley buildings both exceeded the 12-week time frame, at 13 weeks and 14 weeks, respectively due to complications outside the vendor’s control, such as the COVID-19 pandemic.

The additional capability performance objective of GSALink compatibility was measured by successful connection via application programming interface (API) from BOS API to GSALink.

The EMIS with ASO platform shows promise as an effective means to implement supervisory control capability to realize energy and cost savings, predict peak demand, and enable KPI tracking of portfolio-wide energy use trends via SPOG capabilities; however, the EMIS with ASO platform did not meet the defined cost-effective objective since the calculated payback exceeded 5 years at both the Austin Courthouse and the Terminal Annex Federal Building. Going forward, the utility rate should be considered when selecting sites for potential future installations. Another important factor that should be considered is the installation and operational costs, which can vary depending on BMS vendor, naming convention, and language protocol. This can affect the installation time and/or the operability of the software as well.

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I. Introduction

A. WHAT WE STUDIED

The U.S. General Services Administration's (GSA's) Green Proving Ground (GPG) program, in partnership with the National Renewable Energy Laboratory (NREL), completed a large pilot study of an energy management information system (EMIS) with automated system optimization (ASO). Four different test bed facilities, each with different building characteristics and systems, were chosen for the implementation of EMIS with ASO.

EMIS with ASO, depending on functionality, can be an extremely powerful tool for energy management and energy optimization in buildings. This project focuses on the validation of a cloud-based EMIS with ASO. This specific EMIS with ASO furthers building automation system (BAS) functionality while predicting building energy consumption to inform operational decisions to, in theory, optimize the efficiency of operations. GSA has identified two use cases for this technology: (1) optimization of heating, ventilating, and air-conditioning (HVAC) based on factors such as occupancy and weather; and (2) aggregation and viewing of multiple streams of data in one place. For this study, the EMIS with ASO used two-way communications with the BAS. The EMIS with ASO aggregated historical data from the buildings using machine learning and thermal modeling to optimize the performance and write analytically based optimal schedule or set points back to the BAS.

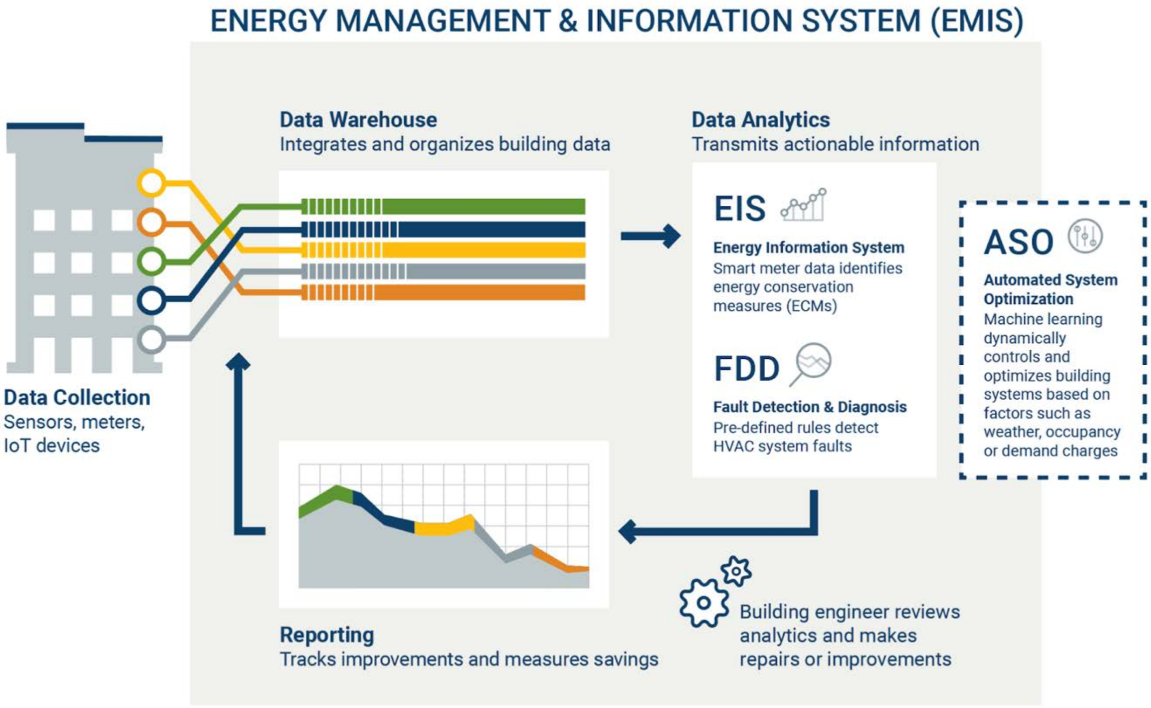

Figure 1: EMIS overview.

Image adapted from Image LBNL (Kramer et al. (2020))

EMIS with ASO Platform Overview

The EMIS with ASO was provided by Prescriptive Data, which offers a modular software-as-a-service (SaaS) EMIS with ASO solution called Nantum. Occupancy-driven machine learning algorithms aimed to predictively ramp up and ramp down the building air handling units (AHUs) to optimize efficiency based on occupancy, weather data, electrical consumption, and integration of third-party data.

Depending on the Internet of Things integrated devices, building systems, corresponding data sets, and desired application features, certain EMIS with ASO capabilities were the focus of the evaluation. The capabilities evaluated in the pilot ranged from energy savings and energy consumption predictions to evaluations of user acceptance, operability, and ease of installation. Further details are found in Section II: Evaluation Plan.

Visual representations of the primary features and capabilities of the EMIS with ASO evaluated in this project are shown in Figure 2.

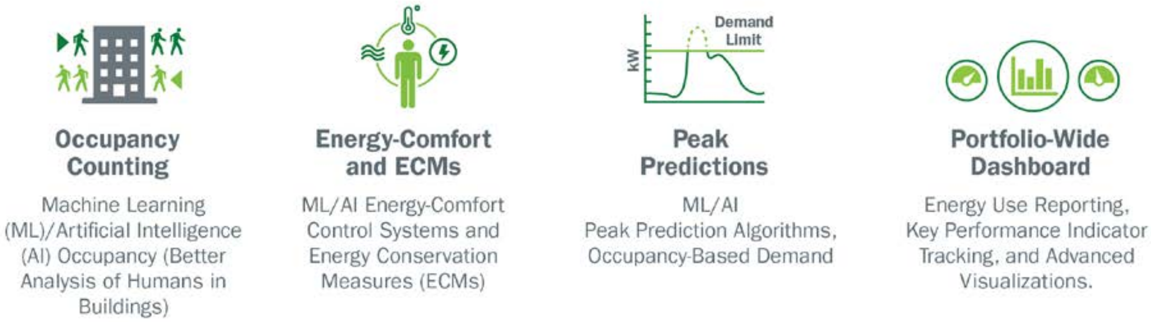

Figure 2: EMIS with ASO features being evaluated.

Image from Prescriptive Data, modified by Fred Zietz, NREL

Occupancy Counting

The EMIS with ASO uses occupancy counting technology to optimize building energy use. Occupancy counters can be installed at the building entrances and exits, or they can be installed throughout the facility to enable more granular zone-level occupancy tracking and control.

As a part of this project, stereoscopic and light detection and ranging (lidar)-based occupancy counting sensors were installed at the entrance and exit of each building to track building occupancy, as shown in Figure 3 for the Terminal Annex Federal Building entrance.

Figure 3: Stereoscopic occupancy counter at Terminal Annex Federal Building.
Photo by Joshua Banis, GSA

The EMIS with ASO platform uses these occupancy data along with thermal modeling, weather data, and machine learning algorithms to optimize AHU fan startup scheduling through a machine learning-based optimum start strategy. The EMIS with ASO also uses the occupancy data to ramp AHU fans at lunchtime and at the end of the workday, when people are departing. The respective times, which are predicted and prescribed by machine learning algorithms, improve over time by capturing data from the building's behavioral patterns. Figure 4 shows an hourly occupancy profile for the Terminal Annex Federal Building for a 24-hour period from February 1, 2021, to February 7, 2021, and indicates an occupancy pattern with fewer people coming into the office Wednesday through Friday.

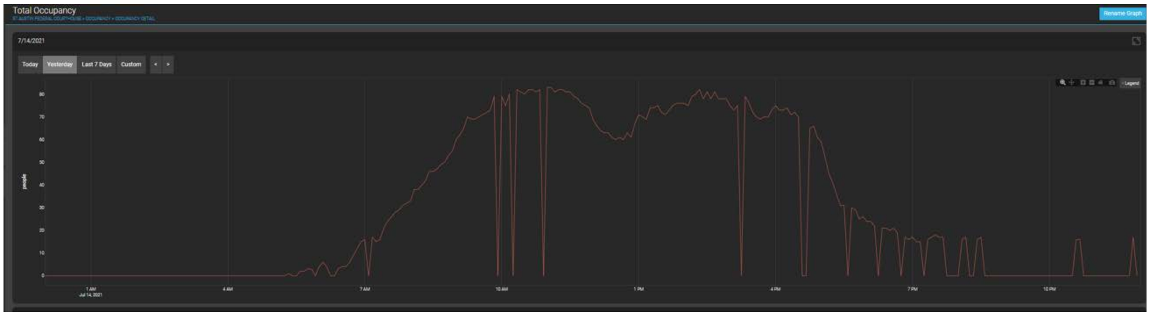

Figure 4: Hourly occupancy profile for 7-day period for Terminal Annex Federal Building.
Image from Prescriptive Data

The occupancy data allow building owners to:

- View their building, floor, or zone, depending on occupancy counter locations, occupancy levels in real time.
- Analyze historical occupancy patterns.
- Receive real-time occupancy anomaly alerts.

The primary key performance indicators (KPIs) displayed in the EMIS with ASO dashboard for occupancy counting are (1) people per building and (2) electrical demand per person. Detailed occupancy counting allows for tracking the percentage of occupants in the office, including overall occupancy rates in each building and across a portfolio of buildings.

Optimum Start

Traditional optimum start algorithms for BAS have been around for more than 30 years; however, they are infrequently implemented, and the algorithms are not used to determine optimum start times for HVAC equipment. Typically, start times are based on a rolling average of the previous 3 to 7 days. The typical algorithm looks at the recovery rate of each thermal zone (i.e., amount of time required to get the space temperature to the set point based on the zone temperature, zone temperature set point, and outside air temperature) to determine when to start the HVAC equipment to minimize energy use and meet an interior space temperature set point at a defined time. With this sequence, major changes or anomalies in outside air temperature can alter the algorithm, resulting in inaccurate start times and problems with thermal comfort in the space.

The EMIS with ASO implements an optimum start algorithm for AHU fans using machine learning that aggregates historical data—including zone temperature, zone temperature set point, outside air temperature, local weather forecasts, occupancy data, and complex time-of-use utility rates—to decide the optimal start/stop time for AHU fans. This algorithm provides precooling and preheating recommended startups to minimize total energy consumption while satisfying thermal comfort requirements. It uses day-ahead prediction of interior space conditions, occupancy profile, and outdoor conditions developed using machine learning methodologies.

A comparison demonstrating the difference between standard and EMIS with ASO start times is provided in Figure 5 and denoted “Calculated Startup.”

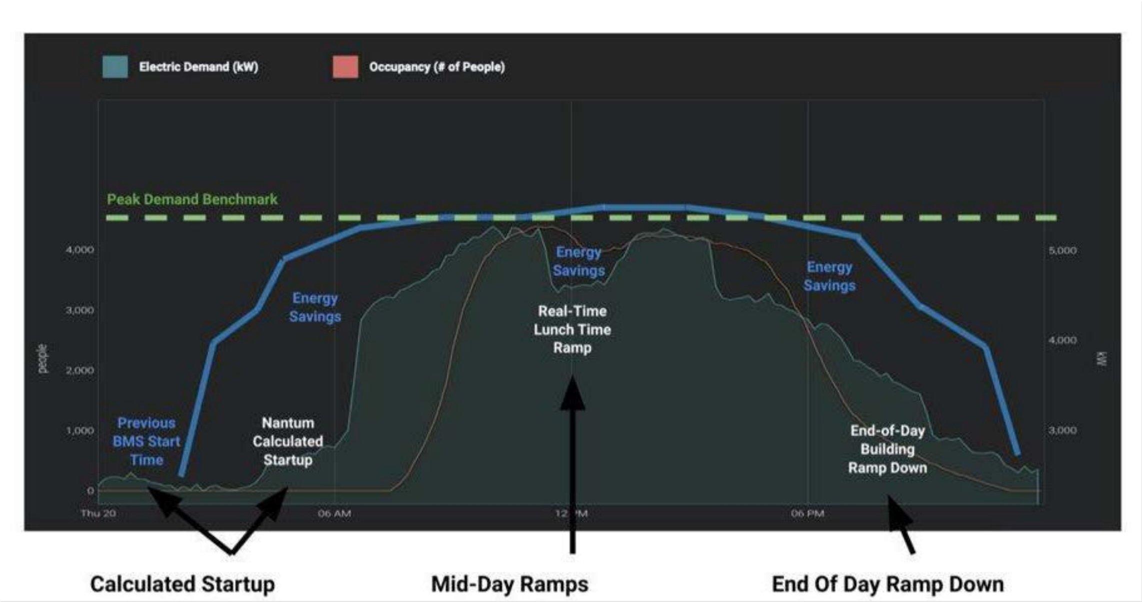

Figure 5: Example of EMIS with ASO supervisory control.

Image from Prescriptive Data

Midday and End-of-Day Ramps

The EMIS with ASO's intraday adjustments to the static pressure of each AHU are automated, based on real-time occupancy data, thermal modeling, and machine learning algorithms at the beginning, middle, and end of each day. The midday and end-of-day ramps are completed through a set of EMIS with ASO commands that trigger a temporary fan speed reduction based on static pressure set points that increase or decrease based on occupancy levels. Based on current conditions and past learning, the technology determines both the latest time to initiate the startup and how the building can be ramped down earlier in the day. This is different from the current method most buildings follow, including the GSA, which is based on a scheduled startup and shutdown with no capability for intraday adjustments. Additional details on the difference between standard and EMIS with ASO start times are provided in Figure 5 and denoted "Midday Ramps" and "End-of-Day Ramp Down."

Peak Demand Prediction

The EMIS with ASO machine learning capabilities enable predictive analysis for daily peak demand, allowing operators to make informed adjustments to mechanical systems to reduce peak demand charges. Further, the vendor's technology alphanumerically and graphically presents key energy usage data to building operators to improve the efficiency of the building. Automated demand management strategies were not implemented as part of this project, but they are a new capability within the EMIS with ASO, and they are being deployed at the Foley Federal Building and U.S. Courthouse via a separate grid-interactive efficient building pilot project.

Anomaly Detection and Alerts

The EMIS with ASO platform includes data visualization, predictive analytics, occupancy-based HVAC optimization, billing/metering measurement and verification, reporting, and data export.

Portfolio-Wide Dashboard

The EMIS with ASO provides the ability to view similar data across multiple buildings via a portfolio-wide dashboard. This portfolio view of building performance across multiple properties as well as the "cockpit view" of the performance of individual building systems within a single property is defined in this report as single pane of glass (SPOG) functionality. The portfolio view can support a facility operator's ability to monitor multiple sources of information more effectively.

In addition to the energy savings potential of the vendor's technology, several capabilities are anticipated to add value to building operators and those with portfolio management responsibilities. The EMIS with ASO offers a SaaS solution. The EMIS with ASO software can provide added benefits if it is correctly integrated with other relevant systems, such as circuit-level metering, occupancy data, environmental sensors, and other third-party solutions yet to be brought to market.

B. WHY WE STUDIED IT

"The GSA is responsible for the single largest portfolio of commercial office space in the United States, comprising more than 8,500 properties. This includes more than 370 million square feet of building space, including more than 180 million square feet of federally owned building space" (GSA 2018). "In 2018 alone, the annual energy cost for the federally owned portion of this real estate portfolio amounted to $280 million, at 52.2 kBtu/ft^2/yr. GSA buildings are 33% more efficient than typical U.S. commercial buildings" (GSA n.d.). Given the GSA's large portfolio of buildings and aggressive energy reduction goals, the agency was an early adopter of smart building technologies and created a national Smart Building program. This program focused on "leveraging technology to improve building performance, enhance occupant well-being, increase productivity, and manage risk from climate change, public health, and cybersecurity" (GSA n.d.).

In the fall of 2018, the GSA and the U.S. Department of Energy (DOE) Building Technologies Office issued a joint request for information for "Behind the Meter Load Optimization" focused on "technologies that optimize behind the meter generation, building loads, storage, or any combination of these to provide resiliency, energy efficiency, or enable participation in dynamic rate structures, or any combination thereof" (GSA 2017). The EMIS with ASO platform evaluated in this report was selected in the spring of 2019 from among 34 other submissions in this category. The GSA selected this technology because it was interested in validating the following benefits and capabilities for broader GSA deployment:

- Provide accurate, real-time, whole-building occupancy information.
- Apply occupancy-based machine learning to optimize HVAC start times and midday and end-of-day ramp times.
- Deliver a common, intuitive interface (i.e., SPOG) for facility operators and portfolio managers to view data from multiple locations.
- Provide the ability to converge and normalize data from multiple vendors and products into a SPOG.
- Leverage the GSA's investment in GSALink, Java Application Control Engine (JACE) hardware, and smart, connected building technology.
- Enable the GSA to procure sensors, controls, and equipment with similar capabilities from multiple vendors.

- Evaluate a SaaS model that avoids upfront development and infrastructure costs and facilitates continual improvement of the EMIS with ASO platform, allowing for more features to be added over time.

II. Evaluation Plan

A. TEST BED SITES

A summary of the four locations serving as test beds for this evaluation is provided in Table 3. Site selection criteria that were used to recruit these locations are described in Appendix 2. Detailed descriptions of the technical attributes of building systems and instrumentation points per building are provided in Appendix 3.

Table 3: Test Bed Locations

Building Name	Building Location	Building Size (ft^2)	Building Use Type
Site 1: Austin Courthouse	501 W. 5th St., Austin, TX 78701	250,995	Courthouse
Site 2: Terminal Annex Federal Building	207 S. Houston St., Dallas, TX 75202	253,112	Office
Site 3: Harvey W. Wiley Federal Building	5001 Campus Dr., College Park, MD 20740	441,305	60% office/40% laboratory On-site data center
Site 4: ATF Headquarters	99 New York Ave. NW, Washington, DC 20226	422,000	Office

The ***Austin Courthouse*** is a 250,995 ft^2 building located at 501 West 5th St., Austin, TX 78701. This courthouse, completed in 2012, consists of 10 stories. At the time of the project, the building had partial occupancy due to the GSA's COVID-19-related mandatory telework policy for nonessential personnel.

Figure 6: Austin Courthouse

Image from GSA

The building's HVAC system comprises a chilled water plant, replaced and recommissioned during the GPG pilot; high-efficiency condensing boilers; two dedicated outside air systems (DOAS) units; AHUs; fan coil units (FCUs); computer room air-conditioning (CRACs) units; and variable air volume (VAV) boxes. The BAS is a Tridium Niagara AX and integrated on the GSA Office of the Chief Information Officer Entity Network Translation. Unitary controls, an electronic device for the digital control of packaged AHUs, unit ventilators, fan coils, heat pumps, and other terminal units serving a single zone or room are Honeywell Comfort Point BACnet. The courthouse has whole-building electric and gas meters on the GSA advanced metering infrastructure (AMI) system. This building also has 17 submeters, including two meters per floor to measure lighting energy usage within the building. The central chilled water plant is set up with KPIs to log chiller kilowatts/ton over time, and the boiler plant has flow meters to measure the British thermal units (Btu) of heat delivered. Prior to the installation of this EMIS with ASO, the energy use intensity (EUI) of the Austin Courthouse was 80.3 kBtu/ft^2.

This building exemplifies the GSA's Design Excellence Program, which includes a streamlined, two-step architect/engineer selection process and the use of private-sector peers to provide feedback to the architect/engineer of record. The program stresses creativity. It also streamlines the way GSA hires architects and engineers, substantially reducing the cost of competing for GSA design contracts. This courthouse is representative of multiple facilities in the GSA's inventory; it was recently constructed with modern BAS and building systems and has high-quality AMI and granular (floor by floor) submetering that will facilitate the accuracy of measurement and verification. The GSA team has had challenges effectively operating the facility and issues with building energy performance. An overview of the EMIS with ASO implementation at the Austin Courthouse is provided in Table 4.

Table 4: EMIS with ASO Integration Summary for Austin Courthouse

Hardware	Integration	Supervisory Controls	Other Use Cases
- Whole-building occupancy counter through density lidar sensors(five)	- Integration of on-site AMI and BAS data - 1,882 total BAS and AMI points integrated - Integration start 11/01/2019 and finish 02/15/2020	- Optimum start on AHU fans (03/09/2020 through 06/24/2020) - Midday and end-of-day ramps on AHU fans through static pressure reset	- Cloud-based data storage - Custom KPI - Graphical anomaly detection

The ***Terminal Annex Federal Building*** is a 253,112 ft^2 building located at 207 S. Houston St., Dallas, TX, 75202. This office building, built in 1937, consists of five stories and a basement. It primarily functions as an office and childcare center, with a normal occupancy of approximately 70%. The building currently has only partial occupancy because the second floor was under renovation for a portion of the GPG pilot. After GSA took ownership, it invested more than $7 million in the building to complete major renovations.

Figure 7: Terminal Annex Federal Building

Image from Library of Congress

The building's HVAC system comprises a chilled water loop fed by three chillers, AHUs, and VAVs. The BAS is Tridium Niagara AX and integrated on the GSA Office of the Chief Information Officer Enterprise Network. The Terminal Annex Federal Building has whole-building electric and gas meters on the GSA AMI system. Prior to the installation of this EMIS with ASO, the EUI of the building was low, 41.8 kBtu/ft^2. An overview of the EMIS with ASO implementation at the Terminal Annex Federal Building is provided in Table 5.

Table 5: EMIS with ASO Integration Summary for Terminal Annex Federal Building

Hardware	Integration	Supervisory Controls	Other Use Cases
Whole-building occupancy counter through density lidar sensors (four)	- Integration of on-site AMI and BAS data - 998 total BAS and AMI points integrated - Integration start 11/01/2019 and finish 02/15/2020	- Optimum start on AHU fans (03/20/2020 through 07/03/2020) - Midday and end-of-day ramps on AHU fans through static pressure reset (continuously)	- Cloud-based data storage - Custom KPIs - Graphical anomaly detection

The ***Harvey W. Wiley Federal Building*** is a 441,305 ft^2 building located at 5001 Campus Dr., College Park, MD, 20740. The building was constructed in 2001, has 600 tenants on 4 floors plus a basement, and consists of 60% office space and 40% laboratories.

Figure 8: Harvey W. Wiley Federal Building

Image from GSA Design Excellence

This building is occupied by a single occupant agency interested in energy reduction, and the dedicated AHUs for the office space provide a use case for fan power savings analysis. The EUI for the Harvey W. Wiley Federal Building is 200.7 kBtu/ft^2. An overview of the EMIS with ASO implementation at the Harvey W. Wiley Federal Building is provided in Table 6.

Table 6: EMIS with ASO Integration Summary for Harvey W. Wiley Federal Building

Hardware	Integration	Supervisory Controls	Other Use Cases
- Whole-building occupancy counter through FLIR lidar sensors (three: two at main entrance and one at loading dock)	- Integration of on-site AMI and BAS data - 4,290 points integrated - Integration midday ramps start 11/06/2020 and finish 07/22/2021	- Optimum start on AHU fans not implemented due to COVID-19 - Midday and end-of-day ramps on AHU fans through static pressure reset (on Fridays) - 8 AHUs included for ASO	- Cloud-based data storage - Custom KPIs - Graphical anomaly detection

The ***Bureau of Alcohol, Tobacco, Firearms (ATF), and Explosives Headquarters*** is a 422,000 ft^2 building located at 99 New York Ave. NW, Washington, D.C., 20226. Completed in 2008, the ATF Headquarters facility meets the most stringent blast-resistance requirements and is certified at the silver level of the U.S Green Building Council's Leadership in Energy and Environment Design rating system. The ATF building accommodates general office space, training rooms, an auditorium, and auxiliary services. The ATF Headquarters building has four main electrical meters on the GSA AMI. Through this GPG pilot project, the whole-building gas meter was added to GSA's AMI.

Figure 9: ATF Headquarters

Image from Dick Lyon provided under Creative Commons Attribution-Share Alike 4.0 International

The ATF Headquarters is also a large Design Excellence Program office building representative of multiple facilities in the GSA inventory. Underfloor air distribution design enables the assessment of technology fit with multiple other GSA facilities with this HVAC system. A recent Energy Services Company deep energy retrofit shows an assessment of whether the technology holds value post upgrades. In the original plan, pre- and post-quantitative objectives were only to be evaluated for electricity savings and demand reduction because the whole-building gas AMI meters would not be installed on time for baselining the building gas consumption. The EUI for the building is 81.9 kBtu/ft^2. An overview of the EMIS with ASO implementation at the ATF Headquarters is provided in Table 7.

Table 7: EMIS with ASO Integration Summary for ATF Headquarters

Hardware	Integration	Supervisory Controls	Other Use Cases
- Whole-building occupancy counter through FLIR lidar sensors (one at main entrance)	- Integration of on-site AMI and BAS data (HVAC) -1,221 total BAS and AMI points integrated - Integration 04/22/20 through 7/30/2020	- Optimum start on AHU fans not implemented due to COVID-19 - Intermittent issues with midday ramps, consistent issues with programming	- Cloud-based data storage - Custom KPIs - Graphical anomaly detection

B. METHODOLOGY

The EMIS with ASO evaluation plan, originally finalized in March 2020, was modified in November 2020 to capture changes to building operations and associated impacts on measurement and verification due to performance objectives impacted by COVID-19. Starting on March 16, 2020, the GSA implemented a mandatory work-from-home policy for nonessential GSA staff. This resulted in low occupancy rates for GSA employees; however, other agencies dictated their own policies within the buildings. Thus, each facility had variability in the occupancy rates after the telework posture, based on the type of work being conducted and occupant agencies. With more than 80% of occupants now working from home, the building energy use was impacted, with lighting and plug load energy use dropping significantly, making normal procedures for baseline energy savings calculations nonviable. Finally, and most notably, GSA pushed out a series of changes to the HVAC systems sequence of operation that were in line with the ASHRAE Epidemic Task Force recommendations related to HVAC operation (ASHRAE 2021). These included:

- Increased AHU run time 2 hours pre-occupancy and 2 hours post-occupancy across the GSA portfolio.
- Occupant agencies requested 24/7 overtime utilities to operate AHUs 24/7 at occupied set point temperatures.

Figure 10 shows the occupancy in the four buildings for the week of February 29, 2020, through March 14, 2020, and then the occupancy starting March 21, 2020, after the work-from-home order, when the occupancy for each building dropped to less than 20% of normal.

Building ↕	Value ↕	Time ↕
Portfolio Total Occupancy	502 People	10:59 AM
R7 Terminal Annex	187 People	10:45 AM

Figure 10: Building occupancy pre- and post-work-from-home order

The new GSA COVID-19 HVAC guidelines required GSA facilities to operate AHUs 2 hours prior to normal building occupancy and 2 hours post occupancy to help flush airborne particulates from the facility. This new operational guidance resulted in revised start and stop times that negate savings potential from the EMIS with ASO supervisory control sequence for optimized start and end-of-day ramp downs. In response to new HVAC guidelines, buildings were not allowed to enable morning startup and afternoon ramp down. As a result, the measurement and verification methodology shifted away from directly measuring savings to modeling energy savings. In addition, the Austin Courthouse experienced a chiller failure that required a full replacement of the chiller plant, which also prohibited the EMIS with ASO supervisory controls from being implemented. The following performance objectives were modified or removed from the project plan due to changes associated with COVID-19:

- **Energy savings**: Measured energy savings were replaced with modeled energy savings.
- **Occupant satisfaction**: Occupant selection was deleted from the project plan due to buildings having very little occupancy during COVID-19 and the EMIS with ASO not consistently implementing supervisory control sequences.
- **Measurement and verification for third-party energy conservation measures**: This additional objective was dropped because third-party energy conservation measures are not being implemented due to COVID-19 staffing restrictions and the capability not being available through the EMIS with ASO platform within the timeline of the evaluation.

Fortunately, although the building occupancy rate dropped to less than 20% of total occupancy for the Terminal Annex Federal Building and the Austin Courthouse, the normalized occupancy profile stayed relatively constant before and after COVID-19 for both buildings (Figure 11 and Figure 12).

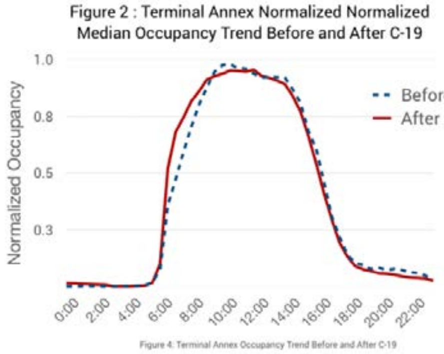

Figure 11: Terminal Annex normalized occupancy data

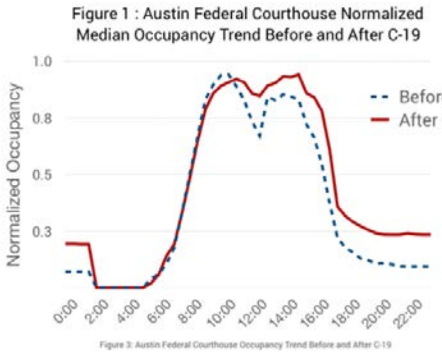

Figure 12: Austin Courthouse normalized occupancy data

Given that the occupancy profile was similar pre- and post-COVID-19, the occupancy data that were collected could be used by the vendor to determine when they would have done the following:

- Initiated optimum start for each AHU for each day of the year
- Initiated midday ramps and end-of-day ramps for each AHU for each day of the year.

The measurement and verification baseline period used for the energy model calibration was calendar year 2019. For the Austin Courthouse, the site has AMI data for the two main electrical meters for the building, the whole-building gas meter, and 17 floor-level lighting submeters. The whole-building AMI data combined with the submeter data and select BAS points were used to calibrate the Terminal Annex Federal Building and Austin Courthouse energy models based on 2019 data with a required coefficient of variation (CV) root mean square error (RMSE) <25%, R2 >0.7, and a normalized mean bias error (NMBE) of <0.5%.

For the Harvey W. Wiley Federal Building, all BAS points are trended through the Cimetrics monitoring-based commissioning system. Baseline data were collected for 2019 for select BAS and AMI points to build the baseline fan performance model.

III. Demonstration Results

The demonstration assessed the EMIS with ASO at four GSA facilities. The study was coordinated with a parallel assessment of the same technology in a commercially owned private-sector facility by Lawrence Berkeley National Laboratory through the DOE Building Technologies Office Better Buildings Alliance partners. Quantitative and qualitative performance objectives and associated results for the demonstration project are summarized in Table 8 and Table 9.

Table 8: Quantitative Performance Objectives Results

Quantitative Objectives			
Objective	**Metric**	**Success Criteria**	**Final Results**
Energy savings	Modeled EUI reduction	Whole-building energy savings: >5%	– 11% modeled whole-building energy savings, Austin Courthouse – 5.1% modeled whole-building energy savings, Terminal Annex Federal Building
	Modeled kWh reduction	AHU fan energy savings >8%	– 8% modeled AHU fan energy savings, Harvey W. Wiley Federal Building
Peak demand prediction	Daily peak demand (kW)	Predicted electrical demand within 5% of measured electrical demand	– 97.5% accuracy, Terminal Annex Federal Building – 98.5% accuracy, Austin Courthouse – 95% accuracy, ATF Headquarters – 96.5% accuracy, Harvey W. Wiley Federal Building
Cost-effectiveness	Simple payback	Payback <5 years	Annual subscription costs exceed annual savings with the region's low utility costs at the Terminal Annex Federal Building ($0.066/kWh) and Austin Courthouse ($0.082/kWh) Austin Courthouse payback could be <5 years assuming the GSA average facility electricity rate of ($0.11/kWh) vs. the $0.082/kWh actual rate
Integration/ platform functionality	Third-party systems integration	Integration of two third-party application systems	Integration of multiple BAS, GSA AMI, density lidar sensor, FLIR sensor

Table 9: Qualitative Performance Objectives Results

Qualitative Objectives			
Objective	**Metric**	**Success Criteria**	**Final Results**
SPOG/portfolio view	Ability to review similar data across multiple buildings via multiple choice (1–5 Likert scale) survey and interview questions for GSA and O&M personnel	An Aggregate score above 3 for all factors	Aggregate score of 3.87 of 5 in focus group polling
Ease of installation	Time required to install and commission	Less than 12 weeks to install and commission the system	10-week installation at Terminal Annex Federal Building and Austin Courthouse 13-week installation at ATF Headquarters and 14 weeks at Harvey W. Wiley Federal Building due to complications outside the vendor's control, such as COVID-19
Operability	Multiple choice (1-5 Likert scale) survey and interview questions for GSA and O&M personnel	An Aggregate score above 3 for all factors	Aggregate score of 3.99 of 5 in focus group polling
Additional Capabilities			
Objective	**Metric**	**Success Criteria**	**Final Results**
GSALink compatibility	API integration from BOS API to GSALink	Successful API integration from BOS API to GSALink	Successful integration capability confirmed through BOS API

A. QUANTITATIVE RESULTS

Quantitative Objective 1: Energy Savings

The success criterion for this objective is a cumulative 5% whole-building energy savings for the Terminal Annex Federal Building and the Austin Courthouse and 8% fan energy savings from optimizing HVAC control sequences for the Harvey W. Wiley Federal Building.

Terminal Annex Federal Building Energy Model

The baseline energy model for the Terminal Annex Federal Building was created in OpenStudio with the following high-level assumptions and modeling procedures:

- Actual meteorological year (AMY) 2019 weather data were used from Dallas Love Field Airport.
- The building geometry was created using the construction drawings.

- The building materials for the roofs, walls, and vertical fenestrations were based on the 2004 DOE prototype building model for large office buildings.
- The HVAC equipment was modeled using the mechanical drawings.
- Fan curves for the modeled AHUs were built using time-series data from the building.
- Heating and cooling set point schedules were obtained from the building's operation-and-maintenance (O&M) team.
- Occupancy schedules were provided from the O&M team.
- Additional building loads from interior lighting and office equipment were based on the ASHRAE 90.1-2010 user's manual default values for large office buildings.

A visual rendering of the Terminal Annex Federal Building energy model is provided in Figure 13, and more information on the modeling can be found in Appendix B.

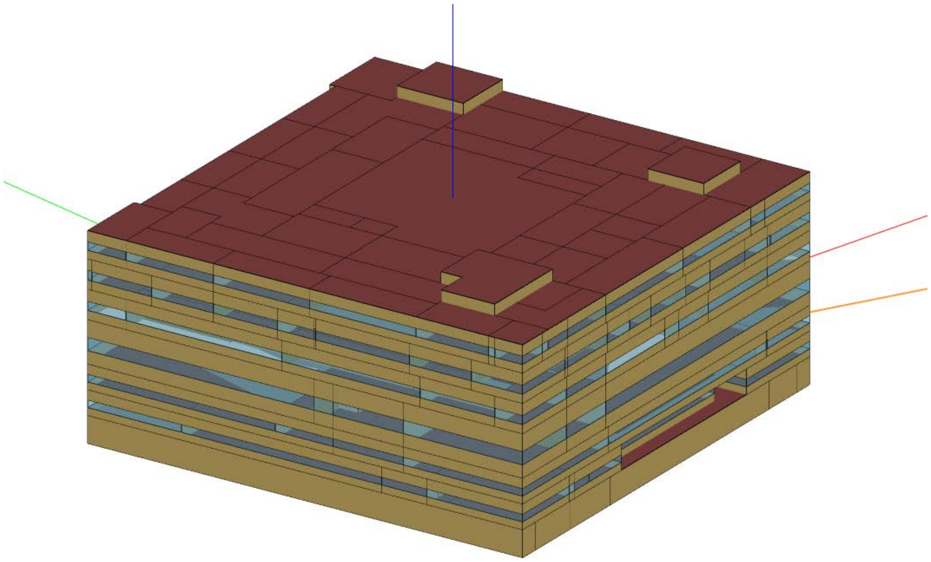

Figure 13: Terminal Annex Federal Building energy modeling rendering

Terminal Annex Energy Modeling Results

Table 10 provides a breakdown of the annual energy savings per end use for the Terminal Annex Federal Building for the baseline 2019 energy model and the EMIS with ASO energy model in units of gigajoules (GJ) and percentage annual energy savings.

Table 10: Terminal Annex Percentage Annual Energy Savings Summary

End Use	Baseline (Annual GJ)	EMIS with ASO (Annual GJ)	Percentage Annual Energy Savings (%)
Chiller	1,093	949	13.0%
Pumps	473	517	-9.0%
Heat rejection	195	185	5.0%
Fan (flow rate and pressure)	670	638	5.0%
Gas heating	1,605	1,168	27.0%
Total facility site energy	11,270	10,699	5.1%

The total on-site energy savings was 5.1%, and the end use with the largest energy savings was heating energy use, where annual natural gas heating savings were 27%. Heating energy savings were high due to the reduced run time of the AHU fans during early morning startups, which eliminated unnecessary heating of the facility during unoccupied hours. The end use with the second highest savings was the chilled water plant, with a 13% reduction in annual chiller energy usage. The savings from the chiller plan and natural gas heating were the primary drivers for energy savings in the facility. Detailed savings from each AHU fan are provided in Appendix X.

One unanticipated consequence of implementing an optimum start at the Terminal Annex Federal Building is that the reduced run time of the AHUs reduced the amount of time the building was cooled to the occupied set point temperature, which had the effect of reducing the charging of the thermal mass in the building. In a hot and humid climate like Dallas, this can impact the building’s peak demand, increasing the peak demand in the hottest summer months of July, August, and September. In Figure 14, this increased daily peak demand is shown as the orange lines versus the baseline case in blue. Although the cumulative daily building loads are the same, the increased and time-delayed building peak cooling demand value on summer days (with EMIS with ASO applied) lead to increased cooling electricity usage over the baseline when chillers should have more run times at high lift conditions. During the winter and shoulder seasons, the reduced run time of the AHU fans saves energy without increasing peak demand.

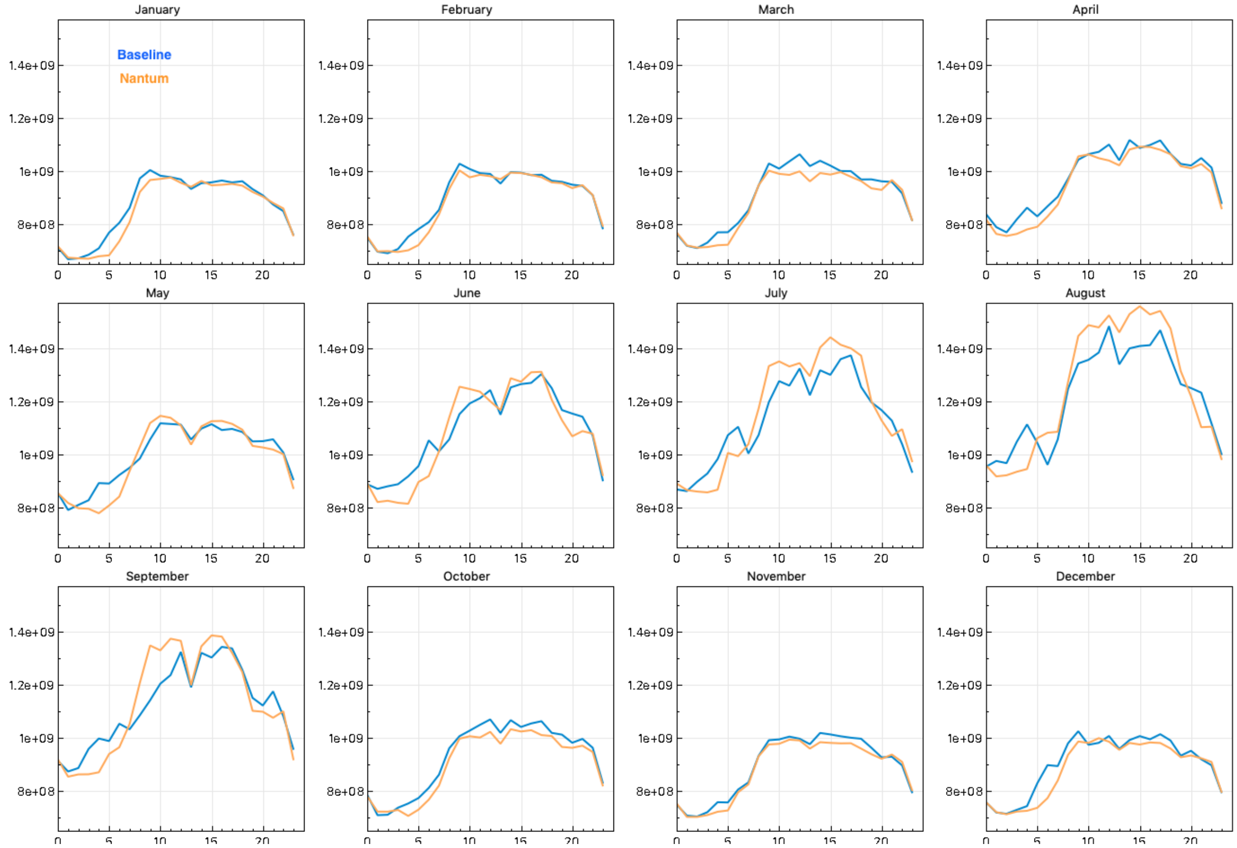

Figure 14: Terminal Annex Federal Building average daily building load profile pre- and post-EMIS with ASO

In addition to the increase in peak demand in the summer months, another complicating factor from the facility is that the 300-ton chiller runs 24/7 to meet a small data center load in the facility and operates at the lowest point on the chiller curve during this time. This results in a smaller net decrease in chiller energy usage when the cooling load is reduced by the EMIS with ASO compared to a facility with a right-sized chilled water plant because the chiller is already operating at its lowest point on the chiller curve. To quantify this issue, histograms were created of the chiller's modeled output at nighttime (12 a.m.–6:00 a.m.) corresponding to the part-load ratio (Figure 15) and energy usage in kWh (Figure 16) between the baseline (blue) and EMIS with ASO (orange) model data. The chiller's run time hours are the highest when the output is in the lowest range, shown in Figure 15, where most of the operation occurs when the chiller load is 0 to 0.2, or 0% to 20%, of the rated chiller plant capacity. In addition, there is almost no operation from 0.6 to 1.0, or 60% to 100%, of the rated chiller plant capacity from 12 a.m.–6 a.m., shown in Figure 15.

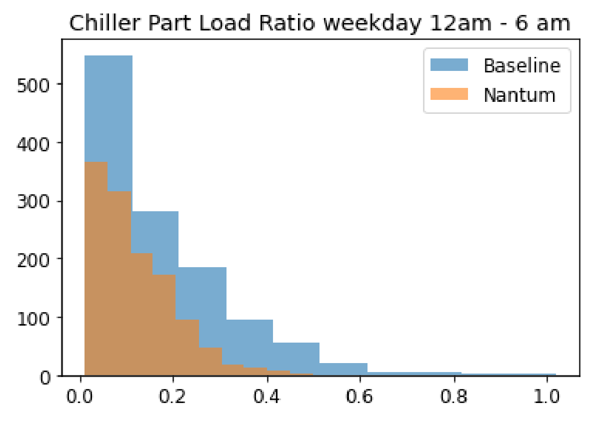

Figure 15: Terminal Annex chiller histogram of part-load ratio 12 a.m.–6 a.m.

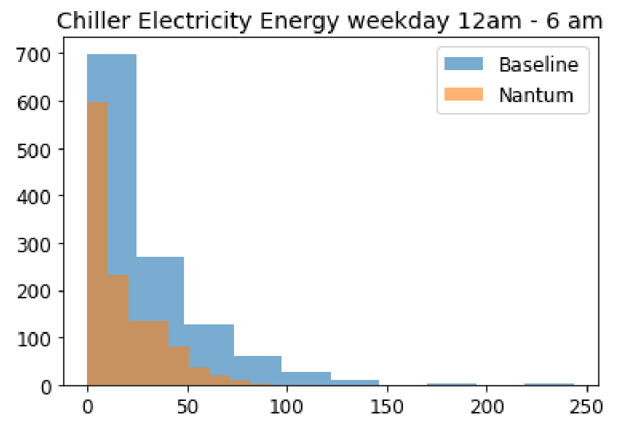

Figure 16: Terminal Annex chiller histogram of electricity energy 12 a.m.–6 a.m.

The cumulative impacts of the reduction in the occupied set point times and oversized chiller result in negative energy savings for the months of July, August, and September and positive savings for the rest of the year (Figure 17). In the final version of the recommended schedule for the Terminal Annex Federal Building, the optimized start times were removed for three peak summer months (July, August, September) to reduce an energy penalty during these months.

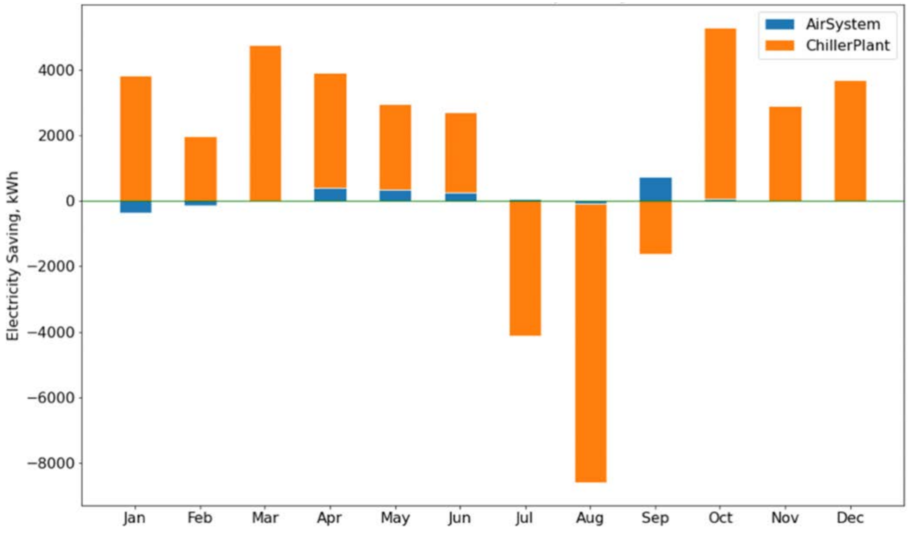

Figure 17: Terminal Annex Federal Building monthly AHU and chiller plant savings comparison

The EMIS with ASO current optimum start algorithm is intended to optimize the energy consumption of the building during startup and does not consider the effect of peak demand during startup optimization. Not considering the peak demand reduction in real-time startup scheduling optimization can negatively impact the startup electricity peak demand of the building.

This finding provides valuable lessons learned for both the GSA and the vendor because a refined algorithm that accounts for both the energy peak and consumption of the building could be helpful to optimize both the optimum start and peak demand for hot and humid climates.

Austin Courthouse Energy Model

The baseline energy model for the Austin Courthouse building was created in OpenStudio (Figure 18) with the following high-level assumptions and modeling procedures:

- AMY 2019 weather data were used from Austin, Texas, for the baseline energy model.
- The building geometry was created using the construction drawings.
- The building materials for the roofs, walls, and vertical fenestrations were based on the 2007 DOE prototype building model for large office buildings.
- The HVAC equipment was modeled using the mechanical drawings and schedules.
- Fan curves for the modeled AHUs were built using time-series data from the building.
- Heating and cooling set point schedules were obtained from the building's O&M team.
- Additional building loads from interior lighting and office equipment were based on the ASHRAE 90.1-2010 user's manual default values for large office buildings; these values were tuned in the calibration to match the AMI submeter data for the lighting systems in the building.

A visual rendering of the facility is provided in Figure 18, and more information on the modeling can be found in Appendix C.

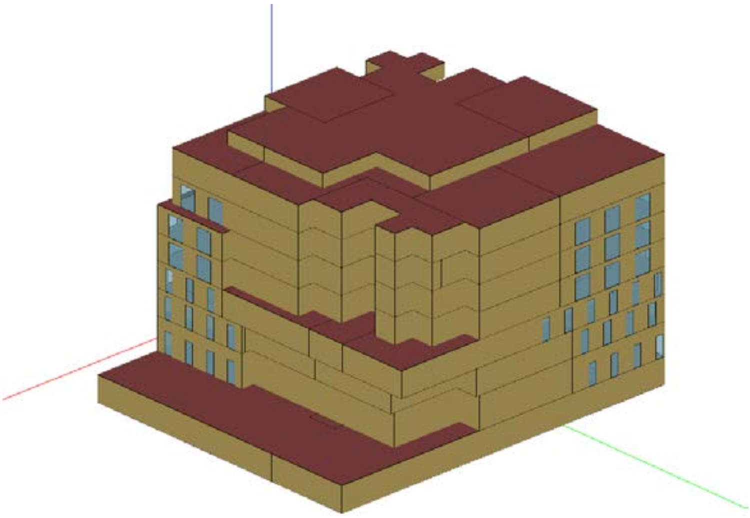

Figure 18: Austin Courthouse energy modeling rendering. ***Image from Prescriptive Data***

Table 11 shows the energy savings for the chillers, pumps, fans, heating system, and the total facility. The savings on chiller electricity were calculated with the difference in the modeled cooling demand between the baseline and EMIS with ASO models along with the same average monthly calculated coefficient of performance (COP) from the baseline model.

Table 11: Austin Courthouse Annual Energy Savings by End Use

End Use	Baseline (Annual GJ)	EMIS with ASO (Annual GJ)	Percentage Annual Energy Savings (%)
Chiller	3421	2417	29%
Pumps	1132	959	15%
Fan (flow rate only)	3205	2619	18%
Gas heating	6175	4987	19%
Total facility (site energy)	34461	30487	11%

The annual on-site energy savings for the Austin Courthouse was 11%. The whole-building energy savings for the Austin Courthouse was more than twice as high as the 5% performance objective due to the facility having a much higher energy use intensity and more energy savings potential.

Harvey W. Wiley Federal Building Component-Level Fan Modeling

The Harvey W. Wiley Federal Building is a 441,305 ft^2 facility comprising 60% office space and 40% laboratory space. The laboratory space operates 24/7 and is responsible for most of the energy use in the building. Consequently, changes to the AHU fan operation for the office area in the building will have a small impact on the total energy usage of the facility, and the analysis focused on measuring the fan savings from the office AHUs (11 AHUs of the 22 total in the building). The performance objective was an 8% annual fan energy savings. A detailed description of the energy modeling procedures for the Harvey W. Wiley Federal Building fan can be found in Appendix D.

Annual energy savings from each AHU ranged from 7% to 19%, and the total annual savings from all AHUs was 8%, as shown in Table 12.

Table 12: Harvey W. Wiley Federal Building Fan Energy Savings per AHU

AHU	Supply Fan Baseline (kWh/yr)	Supply Fan Savings (kWh/yr)	Return Fan Baseline Usage (kWh/yr)	Return Fan Savings (kWh/yr)	Annual Fan Savings (%)
AHU_05	107,796	9,120	72,761	3,064	7%
AHU_06	65,353	7,177	48,601	1,958	8%
AHU_07	66,762	7,007	56,806	2,858	8%
AHU_08	61,463	4,144	46,290	2,095	6%
AHU_09	80,291	6,951	33,197	1,318	7%
AHU_10	48,657	3,400	28,750	1,815	7%
AHU_14	15,956	3,018	4,888	900	19%
AHU_15	92,712	9,818	27,288	1,225	9%
Total	**538,989**	**50,634**	**318,581**	**15,234**	**8%**

Quantitative Objective 2: Peak Demand and Load Profile Prediction

The EMIS with ASO provides current-day and week-ahead predictive analytics for energy consumption and peak demand. The intent is to enable building operators to optimize operations to reduce utility costs associated with demand charges. An assessment of the accuracy of the machine learning algorithm's ability to predict the building load peak electrical demand (kW) for each day was conducted. This was achieved by comparing a statistical analysis of the EMIS with ASO platform's predictive analytics relative to the actual demand measured using on-site AMI meters.

The success criterion for this is day-ahead predictions that are within 5% of the actual measured demand for each building. The testing process for this performance objective was completed by comparing multiple readings of kilowatt demand versus prediction. The daily kilowatt demand reading was compared to the daily kilowatt prediction for approximately 1 calendar year for the Texas sites and 3 months for the Washington, D.C. sites. Two methods were used to compare the results to the performance criteria. The two one-sided test (TOST) was used to judge the prediction, and ASHRAE's Guideline 14 minimum CV. (RMSE and NMBE values were also calculated to ensure the values fell within ASHRAE Guideline 14's required accuracy range).

The TOST, a variation of the t-test, is a standard method of making inferences on the difference in the means of paired data. For all four test buildings, the confidence intervals were within the bounds of the acceptance intervals, meaning that the success criteria were met. The peak demand predictions had a statistical equivalency ranging from 1.5% to 4.8% across the four buildings. The start date, end date, number of days included in the analysis, TOST, CV (RMSE), and NMBE for the peak demand prediction for all four buildings are summarized in Table 13.

Table 13: Peak Demand Prediction Statistical Analysis Results

	Terminal Annex	Austin Courthouse	ATF Headquarters	Harvey Wiley
Start date	5/1/20	5/1/20	4/23/21	4/27/21
End date	5/4/21	5/4/21	7/22/21	7/21/21
Number of days included	225	226	61	33
TOST	± 2.48	± 1.54	± 4.77	± 3.45
CV (RMSE)	13%	7%	11%	9%
NMBE	-3%	-1%	-4%	-1%
Percentage accuracy	2.5%	1.5%	4.8%	3.5%

Section 4.3.2.4 of ASHRAE Guideline 14 states that the NMBE and the CV (RMSE) should be less than or equal to 5% and 15%, respectively, for this type of modeled utility data. As shown in Table 14, all the values are within the required CV (RMSE) and NMBE range for the four buildings. Given the technology installation occurred much sooner in the Texas sites, a larger data set was available for these two sites. For both Terminal Annex Federal Building and Austin Courthouse, approximately one years' worth of data was used in the analysis (excluding weekends and holidays).

A graphical representation of the actual versus predicted demand for all four buildings is provided in Figure 19 through Figure 22.

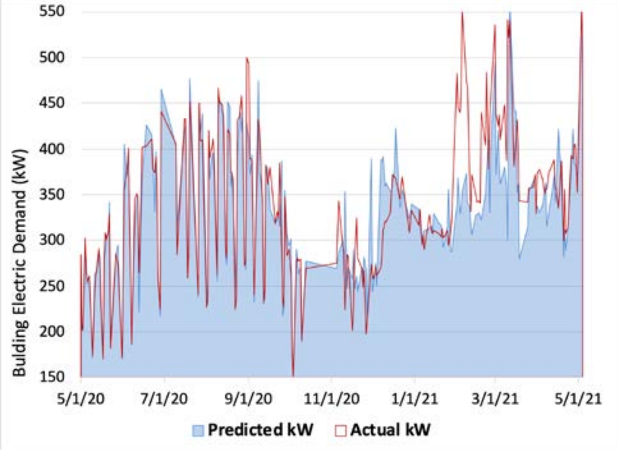

Figure 19: Terminal Annex predicted building demand vs. actual building demand

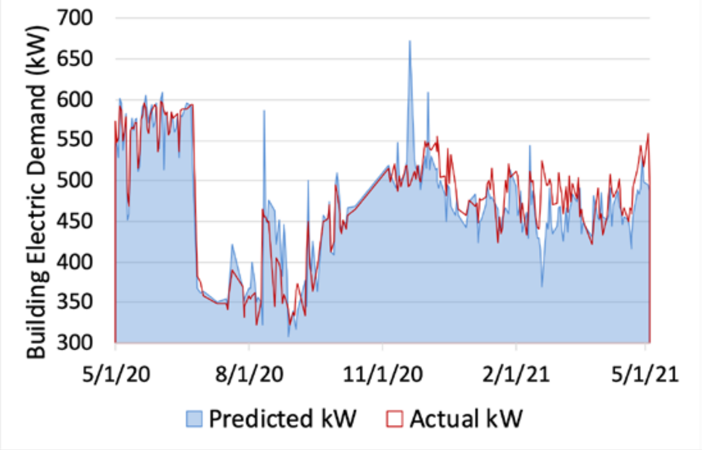

Figure 20: Austin Courthouse predicted vs. actual building demand

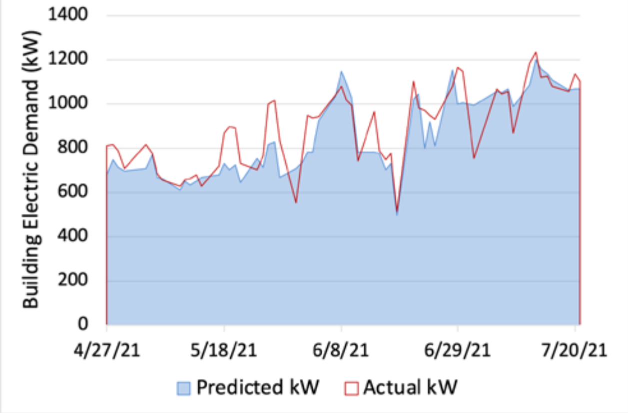

Figure 21: ATF Headquarters predicted vs. actual building demand

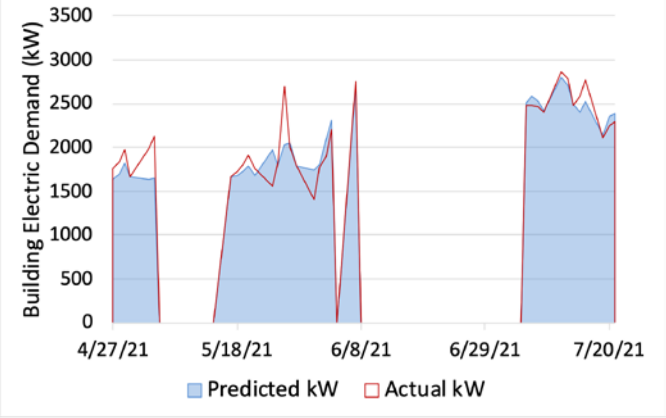

Figure 22: Harvey W. Wiley Federal Building predicted vs. actual building demand

Figures 19–22 show that although these four GSA facilities were operating with irregular occupancy and modified HVAC sequences of operation due to COVID-19, the EMIS with ASO was still able to accurately predict building demand. Following is a summary:

- For the Terminal Annex Federal Building (Figure 19), of the 235 daily demand predictions made, 91 were within ±10 kW of their true value, and the data were normally distributed.
- For the Austin Courthouse (Figure 20), of the 235 daily demand predictions made, 83 were within ±10 kW of their true value, and the data were normally distributed.
- For the ATF Headquarters (Figure 21), of the 61 daily demand predictions made, 14 were within ±10 kW of their true value. Overall, the data appear to be approximately normally distributed.
- For the Harvey W. Wiley Federal Building (Figure 22), of the 33 daily kilowatt demand predictions made, 4 were within ±10 kW of their true value. The Harvey W. Wiley Federal Building data set was

smaller due to complications in the on-site AMI system going down and not connecting to the EMIS with ASO for certain periods of time, as depicted in Figure 22.

In addition to the demonstrated accuracy in predicting building demand, the software has more time to learn the behavior of the building, and as the building occupancy profile returns to a more stable level, these predictions should continue to improve.

Quantitative Objective 3: Cost-Effectiveness

The cost-effectiveness performance objective success criteria were analyzed for two separate test bed locations: the Terminal Annex Federal Building and the Austin Courthouse. The target for the success criteria provided by the vendor was for both buildings to have a simple payback period of 5 years or less calculated from the energy reduction achieved.[1] The simple payback period requires inputs, including the recurring SaaS fee, installation and integration costs, the whole-building energy savings from the product used in the two test bed locations, and additional/reduced O&M costs (if any).

The Terminal Annex Federal Building had a blended electric rate of \$0.066/kWh, which is substantially less than the GSA national average blended rate of \$0.11/kWh. The detailed electric rate components used in the cost-effectiveness analysis are provided in Table 14.

Table 14: Terminal Annex Federal Building Electric Utility Rate Structure

Category	Value
Fixed monthly fee (\$/Month)	\$40.07
Energy rate (\$/kWh)	\$0.0452
Demand rate (\$/kW)	\$8.33
Gas rate (\$/mmBtu)	\$5.52

The installation cost for Terminal Annex Federal Building was \$37,082 and based on a SaaS fee of \$0.10/ft^2/yr. The software has an annual subscription cost of \$25,311 per year.

The Austin Courthouse had a blended electric rate of \$0.082/kWh, which is less than the GSA national average blended rate of \$0.11/kWh. The detailed electric rate components used in the cost-effectiveness analysis are provided in Table 15.

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[1] Simple payback [yr] = (Building energy savings [\$/yr] – SaaS [\$/yr]) / Installation cost [\$]

Table 15: Austin Courthouse Electric Utility Rate Structure

Category	Value
Fixed monthly fee ($/month)	$40.00
Energy rate ($/kWh)	$0.054
Demand rate ($/kW)	$14.64
Gas rate ($/mmBtu)	$5.06

The installation cost for the Austin Courthouse was $42,925 and based on a SaaS subscription fee of $0.10/ft^2/yr. The software has an annual subscription cost of $25,100 per year. The Terminal Annex Federal Building has a natural gas rate of $5.06/MMBtu, and the Austin Courthouse has a natural gas rate of $5.42/MMBtu.

The life cycle cost assessments for the Terminal Annex Federal Building and Austin Courthouse are provided in Table 16. The product lifetime was assumed to be 15 years, and there was no observed reduction in site staff O&M cost.

Table 16: Life Cycle Cost Assessment for Terminal Annex and Austin Courthouse

Category	Terminal Annex (~5% savings)	Austin Courthouse (~11% savings)
Building square footage	253,112	250,995
Installation cost	$37,082	$42,925
Annual subscription cost ($0.10/ft^2/yr)	$25,311	$25,100
Annual electricity consumption savings (kWh/yr)	37,299	234,122
Annual electricity demand savings (kW/yr)	428	354
Annual gas savings (MMBtu/yr)	414	1,105
Annual electricity savings, local utility rate ($/yr)	$5,247	$17,831
Annual gas savings, local utility rate ($/yr)	$2,096	$5,990
Annual energy cost savings, calculated with local utility rate ($/yr)	$7,343	$23,822
Annual cash flow ($/yr)	-$17,968	-$1,278
Simple payback, test bed	Negative	Negative
Savings-to-investment ratio, test bed	-7.268	-0.447
Annual electricity, GSA avg. blended utility ($/yr)	$4,103	$25,753
Annual gas savings, GSA avg. utility ($/yr)	$3,078	$8,212
Annual energy cost savings, GSA avg. utility ($/yr)	$7,181	$33,965
Annual cash flow ($/yr)	-$18,130	$8,866
Simple payback, GSA avg. utility	<0	4.84
Savings-to-investment ratio, GSA avg. utility	-7.33	3.10

With all factors accounted for, neither test bed location achieved the simple payback period success criteria of 5 years or less. The cost-effectiveness analysis shows that the simple payback period metric was met for the Austin Courthouse when using the GSA national average rate of $0.11/kWh, and it had a simple payback period of 4.84 years in that case. Some key factors contributing to the simple payback period objective not being met using the local utility rates are: (1) Both sites have low utility rates relative to the GSA national average rate; (2) the Terminal Annex Federal Building had a low energy use intensity and an oversized chiller plant that needed to operate 24/7, contributing to reduced savings; and (3) the installation costs for the two sites were higher than the vendor normally sees with private-sector installations, which is typically around $25,000 per building. These costs can be broken down into the following categories: hardware costs: 35%, building management system (BMS) programming costs: 30%, EMIS with ASO integration costs: 20%, and hardware installation (subcontractor): 15%.

Quantitative Objective 4: Integration Platform Functionality

The EMIS with ASO provides functionality to integrate multiple third-party data sources that support the tracking and aggregation of this information within the EMIS with ASO dashboard. The success criteria for this performance objective were the successful integration of a minimum of two third-party applications through the EMIS with ASO platform application programming interface (API) or other standard data collection protocol. A total of eight third-party applications were integrated into the EMIS with ASO platform using the following protocols:

- **Building system protocols**: Building systems protocols common to metering and building automation systems that were able to be integrated into the EMIS with ASO without modification included BACnet/IP, BACnet/MSTP, Modbus/IP, and Modbus remote terminal unit (RTU). Use of the BACnet protocols enabled integration to Tridium Niagara AX, Johnson Controls' Metasys, and Schneider Electric's EcoStruxure applications. Modbus protocols were used to integrate energy metering data from Schneider Electric's ION platform and Vata Verks clamp-on gas meters. Notably, the EMIS with ASO has the capability to integrate natively with the Tridium Niagara 4, which allowed for the integration of 15 additional sites to the SPOG. This capability reduces the cost of implementation of the EMIS with ASO and the time required to complete it. For portfolios like the GSA that have a significant percentage of sites with the Tridium Niagara 4 as their BAS application, this could enable an expedited technology deployment.
- **API integration**: The EMIS with ASO was able to integrate data from two different occupancy counting sensor manufacturers via an API connection. In the case of Density, the EMIS with ASO was able to integrate occupancy counting data in nearly real time using Density's API. In the case of the forward looking infrared (FLIR) Teledyne occupancy counting sensors, the EMIS with ASO was able to use their own API to acquire that data.

This objective was met with a total of eight third-party integrations. These integrations were successful and enabled the core capabilities of (1) occupancy counting, (2) supervisory control-related energy conservation measures, (3) peak demand predictions using machine learning, and (4) portfolio-wide dashboards. The success of these implementations and the required systems integration across multiple sites are important indications of the potential for cost-effective, broad deployment.

B. QUALITATIVE RESULTS

Qualitative Objective 5: SPOG/Portfolio View

The EMIS with ASO provides the ability to view similar data across multiple buildings using a portfolio-wide dashboard. This portfolio view of building performance across multiple properties as well as the “cockpit view” of the performance of individual building systems within a single property is defined in this report as SPOG functionality. The portfolio view can support the establishment of a regional operations center where the performance of building systems can be remotely monitored and managed. Regional operations centers have historically experienced challenges in developing custom applications to create a portfolio-wide dashboard to help optimize decision making across a portfolio of buildings. That incumbent practice is limited by the costs associated with the development of the application and the challenges associated with scaling that solution to the enterprise. The use of EMIS products, including this one, allows for the integration of different data sources into a regional dashboard at a lower cost. The SPOG dashboard can support a facility operator’s ability to more effectively monitor multiple streams of information.

Finally, because most EMIS solutions, including the EMIS with ASO product, are delivered in a SaaS format, the customer acquires the flexibility to switch to other products in the future without being locked in to already purchased proprietary solutions.

For this project, several different buildings were integrated into the EMIS with ASO, totaling more than 5.3 million square feet. These buildings took approximately 1–2 hours per site to bulk upload points, depending on metadata naming conventions with other vendor integration times. The buildings all have different levels of integration, but almost all include specific KPIs, such as temperature, occupancy, electric consumption, gas consumption, water consumption, carbon dioxide (CO_2), and other details, such as AHU startup time. Data were sourced from AMI and BAS and sometimes including submetering as well. The buildings integrated from regions 7 and 11 are shown in Table 17.

Table 17: Regions 7 and 11 EMIS with ASO Integrated Buildings (SPOG)

Building Number	Building Name	GSF
LA0035ZZ	John Minor Wisdom U.S. Court of Appeals Building	246,498
LA0085ZZ	Hale Boggs Federal Building and U.S. Courthouse	706,401
NM0030ZZ	Dennis Chavez Federal Building	365,115
NM0032SN	Santiago E. Campos U.S. Courthouse and Joseph M. Montoya Federal Building	184,423
NM0035ZZ	Joe Skeen Federal Building and U.S. Courthouse	63,625
NM0038ZZ	Gallup Federal Building	89,032
NM0042ZZ	Harold L. Runnels Federal Building and U.S. Courthouse	67,883
NM0061ZZ	Las Cruces Courthouse	231,565
OK0046CT/OK0072CT (OK0000CT)	Oklahoma City U.S. Post Office and Courthouse	758,035
OK0074ZZ	Lawton Federal Building and U.S. Courthouse	27,754
OK0101ZZ	Oklahoma City Federal Building	178,342
TX0210ZZ	Paul Brown U.S. Courthouse	34,820
TX0224ZZ	Fritz G. Lanham Federal Building	766,985
TX0284DA	Santa Fe Federal Building and Earle Cabell FOB/USPO/CTHS	1,449,689
TX0292ZZ	A. Maceo Smith Federal Building	198,403
TX0397ZZ	Austin Courthouse	250,995
TX0057ZZ	Terminal Annex Federal Building	253,112
DC0566ZZ	ATF Headquarters	422,000
MD0334ZZ	Harvey W. Wiley Federal Building	441,305

To evaluate the usefulness of the SPOG for GSA staff, qualitative success was assessed by multiple choice (1–5 Likert scale) survey questions within focus groups, which included O&M and GSA Public Buildings Service staff. The success criteria require the polling questions within the focus groups to result in a score of 3 or higher on the Likert scale. The questions focused on specific capabilities/KPIs provided by the SPOG and their deemed usefulness for O&M and Public Buildings Service staff. Examples of the roles of the survey and focus group attendees are as follows:

- Energy managers—focus on the energy consumption of the buildings within the portfolio

- Regional managers—focus on the region's performance at a high level.

Success of the portfolio view was measured by operators' opinions of the EMIS with ASO's ability to aggregate information needed to track several KPIs across two or more geographically dispersed facilities and present this information in a single view and remotely. Capability to set alerts and provide customized views of overall energy performance and occupancy data is noted. Other use cases were considered as well, depending on the type of software user. All feedback on these use cases was considered; however, regional management could have different use cases for the software compared to a building operator.

Many use cases were considered depending on job function; some examples are:

- Regional managers:
    - Portfolio use trends
    - Occupancy count and trends
    - Various other KPI viewing and performance tracking.
- Energy managers:
    - Peak demand alerts and viewing
    - Monthly energy reporting
    - Abnormal data trending.

The SPOG survey questions and average Likert scores are provided in Table 18.

Table 18: SPOG Survey—Building Responsibilities

SPOG—EMIS with ASO Responsibilities	Number of Respondents	Score
Rate the usefulness of Nantum in your day-to-day operations over current practices. (5 is best)	20	3.50
How well did Nantum help you track your KPIs, such as energy consumption, in your building and across your portfolio? (5 is best)	11	3.73
Rate the value of Nantum's ability to view historical usage trends and create monthly reports? (5 is best)	20	4.10
Rate the value of Nantum's use of real-time occupancy data to control fan speeds and set points. (5 is best)	12	4.08
Overall Likert Score		**3.87**

Results of the polling questions and focus groups showed a Likert score of 3.87, which met the required success criteria for the performance objective. Based on the survey results, 20/21 participants indicated they would continue to use the product for its SPOG capability. The primary benefits included: historical and real-time data, multiple data streams in one place, access to remote facilities, and ease of use. Following are quotes from eight respondents to the SPOG survey:

- “Helps with situational awareness and troubleshooting and scales back guesswork. Sensor data can be used to quickly track anomalies. Data can be shared with O&M to pinpoint issues, and then I can remotely track the building to see that issues are resolved.”
- “Having the data live as opposed to historical EUAS data helps us make decisions and run our buildings better, reduces our energy costs, and keeps peak demand down.”
- “I can drill down, go from macro to micro views. And it’s aesthetically pleasing, which makes the data more useful. Helps in reporting out, though to satisfy KPI, reporting would need a large subset of buildings represented.”
- “It’s much easier and quicker than accessing data in the BAS, which allows me to do more work. Previously, I would have to pull a data set from the BAS or meters, tag which buildings I’m interested in, weather-normalize the data, then make a custom graph for it.”
- “Long-term trends are much easier to see in in EMIS with ASO. Currently, only have 2 weeks of historical data in BAS, and EUAS reports are 1 month out and hard to read. GSALink is not real-time but 1-day old.”

“The ability to see what happens in a remote building in real-time is invaluable. Previously, if I wanted to see what was happening in Gallup, New Mexico, I would have to fly to Albuquerque and then drive 3 hours.”

Questions asked during the focus groups overlap with SPOG and operability, allowing the same questions to be interpreted in different ways, depending on the use case and attendee.

Qualitative Objective 6: Ease of Installation

The results for the ease of installation performance objective showed that 50% of the test bed locations met the success criteria. Success was measured quantitatively as the installation and commissioning of software to achieve full functionality within 12 weeks. Qualitative feedback relative to ease of installation was gathered though the survey, but this was not part of the performance objective’s success criteria, which is why we see so few respondents below.

For both Texas sites, the Austin Courthouse and the Terminal Annex Federal Building, the performance objective of achieving full functionality of the software within 12 weeks was met. The installation and commissioning started on November 1, 2019, and finished on February 15, 2020. This time frame does not include the holidays that occurred between November and February.

For the other two test bed locations, the performance objective success criteria were not met. Both the Harvey W. Wiley Federal Building and the ATF Headquarters exceeded the 12-week ease of installation deadline. For the Harvey W. Wiley Federal Building, the process began on March 15, 2020, and ended on June 15, 2020, for a total of 13 weeks. The installation at the ATF Headquarters started on April 22, 2020, and ended on July 30, 2020, totaling 14 weeks. Although both exceeded the performance objective success criteria, complications outside the vendor’s control, such as COVID-19, influenced the installation and commissioning timeline.

An ease of installation survey was included for more transparency within the performance objective; however, these survey results are not part of the performance objective relative to meeting or exceeding the 12-week timeline. The ease of installation survey breaks down the installation into four categories: system integration, information technology integration, cybersecurity, and contracting. Each category is split into two survey sections: the vendor's area of responsibilities and the GSA's area of responsibilities. The vendor's section consists of the Likert scale format, with options for comment, whereas the GSA's section consists of questions that require a written answer. After the surveys were completed, a Likert score was calculated based on the feedback, resulting in 3.92 (Table 19).

Table 19: Ease of Installation Survey Results

Category	Number of Questions	Number of Respondents	Results
System integration	3	2	4.67
Information technology integration	2	1	4.5
Cybersecurity	2	3	5
Contracting	4	3	3.5
Total	11		**3.92**

The following system integration, information technology integration, cybersecurity, and contracting survey questions were scored in the Likert survey and were considered part of the EMIS with ASO team's responsibilities:

System Integration Survey Questions Related to EMIS with ASO Responsibilities

- Was the scope documentation and support provided sufficient time to complete the programming of the BAS in the planned time frame?
- Once the programming was completed, did the vendor's dashboard and ramp function perform as intended?
- How did the ease of the physical installation of the hardware components (i.e., the vendor's gateway appliance and occupancy sensors) match up with expectations?

Cybersecurity Survey Questions Related to EMIS with ASO Responsibilities

- Were there aspects of the GSA information technology security assessment and authorization processes that resulted in project delays?
- Will the authorizations already have required benefit potential future implementations of Prescriptive Data's solution?
- Are there cybersecurity issues that would prevent this solution from being widely deployed at the GSA?

Information Technology Survey Questions Related to EMIS with ASO Responsibilities

- Once the GSA configured their network as requested, did the vendor's technology perform as expected?
- Did the experience gained through the initial integrations provide insight that would make future integrations more efficient?

Contracting Survey Questions Related to EMIS with ASO Responsibilities

- Was the supporting scope of work document that the vendor provided adequate to complete the contracting process?
- Did the vendor provide the required scope of work documentation in a timely manner such that there was no attributable delay to the contracting process?
- In your experience, regardless of contract vehicles, are there enough local qualified vendors who could perform the work required for installation?
- Did the amount of time required to establish the contract seem consistent with other contracts established for similar types of work?

Additional ease of installation survey questions that were associated with the GSA's responsibilities are provided in the Appendix F: Surveys.

Qualitative Objective 7: Operability

A core consideration for the successful deployment of any EMIS with ASO technology is its operability and perceived effectiveness by those who interact with it. Success was assessed by both a multiple choice (1–5 Likert scale) survey and focus groups with O&M and facility management staff requiring a Likert score of 3 or higher to meet the success criteria. The survey and focus groups assessed the potential burden of an increased effort to manage the EMIS with ASO platform relative to the potential benefit of multiple aspects, including:

- Streamlined access to required operational data
- Energy management information
- Improvements to emergency and predictive maintenance activity
- Compliance reporting
- Various other capabilities provided by the EMIS with ASO platform
- Supervisory control features of the EMIS with ASO.

Building operators and facility staff were the individuals attending the operability focus groups. Questions involved many different roles and use cases for these staff, including:

- Focus on historical trend reporting
- Continuous commissioning of equipment using data
- Value of trending with submeters
- Value of trending weekend consumption within the building.

Results of the polling questions and focus groups showed a Likert score of 3.99, which met the required success criteria for the performance objective (Table 20). Some consistent themes from the operability focus groups were that the EMIS with ASO provides a one-stop shop for all building data requirements, participants wanted kilowatt prediction to facilitate the automation of the changing of set points to save money and energy features, and the solution could be improved with enhancements to customized reporting.

Table 20: Operability Survey Likert Scores

Operability—EMIS with ASO Responsibilities	Number of Respondents	Score
Rate the usefulness of the EMIS with ASO in your day-to-day operations over current practices. (5 is best)	20	3.50
Rate the value of the EMIS with ASO's ability to show all metering and sensor data in one application. (5 is best)	23	4.17
Rate the value of the EMIS with ASO's ability to view historical usage trends and create monthly reports? (5 is best)	20	4.1
Rate the value of the EMIS with ASO's use of real-time occupancy data to control fan speeds and set points. (5 is best)	12	4.08
Rate the EMIS with ASO's user experience in comparison to other apps you might be familiar with, like Niagara, GSALink, or EUAS. (5 is best)	17	4.06
Overall Likert Score		**3.99**

Some consistent themes from the operability focus groups were: (1) The EMIS with ASO provides a one-stop shop for all building data requirements, (2) automatic control simplifies running the building, (3) staff appreciate using kilowatt prediction to set the startup time, and (4) occupancy counters to control the end-of-day ramp. Based on the survey results, 10/21 of the focus group participants would continue using supervisory control, and the responses were largely influenced by job title. Following are quotes from the survey respondents:

- "Takes the pressure off running a building. It's impossible to track 30,000 points in a building. The margin of error is small, and the scope is huge."
- "The most useful function was the end-of-day ramp. This could be done now but would need a person in the seat at the right time to manually make it happen."
- "Before using the EMIS with ASO, we were just guessing at when we should turn on our buildings to be at the proper temp. And to be on the safe side, we gave our buildings a huge buffer and started our buildings every day at the same time for the worst-case scenario. It's so much better to know that using predictive data, we will hit the temp when we need to."
- "Using occupancy data to scale back BAS was great, though I would like more granular occupancy data to be able to control floors and individual spaces."
- "COVID and mandatory work from home make it challenging to fully test using occupancy-based control. Midday ramps were ill-timed based on total occupancy of 30 people and 6 people leaving the building."
- "ROI is a sticky point, value vs. payback. I think there is real payback, but it's hard to measure."
- "Because it's real time, it can help protect equipment."

- “Would choose supervisory control but not for a building with a lab where you have very specific needs for temperature and humidity and risk ruining an experiment if it’s not right.”
- “Test new system commands at the end of the day rather than at the beginning, so if it doesn’t work, you can fix it before people are in the building.”

In addition, focus group participants were asked about the interface and the technology’s ease of use. The primary themes were: (1) The EMIS with ASO is easy to learn and access; (2) the software is dynamic, flexible, and modular; and (3) the reporting features could be enhanced. Following are quotes from six survey respondents:

- “The EMIS with ASO is easier to learn. GSALink may have more control, but one energy manager says you need a college degree to take advantage of it, those who are familiar with GSALink like the control.”
- “Easier to access than other GSA systems. Don’t need VPN, don’t get bumped off the system if you don’t use it for 30 days, mobile phone access is great.”
- “Software is dynamic and flexible. We identified something we wanted to see and were able to have it implemented the following week. The portal can easily be customized for different offices and buildings. We’ve never had that kind of flexibility before.”
- “Software is modular, so not all buildings need automated control, but all buildings could have the single pane of glass view. EMIS with ASO seems like the next natural step for building automation and management.”
- “Really liked that I could see this on my cell phone, it felt like a social media app and was easy to use.”
- “Software would be better with more customization and control.”

As noted, questions asked during the focus groups overlap with operability and SPOG, thereby allowing the same questions to be interpreted in different ways, depending on the use case and attendee.

C. ADDITIONAL CAPABILITIES

The following objective represents capabilities the EMIS with ASO could offer the GSA and what GSA believes could be of value; achievement of these objectives is not considered core to the success of this technology.

Objective 9: GSALink Compatibility

“GSA has developed a world-class Smart Buildings program leveraging technology to improve energy performance, enhance occupant well-being, increase productivity, and manage risk from climate change, public health, and cybersecurity” (GSA n.d.). The Smart Buildings program provides:

- New standards and leveraged data for design, construction, and facility management that allows interoperability, flexibility, scalability, and changing priorities.
- Superior and cost-effective workplaces for federal customer agencies and U.S. taxpayers.

A key component of the GSA Smart Buildings program is the deployment of GSALink software, which is an automated fault detection, diagnostics, and AMI analytics program that integrates AMI and BAS data that can push work orders to GSA’s computerized maintenance management system. For this performance objective, the GSALink team successfully connected GSALink to the EMIS with ASO database and transferred BAS data through the vendor's API to GSALink; thus, this performance objective was met. This validates that if a site had the EMIS with ASO installed, the GSA could use the API to facilitate the data acquisition necessary for a GSALink site.

The GSALink team estimated that integration through this method would entail a level of effort equivalent to any other non-GSALink site. This assessment is based on GSALink's experience with the level of effort required to understand and map points. The GSA team estimated that it would take up to 7 days of labor hours for new site integrations.

IV. Summary Findings and Conclusions

A. OVERALL TECHNOLOGY ASSESSMENT AT DEMONSTRATION FACILITY

The EMIS with ASO platform was demonstrated at 4 sites, and the SPOG functionality was evaluated at 19 sites. Although the operation of the EMIS with ASO was impacted by COVID-19 and the GSA implementing the ASHRAE Epidemic Task Force recommendations for HVAC systems, the supervisory control capability was successfully demonstrated at all four facilities.

Supervisory control was informed by occupancy data from thermal occupancy counters installed at the building entrances and exits, as well as weather data, which were processed/analyzed via machine learning for optimal operation. This supervisory control from the EMIS with ASO was used to determine the optimum start of the AHU fans and the midday and end-of-day ramps. The optimum start was implemented for only a short time pre-COVID-19 at the Terminal Annex Federal Building and the Austin Courthouse, and midday ramps were successfully implemented at all four facilities.

The energy savings performance objective was met with 5% whole-building savings at the Terminal Annex Federal Building, 11% whole-building savings at the Austin Courthouse, and 8% fan savings at the Harvey W. Wiley Federal Building. Savings for this project were found by comparing the baseline to the modeled results. The peak demand prediction was met with prediction accuracy ranging from 95% to 97.5%. The simple payback of 5 years was not met due to high installation costs and low local utility rates, but it could have been met at the Austin Courthouse assuming the national average GSA utility rates of $0.11/kWh vs the actual $0.082/kWh rate. A main driver of the installation cost is the labor hours needed for the BMS programming from the site's BMS vendor. For the Tridium Niagara-based BAS/BMS systems, these costs could be significantly reduced, resulting in better payback. The third-party integration objective, SPOG, ease of installation, operability, and GSALink integration objectives were all met.

The SPOG capabilities enable KPI tracking of portfolio-wide energy usage trends, occupancy counting, peak demand alerts, monthly energy reporting, and trending of abnormal data anomalies. These views were noted to be easy to use and address several real-world problems with being able to remotely address building energy usage and operational problems. Given the timing of this project during the COVID-19 pandemic, the occupancy counting tied to supervisory controls allows for a more informed and intelligent return-to-work strategy for the GSA and other federal agencies. In addition, although this was not evaluated as part of this project, this occupancy counting technology could be used to determine occupancy rates in the future.

B. LESSONS LEARNED AND BEST PRACTICES

Several valuable best practices were identified throughout this project:

- **System integration**: Two different contracting mechanisms were used for system installation—a task order through an O&M contractor for the Region 11 sites and an indefinite delivery and indefinite quantity contract with an existing contractor for the Region 7 sites. From this process, the GSA recommends using a contracting approach that can accomplish cabling installation, BAS integration, and any required electrical work under one contracting vehicle, such as an indefinite delivery and indefinite quantity contract. It is important to identify within the performance work statement the skills and expertise needed to effectively install the EMIS with ASO and in a timely manner.
- **GSA information technology**: During this process, the GSA implemented firewall changes that can be applied to future projects. The GSA's Power-over-Ethernet switches needed to be installed as part of the integration and should be included in future installations where an on-site gateway is installed.
- **Site selection**: Each GSA building is unique, and a detailed assessment of the building characteristics—including an analysis of end use loads that cannot be controlled by the EMIS with ASO or that could negatively impact energy savings—should be characterized and understood up front. The GSA offers the following best-practice deployment recommendations:
  - Prioritize GSA office and courthouse buildings that meet the 5% annual cost savings screening (approximately 90 facilities) with high energy use intensity (typically >75 kBtu/ft^2) and high energy cost (typically >\$3/ft^2/yr).
  - Consider EMIS with ASO deployment at GSA federal office buildings and courthouses that are on the GSA network and use an open protocol such as BACnet for their BAS. These buildings have gone through GSA cybersecurity protocols and enable both lower installed costs and shorter installation times.
- **GSA site staffing**: EMIS solutions that include supervisory control typically encounter issues with building operators not being open to turn over control of the facility to a third-party software tool. This happens in both the private and federal sectors. For future installations, the GSA recommends meeting with GSA facility staff to ensure that there is a site champion who can lead the project and that BAS operators are willing to turn over operation of AHUs to the EMIS with ASO. As part of this process, site staff should receive adequate training to operate the software, and an accountability mechanism should be created to facilitate the EMIS with ASO use to its fullest capabilities.

The primary lesson learned was related to the additional considerations of effects on startup peak demand in generating optimal start times for the Terminal Annex Federal Building. The current optimum start algorithm has a primary objective of minimizing the electricity consumption of the building. A potential improvement to the startup algorithm is to account for both electricity consumption and demand.

C. DEPLOYMENT RECOMMENDATIONS

EMIS with ASO Supervisory Control Deployment Recommendations

A market analysis was conducted for the GSA's 504 federally owned facilities currently included in GSA's goals for energy use intensity reduction, on-site renewable energy production, and other agency-level or federal mandates to help frame the deployment potential of the EMIS with ASO solution for direct supervisory control. Within the GSA, these facilities fall under one of the following designations:

- A: federally owned building, subject to energy measure
- I: federally owned building, energy intensive, subject to measure.

The total square footage for the 504 buildings is 173,759,009 ft^2, with a combined total annual utility cost of $255,542,143 (electricity, steam, natural gas, chilled water, other). The portfolio-wide market analysis was conducted with the following assumptions:

- Whole-building energy cost savings: 5%, 7.5%, 10%, and 12.5%
- SaaS fee: $0.10/ft^2/yr
- GSA blended utility rates, converted to $/Btu for each facility
- Due to varying installation and integration costs, these details were not included in simple payback calculations. The market analysis takes the difference of the SaaS fee and the whole-building energy savings.

A sensitivity analysis was conducted on the whole-building energy cost savings, with assumed savings ranging from 5% to 12.5%, based on the whole-building cost savings from the two Texas sites, 5% for the Terminal Annex Federal Building and 11% for the Austin Courthouse.

Site-specific installation costs will change depending on the size of the building, the number of AMI meters, the number of occupancy-counting sensors, and the number of BAS points integrated into the system. Because this information was not known for each building, installation costs and simple payback were not included in the analysis.

The analysis was conducted for all 11 GSA regions and is shown in Table 21 as rolled up into the total for the GSA. Utility cost per square foot can be compared to different whole-building energy cost savings assumptions of 5%, 7.5%, 10%, and 12.5 to show the breakeven point. The number of positive cash flow facilities under each whole-building energy cost savings scenario is also shown in Table 21.

Table 21: Market Analysis of 504 GSA Federally Owned Buildings

Category	Assumed 5% Annual Cost Savings	Assumed 7.5% Annual Cost Savings	Assumed 10% Annual Cost Savings	Assumed 12.5% Annual Cost Savings
Number of positive cash flow facilities (of 504)	**90**	**223**	**322**	**424**
Total building area (GSF)	30,488,470	77,028,119	106,211,953	139,233,885
Gross annual cost savings pre-SaaS ($/yr)	$4,538,021	$12,467,287	$19,949,064	$28,689,424
Net annual cost savings after SaaS ($/yr)	**$1,489,174**	**$4,764,475**	**$9,327,869**	**$14,766,035**
Annual subscription cost ($0.10/GSF/yr)	$3,048,847	$7,702,812	$10,621,195	$13,923,389

Table 21 indicates that when equipment, installation, and integration costs are excluded, there are 90 buildings where energy cost savings could exceed SaaS fees with 5% annual cost savings and 424 buildings where energy cost savings could exceed SaaS fees with 12.5% annual cost savings. Of 504 buildings, only 80 had SaaS fees that exceeded annual energy cost savings with 12.5% annual savings. Future deployments of the EMIS with ASO in the GSA portfolio would focus on existing facilities with the following characteristics:

- GSA office and courthouse buildings that could meet the 5% annual cost savings screening (approximately 90 facilities) with high energy use intensity (typically >75 kBtu/ft^2) and high energy cost (typically >$3/ft^2/yr) should be prioritized.
- GSA office and courthouse buildings that are on the GSA network and use an open protocol such as BACnet for their BAS should be considered candidates for EMIS with ASO deployment. These buildings have gone through GSA cybersecurity protocols and enable both lower installed costs and shorter installation times.
- GSA buildings that have been recommissioned in the last 4 years and have no major operational issues should be prioritized. If a facility has too many HVAC control problems prior to the implementation of the EMIS with ASO, this will negatively impact the operation of the EMIS with ASO and should be fixed prior to installation.
- GSA facilities that have more advanced smart building technologies—such as automated lighting controls, plug load controls, and on-site batteries—that can all tie into and benefit from the EMIS with ASO should be targeted.
- GSA buildings with large energy loads, such as data centers and laboratories, should be evaluated on a case-by-case basis because these buildings will likely have large sections that are not able to be controlled by the EMIS with ASO.

EMIS with ASO SPOG Deployment Recommendations

Having a portfolio-wide dashboard improves regional energy management for the GSA's nine regions where the performance of building systems can be remotely monitored and managed. SPOG allows the GSA portfolio and facility managers to view key metrics on energy consumption, indoor air quality, and occupancy across all the connected buildings. When viewing KPIs, such as energy consumption or occupancy, from a regional level, trends can be found. Depending on the task or occupation, SPOG can provide better visibility into the portfolio as a whole, so SPOG functionality is recommended, depending on the use case.

At a high level, the deployment of a portfolio-wide dashboard should focus on buildings with AMI and BAS infrastructure that meet the following requirements. If occupancy data are available, it is helpful but not required to deploy the dashboard. Per these recommendations, the GSA's federally owned facilities that are subject to federal mandates and energy use intensity reductions should be targeted first.

- AMI data (electricity, gas, steam, water):
  - Buildings with meters already integrated into the BAS network can be connected to the EMIS with ASO without the need for additional hardware, leading to quicker integration.
  - For buildings where meter data are not available via the BAS network, prioritize buildings with meters that can transmit data via BACnet, Modbus, or pulse output.
  - Data validation and meter commissioning are key to ensuring that SPOG data are trustworthy, reliable, and actionable.
- BMS data:
  - EMIS with ASO can integrate with the Tridium Niagara and Schneider Electric EcoStruxure systems without any additional hardware.
  - BAS data are easy to bring into the EMIS with ASO given that the building is on the GSA's network, is using the GSA's standard naming conventions, and no remapping is needed.
  - Verify that any additional data points—such as CO_2, interior space temperature, and humidity—are available via the BMS. These can be displayed on the SPOG to give portfolio managers metrics on the indoor air quality and thermal comfort inside their buildings.
- Occupancy:
  - Occupancy data collected via Wi-Fi scrubbing with 33 access points is a lower cost and hardware-free option for buildings interested in tracking occupancy.
  - If WiFi access point-based occupancy data are not an option, look to buildings with security or turnstile systems that support occupancy counting.
  - If occupancy sensors will be used, prioritize buildings with controlled entrance and exit points because this means whole-building occupancy can be accurately captured with fewer sensors.

V. Appendices

A. SITE SELECTION REQUIREMENTS

The following site selection requirements were developed with input from the U.S. General Services Administration (GSA) and the vendor and were used by the GSA and Lawrence Berkeley National Laboratory to recruit and select four test bed locations (Table 22). Note that site selection and contracting for the technology installation happened before NREL was involved with the project.

Table 22: Site Selection Requirements

System	Required Characteristics	Preferred Characteristics
Facility type	Medium to large building with AHUs, a central chilled water plant for cooling, a central heating plant for heating, and a modern building automation system	Office building
Size	>100,000 ft^2	Midsize to larger facility (100,000 or more ft^2)
Location		Region with high energy costs or local utility rebate incentives (or both) that offset costs
Occupancy	Several hundred occupants or more per building	Stable occupancy, operations, and internal loads during 12 months prior to pilot start (to develop measurement and verification baseline). To maximize savings potential, there would be an expectation of reduced occupancy during lunch periods and nighttime.
Site engagement	Facility staff will take training and operate the EMIS with ASO daily.	Communication with occupants if occupancy sensors are installed. Facility staff are committed to using the system for O&M improvement beyond the start/stop optimization capabilities.
Whole-building energy data	Monthly whole-building gas use, electric use, and peak demand. Interval whole-building electricity usage data (hourly or subhourly)	Interval whole-building gas data, water usage
Submetered electricity data		Submetering at the panel level to disaggregate HVAC, lighting, and plug load energy consumption
Historical electricity data	Historical baseline electrical (interval) and gas (monthly) data for 12 months	Historical baseline electrical (interval) and gas (monthly) data for 36 months
HVAC operational data		Trend logs of zone temperatures and key operational points to evaluate start/stop and demand response effectiveness and system response—e.g., verification of control outcomes
Control system	BACnet based. Site needs to have internet tied directly to the BMS server or site should be able to provide Prescriptive Data with internet access to BOS gateway. Resets implemented for unoccupied periods.	BAS with direct digital controls addressable with BACnet protocol. Control sequence of operations: HVAC system has programmed start/stop scheduling sequence (also an application for multiple buildings).
HVAC	HVAC system has direct digital control to the zone level.	Built-up HVAC systems are in good working condition and are equipped with VFDs to allow for variable air and water flow. No existing design issues, such as insufficient capacity for the building load. Further, ideal HVAC specs include

System	Required Characteristics	Preferred Characteristics
		floor-by-floor AHUs with VFDs, chilled water systems, VFDs on pumps, and a BMS that is BACnet compatible.
Documentation	Full documentation of as-built drawings, including equipment schedules, electrical and mechanical riser diagrams, and records/logs of occupant trouble calls. Good documentation of control systems, e.g., control drawings, control sequences, set points, and occupancy schedules.	

Table 23: Terminal Annex Federal Building Energy Model Inputs

Building Component	Baseline Building Design	Location	Comments
Weather file	AMY 2019 weather file for Dallas Love Field	www.whiteboxtechnologies.com	
Space use classification	Large office building	N/A	
Roofs	Type: Built up roof,	DOE prototype building—2004	https://www.energycodes.gov/development/commercial/prototype_models
	Roof membrane + roof insulation + metal decking		
	Gross area: 44,028 ft^2	DOE prototype building—2004	https://www.energycodes.gov/development/commercial/prototype_models
	U-factor: 0.070		
	Solar absorptance: 0.75		
	Emittance: 0.90		
Walls, above grade	Type: Steel frame walls (2 x 4 16 in. OC)	DOE prototype building—2004	https://www.energycodes.gov/development/commercial/prototype_models
	0.4-in. stucco + 5/8-in. gypsum board + wall insulation + 5/8 in.		
	Gross area: 68,724 ft^2	DOE prototype building—2004	https://www.energycodes.gov/development/commercial/prototype_models
	U-factor: 0.125		
	Solar absorptance: 0.75		
	Emittance: 0.90		
Walls, below grade	Type: Mass wall	DOE prototype building—2004	https://www.energycodes.gov/development/commercial/prototype_models
	Gross area: 8,485 ft^2		
	U-factor: 0.125		
Vertical fenestration other than opaque doors	Area: 14,077 ft^2	Section and elevation drawings	
	North: 19%		
	East: 18%		
	South: 18%		

Building Component	Baseline Building Design	Location	Comments
	West: 18%		
	Building average: 18%		
	Assembly U-factor: 0.57	DOE prototype building—2004	https://www.energycodes.gov/development/commercial/prototype_models
	SHGC: 0.25		
	External shading and projection factor: None		

Table 24: Additional Terminal Annex Federal Building Energy Model Inputs

Building Component	Baseline Building Design	Data Source
Lighting, interior	0.82 W/ft^2 office spaces 1.30 W/ft^2 mechanical/electrical rooms 0.85 W/ft^2 information technology rooms	ASHRAE 90.1-2010 user's manual as default, electrical drawings when applicable
Internal gains	1.0 W/ ft^2 office spaces	ASHRAE 90.1-2010 user's manual as default, electrical drawings when applicable
Schedules	90.1-2010 user's manual schedules for office	N/A
Cooling systems	Primary cooling system: RTUs with chilled water cooling (1) 300-ton, (2) 500-ton chillers with cooling tower	Mechanical drawings, SOO
Heating systems	Primary heating system: RTUs with hot water heating and hot water reheat(2) 2,500-MBH natural gas boiler plants	Mechanical drawings, SOO
Service water heating	N/A	N/A

The heating system model inputs and set points were modeled to match the mechanical system drawings and the BAS controls, as outlined in Table 25.

Table 25: Heating System Model Inputs

Hot Water System Component	Value
Hot water boiler	2,000 MMBtu/hr (heating capacity)
Boiler efficiency	80% to calibrating for gas usage to be 70% of all year energy use
Hot water pump	15 HP, 150 GPM
Hot water set point	180°F
Hot water coil Delta T	30°F
Hot water reset	Based on outside air 125°F–80°F/turn off when outside weather is <60°F. Boiler available when outside air <60°F.

The AHU control sequence and set points were modeled to match the BAS controls, as outlined in Table 26.

Table 26: Heating Control Set Points

Heating Control Set Points	Value
Supply air temp. set point heating	50°F minimum heating, 69°F Maximum heating
Supply air temp. set point cooling	Fixed 52°F cooling
Supply air static pressure	0.25 in. w.c. minimum, 1.5 in. w.c. maximum
Minimum outdoor air cfm	10%
Minimum supply fan VFD speed	5%
Minimum return fan VFD speed	5%
Economizer dew point limit	55°F
Economizer dry-bulb limit	75°F
Economizer lockout	40°F
Minimum supply air fraction	5%
Unoccupied space temp. set point	80°F cooling–60°F heating
Occupied space temp. set point	74°F cooling–68°F heating (from BAS screenshots)

The zone cooling set point temperature is 72°F occupied and 80°F unoccupied with a supply air set point of 52°F and no reset. The supply air set point in heating mode is 69°F and 50°F unoccupied with no outside reset.

The AHU supply and return fan motor horsepower (Hp) and flow rates (cfm) were taken from mechanical schedules. The cooling and heating coil capacity (tons) and temperature differential (Delta T) were automatically sized in EnergyPlus® (Table 27).

Table 27: Terminal Annex AHU Model Assumptions

AHU	Return Fan Motor (Hp)	Return Fan Flow (cfm)	Cooling Coil Capacity (Tons)	Cooling Coil DT Flow Rate	Heating Coil Capacity (Tons)	Heating Coil Delta T	Supply Fan Motor (Hp)	Supply Fan Flow (cfm)
AHU 10	10	14,380	Auto size	Auto size	Auto size	Auto size	20	14,380
AHU 11	15	42,000	Auto size	Auto size	Auto size	Auto size	50	42,000
AHU 22	10	18,040	Auto size	Auto size	Auto size	Auto size	25	18,040
AHU 31	10	18,040	Auto size	Auto size	Auto size	Auto size	25	18,040
AHU 32	10	15,100	Auto size	Auto size	Auto size	Auto size	25	15,100
AHU 41	10	15,100	Auto size	Auto size	Auto size	Auto size	25	15,100
AHU 42	10	18,800	Auto size	Auto size	Auto size	Auto size	25	18,800
AHU 51	10	18,040	Auto size	Auto size	Auto size	Auto size	25	18,040
AHU 52	10	18,040	Auto size	Auto size	Auto size	Auto size	25	18,040
AHU 61			26	Auto size	Auto size	Auto size	7.5	9,000
AHU 62			17	Auto size	Auto size	Auto size	5	6,000
AHU 63			40	Auto size	Auto size	Auto size	10	14,000

Given that the supervisory control for the EMIS with ASO is for AHU fans, a significant portion of the modeling effort focused on developing the most accurate fan performance model possible. Time-series data for each AHU and air terminal unit (ATU) were used to develop the fan performance curves.

For the Terminal Annex Federal Building, most ATUs are parallel-powered induction fan VAV boxes. A parallel-powered induction terminal unit comprises three components: a constant volume fan; a zone mixer; and a heating coil, typically hot water, electric, or gas (Figure 23).

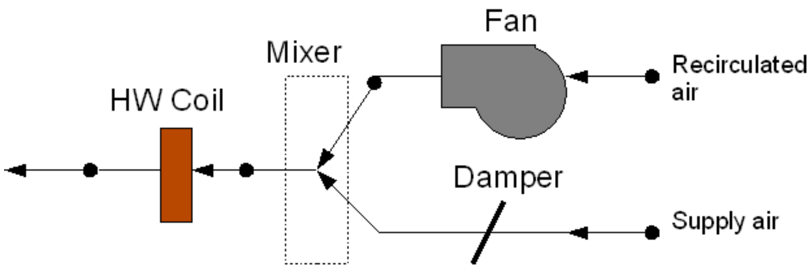


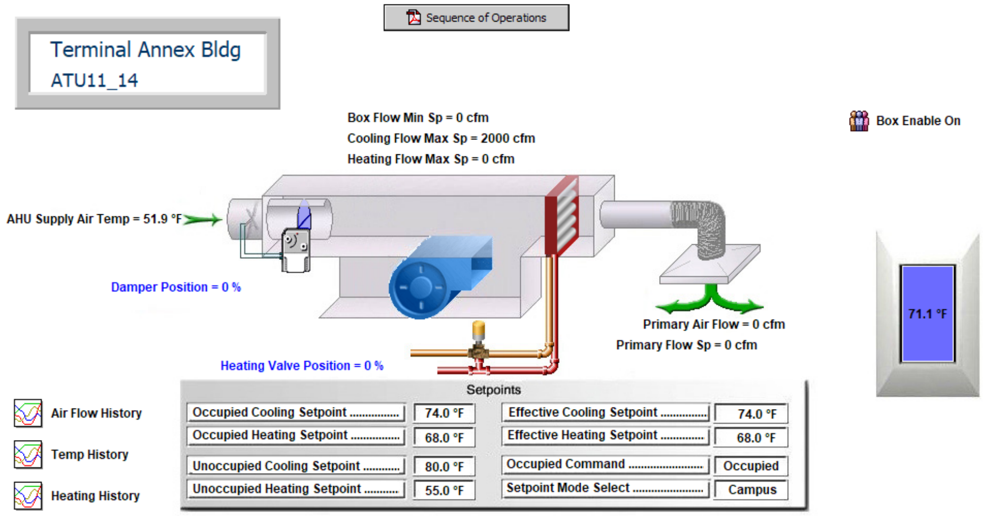
Figure 23: Parallel-powered induction ATU (DOE 2022, 1204)

“The parallel-powered induction unit is an air system terminal unit that mixes varying amounts of secondary (recirculated) air and primary (conditioned supply) air to produce a variable total flow of air to a zone. The unit contains a small fan that acts to induce the secondary air and a heating coil for heating the mixed secondary and primary air. The secondary and primary airstreams enter the unit in parallel. The fan sits in the secondary airstream and runs only when the primary airflow is below the Fan On Flow Fraction and the fan’s availability schedule is on or is activated by an availability manager. The primary air inlet contains a damper that can move from fully open (maximum primary air) to a minimum stop (minimum primary air).

At full cooling load, the primary air damper is fully open, and the fan is off. The primary airflow is at maximum, and there is little or no secondary airflow. As the cooling load decreases, the primary air damper gradually closes, and the secondary airflow remains near zero. At some point, usually when the primary airflow has reached the minimum, the fan switches on, and secondary air is induced.

The heating coil will switch on as needed to meet any heating demand. The Fan On Flow Fraction field controls the fan operation” (DOE 2022, 1203–1204).

The AHUs at the Terminal Annex Federal Building do not have flow stations, but the ATUs do have a flow measurement that allowed for the comparison of VFD speed or fan percentage to the sum of the airflow. The ATUs do not have a fan command or status point, and the flow rate was omitted anytime there was heating.



Box Flow Min Sp = 0 cfm
Cooling Flow Max Sp = 2000 cfm
Heating Flow Max Sp = 0 cfm
AHU Supply Air Temp = 51.9 °F
Damper Position = 0 %
Primary Air Flow = 0 cfm
Primary Flow Sp = 0 cfm
Heating Valve Position = 0 %

Occupied Cooling Setpoint .... 74.0 °F
Occupied Heating Setpoint .... 68.0 °F
Unoccupied Cooling Setpoint .... 80.0 °F
Unoccupied Heating Setpoint .... 55.0 °F
Effective Cooling Setpoint .... 74.0 °F
Effective Heating Setpoint .... 68.0 °F
Occupied Command .... Occupied
Setpoint Mode Select .... Campus

Figure 24: Example ATU for the Terminal Annex Federal Building. *Image from Joshua Banis, GSA.*

Data were collected from 3/1/20–3/21/20 and 8/1/20–8/21/20 from the EMIS with ASO, and data were trended on 15-minute intervals. BAS points that were collected through the EMIS with ASO are outlined as follows:

- AHU BAS points:
    - Discharge air temperature
    - Discharge air temperature set point
    - Discharge air pressure
    - Discharge air pressure set point
    - Discharge fan VFD speed (%)
    - Return fan VFD speed (%)
    - Outdoor air temperature
    - Outdoor air wet-bulb temperature.
- ATU BAS points:
    - Airflow
    - Damper position (%)
    - Hot water heating valve (%).

The BAS trend data were used to create two fan curves: one for the baseline operation with no AHU static pressure reset and one that includes a static pressure reset based on the supervisory controls that the EMIS with ASO sends to the BAS. Airflow rate data were summed for all ATUs serving a single AHU. The total cubic feet per minute was increased by 15 to account for duct leakage from the AHU to the ATUs. The 15% duct leakage assumption comes from the limit for the ductwork testing according to the guidelines from the Sheet Metal and Air Conditioning Contractors' National Association.

Based on the sequence of operations for the building, if the parallel-powered induction ATU box fan is on, (for example, when the hot water valve is open), these data are not used in the regression. All times when the fan static set point or fan speed showed zero value were removed from the data set.

The ATU total flow rate data were then correlated with the AHU VFD speed feedback data from the drive, defined here as the assumed fan kilowatt design ratio specification from VFD manufacturer ABB. This builds the fan curve for each AHU system. This was done multiple times with the sum of the flow, the sum of the flow +15%, the sum of the flow without hot water valve numbers, and the sum of the flow without hot water valve numbers +15%. This resulted in very similar fan curves and was done for data from March and August (pre-COVID-19 and post-COVID-19; summer max cooling load). At the end of this step, the data set describes the relationship between the fan power and the fan flow rate.

The performance curves of the AHU 41 supply fan (SA) and return fan (RA) are chosen to be set as the typical fan performance curves of the ATU control type AHU given they had the cleanest data set. The measured fan speed versus supply airflow rate is provided in Figure 25.

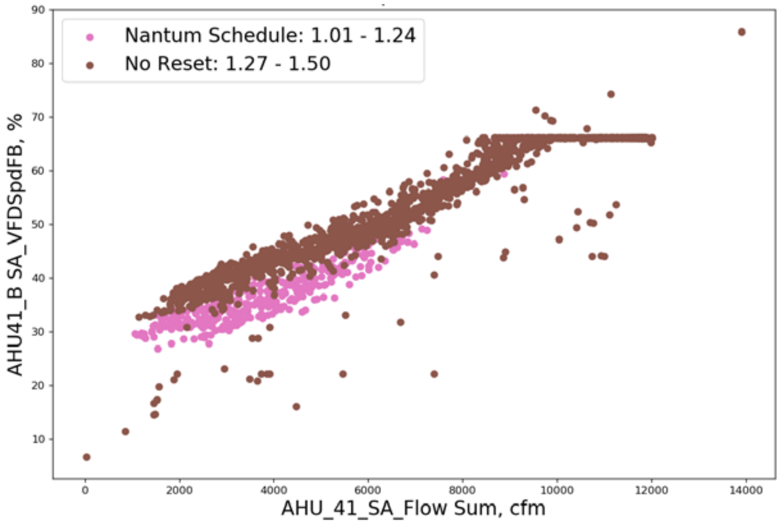


Figure 25: Terminal Annex Federal Building AHU 41 measured fan speed part-load ratio versus supply airflow

The calculated fan power part-load ratio versus fan flow rate part-load ratio is shown in Figure 26 using the regression technique from the normalized measured power and fan flow rate.

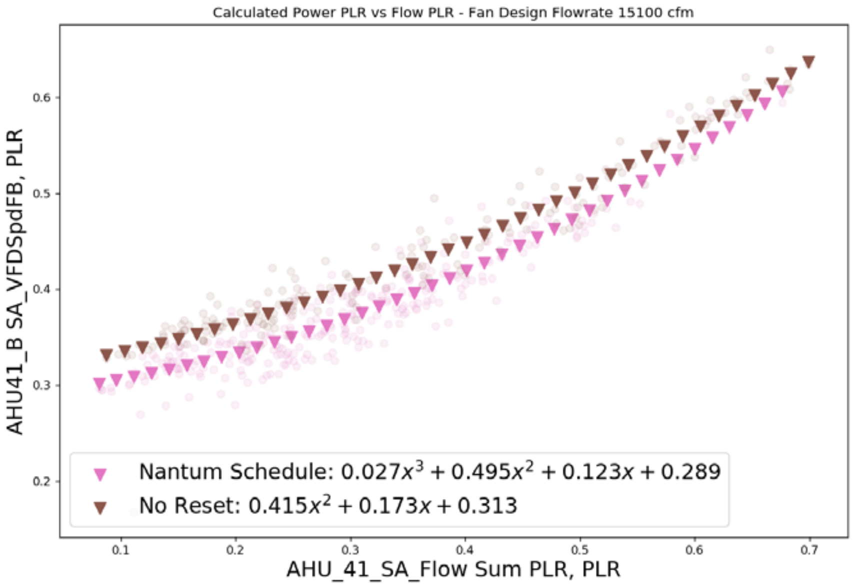


Figure 26: Terminal Annex Federal Building AHU 41 calculated fan power part-load ratio versus flow rate part-load ratio

Cooling System Model Inputs

The cooling system energy model inputs and set points were modeled to match the BAS controls, as outlined in Table 28.

Table 28: Terminal Annex Federal Building Cooling System Components

Cooling System Component	Value
Chiller capacity:	Chiller 1: 300 tons Chiller 2: 500 tons Chiller 3: 500 tons
Chiller efficiency:	York YT has a COP of 6.4 with VSD
Primary chilled water pumps	PCWP 1 10 HP, 720 GPM PCWP 2 15 HP, 1,200 GPM PCWP 3 15 HP, 1,200 GPM Constant volume without VFD
Secondary chilled water pumps	SCHWP 60 HP x 2 pumps total GPM 2400 VFD with 2-way control valve at AHU
Condenser pump	Auto size
Condenser loop	3,900 GPM
Cooling tower	2 cells with 7°F Delta T
Chilled water supply temp. set	45°F (no reset)

There are two small data centers in the facility, the Equal Employment Opportunity Commission and the Military Entrance Processing Station, and the site runs the 300-ton chiller 24/7 to meet this load. There is no outside air control that will turn off the chillers below a certain temperature; and at outside air temperatures above 60°F, the larger chillers are enabled to turn on based on the building's cooling demand.

The standard chiller energy model was used with the default cooling capacity function of temperature curve, the electric input to cooling output ratio function of temperature, and the electric input to cooling output ratio function of part-load ratio. Both the cooling capacity function of temperature curve and the electric input to cooling output ratio function of temperature formulas have a condensing return temperature as input. For chiller centrifugal type, the COP value is highly dependent on condensing temperature (OA WB), especially with VSD control, as in the Terminal Annex Federal Building. The chiller performance curve source was given in Table 29 from the EnergyPlus chiller data set (GitHub n.d.).

Table 29: Terminal Annex Federal Building Chiller Performance Curve

Chiller Capacity (Tons)	Chiller No.	Performance Curve Source
300	1	ElectricEIRChiller York YT 1090kW/7.57COP/VSD
500	2/3	ElectricEIRChiller York YT 1794kW/7.90COP/VSD

The typical chiller plant efficiency at various loads and outdoor wet-bulb temperatures for both constant and variable-speed chiller plants is shown in Figure 27.

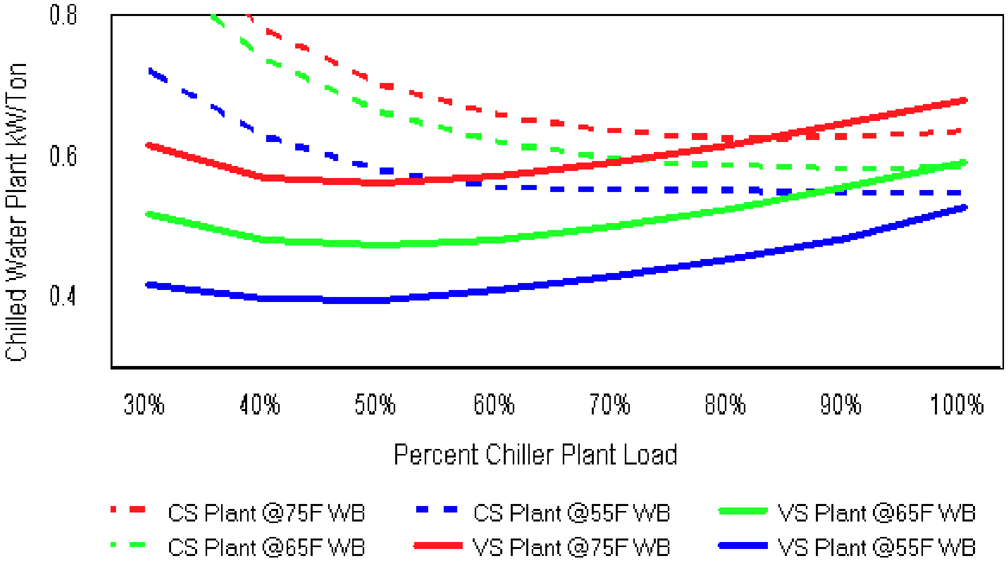


Figure 27: Chiller energy model part-load curves

Terminal Annex Federal Building Energy Model Calibration

The baseline energy model for the Terminal Annex Federal Building was then calibrated to meet ASHRAE's Guideline 14-2014, *Measurement of Energy, Demand and Water Savings*, requirements for monthly and hourly RMSE and NMBE (ASHRAE 2014). Given that the models were created during COVID-19 and that an on-site energy audit was not conducted to collect all energy model input parameters, certain input parameters that were unknown were iteratively changed. During the calibration process, known input parameters—such as building size; orientation; and HVAC mechanical design, including HVAC set points, control sequences, and schedules—were modeled to match actual building operation unknown input parameters. Mechanical systems (chiller plant, boiler plant, AHUs) were modeled based on building drawings. The sequence of operation (SOO) of the HVAC system was modeled based on BAS data, and the SOO was verified with site O&M—details of all set points and sequences. Unknown variables—such as the operational schedules for occupancy, lighting, plug loads, and domestic hot water—were varied within a reasonable range. The lighting power density and plug load density values provided in Table 30 were modified using the calibration parameters shown in Table 30.

Table 30: Terminal Annex Federal Building Lighting and Plug Load Calibration Multipliers

Calibration Parameters	Minimum Value	Maximum Value	Calibration Value
Office lighting multiplier	0.3	1	0.6
Office plug load multiplier	0.3	1	0.6

Lighting and plug load schedules were iteratively changed on an hourly basis to calibrate electricity usage to hourly data. Figure 28 shows the lighting schedule used for the week of June 8, 2019.

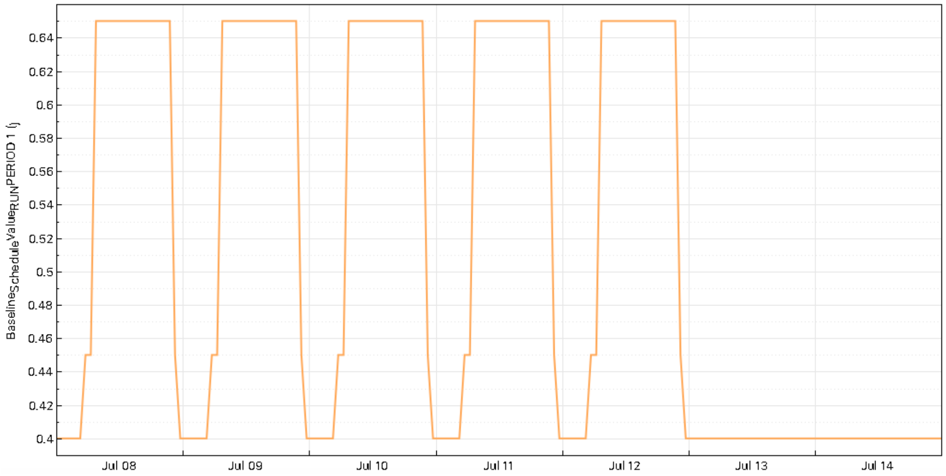


Figure 28: Terminal Annex Federal Building lighting schedule for June 8–14, 2019

Based on AMI hourly data and BAS data, the Terminal Annex Federal Building has a relatively high average energy use (50%–70%) during nighttime compared with peak daytime and a low chiller utilization rate (lower than minimum capacity, which results in a low part-load ratio of one chiller that wastes energy and reduces the EMIS with ASO chiller savings potential).

The modeled baseline building energy use intensity was 40.11 kBtu/ft^2, with an annual energy cost of $175,944. A breakdown of annual energy use by end use is provided in Figure 29.

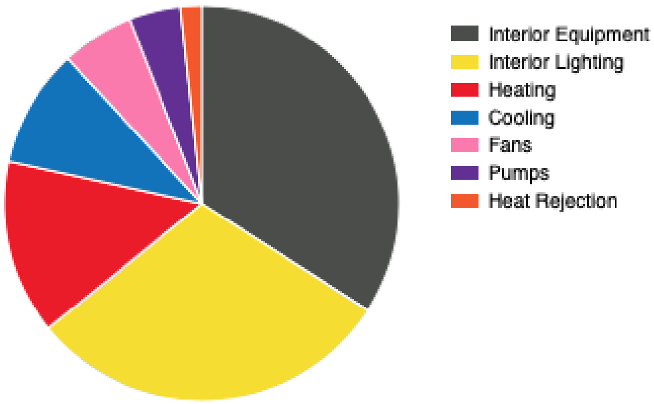
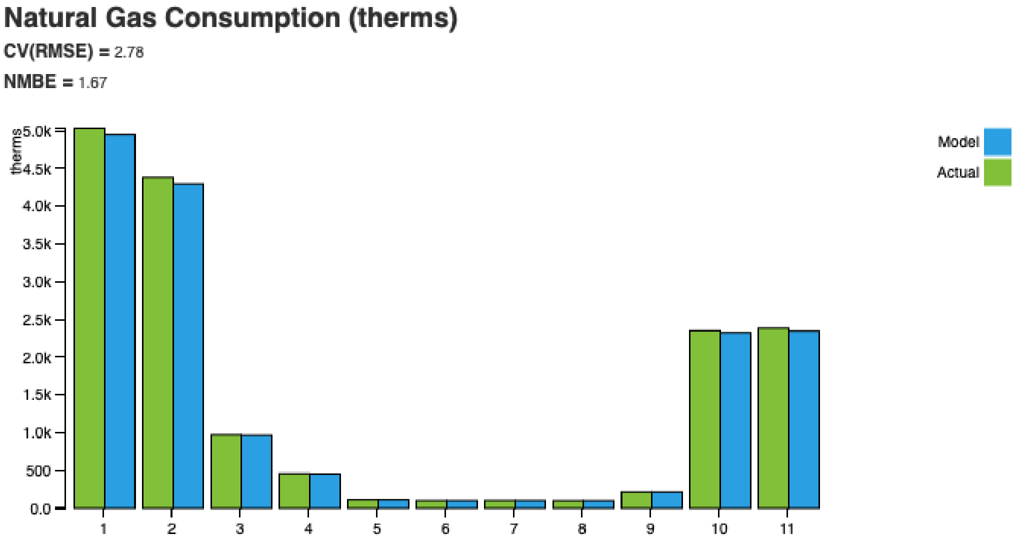


Figure 29: Terminal Annex Federal Building annual energy end use breakdown

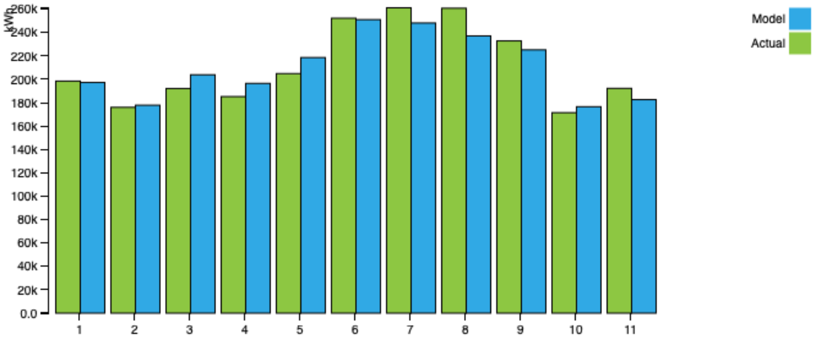
The monthly gas usage was calibrated at 2.78 CV (RSME) and at 1.67 NBME, as shown in Figure 30. The parameters used in the calibration are that the furnace efficiency was reduced from its 80% nameplate efficiency, and "other gas usage" was taken from the audit report, which takes 30% of annual natural gas consumption.



	1	2	3	4	5	6	7	8	9	10	11
Start	1/16	2/15	3/16	4/13	5/14	6/13	7/13	8/14	9/17	10/16	11/15
End	2/14	3/15	4/12	5/13	6/12	7/12	8/13	9/16	10/15	11/14	12/13
Actual	5,034.72	4,381.92	971.04	457.98	109.14	98.94	99.96	97.92	215.22	2,353.14	2,384.76
Model	4,951.43	4,294.83	965.53	453.72	109.13	98.93	99.95	97.91	214.81	2,325.81	2,347.09
NMBE	-1.65%	-1.99%	-0.57%	-0.93%	-0.01%	-0.01%	-0.01%	-0.01%	-0.19%	-1.16%	-1.58%

Figure 30: Terminal Annex Federal Building monthly natural gas calibration

The monthly electricity usage was calibrated to a CV (RMSE) of 5.52 (less than the 15 required by ASHRAE Guideline 14-2014) and an NMBE of 0.6 (less than the 5 required by ASHRAE Guideline 14-2014); see Figure 31.



	1	2	3	4	5	6	7	8	9	10	11
Start	1/18	2/20	3/21	4/22	5/21	6/20	7/22	8/21	9/20	10/22	11/20
End	2/19	3/20	4/21	5/20	6/19	7/21	8/20	9/19	10/21	11/19	12/19
Actual	198,461	176,017	192,122	185,214	204,887	252,245	261,154	260,767	232,839	171,474	192,257
Model	197,291.12	177,848.33	203,883.98	196,494.65	218,605.56	251,045.29	248,152.78	237,117.46	225,205.19	176,564.27	182,626.32
NMBE	-0.59%	1.04%	6.12%	6.09%	6.7%	-0.48%	-4.98%	-9.07%	-3.28%	2.97%	-5.01%

Figure 31: Terminal Annex Federal Building monthly electricity usage calibration

The hourly electricity usage was calibrated to a CV (RMSE) of 18.4 (less than the 30 required by ASHRAE Guideline 14-2014) and an NMBE of 0.4 (less than the 10 required by ASHRAE Guideline 14-2014 for hourly calibrations). A sample comparison of modeled versus measured energy usage for the week of August 17 is provided in Figure 32, with the modeled hourly electricity usage shown in orange, and the measured hourly electricity usage from 2019 AMI data shown in blue.

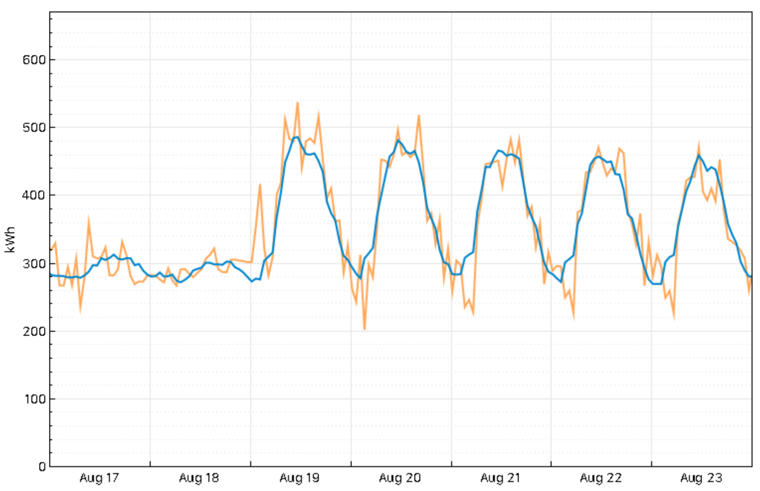


Figure 32: Terminal Annex Federal Building hourly electricity usage calibration August 12–23, 2019

Terminal Annex Federal EMIS with ASO Supervisory Control Modeling Procedures

Given that the EMIS with ASO supervisory controls for optimum start were implemented for only a short time prior to the GSA issuing COVID-19 changes to HVAC operation, the time of day when the optimum start would have been initiated for each AHU was modeled.

The EMIS with ASO provider used its internal model to determine when each AHU should be started to meet the desired zone temperature set point based on the 2021 building occupancy profile, historic weather data from 2019, and BAS trend log data from 2019. This included zone temperature readings and zone temperature set points.

For the Terminal Annex Federal Building, the baseline occupied set point schedule for each AHU is provided as follows. With this sequence, AHUs are started at the designated occupied set point time and run intermittently, as needed, during unoccupied hours to meet the unoccupied space set point temperature:

- AHU 10: 2:30 a.m.–6 p.m. Monday–Friday, 6 a.m.–1 p.m. Saturday
- AHU 11: 2:00 a.m.–6 p.m. Monday, 3 a.m.–6 p.m. Tuesday–Friday, 5 a.m.–1 p.m. Saturday
- AHU 22/31/32: 6:00 a.m.–6 p.m. Monday–Friday
- AHU 41/42: 1:00 a.m.–8:30 p.m. Monday, 2 a.m.–8:30 p.m. Tuesday–Friday
- AHU 51/52: 4:30 a.m.–10:30 p.m. Monday–Friday, 6 a.m.–1 p.m. Saturday
- AHU 61/62/63: 6 a.m.–6 p.m. Monday–Friday

Given the baseline set points, that the AHU schedule did not use an optimum start, and that AHUs were started on a simple schedule, the occupied set point time needed to be adjusted to apply an optimum start and to ensure that the space temperature was at the desired level by the occupied start time. A new AHU schedule with new target occupied space temperature times and end-of-day ramp times is provided in Table 31.

Table 31: Terminal Annex Federal Building AHU EMIS with ASO Optimum Start Schedule

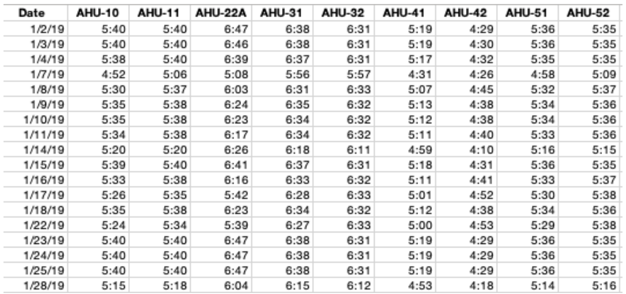
AHU Number	Target Comfort Time	EMIS with ASO Optimum Start Time	Lunch Ramp Down	Lunch Ramp Up	End-of-Day Ramp Down	End of Occupied Set Point	Note
AHU 10	6:00:00 a.m.	AHU 10 Nantum schedule	Nantum schedule	Nantum schedule	Nantum Schedule	6:00:00 p.m.	Lunch ramp-down, lunch ramp-up, and end-of-day ramp-down daily inputs are the same for all AHUs.
AHU 11	6:00:00 a.m.	AHU 11 Nantum schedule	Nantum schedule	Nantum schedule	Nantum Schedule	6:00:00 p.m.	
AHU 22A	7:00:00 a.m.	AHU 22A Nantum schedule	Nantum schedule	Nantum schedule	Nantum Schedule	6:00:00 p.m.	
AHU 22B	7:00:00 a.m.	AHU 22B Nantum schedule	Nantum schedule	Nantum schedule	Nantum Schedule	6:00:00 p.m.	
AHU 31	7:00:00 a.m.	AHU 31 Nantum schedule	Nantum schedule	Nantum schedule	Nantum Schedule	AHU 31	
AHU 32	7:00:00 a.m.	AHU 32 Nantum schedule	Nantum schedule	Nantum schedule	Nantum Schedule	AHU 32	
AHU 41	6:00:00 a.m.	AHU 41 Nantum schedule	Nantum schedule	Nantum schedule	Nantum Schedule	AHU 41	
AHU 42	6:00:00 a.m.	AHU 42 Nantum schedule	Nantum schedule	Nantum schedule	Nantum Schedule	AHU 42	
AHU 51	7:00:00 a.m.	AHU 51 Nantum schedule	Nantum schedule	Nantum schedule	Nantum Schedule	AHU 51	
AHU 52	7:00:00 a.m.	AHU 52 Nantum schedule	Nantum schedule	Nantum schedule	Nantum Schedule	AHU 52	

The baseline AHU operation schedule, occupied heating and cooling thermostat set point schedule, midday and end-of-day ramp schedule, and the new EMIS with ASO occupied heating and cooling thermostat set point schedule are shown in Figure 33.

Figure 33: Terminal Annex Federal Building daily AHU schedule

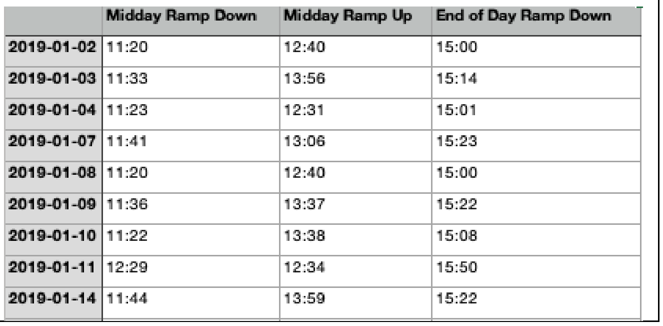
The EMIS with ASO determines when to start the AHUs to meet the 6 a.m.–7 a.m. space temperature set points for each AHU and for each day of the year and determines when to apply midday and end-of-day ramp times (Table 32 and Table 33).

Table 32: Terminal Annex Sample Optimum Start Times for January



Date	AHU-10	AHU-11	AHU-22A	AHU-31	AHU-32	AHU-41	AHU-42	AHU-51	AHU-52
1/2/19	5:40	5:40	6:47	6:38	6:31	5:19	4:29	5:36	5:35
1/3/19	5:40	5:40	6:46	6:38	6:31	5:19	4:30	5:36	5:35
1/4/19	5:38	5:40	6:39	6:37	6:31	5:17	4:32	5:35	5:35
1/7/19	4:52	5:06	5:08	5:56	5:57	4:31	4:26	4:58	5:09
1/8/19	5:30	5:37	6:03	6:31	6:33	5:07	4:45	5:32	5:37
1/9/19	5:35	5:38	6:24	6:35	6:32	5:13	4:38	5:34	5:36
1/10/19	5:35	5:38	6:23	6:34	6:32	5:12	4:38	5:34	5:36
1/11/19	5:34	5:38	6:17	6:34	6:32	5:11	4:40	5:33	5:36
1/14/19	5:20	5:20	6:26	6:18	6:11	4:59	4:10	5:16	5:15
1/15/19	5:39	5:40	6:41	6:37	6:31	5:18	4:31	5:36	5:35
1/16/19	5:33	5:38	6:16	6:33	6:32	5:11	4:41	5:33	5:37
1/17/19	5:26	5:35	5:42	6:28	6:33	5:01	4:52	5:30	5:38
1/18/19	5:35	5:38	6:23	6:34	6:32	5:12	4:38	5:34	5:36
1/22/19	5:24	5:34	5:39	6:27	6:33	5:00	4:53	5:29	5:38
1/23/19	5:40	5:40	6:47	6:38	6:31	5:19	4:29	5:36	5:35
1/24/19	5:40	5:40	6:47	6:38	6:31	5:19	4:29	5:36	5:35
1/25/19	5:40	5:40	6:47	6:38	6:31	5:19	4:29	5:36	5:35
1/28/19	5:15	5:18	6:04	6:15	6:12	4:53	4:18	5:14	5:16

Table 33: Terminal Annex Sample Midday and End-of-Day Ramp Times for January



	Midday Ramp Down	Midday Ramp Up	End of Day Ramp Down
2019-01-02	11:20	12:40	15:00
2019-01-03	11:33	13:56	15:14
2019-01-04	11:23	12:31	15:01
2019-01-07	11:41	13:06	15:23
2019-01-08	11:20	12:40	15:00
2019-01-09	11:36	13:37	15:22
2019-01-10	11:22	13:38	15:08
2019-01-11	12:29	12:34	15:50
2019-01-14	11:44	13:59	15:22

Detailed savings from each AHU fan are provided in Table 34. This considers only fan power savings due to pressure reset and not the savings from the fan flow rate reduction due to the morning setback for nonoccupied mode with modified thermostat set point and operational fan mode, which can be found in Table 34.

Table 34: Terminal Annex Federal Building Fan Energy Savings

System	Fan Location	Fan Energy Use During EMIS with ASO Applied Hours with No Static Pressure Reset (kWh/yr) – (2)	Fan Energy Savings During EMIS with ASO Applied Time with Pressure Reset (kWh/yr) – (3)	Savings in % (3/2)
AHU	Fan location	kWh	kWh	%
AHU 10	RETURNFAN	1,087	76	6.95%
	SUPPLYFAN	2,174	151	6.95%
AHU 11	RETURNFAN	1,214	93	7.67%
	SUPPLYFAN	4,045	310	7.67%
AHU 22	RETURNFAN	588	49	8.39%
	SUPPLYFAN	1,470	123	8.39%
AHU 31	RETURNFAN	1,046	73	6.93%
	SUPPLYFAN	2,616	181	6.93%
AHU 32	RETURNFAN	1,280	80	6.27%
	SUPPLYFAN	3,201	201	6.27%
AHU 41	RETURNFAN	1,698	84	4.92%
	SUPPLYFAN	4,245	209	4.92%
AHU 42	RETURNFAN	882	69	7.80%
	SUPPLYFAN	2,205	172	7.80%
AHU 51	RETURNFAN	947	66	6.93%
	SUPPLYFAN	2,367	164	6.93%
AHU 52	RETURNFAN	768	58	7.60%
	SUPPLYFAN	1,921	146	7.60%
Total		**33,756**	**2,305**	**6.83%**

Fan Power Savings Calculation Equations

EMIS with ASO pressure reset saving calculations use the performance curve AHU 41 shown from the measured data. This calculated savings from the pressure reset during Nantum ramps down as a baseline. From the EMIS with ASO model outputs, the applied hours from the fan electricity and flow rate values during the EMIS with ASO schedule were extracted. Then the flow rate values are divided by fan designed cfm to get a fan flow rate part-load ratio. With the fan flow rate part-load ratios, we can get the estimated fan energy, $Fan_{ElecBuildingOs}$ and $Fan_{ElecPLRBaseline}$, using performance curve formulas, Equation 3, and Equation 4, respectively. The fan energy with pressure reset is calculated as a multiplication of the ratio between the estimated measured fan electricity of the baseline and the pressure reset fan curve, with the modeled baseline fan power calculated in Equation 1 and the fan savings calculated in Equation 2 , which is the difference between the baseline fan energy and the fan.

Equation 1: Modeled baseline fan power

$$Fan_{ElecBuildingOs} = \frac{Fan_{ElecPLRBuildingOs}}{Fan_{ElecPLRBaseline}} * Fan_{kwh}$$

Equation 2: Modeled fan savings

$$Fan_{saving} = Fan_{ElecBuildingOs} - Fan_{kwh}$$

Fan_{kwh}: Fan electricity energy given by model, kWh
$Fan_{ElecBuildingOs}$: Calculated fan energy usage with pressure reset, kWh
Fan_{saving}: Calculated fan energy usage with pressure reset, kWh.

The performance curve for AHU 41 is used to calculate the savings from the static pressure reset during the EMIS with ASO midday and end-of-day ramps as follows:

- Baseline (no reset):

Equation 3: Baseline fan part-load ratio

$$Fan_{ElecPLRBaseline} = 0.415 * Flow_{PLR}^2 + 0.173 * Flow_{PLR} + 0.313 \text{ (1)}$$

- EMIS with ASO (25% static pressure reset):

Equation 4: EMIS with ASO Fan Part-Load Ratio with Static Pressure Reset

$$Fan_{ElecPLRBuildingOs} = 0.027 * {Flow_{PLR}}^3 + 0.495 * {Flow_{PLR}}^2 + 0.123 * Flow_{PLR} + 0.289 \text{ (2)}$$

Where $Fan_{ElecPLR} - Fan\ energy\ fraction, PLRFlow_{PLR} - Fan\ flow\ fraction, PLR$

Those formula are applied as inputs (fan power coefficient fields for fan: variable volume (Big Ladder Software 2020) object) in the baseline and EMIS with ASO models.

B. AUSTIN COURTHOUSE ENERGY MODELING PROCEDURES

A zoning pattern was used in the Austin Courthouse energy model for the basement through the eighth floor. A high-level description of the energy model inputs for the Austin Courthouse building for the walls, roof, windows, lighting, HVAC, and plug loads Is provided in Table 35 and Table 36.

Table 35: Austin Courthouse Energy Model Inputs for Geometry and Building Envelope

Building Component	Baseline Building Design	Location	Comments
Weather file	AMY 2019 weather file for Austin, TX	www.whiteboxtechnologies.com	
Space use classification	Courthouse	N/A	
Roofs	Type: IEAD Roof—highly reflective	DOE prototype building—2007	https://www.energycodes.gov/development/commercial/prototype_models
	Roof membrane/typical insulation R-19.72/metal		
	Gross area: 59,068 ft^2		
	U-value: .04	DOE prototype building—2007	https://www.energycodes.gov/development/commercial/prototype_models
	Solar absorptance: 0.45		
	Thermal absorptance: 0.75		
Walls, above grade	Type: TYPICAL INSULATED EXTERIOR MASS WALL U: .151	DOE prototype building—2007	https://www.energycodes.gov/development/commercial/prototype_models
	1-in. stucco/8-in. concrete HW ref. bldg./typical insulation R: 4.23/0.5-in. gypsum		
	Gross area: 64220 ft^2		
	U-value: .151	DOE prototype building—2007	https://www.energycodes.gov/development/commercial/prototype_models
	Solar absorptance: 0.7		
	Thermal absorptance: 0.75		
Walls, below grade	Type: 8-in. concrete block basement wall	DOE prototype building—2007	https://www.energycodes.gov/development/commercial/prototype_models
	Gross area: 4800 ft^2		
	U-factor: 6.526 W/m^2-K		
Vertical fenestration other than opaque doors	Area: 10495 ft^2	Section and elevation drawings	
	North: 2120.5		
	East: 1184		
	South: 3498		

Building Component	Baseline Building Design	Location	Comments
	West: 3434		
	Building average: 11%		
	Assembly U-factor: 0.72	DOE prototype building—2007	https://www.energycodes.gov/development/commercial/prototype_models
	SHGC: 0.25		
	External shading and projection factor: TBD		

Table 36: Austin Courthouse Energy Model Inputs for Lighting and Mechanical

Building Component	Standard Reference Design	Sheet Location	Comments
Lighting, interior	1.0 W/ft^2 office spaces	ASHRAE 90.1-2010 user's manual as default, electrical drawings when applicable	
	1.5 W/ft^2 mechanical/electrical rooms		
	1.0 W/ft^2 data center		
	0.2 W/ft^2 parking		
Internal gains	0.75 W/ft^2 office spaces	ASHRAE 90.1-2010 user's manual as default, electrical drawings when applicable	
	20.0 W/ft^2 data center		
Cooling systems	90.1-2007 user's manual schedules for office	Mechanical drawings, SOO	
	Primary cooling system: RTUs with chilled water cooling		
	(1) 140-ton, (2) 300-ton chillers with cooling tower		
Heating systems	Primary heating system: RTUs with hot water heating and hot water reheat	Mechanical drawings, SOO	
	(3) 3,000-MBH natural gas boiler plants		

Heating System Inputs

The building's heating hot water system includes three 3.0-MMBtu/hr high-efficiency Aerco condensing boilers operating year-round, 24/7 to supply AHU heating coils, fan-powered box reheat coils, FCUs, VAV box reheat coils, lobby perimeter baseboard reheat, and a few ancillary heating loads. The hot water loop is configured as a variable-volume, primary-only loop with three 15-hp pumps equipped with VFDs. Domestic hot water is provided by two Tri-Con 250-gallon condensing hot water heaters (500,000 Btu/hr.) with dedicated circulating pumps. A solar hot water system on the roof is not used. The heating system model inputs and set points were modeled to match the mechanical system design and the BAS controls, as outlined in Table 37.

Table 37: Austin Courthouse Heating System Component

Heating System Component	Value
Hot water boiler	(3) 3.0 MMBtu/hr
Boiler efficiency	90% condensing boilers
Hot water pump	15-hp VFD, 164 GPM
Hot water coil Delta T	35°F
Hot water set point	180°F when OA <50°F/130°F for others
Domestic hot water	Modeled as a building load vs. modeling system directly

Air-Side System Inputs

Ventilation and conditioned air are delivered to the building by 14 AHUs (AHU A through AHU N). There are two DOAS units providing preconditioned outdoor air to the AHUs. The DOAS are equipped with variable-speed enthalpy wheels between the supply and exhaust airstreams to help control the latent and sensible load being delivered to the AHUs. The AHUs can economize via the DOAS supply airstream, but the return air from the spaces cannot be directly controlled (i.e., there are no return air dampers in the ductwork).

The DOAS have chilled and hot water coils and VFDs on the supply and exhaust fans. Of the AHUs, 13 are cooling only and supply approximately 137 series fan-powered boxes in the mezzanine levels of each floor. These fan-powered boxes have discharge reheat coils to maintain space temperature requirements. They also serve a few VAV boxes in the building, some cooling only and some with hot water reheat coils. One AHU, AHU C, has both hot and chilled water coils and serves the first-floor lobby of the building. All the AHUs have VFDs, electrically generated steam humidifiers, ultraviolet lights, and humidity and CO_2 sensors in the return ductwork. The lobby spaces of each floor have perimeter baseboard hot water reheat, and there are some dedicated FCUs serving elevator machine rooms as well as mechanical/electrical rooms throughout the building.

Additional exhaust fan systems serve the garage, sally port, generator room, chiller and boiler mechanical rooms, electrical equipment closets, and audio/visual equipment locations. Specialty exhaust systems with high-efficiency particulate air (HEPA) filters serve the prisoner holding and processing areas on floors three through seven. Specialty exhaust systems with carbon and HEPA filters serve the mail room. Makeup air is served to the garage and boiler room spaces. There are 36 FCUs with either chilled water coils or chilled water and hot water coils serving multiple spaces on each floor. Primary spaces served by FCUs include telephone and electrical closets, mechanical rooms, mail room, and prisoner holding cells. Five CRAC units serve process cooling loads on the first and third floors, which require continuous cooling tower and condenser water pump operations.

AHU Controls

The zone cooling set point temperature is 72°F occupied and 80°F unoccupied. The zone heating set point temperature is 68°F occupied and 60°F unoccupied. The minimum supply air fraction was set to 30%, and the supply air set points and demand-controlled ventilation sequence is outlined in Table 38.

Table 38: Austin Courthouse AHU Modeled Sequence of Operation

AHU Type	1	1A	2	2A	3	OAHU
Supply air set point	Cooling only static pressure based on zone VAV box 55°F–60°F				CAV: 7°C–35°C	Cooling 52°F
						Heating 48°F
Ventilation on demand	CO_2 based, set point 1000 ppm, SOO or 700 ppm, BAS					DOAS

The AHU type, flow rate, motor horsepower, and cooling and heating coil capacity (tons) are listed in Table 39.

Table 39: Austin Courthouse AHU Model Assumptions

AHU name	Function	AHU Type	Ventilation Max Flow Rate/s	Ventilation Min Flow Rate/s	Fan Max., l./s.	Exhaust	Fan Supply, hp	Fan Exhaust, hp	Cooling Coil (GPM)	Heating Coil (GPM)
AHU A	VAV	1	743	330	743	N/A	20	N/A	46	
AHU B	VAV	1A	1,731	182	1,731	N/A	15	N/A	17.4	
AHU C	CAV	3	438	82	438	N/A	20	N/A	47.6	26.8
AHU D	VAV	1	66	66	66	N/A	10	N/A	23.8	
AHU E	VAV	2	2,689	248	2,689	N/A	30	N/A	44.4	
AHU F	VAV	1	60	60	60	N/A	7.5	N/A	25.4	
AHU G	VAV	1	151	100	151	N/A	7.5	N/A	19	
AHU H	VAV	1	720	82	720	N/A	5	N/A	11.1	
AHU I	VAV	1	1,576	82	1,576	N/A	20	N/A	34.9	
AHU J	VAV	1A	4,757	330	4,757	N/A	20	N/A	41.2	
AHU K	VAV	1A	1,037	100	1,037	N/A	15	N/A	25.4	
AHU L	VAV	1	660	148	660	N/A	10	N/A	25.4	
AHU M	VAV	2A	2,691	298	2,691	N/A	25	N/A	41.2	
AHU N	VAV	1	2,006	298	2,006	N/A	25	N/A	41.2	
AHU P	DOAS	OAHU	1,963	N/A	1,963	1,100	32	9	185.4	54.5
AHU R	DOAS	OAHU	2,650	N/A	2,650	1,100	45	18	250.4	74

Note: AHU P uses the same pressure rise as AHU R to find the fan motor size.

Cooling System Description

Cooling is provided by two 300-ton, high-efficiency, York magnetic bearing centrifugal chillers and one 120-ton York scroll chiller. The scroll chiller was originally designed to maintain unoccupied cooling loads in the building, but this chiller is currently not being used. The chilled water loop piping configuration is a variable-volume, primary-only loop with a common header and VFDs on three 30-hp chilled water pumps. The condenser water loop features three 50-hp pumps with VFDs, and a three-cell Marley SPX cooling tower (with common header) equipped with three 15-hp fans with VFDs, one per cell. A plate-and-frame heat exchanger is used for waterside economizing during the winter months because the building was designed for cooling loads year-round. There is a 3-hp pump that was originally dedicated to run with the waterside economizer, but it no longer operates. Instead, the main condenser water loop pumps are used with the waterside economizer operations. The waterside economizer is configured to operate when the outdoor wet-bulb temperature is less than 44°F.

Calibration

The baseline energy model for the Austin Courthouse building was calibrated to meet ASHRAE's Guideline 14-2014, *Measurement of Energy, Demand and Water Savings*, requirements for monthly RMSE and NMBE (ASHRAE 2014). Given that the models were created during COVID-19 and that an on-site energy audit was not conducted to collect all energy model input parameters, certain input parameters that were unknown were iteratively changed. During the calibration process, known input parameters—such as building size; orientation; and HVAC mechanical design, including HVAC set points, control sequences and schedules—were modeled to match actual building operation unknown input parameters. Mechanical systems (chiller plant, boiler plant, AHUs) were modeled based on building drawings. The SOO of the HVAC system was modeled based on BAS data, and the SOO was verified with site O&M—details of all set points, sequences, etc., and unknown variables, such as the operational schedules for occupancy, lighting, plug loads, and domestic hot water—were varied within a reasonable range. The lighting power density and plug load density values provided in Table 36 were modified using the calibration parameters shown in Table 40.

Table 40: Austin Courthouse Lighting and Plug Load Calibration Multiplier

Calibration Parameters	Minimum Value	Maximum Value	Calibration Value
Office lighting multiplier	0.3	1	0.6
Office plug load multiplier	0.3	1	0.6

The Austin Courthouse building had electrical submeters metering lighting energy usage. The measured lighting energy usage was used to calibrate the modeled lighting energy usage on a monthly basis. Figure 34 shows the lighting energy use calibration, which had an NMBE of 0.38% and a CV (RMSE) of 1.18%.

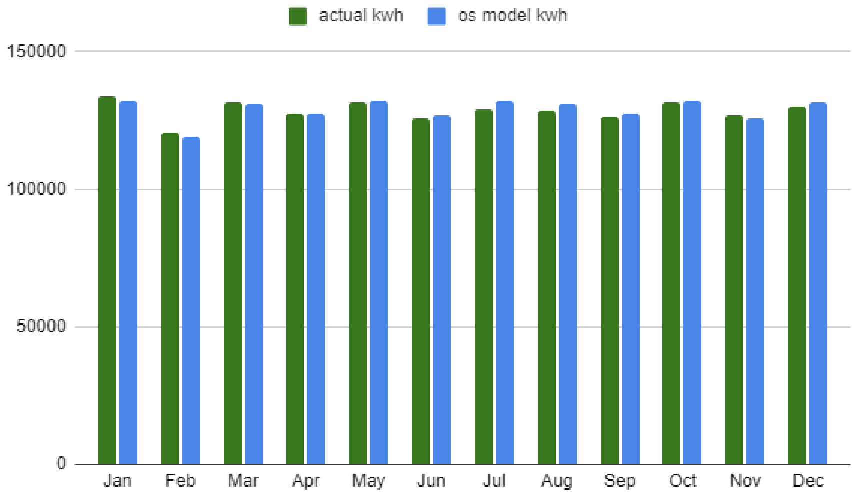


Figure 34: Austin Courthouse lighting energy usage monthly calibration

The modeled baseline building EUI was 142.2 kBtu/ft^2, with an annual energy cost of $378,058. A breakdown of annual energy use by end use is provided in Figure 35.

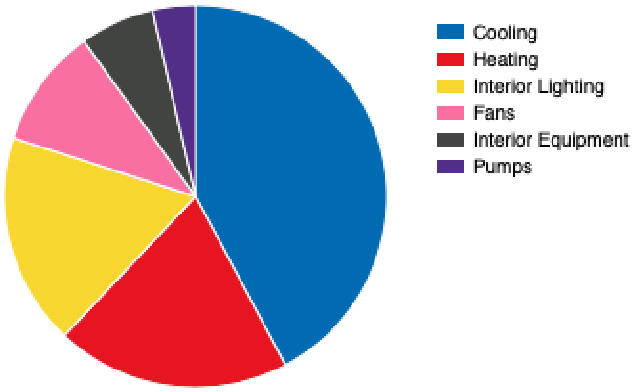


Figure 35: Austin Courthouse annual end use breakdown

Because the chiller plant was being replaced at the time of the baseline model calibration, NREL decided to model it with a black-box approach to match the measured chilled water flow rate (total cooling provided to the facility) to the modeled air-side systems (AHU/FCU). As a result, the operating system model cooling output does not have cooling electricity. To account for the chiller plant electricity demand, NREL used time-series BAS data recorded for calibration periods (2019) to summarize the chiller electricity in Column 1 in Table 41, then used an assumed coefficient, K, in Column 2, which ranges from 0.6 (winter) to 0.85, depending on the weather conditions, as a ratio of chiller electricity to total chiller plant electricity (chiller, cooling tower fan, condenser pump, other) in Column 3. Summarizing the assumed chiller plant electricity (3) and the OS model electricity (4) to the total energy usage in Column (5), NREL was able to calibrate the whole-building electricity use within ASHRAE Guideline 14 limits, as shown in Table 41.

Table 41: Austin Chiller Plant Baseline Performance

Month	Chiller, kWh (From BAS Data)	k (Assumed)	Assumed Chiller Plant, kWh (Calculated)	OS Model Output, kWh (Simulation Output)	Total Model, kWh (Calculated)	Monthly Cooling Production, Tons (Calculated from BAS)	Monthly kW/Tons (Calculated)
Jan-19	6,491	0.60	10,819	237,809	248,628	5,244	0.48
Feb-19	13,739	0.60	22,898	226,592	249,489	7,920	0.35
Mar-19	31,010	0.70	44,299	265,311	309,610	18,821	0.42
Apr-19	40,768	0.80	50,960	285,287	336,247	31,085	0.61
May-19	75,339	0.80	94,173	292,073	386,246	72,173	0.77
Jun-19	87,080	0.80	108,850	293,994	402,844	75,284	0.69
Jul-19	96,390	0.85	113,400	320,322	433,722	76,729	0.68
Aug-19	103,686	0.85	121,983	327,401	449,384	106,060	0.87
Sep-19	89,345	0.65	137,453	295,765	433,218	122,694	0.89
Oct-19	65,423	0.65	100,650	284,904	385,554	84,588	0.84
Nov-19	39,906	0.60	66,509	250,505	317,014	18,085	0.27
Dec-19	24,683	0.60	41,138	259,974	301,111	19,941	0.48

The assumed chiller plant electricity for the baseline was included in the OS model as “other equipment” without heat gain to the building. For the EMIS with ASO supervisory control changes, NREL used the OS calculated chiller cooling production rates with the same monthly kW/tons from the baseline (Column 7) to estimate the chiller plant electricity usage and demand with the EMIS with ASO chiller impacts applied.

The monthly electricity usage was calibrated to a CV (RMSE) of 8.65% (less than the 15% required by ASHRAE Guideline 14-2014) and an NMBE of -0.23 (less than the 5 required by ASHRAE Guideline 14-2014); see Figure 36.

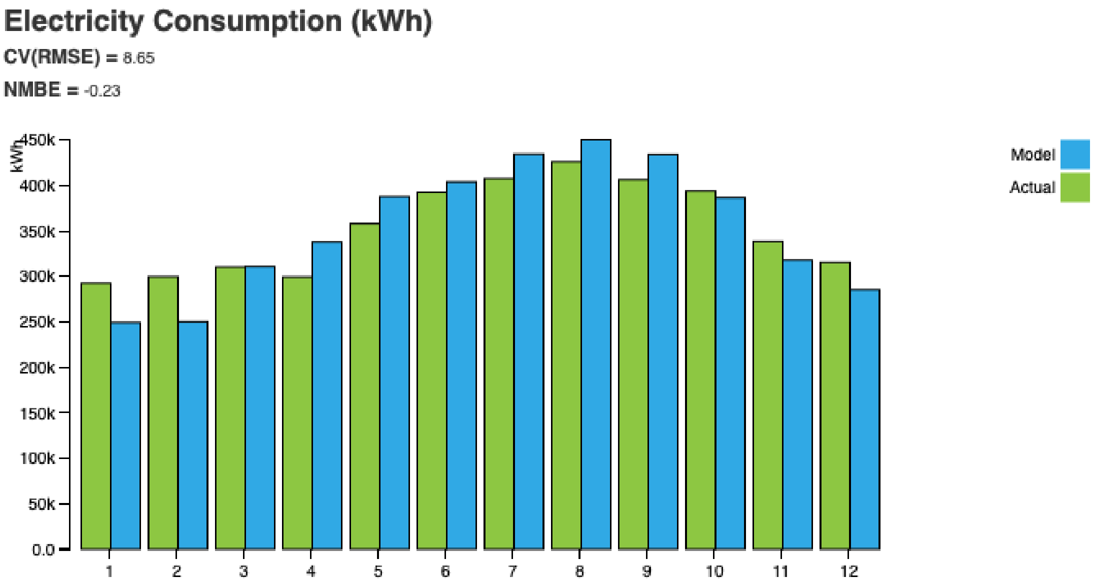


Figure 36: Austin Courthouse baseline monthly electricity usage calibration with chiller plant consumption accounted for

For the natural gas calibration, heating component properties and domestic hot water schedules were adjusted. In the summer months, when there is no space heating load in the building, the natural gas consumption was calibrated to match the domestic hot water usage. During the winter months, when space heating and domestic hot water heating both contribute to the building's gas consumption, a reference month was chosen and calibrated to match the usage. The remaining months are then calibrated by modifying each month's domestic hot water schedule. The monthly natural gas usage was calibrated to a CV (RMSE) of 13.47% (less than the 15% required by ASHRAE Guideline 14-2014) and an NMBE of -3.35 (less than the 5 required by ASHRAE Guideline 14-2014); see Figure 37.

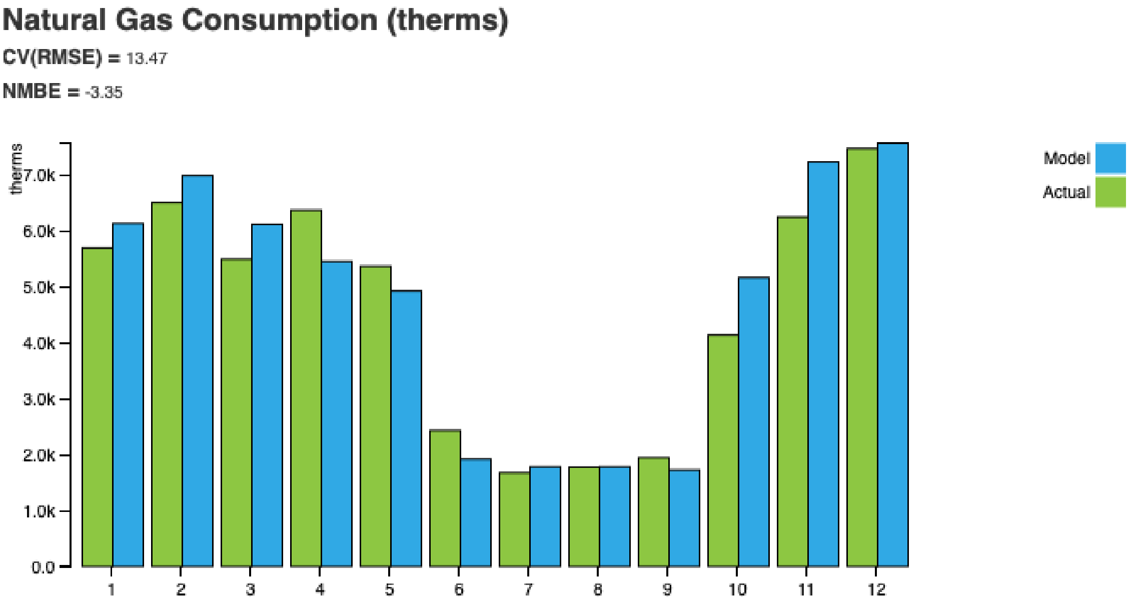


Figure 37: Austin Courthouse monthly natural gas usage calibration

BOS Supervisory Controls

Given that the EMIS with ASO supervisory controls for optimum start were implemented for only a short time prior to the GSA issuing COVID-19 changes to HVAC operation, the time of day when the optimum start would have been initiated for each AHU had to be modeled.

The EMIS with ASO provider used its internal model to determine when each AHU should be started to meet the desired zone temperature set point based on the 2021 building occupancy profile, historic weather data from 2019, and BAS trend log data from 2019, including zone temperature readings and zone temperature set points.

In the proposed modeling scenario with the EMIS with ASO, the building AHUs were set to change to unoccupied mode after normal building occupancy hours. The AHU fans remain on and cycle based on temperature. The unoccupied temperature set points have been recommended by O&M and were verified to comply with the GSA's P100 Facilities Standards for the Public Buildings Service. These temperature set points are 55°F during winter and 80°F during summer.

The range of allowable EMIS with ASO optimal schedule inputs were confirmed with the GSA and the O&M team at the Austin Courthouse. The EMIS with ASO produces optimal startup times based on a machine learning model that considers many variables, such as space conditions, weather, and comfort constraints. Ramps and shutdown times are generated based on occupancy trends observed from actual building data. Based on O&M feedback and actual operating hours of the building HVAC, overtime cooling hours are added to AHU A, AHU L, and AHU M. CRAC units serving the data center spaces are kept on 24/7. Table 42 shows the required additional run times for the AHUs and CRAC units.

Table 42: Austin Courthouse Lighting and Plug Load Calibration Multiplier

Unit	Additional Cooling Hours Required
AHU L	50
AHU M	50
AHU A	50
CRAC 3-02	8,760
CRAC 3-03	8,760
CRAC 1-01A	8,760
CRAC 1-01B	8,760
CRAC 3-01	6,258

For the Austin Courthouse, the baseline occupied set point schedule for each AHU is provided in the following. With this sequence, the AHUs start at the designated occupied set point time and run intermittently, as needed, during unoccupied hours to meet the unoccupied space set point temperature.

- AHU A: 3 a.m.–6 p.m., Monday–Friday
- AHU B: 3 a.m.–6 pm Monday–Friday
- AHU C: 24/7
- AHU D: 3 a.m.–6 p.m. Monday–Friday
- AHU E: 3 a.m.–9 p.m. Monday–Friday
- AHU F: 3 a.m.–6 p.m. Monday–Friday
- AHU G: 3 a.m.–6 p.m.
- AHU H: 3 a.m.–6 p.m. Monday–Friday
- AHU I: 3 a.m.–6 p.m. Monday–Friday
- AHU J: 3 a.m.–6 p.m. Monday–Friday
- AHU K: 3 a.m.–6 p.m. Monday–Friday
- AHU L: 3 a.m.– 6 p.m. Monday–Friday
- AHU M/N/P/R: 24/7.

Because the baseline set points and the AHU schedule did not use an optimum start and the AHUs were started on a simple schedule, the occupied set point time needed to be adjusted to apply an optimum start and to ensure that the space temperature was at the desired space temperature by the occupied start time. A new AHU schedule with new target occupied space temperature times and end-of-day ramp times is shown in Table 43.

Table 43: Austin Courthouse AHU EMIS with ASO Optimum Start Schedule

AHU Number	Target Comfort Time	EMIS with ASO Optimum Start Time	Lunch Ramp Down	Lunch Ramp Up	End-of-Day Ramp Down	End of Occupied Set Point	Note
AHU A	6:00:00 a.m.	AHU A Nantum optimal	Nantum schedule	Nantum schedule	Nantum schedule	6:00:00 p.m.	Lunch ramp-down, lunch ramp-up, and end-of-day ramp-down daily inputs are the same for all AHUs applied. Other spaces use the building Nantum optimal schedule as a cooling and heating set point schedule.
AHU B	6:00:00 a.m.	AHU B Nantum optimal	Nantum schedule	Nantum schedule	Nantum schedule	6:00:00 p.m.	
AHU D	6:00:00 a.m.	AHU D Nantum optimal	Nantum schedule	Nantum schedule	Nantum schedule	6:00:00 p.m.	
AHU E	6:00:00 a.m.	AHU E Nantum optimal	Nantum schedule	Nantum schedule	Nantum schedule	6:00:00 p.m.	
AHU F	6:00:00 a.m.	AHU F Nantum optimal	Nantum schedule	Nantum schedule	Nantum schedule	6:00:00 p.m.	
AHU G	6:00:00 a.m.	AHU G Nantum optimal	Nantum schedule	Nantum schedule	Nantum schedule	6:00:00 p.m.	
AHU H	6:00:00 a.m.	AHU H Nantum optimal	Nantum schedule	Nantum schedule	Nantum schedule	6:00:00 p.m.	
AHU K	6:00:00 a.m.	AHU K Nantum optimal	Nantum schedule	Nantum schedule	Nantum schedule	6:00:00 p.m.	
AHU J	6:00:00 a.m.	AHU J Nantum optimal	Nantum schedule	Nantum schedule	Nantum schedule	6:00:00 p.m.	
Other spaces	6:00:00 a.m. or 24-hour spaces						

The baseline AHU operations schedule, occupied heating and cooling set point schedule, midday and end-of-day ramp schedule, and the new EMIS with ASO occupied heating and cooling set point schedule are shown in Figure 38.

The EMIS with ASO determines when to start the AHUs to meet the 6 a.m.–7 a.m. space temperature set point for each AHU, for each day of the year, and determines when to apply the midday and end-of-day ramp times; see Table 44 and Table 45.

Table 44: Austin Courthouse Sample Optimum Start Times for January

Date	AHU A	AHU B	AHU D	AHU E	AHU F
1/2/20	5:34:00 a.m.	5:49:00 a.m.	5:45:00 a.m.	5:52:00 a.m.	5:44:00 a.m.
1/3/20	5:33:00 a.m.	5:42:00 a.m.	5:45:00 a.m.	5:53:00 a.m.	5:45:00 a.m.
1/6/20	5:12:00 a.m.	5:11:00 a.m.	5:25:00 a.m.	5:35:00 a.m.	5:26:00 a.m.
1/7/20	5:32:00 a.m.	5:35:00 a.m.	5:45:00 a.m.	5:54:00 a.m.	5:46:00 a.m.
1/8/20	5:30:00 a.m.	5:20:00 a.m.	5:45:00 a.m.	5:58:00 a.m.	5:47:00 a.m.
1/9/20	5:42:00 a.m.	5:59:00 a.m.	5:39:00 a.m.	5:32:00 a.m.	5:34:00 a.m.
1/10/20	5:36:00 a.m.	5:28:00 a.m.	5:38:00 a.m.	5:10:00 a.m.	5:21:00 a.m.
1/13/20	5:14:00 a.m.	5:32:00 a.m.	5:24:00 a.m.	5:31:00 a.m.	5:24:00 a.m.
1/14/20	5:38:00 a.m.	6:00:00 a.m.	5:39:00 a.m.	5:42:00 a.m.	5:39:00 a.m.

Table 45: Austin Courthouse Sample Midday and End-of-Day Ramp Times for March

Date	Midday Ramp Down	Midday Ramp Up	End-of-Day Ramp Down	Shutdown
3/9/20	11:21:00 a.m.	12:41:00 p.m.	3:01:00 p.m.	6:00:00 p.m.
3/10/20	11:21:00 a.m.	12:41:00 p.m.	3:01:00 p.m.	6:00:00 p.m.
3/11/20	11:21:00 a.m.	12:41:00 p.m.	3:01:00 p.m.	6:00:00 p.m.
3/12/20	11:21:00 a.m.	12:41:00 p.m.	3:01:00 p.m.	6:00:00 p.m.
3/13/20	11:21:00 a.m.	12:41:00 p.m.	3:01:00 p.m.	6:00:00 p.m.
3/16/20	11:21:00 a.m.	12:41:00 p.m.	3:01:00 p.m.	6:00:00 p.m.
3/17/20	11:16:00 a.m.	1:15:00 p.m.	3:40:00 p.m.	6:00:00 p.m.

C. HARVEY D. WILEY FEDERAL BUILDING FAN MODELING

Harvey W. Wiley Federal Building baseline model

For this building, historic trend data for all BAS points were available from a monitoring-based commissioning (MBCx) platform operating at the building for the last few years. For the office AHUs (5–15), 15-minute trend data for 2019 were provided by the site:

- Supply fan %
- Supply fan kW
- Supply fan airflow (l/s)
- Return fan %
- Return fan kW
- Return fan airflow (l/s)
- Return duct pressure
- Return duct pressure set point discharge duct pressure
- Discharge duct pressure set point discharge air temperature discharge air temperature
- Set point outside air damper position cooling coil valve %
- Heating coil valve %
- Humidifier valve output (%) mixed air temp.
- Preheat temperature.

15-minute trend data were provided for all ATU or VAV boxes served by AHUs 5–15:

- Zone temperature
- Zone temperature set point
- Flow rate sensor (cfm or l/s) heating coil %
- Damper percentage
- Fan status.

In addition to collecting 2019 BAS trend data, a short-term fan power test procedure was written to evaluate the impact on fan speed and fan power from implementing a static pressure reset on the AHU fans. This test procedure was implemented by GSA O&M staff at the site.

BAS data were analyzed to see which AHU had the most complete data set and to determine which VAV box flow measurements correlated with the AHU fan airflow and power. This analysis showed the best correlations for AHU 5, which had relatively constant flow rate and pressure data and was reasonably constant over occupied hours, cycling on/off at night, as would be expected. The daily average weekday supply air static pressure and supply fan VFD speed for each month of the year for AHU 5 are shown graphically in Figure 38 and Figure 39.

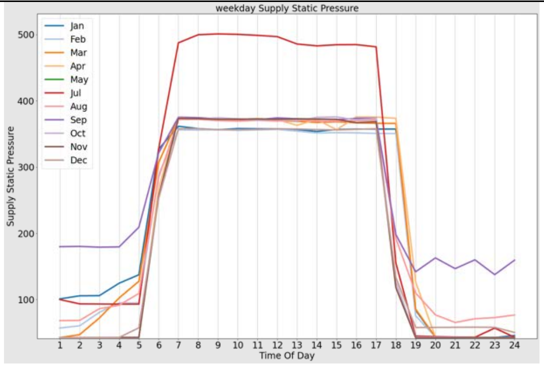


Figure 38: Daily average weekday supply static pressure

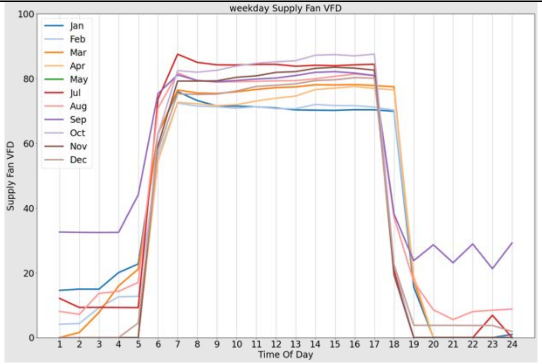


Figure 39: Daily average weekday supply fan VFD speed

For the short-term fan power testing, GSA O&M site staff conducted testing where the static pressure set point for each AHU fan was reduced from its current set point in 15% increments, down from 100% of the current static pressure set point to 85%, 70%, and 55%. For each test, the discharge air pressure set point, discharge air pressure, discharge airflow rate, fan VFD percentage, fan power kilowatts, fan motor current, and fan speed were recorded. A sampling of the data collected for AHU 8 is provided in Table 46.

Table 46: Harvey Wiley Fan Power Testing for AHU 8

AHU Number	Discharge Air Pressure Set Point (%)	Equivalent Discharge Air Pressure Set Point (Pa)	Discharge Air Pressure (Pa)	Discharge Airflow Rate (lps)	VFD (%)	Fan Power (kW)	Fan Current (Amps)	Fan Speed (Hz)
AHU 8: Supply fan	100	370	369	11,606	73	17	43	44
AHU 8: Supply fan	85	315	309	11,188	60	15	40	36
AHU 8: Supply fan	70	259	258	10,856	55	13	38	33
AHU 8: Supply fan	55	204	205	10,507	50	12	34	37

Harvey Wiley EMIS with ASO Supervisory Controls

Using weekday operation data of AHUs (in particular, AHU 5), we have the following observations:

- Most AHUs were running with a narrow range of flow rates (lps) so VFD outputs (%) during daytime were more variable compared with nighttime (Figure 39). The static pressure keeps constant over occupied and unoccupied periods (Figure 38).

Focusing on the fan energy savings only, the fan energy savings model consists of two main items:

- Fan savings with static pressure reset:
  - The fan performance curve built from the BMS is inadequate to build the pressure setback performance curve because the values are only reasonable at high pressure, as shown in Figure 40. The lack of pressure setback during normal business times compromised the reliability of the historical operation data because there is no pressure setback based on a normal business time load dynamic. For the test, standard pressure reset curves with formulas were used as follows:
    - Baseline (no reset):

Equation 5: Standard baseline (No PressureRest) fan curve

$$Fan_{ElecPLRBaseline} = 1.00920344 * {Flow_{PLR}}^3 + (-0.460864118) * {Flow_{PLR}}^2 + 0.385330201 * Flow_{PLR} + 0.070428852$$

- EMIS with ASO (25% static pressure reset):

Equation 6: Standard fan curve with static pressure rest (EMIS with ASO)

$$Fan_{ElecPLRBuildingOs} = 0.9437739823 * {Flow_{PLR}}^3 + (-0.07292612) * {Flow_{PLR}}^2 + 0.08804497 * Flow_{PLR} + 0.040759894$$

Where $Fan_{ElecPLR} - Fan\ energy\ fraction, PLRFlow_{PLR} - Fan\ flow\ fraction, PLR$

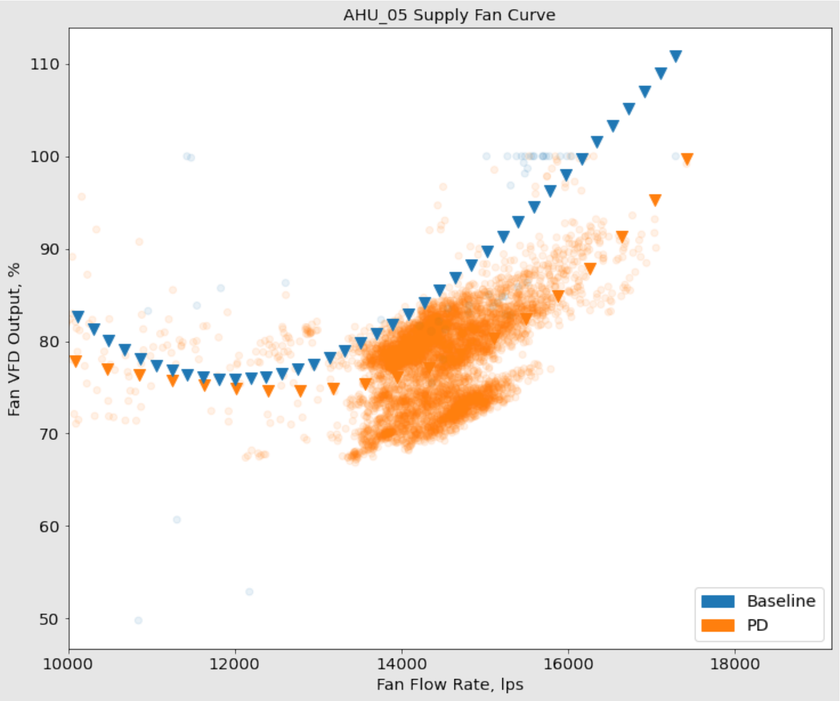


Figure 40: AHU 5 supply fan curve baseline versus EMIS with ASO with static pressure reset

Flow rate variability: With the EMIS with ASO morning optimum start implemented, the AHU running times are extended in unoccupied mode. Considering the constant AHU flow rate during unoccupied time (9 p.m.–6 a.m.), we can use the average flow rate during unoccupied mode for extended times. To compensate for the lack of cooling delivered with (delayed) optimum start, we assume the supply air (discharge air) set point is constant, so the load is always proportional with the flow rate. Any flow reduction by morning optimum (delay) start time should be compensated later, more than 4 hours after the AHU is moved to occupied (continuous fan) mode, by increasing the fan flow rate up to 1.0 (100 fan flow rate) until the increments fill up the summarized flow deduction. The increased flow rate comes along with VFD (%) correction by replacing the new VFD value corresponding to the new flow rate obtained from annual data because the relationship between fan flow rates and VFD outputs is independent from weather conditions.

Like the other buildings, there are energy savings associated with the optimum start in the morning and the midday and end-of-day ramps. Although the midday and end-of-day ramp savings (static pressure setback) are reliably validated with the short-term VFD testing conducted, modifying the start time of the AHUs and the occupied set point time of the AHUs might increase peak demand later in the day; however, due to the operational impacts from COVID-19, fan power savings from the optimum start could not be validated with field-test data. To account for the effect of shifting thermal loads, NREL ensured that the same total airflow rate (e.g., cooling delivered) on a daily basis was maintained within the model. The difference between the baseline and the EMIS with ASO in the AHU fan flow rate and energy use are described in Figure 41 with FanFlow_norm (orange) and supplyFan_power_norm (red) as the normalized fan flow rate and the fan energy use of the baseline case from BMS data. The fanFlow_ecm(blue) and supplyFan_ecm (green) are the flow rate and the energy use for the EMIS with ASO cases. The EMIS with ASO model has fan flow and energy usage lower than the baseline before 6 a.m. but increases after 7 a.m., when the occupied schedule starts. When pressure static is applied, there should be gaps between the baseline (red) and the EMIS with ASO (green), even if the flow rates coincide during the morning startup and midday and end-of-day ramp downs. The compensation flow rate is shown as the max flow rate (blue) at 1.0 from 7 a.m.–9 a.m. in Figure 41.

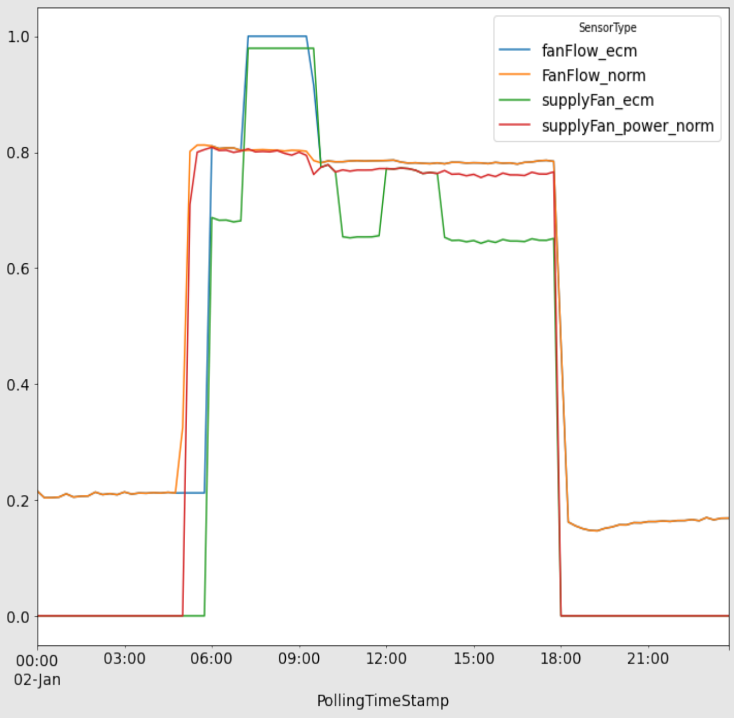


Figure 41: Harvey W. Wiley fan flow rate and energy use

D. PEAK DEMAND PREDICTION STATISTICAL EQUATIONS

The equations used for the TOST method as well as the CV (RMSE) and NMBE, are outlined as follows.

The TOST method was used to evaluate the data for statistical and practical equivalence. The TOST method incorporates an equivalence interval as a test for practical equivalence. If the mean and confidence interval (CI) bounds of a data sample fall completely within the equivalence interval, then the differences in measured peak demand and the predicted peak demand can be considered statistically and practically equivalent. The first step in the TOST method was to normalize the demand readings to a set scale between 0 and 100, as shown in Equation 7.

Equation 7: Data set scaling

$$z_i = \frac{x_i - (x)}{(x) - (x)}$$

- z_i: Scaled value
- x_i: Initial value
- (x):: Minimum value in the data set
- (x): Maximum value in the data set.

A confidence interval was created using the upper and lower tails of the t-distribution of the data set, as depicted in Equation 8:

Equation 8: Confidence Interval

$$CI = \underline{x} \pm t_{2\alpha,n-1}\frac{s}{\sqrt{n}}$$

- $\underline{x}$: Mean of the difference between observed and predicted values
- $t_{2\alpha,n-1}$: T-distribution for a 95% confidence interval
- s: Standard deviation of the difference between observed and predicted values
- n: Number of data points.

An acceptance interval of ±5 was used to check the 5% success criterion for the TOST statistical analysis. In addition to running a TOST statistical analysis on the data, the ASHRAE Guideline 14 Section 4.3.2.4 equations for CV (RMSE) and NMBE were also applied to the data set as follows using Equation 9 and Equation 10:

Equation 9: CV (RMSE)

$$CV(RMSE) = \frac{\sqrt{\frac{\sum_{i=1}^{n} \quad (y_i - \widehat{y}_i)^2}{(n-p)}}}{\underline{y}}$$

Equation 10: NMBE

$$NMBE = \frac{\sum_{i=1}^{n} \quad (y_i - \widehat{y}_i)}{(n-p) \times \underline{y}}$$

- n: Number of data points
- p: Number of parameters (equal to 1 – “energy consumption”)
- y_i: Observed value
- $\widehat{y}_i$: Predicted value
- $\underline{y}$: Mean of the sample of n observations.

E. SURVEYS

Ease of Installation Survey

Table 47: Ease of Installation Questions for System Integration GSA Responsibilities

System Integration—GSA Responsibilities
Were the GSA's organizations required to support the technical integration aspect able to do so in such a manner as to avoid delays?
Were O&M organizations well suited to facilitating the technical implementation of Prescriptive Data's solution?
What were the primary challenges on the GSA side to supporting the integration of Nantum, and are there recommendations for addressing them?

Table 48: Ease of Installation Questions for Information Technology GSA Responsibilities

Information Technology—GSA Responsibilities
How well was GSA information technology able to support the requirements for implementation of the Prescriptive Data's technology?
Are there fundamental technical barriers that would make a larger-scale rollout of Prescriptive Data's technology problematic?

Table 49: Ease of Installation Questions for Cybersecurity GSA Responsibilities

Cybersecurity—GSA Responsibilities
Were there aspects of the GSA information technology security assessment and authorization processes that resulted in project delays?
Will the authorizations already have required benefit potential future implementations of Prescriptive Data's solution?
Are there cybersecurity issues that would prevent this solution from being widely deployed at the GSA?

Table 50: Ease of Installation Questions for Contracting GSA Responsibilities

Contracting—GSA Responsibilities
What contracting mechanism or vehicle was used to procure installation services? Why was it chosen?
What were the benefits and drawbacks of using this contracting mechanism for the installation?
How did you develop your cost estimation for the project? Were there any downfalls to using this method for project cost estimation?
What contracting best practices or lessons learned would you recommend for future installations in the GSA for Prescriptive Data?

F. GLOSSARY

Advanced metering infrastructure (AMI)	An integrated network of advanced meters, communications networks, and data management systems. Advanced metering infrastructure can refer broadly to an agency's entire portfolio of advanced meters and related assets (referred to in this document as the agency's "AMI system") or more narrowly to the assets at a particular site or building.
Covered facility	A facility that an agency has designated as subject to the requirements of Section 432 of the Energy Independence and Security Act of 2007 (EISA), codified at 42 U.S.C. § 8253(f), which requires agencies to designate covered facilities comprising at least 75% of their total facility energy use. A covered facility can be defined as a group of facilities at a single location or multiple locations managed as an integrated operation. A covered facility can also be a single building, if so identified by the agency.
Energy management information system (EMIS)	A broad family of tools and services used to manage commercial building energy use. These technologies include energy-efficient and energy-saving information technologies, energy management systems, fault detection and diagnostic systems, benchmarking and utility bill tracking tools, automated system optimization tools, and building automation systems.
High-performance and sustainable buildings	Federal buildings documented in the Federal Real Property Database as qualifying as a sustainable federal building as outlined in the Implementing Instructions for Executive Order 13834, "Efficient Federal Operations."
Life-cycle cost-effective	Life-cycle cost-effective means, with respect to an advanced meter, that the estimated savings gained by the installation of the advanced meter exceed the estimated costs during the life span of the advanced meter, as determined in accordance with 10 C.F.R. part 436, subpart A.

G. MANUFACTURER CUT SHEET

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