ESTCP

FINAL REPORT

Better Buildings, Smaller Bootprint

Smart Building Program for the DoD

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The utility and operational data generated by the Department of Defense are vast and largely underused. Without a unified system to automatically collect, normalize, and present these data in a meaningful way, DoD energy and facility managers are left with the task of doing this manually. The Switch Platform delivers a holistic and highly configurable building operations solution with extensive data collection capabilities, enterprise-grade data management tools, a unified user interface that simplifies the management of disparate systems, and advanced machine-learning analytics both at the edge and in the cloud in order to address these issues.

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ACRONYMS AND ABBREVIATIONS

ADX	Azure Data Explorer
AFDD	Automated Fault Detection and Diagnostics
AMI	Advanced Metering Infrastructure
API	Application Programming Interface
ARNG	Army National Guard
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
ASO	Automated System Optimization
BAS	Building Automation System
Btu	British thermal unit
DoD	Department of Defense
DOE	Department of Energy
EIS	Energy Information Systems
EMIS	Energy Management Information Systems
EO	Executive Order
EPA	U.S. Environmental Protection Agency
ESTCP	Environmental Security Technology Certification Program
EW	Installation Energy and Water
FedRAMP	Federal Risk and Authorization Management Program
GEB	Grid-Interactive Efficient Building
ICS	Industrial Control Systems
IoT	Internet of Things
ISO	International Organization for Standardization
kW	kilowatt
LBNL	Lawrence Berkeley National Laboratory
NDAA 2007	National Defense Authorization Act of 2007
NGB	National Guard Bureau
NIST	National Institute of Standards & Technology
O&M	Operation and maintenance
SCADA	Supervisory Control and Data Acquisition
UMCS	Utility Monitoring and Control Systems

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Thanks are due to the personnel at Camp Atterbury who allowed this demonstration to take place and to all the team members at Switch Automation, past and present, who helped make this project possible through their support. Furthermore, to the Department of Defense for their commitment to exploring pathways to sustainability within our nation's largest federal agency.

ABSTRACT

At the time of this project the Department of Defense (DoD) occupies an estimated 276,770 facilities throughout the world, valued at more than $585 billion and comprising 2.2 billion square feet. The scale of DoD's physical presence is reflected in its energy *bootprint*. In 2016, DoD consumed an estimated 198,031,000 MMBtus, roughly 57%, of the U.S. Federal Government's total energy budget for the same year. The utility and operational data generated by such a scale of operations are enormous. Without a unified system to automatically collect, normalize, and present these data in a meaningful way, DoD energy and facility managers are left with the task of doing this manually.

The project objective involved implementation of a software-based toolset enabling site operators with the capability to make effective, real-time data-driven decisions to reduce operating and energy expenses while monitoring additional conditions such as occupant comfort.

The User Interface (UI) serves to add analytics capabilities and provide a normalized interface for managing disparate systems. Core functionality is predicated on data access, normalization and management.

The technology costing framework takes several factors into consideration to determine the total value invested to deliver product and service. The scope and detail of each project is considered when applying the framework to accurately assess value input against value output, resulting in a tailored "best support model" for each site. These factors include data connection method, API/driver development, size of site, complexity of site, required training, and consultative support needed. Approximate numbers for common scenarios are provided within the body of this report.

During this demonstration, the team were able to meet several of the outlined Performance Objectives. The energy savings for all identified opportunities was estimated to be greater than 9% across the portfolio of buildings within the project, though not all these opportunities have yet been implemented. Additionally, numerous recommendations were made regarding incorrect or excessive equipment operation: These factor into the estimated energy savings, but also present less quantifiable results realized in reduced maintenance. Unfortunately, due to atypical occupancy, the COVID-19 pandemic, and consistent data quality and granularity issues, reductions in peak energy demand and work order criticality were not able to be completely assessed.

EXECUTIVE SUMMARY

INTRODUCTION

At the time of this project the Department of Defense (DoD) managed an estimated 561,975 real properties spanning all 50 states, seven U.S. territories, and 42 foreign countries. DoD occupies an estimated 276,770 facilities throughout the world, valued at more than $585 billion and comprising 2.2^{+} billion square feet. Sixty-six percent (66%) of these are owned by DoD.[1] The scale of DoD's physical presence is reflected in its energy *bootprint*. In 2016, DoD consumed an estimated 198,031,000 MMBtus, roughly 57%, of the U.S. Federal Government's total energy budget for the same year.[2]

The utility and operational data generated by such a scale of operations is substantial. The task of effectively using this data is equally vast— made more difficult by the fact that data are generated by and stored in disparate systems of varying sophistication and detail. Implementation of a unified system to automate collection, normalization, and presentation of data, empowers DoD energy and facility managers to approach facility and installation management with efficient use of human resources and improved data informed decision-making capability.

OBJECTIVES

The objective of this project has been to demonstrate the capacity for modern, cloud-based software, to improve access to and enhance the quality of facility-related data in a cost-effective and scalable fashion, while also offering services over and above those available in standalone systems. Switch Automation worked with the Army National Guard (ARNG) and the National Guard Bureau (NGB) to collect, aggregate, and normalize disparate sources of information into a single platform and offer new services, including advanced analytics and reporting, AFDD, local and remote control of building systems, and improved energy and energy demand management. This technology provides the opportunity for analysis of energy consumption and cost savings, reduced maintenance costs, and improved time efficiency of facility managers and maintenance staff. The objectives can be grouped into the following three stages of delivery:

- **Integrate and Validate Baseline Data**: The first objective was to integrate AMI and BAS data for 12 months to create a historical database as part of this demonstration project. Data was obtained through direct integration, but challenges with data from direct integration led to flat file (.csv) ingestion methods also being utilized. These complications are discussed further in the body of this report. This historical data used for the baseline included kWh (energy consumption), KW (energy demand), BTU consumption, as well as the typical operating posture of basic control parameters (e.g., setpoints, schedules, etc.).
- **Highlight Findings and Implement Fixes**: After baselining, the demonstration was to promote and implement advanced EMIS technology and demonstrate the capacity of advanced EMIS technology to deliver value and to set forth best practices. Further to demonstration targeted implementation and operationalization of EMIS technology in the traditional DoD context.

[1] https://www.acq.osd.mil/eie/Downloads/BSI/Base%20Structure%20Report%20FY15.pdf
[2] http://ctsedwweb.ee.doe.gov/Annual/Report/Report.aspx

- **Authority to Operate Acceptance**: Upon completion of the demonstration project, the objective was to provide a compelling case for adoption of this technology to the energy and facility management stakeholders. By meeting several of the key performance indicators described in Section 3, and by obtaining a letter of attestation from participants in the demonstration, the objective is to further provide the assurances that most cybersecurity stakeholders require that this technology can complete the Risk Management Framework (RMF) process and achieve Authority to Operate (ATO).

TECHNOLOGY DESCRIPTION

The technology required for this demonstration consisted of hardware to integrate systems "at the edge" (i.e., within the facility), software on the hardware to pre-process the data collected at the edge, and cloud services hosted off-site and applied after data was sent to the cloud.

The hardware used for this demonstration project was the Dell Edge Gateway 3003, and after July 2021 the Advantech UNO 420. This Internet of Things (IoT) device was used to host the full complement of integration drivers and data processing applications of the vendor's software stack. Software hosted on the IoT device are:

- Ubuntu Core 16 (Dell customized)
- Docker version 18.06.1-ce
- Ubuntu Core 20 (Advantech units)
- Switch Janus v1.36

Once data was integrated and sent to the cloud, it was hosted in a Microsoft Azure data center. As part of this project, a private Azure instance was established in a Federal Risk and Authorization Management Program (FedRAMP) compliant Gov. Cloud data center. This instance is available for use should this technology be adopted and ATO is achieved.

The vendor cloud software leverages the following three distinct data ingestion methods: flat file/data mapping (.csv), appliance (edge), and Application Programming Interfaces (APIs). Under this demonstration project, appliance integration was leveraged for AMI, BAS, and any other available data sources at the edge. Historical utility bills were also ingested via flat file/data mapping (.csv) to backfill data which was not uploaded from the edge due to cellular connectivity issues which will be further described.

Data, once integrated to the cloud, was open to several different platform features and applications. These applications include analytics, visualizations and reporting, data tagging and trending tools, control, opportunity tracking (Events) and others briefly described in Figures ES-1 below. Further details on how these applications were applied to the project can be found in Section 2.0.

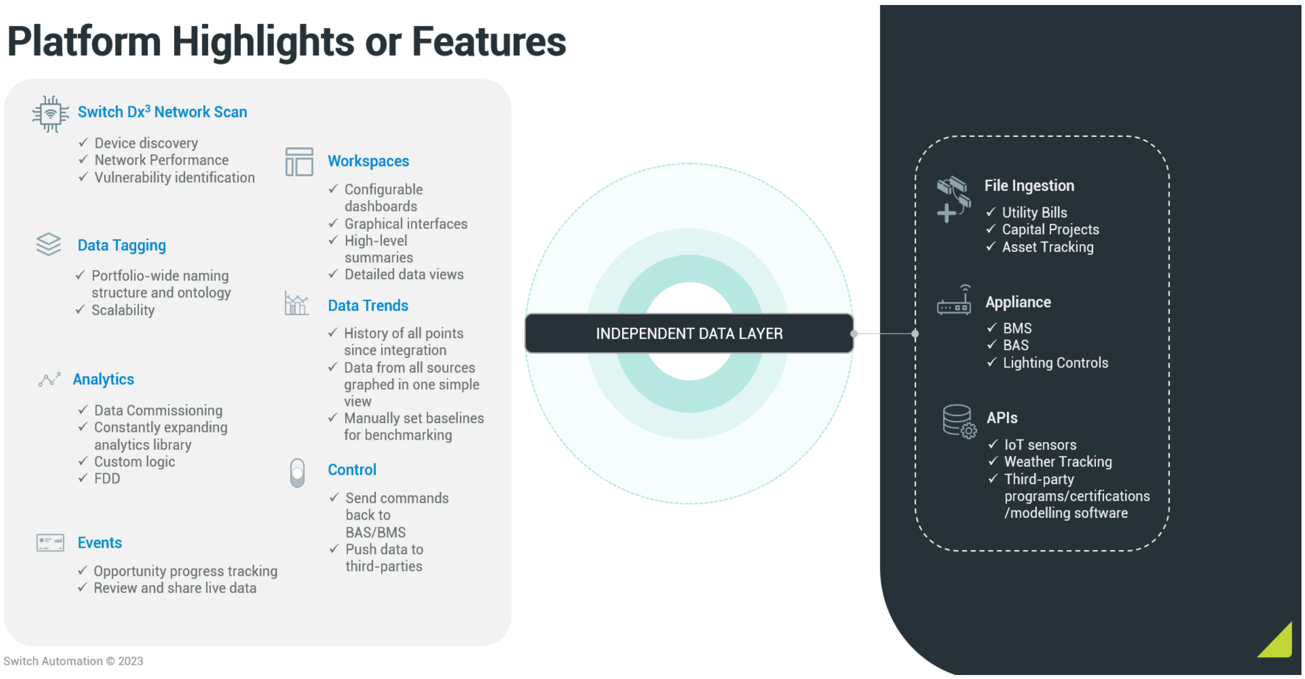

Figure ES-1. Platform Features and Applications

PERFORMANCE ASSESSMENT

Quantitative performance objectives under this demonstration project related primarily to reductions in energy consumption, maintenance costs and equipment failure. Greater flexibility in facility operations, leveraging remote- control of facilities and a greater ability to shed and shift load has financial benefits, as well as enhanced security benefits.

The table below lists each Performance Objective (PO), the data required, the success criteria, and the respective results.

Table ES-1. Performance Objectives

Performance Objective	Metric	Data Requirements	Success Criteria	Results
Quantitative Performance Objectives				
PO 1 Reduced Energy Consumption	kBtu/ft^2	Historical utilities/energy consumption data	Identify opportunities for ≥7% reduction in kBtus, resulting cost savings, weather and occupancy normalized	Approximate calculations show a potential of >9% kBtu reduction if all raised opportunities are implemented. Refer to Appendix B& C for further details.

Table ES-1. Performance Objectives (Continued)

Performance Objective	Metric	Data Requirements	Success Criteria	Results
PO 2 Reduced Power Demand	kW	Energy demand data from AMI	Identify areas for reduction in peak demand (kW) by ≥10%	Peak demand reduction is not able to be accurately compared due to issues relayed in Sections 6 and 8
PO 3 Mechanical Equipment Runtime & Operation	% hours Events Identified	Control parameters from pilot sites Switch Event	≥5% identified opportunities for reduction in equipment runtime and verify desired operational schedules (presently 24/7 for some facilities) Identify events of operational improvement	Approximately 10% of raised opportunities identified equipment or systems running excessively, for 3 of the 5 pilot sites
PO 4 Improved Mechanical Equipment Maintenance Via Work Order Tracking	Count by Severity	Work order (WO) data for pilot sites	Track changes in WO criticality, response time, and maintenance visits (tracking is the first step, with the aim for reduction in quantity and severity)	Several requests for Work Order data were made by the vendor project team. This data was not provided by site team. No specific reason was cited.
itative Performance Objectives				
PO 5 Improved Analytics & Workflow	Satisfaction	User Login Tracking	Adoption of Platform features – user login once per month per site	Site team used Opportunity tracking tool and were educated on use of dashboards, but were not active in the platform on a weekly or even monthly basis

COST ASSESSMENT

The costing framework takes several factors into consideration to determine the total value invested to deliver product and service, including data connection method, API/driver development, size and complexity of site, required training, software features used, and consultative support needed. The scope and detail of each project is considered to apply a tailored "best support model" for each site.

IMPLEMENTATION ISSUES

This demonstration uncovered several implementation issues. Some were known prior to the demonstration, but ended up being a larger issue than expected, whilst others were uncovered through the demonstration process:

Site Team Engagement: The most important factor in the Switch Platform being an effective tool is active engagement and use of the tools by the site and/or facilities team(s). Unfortunately, low engagement limited demonstration effectiveness.

- **Reasons for Lack of Engagement:**
  - Project disruptions due to the COVID-19 pandemic caused several distractions with respect to priorities & availability of site teams.
  - Additionally, site team members present during project kickoff were subsequently deployed and replaced, resulting in a lack of historical knowledge of the project objectives and intent. Stakeholder (and user) buy-in was compromised as a result.
- **Challenges with Lack of Engagement:**
  - The above factors resulted in a lack of platform engagement, which led to low meeting attendance, sub-optimal opportunity resolution, and in some cases a lack of supplementary data provided to vendor.
- **Recommendations for Increased Engagement:**
  - Future uses of this technology would benefit from a "champion" who can be trained in the analytical tools made available within the platform, prioritize insights, and ensure that internal processes for opportunity resolution are followed. These individuals are then able to engage new DoD users with the technology for continuity of use, and continuity and/or expansion of program objectives and outcomes.

Inconsistent Internet Connectivity: The Switch Appliance pushed data to the cloud via a cellular connection. Often, this connection did not work properly, resulting in a loss of data or data that was improperly aggregated. This is not standard operating procedure for deployment but was necessary in this demonstration for security compliance.

- **Reasons for Internet Connectivity Issues**
  - Cellular/SIM data services were utilized as temporary measure for cyber compliance as approval for hardwired internet was not granted during the project.
- **Challenges with Internet Connectivity Issues**
  - Cellular connections regularly have issues maintaining consistent connectivity. This can be due to the location of the modem (in a concrete room or near high interference areas) or due to the location of the site (in a remote location). Cellular connections also have cost implications to the project due to cellular carrier fees and data chargers.
  - Due to poor connectivity, it was difficult to baseline utility data and maintaining a transparent view into the five pilot sites at the beginning of the project.

- **Recommendations for Improved Connectivity**
  - If SIM cards are required, it is recommended that modems with dual SIM card capabilities are utilized for increased resiliency. Dual modems were installed for this project to mitigate the above challenges faced early in the program.
  - If ATO is achieved, internet connectivity issues should decrease significantly as the need for a cellular connection will no longer be present.

As noted previously, the use of cellular connections is not recommended as a primary enabler of data transport for this type of application. While valuable in select scenarios (e.g. this instance for temporary cyber compliance), cellular/SIM data services should generally be considered as a failover mechanism as appropriate.

1.0 INTRODUCTION

At the time of this project, the Department of Defense (DoD) managed an estimated 561,975 real properties spanning all 50 states, seven U.S. territories, and 42 foreign countries. DoD occupies an estimated 276,770 facilities throughout the world, valued at more than $585 billion and comprising 2.2^{+} billion square feet. Sixty-six percent (66%) of these are owned by DoD.[3] The scale of DoD's physical presence is reflected in its energy *bootprint*. In 2016, DoD consumed an estimated 198,031,000 MMBtus, roughly 57%, of the U.S. Federal Government's total energy budget for the same year.[4]

The utility and operational data generated by such a scale of operations are enormous. The task of effectively using this data is equally challenging— made more difficult by the fact that data are generated by and stored in disparate systems of varying sophistication and uniformity. Without a unified system to automatically collect, normalize, and present these data in a meaningful way, DoD energy and facility managers are left with the task of doing this manually. This approach to facility and installation management results in inefficient use of human resources and compromises decision-makers' ability to make data-informed decisions in a timely fashion.

1.1 BACKGROUND

Following the Energy Policy Act of 2005 and the Energy Independence and Security Act of 2007, the DoD has deployed a vast network of advanced metering infrastructure (AMI). The objective is to facilitate the collection of more granular energy and water consumption data and use the insights contained therein to promote more efficient and secure operations across each service.

Although the Services have worked to comply with the requirements under the law, scaling the deployment of AMI hardware has proven difficult. Even more challenging, and perhaps more important, has been harvesting interval and other data for actionable insights. Breakthroughs in cloud computing technology and applications developed specifically for facility management present a significant opportunity to harness the data being generated by the DoD and produce far greater value from these services.

Many organizations, including the United States Department of Energy (DOE), have invested resources in studying Energy Management Information Systems (EMIS). A general taxonomy has emerged to distinguish different EMIS offerings based on data scope and interval, and the sophistication of the application(s). Monthly utility bill management and analysis is the most common and least sophisticated form of energy management. Building automation systems (BAS) have become ubiquitous and are the second most common EMIS.

Energy Information Systems (EIS) are characterized by the software and hardware required to analyze, visualize, and, in the case of Advanced EIS, automatically curate opportunities from granular energy meter data. Automated Fault Detection and Diagnostics (AFDD) systems are characterized by a BAS software overlay that provides advanced analytics.

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[3] https://www.acq.osd.mil/eie/Downloads/BSI/Base%20Structure%20Report%20FY15.pdf

[4] http://ctsedwweb.ee.doe.gov/Annual/Report/Report.aspx

Automated System Optimization (ASO) takes AFDD one step further, continuously analyzing system performance and leveraging supervisory control to optimize operations for different parameters, including energy unit costs or carbon intensity, in real time.[5]

Table 1. Energy Management Information Systems

Classification	Data	
	Scope	Interval
Benchmarking and Monthly Utility Bill Analysis	Whole building energy consumption and cost	Monthly
Energy Information System (EIS)	Whole building energy	Hourly or sub-hourly
Advanced EIS	Whole building energy	Hourly or sub-hourly
Building Automation System (BAS)	Control parameters	Hourly or sub-hourly
Automated Fault Detection and Diagnostics (AFDD)	Control parameters	Hourly or sub-hourly
Automated System Optimization (ASO)	Whole building and system level energy, control parameters	Hourly or sub-hourly

The DoD's current technology posture is a combination of EIS and BAS. Digital automation of facility operations and the inclusion of AMI provide a rich data landscape that, in conjunction with cybersecurity controls, can be built and improved upon in a low-profile and scalable way. Harvesting that data and opening the BAS to advanced cloud-based telemetry services makes the adoption of not just AFDD but ASO a practical next step.

If adopted, AFDD and ASO can facilitate far greater insights into the operation of single buildings and entire campuses, as well as provide new functionality that will promote greater operational flexibility and security.

1.2 OBJECTIVE OF THE DEMONSTRATION

The objective of this project was to demonstrate the capacity for modern, cloud-based software to improve access to and enhance the quality of facility-related data in a cost-effective and scalable fashion, while also offering services over and above those available in standalone systems. Switch Automation worked with the Army National Guard (ARNG) and the National Guard Bureau (NGB) to collect, aggregate, and normalize disparate sources of information into a single platform and offer new services, including advanced analytics and reporting, AFDD, local and remote control of building systems, and improved energy and energy demand management. This technology provides the opportunity for analysis of energy consumption and cost savings, reduced maintenance costs, and improved time efficiency of facility managers and maintenance staff.

[5] https://eta-publications.lbl.gov/sites/default/files/building_analytics_-_kramer.pdf

- **Integrate and Baseline Data**: The first objective was to integrate AMI and BAS data for 12 months to create a historical database as part of this demonstration project. Data was to be obtained through direct integration, but challenges with data from direct integration led to flat file (.csv) ingestion methods also being utilized. These complications are discussed further in the body of this report. This historical data that was to be used for the baseline included kWh (energy consumption), KW (energy demand), BTU consumption, as well as the typical operating posture of basic control parameters (e.g., setpoints, schedules, etc.).
- **Highlight Findings and Implement Fixes**: After baselining, the demonstration was to promote and implement advanced EMIS technology and across the Services. The overall implementation objective was to demonstrate the capacity of advanced EMIS technology to deliver value and to set forth best practices for implementation and operationalization of EMIS technology in the traditional DoD context.
- **Authority to Operate Acceptance**: Upon completion of the demonstration project, the objective was to provide a compelling case for adoption of this technology to the energy and facility management stakeholders through meeting several of the key performance indicators described in Section 3. By obtaining a letter of attestation from participants in the demonstration, this final objective is to provide the assurances that most cybersecurity stakeholders require that this technology can complete the Risk Management Framework (RMF) process and achieve Authority to Operate (ATO).

1.3 REGULATORY DRIVERS

The EMIS market has several key drivers in the private and public sectors. These drivers include both hard (legal, regulatory, policy) and soft incentives (industry standards, certifications, etc.).

Legal / Regulatory / Policy:

- Energy Policy Act of 2005
- Energy Independence and Security Act of 2007
- Executive Orders: EO 13423, EO 13514
- Federal Leadership in High Performance and Sustainable Buildings MOU 2006
- DoD Policy: Strategic Sustainability Performance Plan, Energy Security MOU with DOE
- Inflation Reduction Act of 2022

Industry Standards / Certifications

- American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE): ASHRAE Guideline 36, ASHRAE BACnet Standard 135, ASHRAE Standard 223P
- Data Ontology: Haystack, Brick, Microsoft Digital-Twins Definition Language
- LEED: Energy Analytics and On-going Commissioning
- Health & Wellness: WELL, Fitwel, RESET

2.0 TECHNOLOGY DESCRIPTION

The technology required for this demonstration consisted of hardware to integrate systems “at the edge” (i.e., within the facility), software on the hardware to pre-process the data collected at the edge, and cloud services hosted off-site and applied after data was sent to the cloud. A process of flat file/data mapping (.csv) was employed to supplement data from systems and as a means of addressing challenges with connectivity discussed elsewhere in the demonstration report.

The hardware used for this demonstration project was the Dell Edge Gateway 3003, and after July 2021 was the Advantech UNO 420. This Internet of Things (IoT) device was used to host the full complement of integration drivers and data processing applications of the vendor software stack. Software hosted on the IoT device are:

- Ubuntu Core 16 (Dell customized)
- Docker version 18.06.1-ce
- Ubuntu Core 20 (Advantech units)
- Switch Janus v1.36

Once data was integrated and sent to the cloud, it was hosted in a Microsoft Azure data center. Commercial clients’ data is generally sent to and stored in multi-tenanted data centers. As part of this project, a private instance was established in a Federal Risk and Authorization Management Program (FedRAMP) compliant Gov. Cloud data center. This instance is available for use should this technology be adopted and should ATO be achieved.

2.1 SOFTWARE OVERVIEW

The Vendor software architecture leverages various data ingestion methods to bring structured data into the cloud. These data ingestion methods typically correspond to different sources of data. Once data is brought into the cloud, the software has several features and applications which can be overlaid onto the data for various use cases. As can be seen in Figure 1, after data ingestion, several features can be utilized to meet specific use cases. In summary, the technology stack can be summarized into the following six groups:

- Network Audit
- Data Ingestion
- Data Management
- Data Visualization
- Data Analysis
- Supervisory Control

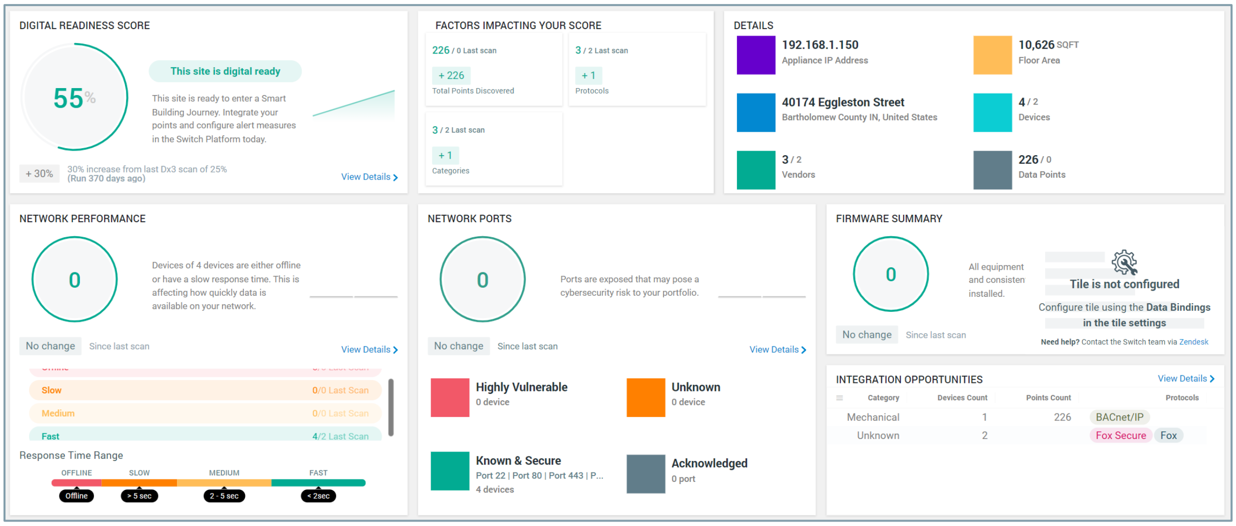
The details of data ingestion and software features that were utilized will be discussed below.

2.1.1 NETWORK AUDIT

The first step to ingesting data from the edge is to utilize the Dx^3 [digital device discovery] feature.

The purpose of this feature is to see what devices are located on the IP network, to assess any potential vulnerable ports which are exposed, to determine what data points are visible on the network, and to check for any network performance issues. This data is then rolled up into a 'digital readiness score' to provide a high-level summary indicating whether a building's network is ready for the next step – data ingestion.

Below is an image showing scan results from one building in the project. This positive score (in green) highlights that a site had enough infrastructure to support edge-based data ingestion.



2.1.2 DATA INGESTION

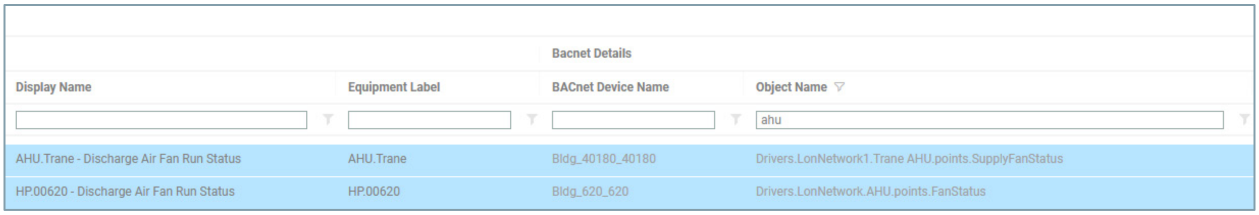
Once a site's network is audited to confirm suitability, the edge appliance integration is configured and shipped to site to ingest data from the network. If there are data sources that also need to be ingested that do not live on the edge network, these can be ingested via flat file transfers (.csv) or via cloud-to-cloud API integrations.

For this demonstration, data was ingested from the edge for all buildings and utility bill data was also ingested via .csv. Work Order data was requested on multiple occasions but was not received by the Vendor project team. Had work order data been available, this would have utilized either the flat file or API data ingestion methods.

2.1.3 DATA MANAGEMENT

After ingesting data points into the cloud, the next feature of the software stack is the data management layer. In this feature, data is brought into a central location for tagging. Ontologies and metadata schemas are applied to all points on all buildings so that the applications can be utilized at scale. This tagging schema is also required for unlocking the next levels of the software stack.

For this demonstration, standard tagging and ontologies were applied to all points. An example can be seen in the image below where device tags on different buildings in the demonstration have been normalized into a common naming structure (note – not all normalization columns have been shown in the example image).



		Bacnet Details	
Display Name	Equipment Label	BACnet Device Name	Object Name
			ahu
AHU.Trane - Discharge Air Fan Run Status	AHU.Trane	Bldg_40180_40180	Drivers.LonNetwork1.Trane AHU.points.SupplyFanStatus
HP.00620 - Discharge Air Fan Run Status	HP.00620	Bldg_620_620	Drivers.LonNetwork.AHU.points.FanStatus

2.1.4 DATA VISUALIZATION

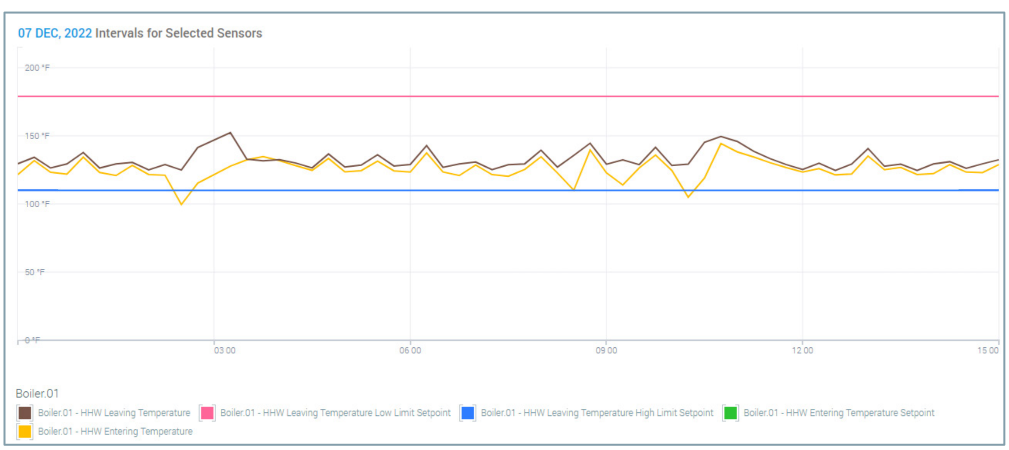
After tagging the data, one application that can be rolled out is configurable dashboards [workspaces] to help site teams interpret the raw data and assess any energy inefficiencies. The underlying infrastructure is data queries which are developed to bind to different tiles in the dashboard. Due to the consistent tagging applied to all buildings, these queries can be easily shared across the entire portfolio of buildings sharing the ontology.

The dashboards are designed to help summarize and aggregate information across buildings so the site teams can save time identifying issues. As noted earlier, support of a ‘champion’ is key in successful creation and adoption of the dashboards. The champion’s role is to advise on key metrics that need to be tracked by the team and to determine actions that need to be taken should the metrics be unfavorable.

Whilst dashboards were created for this demonstration, they were not widely adopted in day-to-day workflows by the site team.

There is also an automatically deployed, non-configurable part of the platform for viewing trend history of all points ingested by the platform. This feature is referred to as ‘Site Analysis.’

In this demonstration, the data trends feature was used when determining if equipment issues were a one-time occurrence or a long-time problem. The below image was taken from this feature.



2.1.5 DATA ANALYSIS

Another application that can be used in the software stack is an analytics tool where raw data (live and historical) can be analyzed to look for equipment faults or performance issues. These rules are deployed from a library of rules based on the equipment and points available in a particular building.

The rules can also be configured to suit specific site conditions.

In this demonstration, these rules were setup to identify energy, maintenance, and comfort issues associated with the equipment.

When issues are found, they are logged within a light ticketing system in the platform called Events. This tool provides quick links to the Site Analysis trending feature in the platform so equipment issues can be quickly reviewed. These 'events' can also be assigned to members of the site team for tracking progress of rectification.

For this demonstration, the alerts generated from the ingested data were rolled up into Events and discussed at a monthly meeting with the site team. If the site team determined the highlighted issues were worth fixing, roles/responsibilities of these issues were logged in the Event, and the potential cost savings were also included. When an issue was deemed 'critical,' an event was created outside of this monthly meeting cadence and raised with the site teams to mitigate potential energy impacts.

2.1.6 SUPERVISORY CONTROL

The final layer of the platform is supervisory control (see figure 1 below and figure 2 on next page). This part of the platform can write commands to systems via (a) manual user input or (b) scene-based rules (i.e. – if 'x' happens, then write 'y' to the system).

In this demonstration, the manual input method was utilized to remotely turn off units that were seen to be operating while buildings were unoccupied, thus saving energy.

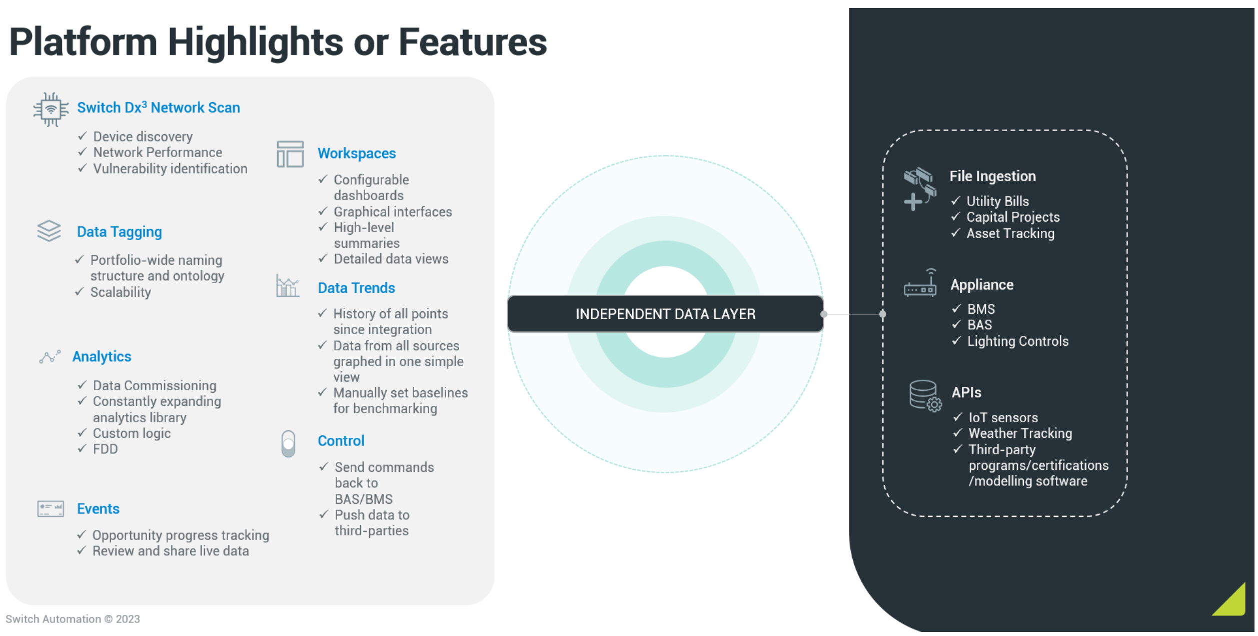


Figure 1. Platform Features and Applications

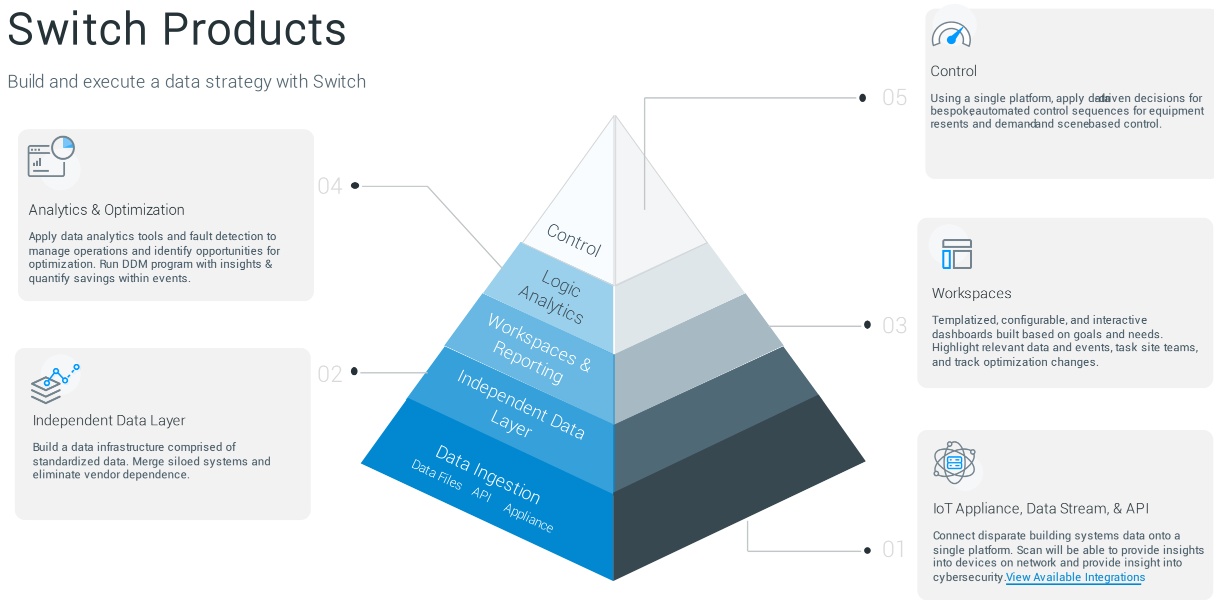


Figure 2. Platform Product Pyramid

2.2 DATA FLOW AND NETWORK CONNECTIVITY

Data flows are a critical element of the platform architecture and a common concern for cybersecurity stakeholders. Data flows to the Switch platform occur via one of the following methodologies:

Gateway [Edge] Data Transmission to Cloud

- Data is ingested from the edge device on the network and pushed up to the cloud. The only requirement for this data transmission is access to internet which has been configured to allow outbound traffic to Switch URL endpoints.
  - Internet can be provided via hardwired internet or cellular connection. Cellular connections are not recommended as a primary method.

Cloud to Cloud [Virtual] Data Transmission

- Data is transmitted from one source via a push or pull (depending on specific requirements) to the Switch cloud.
  - Dedicated API connections can be built, or flat files can be sent to an email/FTP server.

For edge data transmissions, the use of cellular connections is not recommended as a primary enabler of data transport. While valuable in select scenarios (e.g., this instance for temporary cyber compliance), cellular/SIM data services should generally be considered as a failover mechanism as appropriate. Use of cellular/SIM connectivity as a primary data transport mechanism comes with challenges, amongst which are cost and consistent connectivity. The latter is more prevalent with systems commonly deployed or housed in parts of the facility where cellular services are limited/ inconsistent, and where interference or *noise* is greater.

In this demonstration, transmission of data from the facility to the Switch Platform was done using a cellular connection. This connection was the only requirement for both read-only and command integrations. As shown in Figure 3 below, the typical 'Smart Buildings' program transmits data via an HTTPS port 443. This configuration will be an option for DoD sites if adopted after this demonstration, and once the RMF program steps are complete and the Vendor receives ATO. Historical utility data was also provided which was ingested via the flat file method.

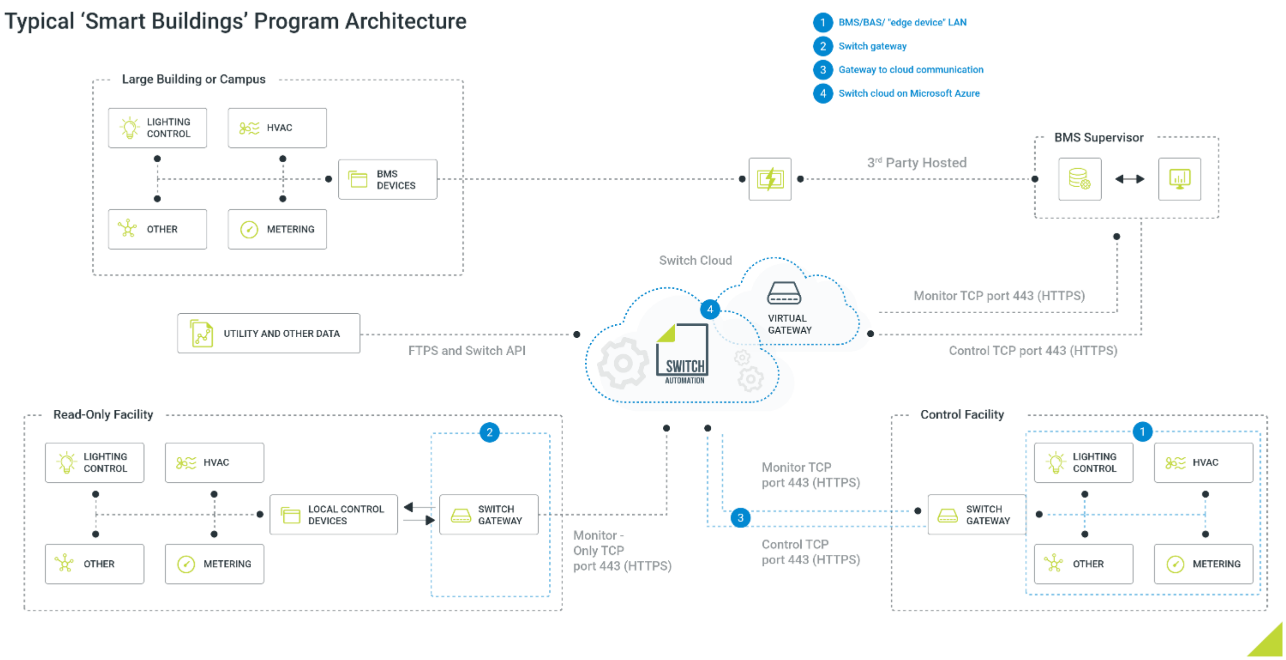


Figure 3. Typical 'Smart Buildings' Program Architecture

AFDD and Grid-Interactive Efficient Building (GEB) practices and services are possible with DoD facilities integrated into the Switch Platform using these data integration methods.

2.3 ADVANTAGES & LIMITATIONS OF THE TECHNOLOGY

Adoption of advanced EMIS technology provides significant advantages:

- **Improved access** to the data generated from facilities and campuses allows for improved decision making and more efficient use of facility management labor.
- **Advanced analytics and enhanced reporting** functionality further promote better, more informed decision making.
- **Increased transparency** and remote control allow DoD staff to better manage vendors, reducing the need for emergency work orders and unnecessary preventative maintenance visits.
- **Energy use reduction** results in overall cost savings and reduction in environmental impact from facilities operations.

- **Dedicated Professional Services** to assist site team and help keep programs going during events that may disrupt standard operating procedures on DoD campuses, i.e., deployments, space use changes, system upgrades.

The adoption of this technology also presents several hurdles:

- The technology does require an annual cloud-based SaaS subscription, which may present procurement challenges. The energy and other cost savings associated with proper implementation will, ideally, fully offset the subscription costs.
- Internet outages prevent or interrupt new edge data from being uploaded to the cloud.
  - Outages may temporarily interrupt any critical alerting or live dashboarding applications which may be in use. While disruptions will generally be considered minor, the alerts and primary venue for teams can be undermined if this type of problem is prevalent or persistent.
  - Caching data is locally enabled to prevent data gaps and loss; however, is not unlimited. Long term connectivity issues may lead to a failure in this mechanism for preventing data loss or gaps.
- The technology produces a dramatic shift in the way the DoD currently manages facilities. Operationalizing a solution like Switch, even after ATO is received, will require support from DoD leadership and a cultural change led from all levels of the Department. This challenge in adoption presents a significant hurdle for EMIS technology. Through continued education and everyday use, this technology will integrate into daily facility operation.
  - Change Management Data latency for the cloud platform also requires a shift in operations workflows. Whilst BMS systems operate at low latency on the network (<5s), the cloud technology typically operates at a higher latency (5min+). As such, workflows should be developed where the cloud platform functions as the first point of investigation.

3.0 PERFORMANCE OBJECTIVES

Quantitative performance objectives under this demonstration project related primarily to reductions in energy consumption, maintenance costs and equipment failure. Greater flexibility in facility operations, leveraging remote control of facilities and a greater ability to shed and shift load has financial benefits, as well as enhanced security benefits.

The table below lists each Performance Objective (PO), the data required, the success criteria, and the respective results.

Table 2. Performance Objectives

Performance Objective	Metric	Data Requirements	Success Criteria	Results
Quantitative Performance Objectives				
PO 1 Reduced Energy Consumption	$kBtu/ft^2$	Historical utilities/energy consumption data	Identify opportunities for ≥7% reduction in kBtus, resulting cost savings, weather and occupancy normalized	Approximate calculations show a potential of >9% kBtu reduction if all raised opportunities are implemented. Refer to Appendix B & C for further details.
PO 2 Reduced Power Demand	kW	Energy demand data from AMI	Identify areas for reduction in peak demand (kW) by ≥10%	Peak demand reduction is not able to be accurately compared due to issues relayed in Sections 6 and 8
PO 3 Mechanical Equipment Runtime & Operation	% of excessive runtime opportunities identified	Control parameters from pilot sites Switch Event	≥5% identified opportunities for reduction in equipment runtime and verify desired operational schedules (Currently 24/7 for some facilities) Identify events of operational improvement	Approximately 10% of raised opportunities identified equipment or systems running excessively, for 3 of the 5 pilot sites.
PO 4 Improved Mechanical Equipment Maintenance Via Work Order Tracking	Count by Severity	Work order (WO) data for pilot sites	Track changes in WO criticality, response time, and maintenance visits (tracking is the first step, with the aim for reduction in quantity and severity)	Several requests for Work Order data were made by the vendor project team. This data was not provided by site team. No specific reason was cited.
tative Performance Objectives				
PO 5 Improved Analytics & Workflow	Satisfaction	User Login Tracking	Adoption of Switch Platform features – user login once per month per site	Site team used Opportunity tracking tool and were educated on use of dashboards, but were not active in the platform on a weekly or even monthly basis

Reduced Energy Consumption: Improved access to data and advanced analytics allowed project stakeholders to identify opportunities to run facilities more efficiently. Tracking and management of these opportunities in the platform's Events feature. The subsequent savings were calculated using AMI data from each facility and approximate utility end use breakdowns based on each building type.

In facilities with simple RTUs and AHUs, such as the facilities in this pilot program, this technology was used to realize reductions in energy-related costs while maintaining or improving occupant comfort. This was done through intelligent monitoring of the operation and outdoor air use of these units. In buildings with more complex systems the potential savings increase due to additional opportunities to improve equipment operation via scheduling, fault detection and diagnostics, and informed optimization.

Reduced Power Demand: Using the Platform's Azure Data Explorer (ADX) time-series database to create a model for each pilot site creating peak demand thresholds based on conditions including weather, time of day, day of the week, and month. The intent was to have the team create active energy management logic to predict peak demand events and encourage subtle changes in operation to reduce peak loads. Unfortunately, due to external factors this goal was not realized.

Unusual changes in occupancy due to the COVID-19 pandemic and the intermittent housing of refugees at Camp Atterbury, coupled with an unreliable data connection discussed herein, prevented development of a functional model.

Equipment Runtime & Operation: Integration to the BAS provided interval (15-minute) data for each control parameter in each facility. Like the Reduced Energy Consumption metric, the Vendor was able to monitor operations via the Platform and then, using in-platform features including Events, Site Analysis, and Workspaces, visualize and easily compare the intended or ideal schedules and/or operation of various pieces of equipment with reality. The Vendor used this interval data to verify that the equipment was not running appropriately and raised these issues to the site team.

Improved Mechanical Equipment Maintenance Via Work Order Tracking: Leveraging the ADX technology described above, a machine learning (ML) model was created to baseline operations at each site. This model was then used to publish an anomaly Workspace to track deviations in expected performance that were indicative of equipment deterioration.

Historical work order data was not made available, which would have allowed the Vendor to track changes in work order criticality, response time, and maintenance visits. The goal was to see a reduction in critical work orders and response times. This reduction due to the Platform's preemptive fault detection would not only have provided cost savings from reduced "truck rolls", but also save the time of on-site users such as the occupant who no longer must send in a complaint about a hot or cold room and the facilities team that no longer must laboriously diagnose the cause behind that occupant's complaint.

Improved Analytics & Workflow: Software tools for analytics, optimization and management are only fully successful if users learn and adopt the tools. The Vendor platform is designed to make operating facilities more efficient and to make the operator more efficient. The longevity of this solution for the DoD requires careful training and adoption of services.

Unfortunately, the site team did not prioritize their own use of the Platform. Instead, they acted on opportunities raised in-platform during regular check-in meetings. For this Platform to truly scale and become useful, site teams will need to take a vested interest in utilizing the analytic tools made available and integrate them into regular workflows and processes.

As noted, high utilization of the software is usually realized when there is a champion driving adoption. This champion is necessary because many parties are unmotivated to change long standing workflows and practices. Additionally, maintenance contracts are commonly structured for scheduled, or time-based, checks. The adoption of this software technology allows sites to maintain building systems based on the highest priority fault; however, if the maintenance contracts are not amended to suit, site teams will continue their normal routines.

4.0 FACILITY / SITE DESCRIPTION

Integration to the Platform required direct digital control (DDC) systems utilizing an IP network infrastructure with devices communicating via open protocols such as BACnet and Modbus. Most modern facilities, including those in the DoD portfolio, have some digital controls infrastructure. Site selection for this demonstration project focused primarily on the availability of DDC infrastructure. Beyond the presence of DDC, the focus stayed on engaged partners willing to commit their facilities and time to a multi-year demonstration project.

4.1 FACILITY/SITE LOCATION AND OPERATIONS

During the project scoping phase, the energy manager for the Indiana Army National Guard (INARNG) volunteered five (5) sites for the demonstration. These facilities were selected because they were representative of the broader INARNG portfolio. These are also facilities that required updated Utility Monitoring and Control Systems (UMCS). Decoupling these facilities from the GuardNet to facilitate the initial Vendor integration was thus expected to be a relatively easy endeavor for this demonstration. Initially, the Maine Army National Guard (MEARNG) volunteered seven (7) sites for this project. However, MEARNG withdrew before those sites could be integrated into the Platform.

The table below lists these five different facilities. It also lists the building areas in square feet (ft^2) and the installation where located.

Table 3. Demonstration Sites

State	Installation	Building	Area (ft2)	Metered Utilities [E = Edge] [U = Utility Bill]	Integrated Systems
IN	**Camp Atterbury**	Bldg. 350, Dining Facility	23,449	Electricity [E,U] Gas [E,U] Water [E]	BACnet/IP enabled JACE
		Bldg. 619, TT Barracks	4,998	Electricity [E,U] Gas [E,U] Water [E]	BACnet/IP enabled JACE
		Bldg. 620, TT Barracks	4,998	Electricity [E,U] Gas [E,U] Water [E]	BACnet/IP enabled JACE
		Bldg. 4087, Conference Center	9,893	Electricity [E,U]	BACnet/IP enabled JACE
		Airfield Fire & Rescue Station	10,626	Electricity [E,U] Gas [U]	BACnet/IP enabled JACE

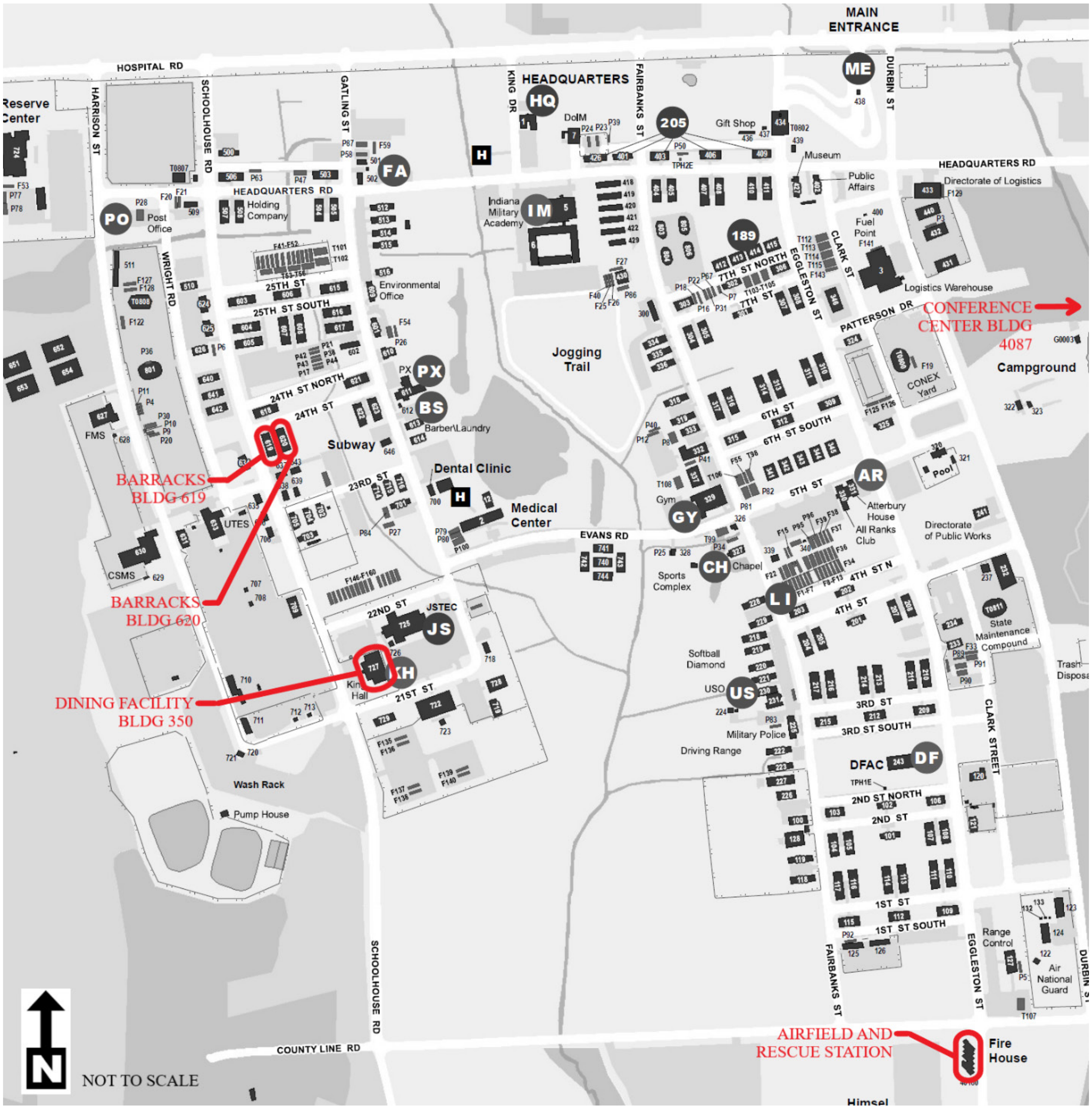


Figure 4. Map of INARNG Demonstration Sites at Camp Atterbury

4.2 FACILITY/SITE CONDITIONS

Smaller facilities like those in this demonstration are often deemed too small to invest in the infrastructure that would allow for full data transparency, which presented an excellent opportunity to demonstrate how Switch can connect to disparate BACnet IP enabled control systems in different locations, integrate them, and view all the subsequent data in a single platform. This enabled a new level of visibility into the building systems of an entire portfolio.

5.0 TEST DESIGN

Operational data generated by most DoD facilities is not captured, managed, analyzed, or utilized to the extent made possible by advanced EMIS technology. Managing data from numerous sites is a difficult task and having the resources to analyze the data for informed decision making is even more arduous. How, then, can the DoD effectively use their collected facilities data to reduce their energy consumption and improve performance of their systems?

5.1 CONCEPTUAL TEST DESIGN

- **Hypothesis**: Application of advanced EMIS technology and techniques should reduce energy consumption, improve energy management, reduce maintenance costs and equipment failures, and improve operator job satisfaction and performance.
- **Independent Variable**: Integration of pilot facilities to the Platform and application of Platform features, including AFDD, advanced modeling analytics, control, and opportunity and workforce management tools.
- **Dependent Variable(s)**:

1.	Energy Consumption	kBtu
2.	Electricity Demand	kW
3.	Equipment Runtime	Hours
4.	Maintenance Expenses	USD ($)
5.	Operator Adoption	Platform Logins

- **Controlled Variable(s)**: Energy and maintenance intensity in the built environment are influenced by two key variables; weather and occupancy. These will be accounted for to the best of the research team's ability. Normalizing for weather is common in energy management and analysis and Switch will follow ASHRAE standards in accounting for weather. Occupancy will be more difficult, but the Vendor will work closely with the host site operators to collect the necessary data.
- **Test Design**: For INARNG demonstration sites, the Vendor collected and trended baseline operations data in the Platform. This provided critical insights into how facilities were operated before the integration to the Platform. Additional sites beyond those in this demonstration will be needed to provide the historical data necessary for testing the hypothesis or allow for a similar 12-month baselining period.
- **Test Phases**:

  Systems Integration: After the five INARNG sites were decoupled from GuardNet, the appliance was installed on site and used the appliance's cellular capabilities to send the facility data to the cloud. This facility data was then imported and integrated into the Platform.

  Commissioning: Once the systems were integrated into the Platform, data collection began. The Vendor used this data to facilitate compilation of facility and systems data and insight into the operation of existing mechanical and electrical systems.

Historical Measurement: The platform collected real time data from the five INARNG sites for 12 months to further develop solid baseline records for each of these sites. These baseline measurements included existing operational energy metrics as well as systems equipment performance and runtime data points.

Managed Services/Delivery: After the baseline measurements were obtained, the Vendor team used the platform's features and applications to analyze the facility data, facilitate solving data quality issues, communicate energy saving opportunities through the Events feature, provide AFDD, and produce visualizations and reporting through Workspaces.

Measurement and Verification: Working in partnership with the demonstration hosts to address opportunities for energy savings and improve systems operations, the resulting energy savings, power demand reduction, and reduced equipment runtimes were measured and reported throughout the demonstration.

5.2 BASELINE CHARACTERIZATION

- **Reference Conditions**: Below is a list of example data points that were integrated into the Platform to monitor and analyze from the facilities base systems. Note that this list is not exhaustive, and not all points apply to all sites. The list is, however, representative, or typical of facilities of this size and purpose.

AHU/RTU

- Alarm Status
- CHW Valve Position
- Cooling Status
- Discharge Air Fan Speed
- Discharge Air Fan Speed Command
- Discharge Air Temperature
- Discharge Air Temperature Setpoint
- Economy Mode Enable Status
- Fan Run Status
- Heating Status
- HHW Valve Position (Primary)
- Mixed Air Temperature
- Occupancy Status
- Outside Air Humidity
- Outside Air Damper Position
- Outside Air Damper Position Low Limit Setpoint
- Outside Air Temperature
- Reheat HHW Valve Position (Secondary)
- Return Air Temperature
- Reversing Valve Command
- Zone Air CO2
- Zone Air Humidity
- Zone Air Temperature
- Zone Air Temperature Occupied Cooling Setpoint
- Zone Air Temperature Occupied Heating Setpoint
- Zone Air Temperature Unoccupied Cooling Setpoint
- Zone Air Temperature Unoccupied Heating Setpoint

Heat Recovery Wheel

- Cooling Lockout Outside Air Temperature Setpoint
- Discharge Air Temperature
- Exhaust Air Temperature
- Heating Lockout Outside Air Temperature Setpoint
- Outside Air Temperature

Chilled and Hot Water Systems

- Boiler - HHW Entering Temperature
- Boiler - HHW Leaving Temperature
- Boiler - HHW Leaving Temperature Setpoint
- HHWS - Heating Lockout Outside Air Temperature Setpoint
- HHWS - HHW Valve Position (Mixing)
- CHWS - CHW Entering Temperature
- CHWS - CHW Leaving Temperature

Electric Meter

- Active Energy Delivered
- Active Energy Received
- Active Power
- Active Power A
- Active Power B
- Active Power C
- Apparent Power
- Apparent Power Phase A
- Apparent Power Phase B
- Apparent Power Phase C
- Current A
- Current B
- Current C
- Current L-L Average
- Frequency
- Peak Demand
- Peak Demand
- Phase Angle
- Phase Angle A
- Phase Angle B
- Phase Angle C
- Power Factor
- Power Factor A
- Power Factor B
- Power Factor C
- Reactive Energy Delivered
- Reactive Power
- Reactive Power A
- Reactive Power B
- Reactive Power C
- Real Electric Energy
- Voltage AB
- Voltage AN
- Voltage BC
- Voltage BN
- Voltage CA
- Voltage CN
- Voltage L-L Average
- Voltage L-N Average

Miscellaneous

- Building Air Pressure
- Building Air Pressure Setpoint
- Building Emergency Switch Status
- Building Max Zone Air CO2
- Building Occupancy Command
- Building Zone Air CO2 Setpoint
- Gas Flow Meter - Flow Rate
- **Water Flow Meter - Flow Rate**

Whilst the above list is quite extensive, there is technically no minimum data requirement. Generally, most sites do not have a full understanding of the data available within their buildings, and as such, it is best to start with performance requirements like those defined in section 6. Once the requirements are known, the network audit can be performed to assess if enough sensors and data points are available. If there are enough sensors, no additional hardware needs to be installed. If there are not enough sensors, additional hardware can be specified and installed prior to moving further into the software stack.

- **Baseline Collection Period**: To account for weather and seasonal influences in operations, the Vendor baselined data for a period of twelve months before beginning to apply/implement changes from the EMIS at the INARNG sites being evaluated under this demonstration project. Due to connectivity issues, historical utility bills were also ingested to achieve a complete data set. In the future, it is recommended additional sites added after achieving ATO provide twelve or more months of historical data to quickly establish the baseline. It would be further required that this data is available prior to connecting to any new site.

- **Baseline Estimation**: The Vendor leveraged all available research from ASHRAE, the DOE, and other industry standard bearers to evaluate facility and system performance, as well as the impact from the EMIS demonstration.

- **Data Collection Equipment**: The Dell Edge IoT and Advantech appliance were utilized to integrate systems and to collect, trend and analyze data.

5.3 DESIGN AND LAYOUT OF SYSTEM COMPONENTS

- **System Design**: As described above, the system being demonstrated consisted of:
  - Hardware: Dell Edge IoT and Advantech Appliances
  - Software on the Appliance: Commercial off the Shelf (COTS) & Proprietary Switch Automation Microsoft Azure Hosted Smart Building Platform

  The system also included the incumbent building DDC, AMI and BAS infrastructure. At the INARNG pilot sites, these included:

  - DDC: Honeywell WEB 8000 & Tridium JACE 8000
  - BAS: Niagara AX 3.8 Supervisor

- **System Depiction**: The picture below shows a control panel at the INARNG Fire Station. The digital controls are wired back to a panel where the vendor Appliance was also integrated. Systems were integrated using Cat 5 Ethernet cabling. Power to the Appliance was delivered over Ethernet in the second port.

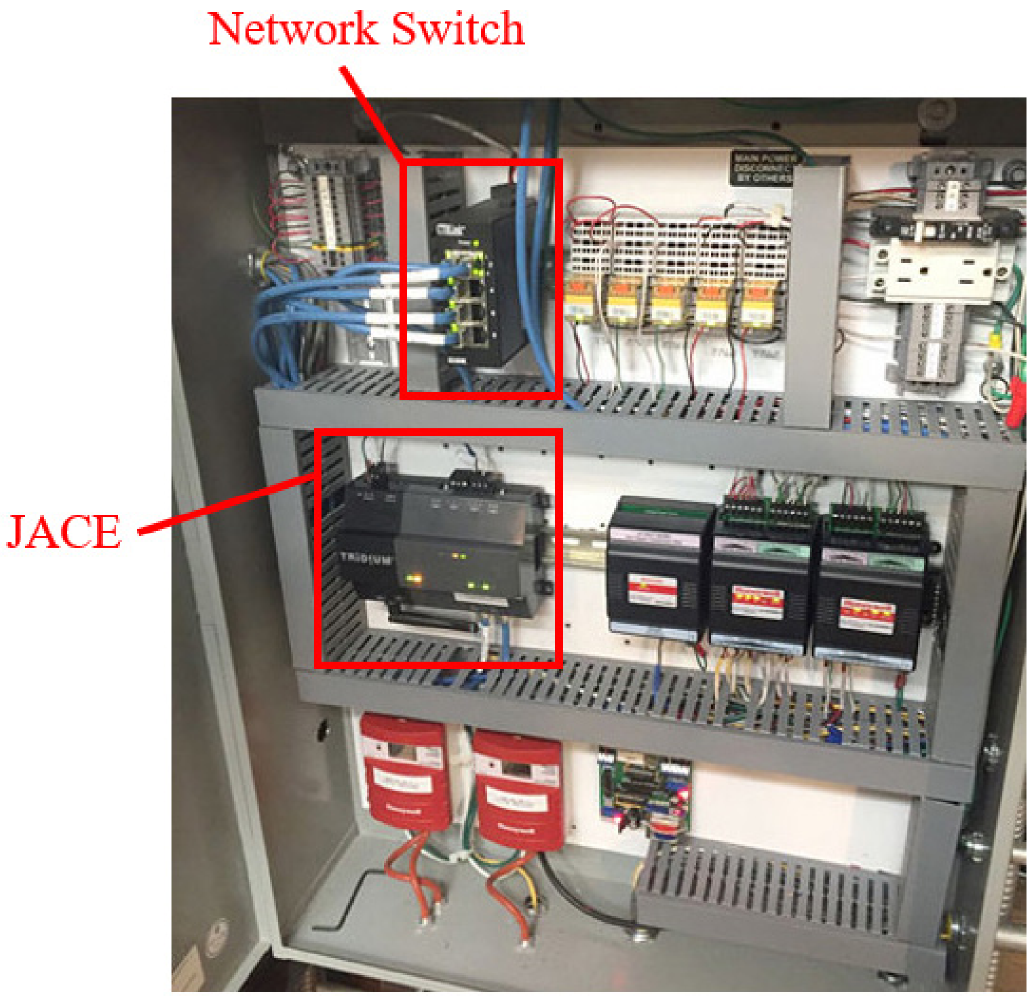


Figure 5. INARNG Fire Station Control Panel

- **System Integration**: Installation of the Vendor Appliance allowed the software to discover digital devices on the facility BAS. The software stack on the appliance enables discovery of available "points" (i.e., control parameters), which were then integrated relevant points and configured the data to fit the program design objectives.

This process effectively created a software middleware for facility monitoring and control equipment. This opened the facilities up to the many advantages of cloud-based services.

The diagram below illustrates the physical data flows for this demonstration integration.

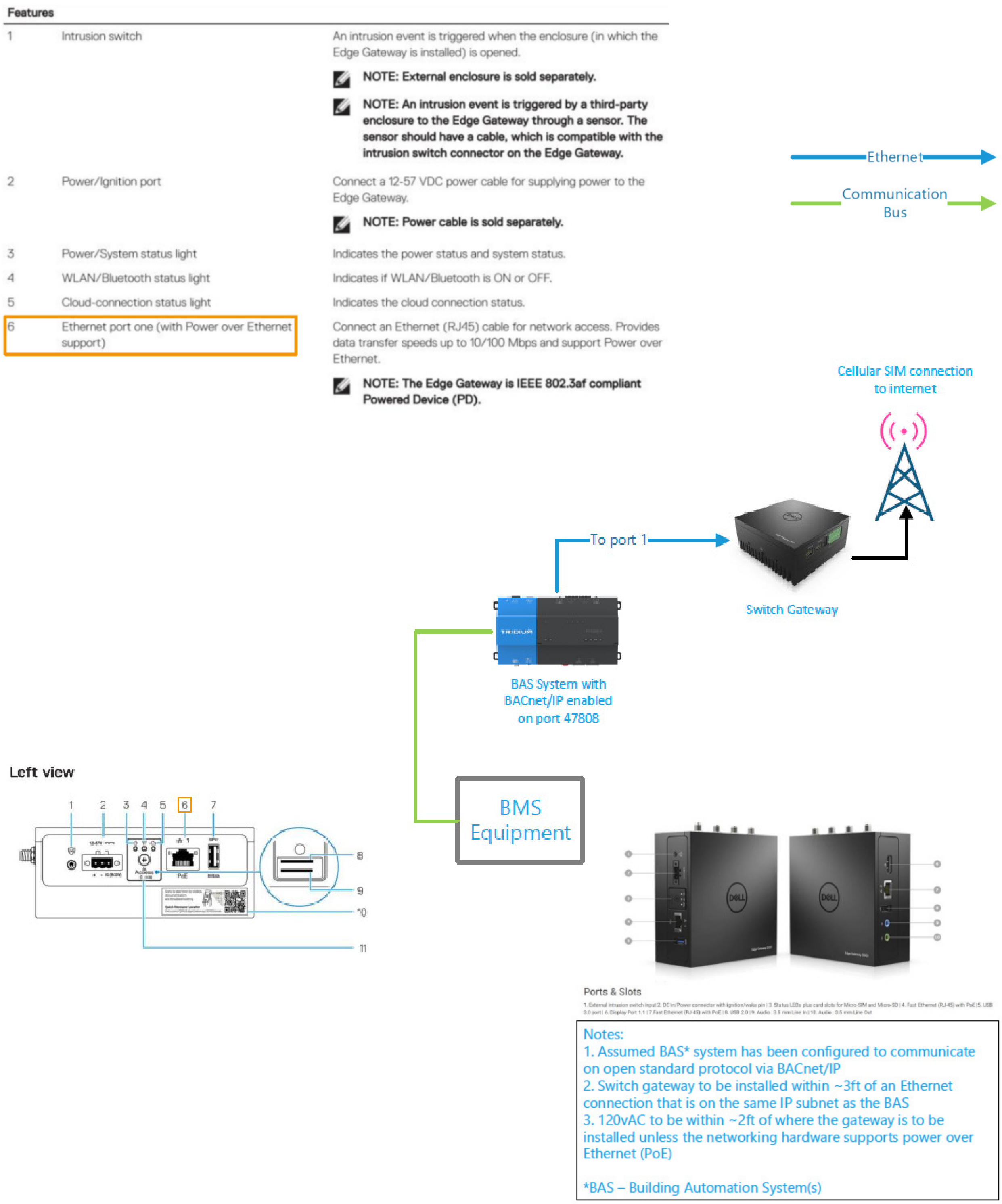


Figure 6. Typical Department of Defense Switch Automation Integration

- **System Controls**: The integration strategy outlined above appears simple (and is). The hardware requirements from the Vendor are minimal. Cellular connection was required for transmission of data to the vendor cloud. Through most of the demonstration, the Platform was simply monitoring the data. Near the end of the demonstration the hosts decided to utilize the control functionality of the Platform. If the loss of cellular connectivity or catastrophic failure of the Vendor Platform occurred, facility operations would revert to native control sequences and command parameters.

5.4 OPERATIONAL TESTING

- **Operational Testing of Cost and Performance**: Vendor analyzed facility operations, evaluated those operations, and prescribed alternative operational strategies expected to be more efficient from an energy and maintenance perspective. It is important to note is that operational strategies suggested will not have compromised occupant comfort or access.
- **Modeling and Simulation**: The Vendor Engineering Services team used building science fundamentals to curate alternative operating strategies. The team also referred to industry standard bearers like ASHRAE and their Guideline 36 to model and implement optimal sequences of operation for HVAC systems.
- **Timeline**: After collecting twelve months of data at the INARNG pilot sites, the team began operational testing in September 2021.

5.5 SAMPLING PROTOCOL

- **Data Collector(s)**: The Platform collected 15-minute interval data from the BAS and AMI using Modbus and BACnet drivers on the Vendor Appliance. Additional data was requested with support from DoD stakeholders that have access to historical and broader data sets, such as occupancy data, work order data, non-digitally metered natural gas consumption, and utility cost data. In cases where any of this information was not made available from the sites, it did not affect the success of the demonstration, only the ability to provide thorough reporting of the results.
- **Data Recording**: Data collection was automated.
- **Data Description**: Vendor expected twelve to twenty-four months of data from each pilot site. At 15-minute intervals, for the expected data readings per site per data point were:
  - Minimum: 26,000
  - Average: 35,000
  - Great: 70,000

See Section 5.2 for a sample of the data points that were collected and analyzed.

- **Data Storage and Backup**: Vendor uses Microsoft Azure data storage and backup practices. These practices offer geographic (data center) redundancy and best-in-industry disaster recovery practices.

- **Data Collection Diagram**: See Section 5.2 for a sample of the data points. Figure 7 illustrates the data flows.

- **Site Engagement**: Site team engagement with the Platform was tracked via number of logins.

5.6 SAMPLING RESULTS

All data was collected, sorted, and appropriately named in the Platform "Points" tool after ingestion into the platform. This tool collates discoverable data from the various BAS into a single location, where the technology was then able to add additional information (common metadata) to make the data manageable. Because each of the hundreds of individual points are being polled on a 15-minute basis, the entirety of the collected data cannot be easily shared. However, an example of the points tool is provided below in Figure 7, showing the points associated with "VAV.02" in the Airfield and Rescue Station

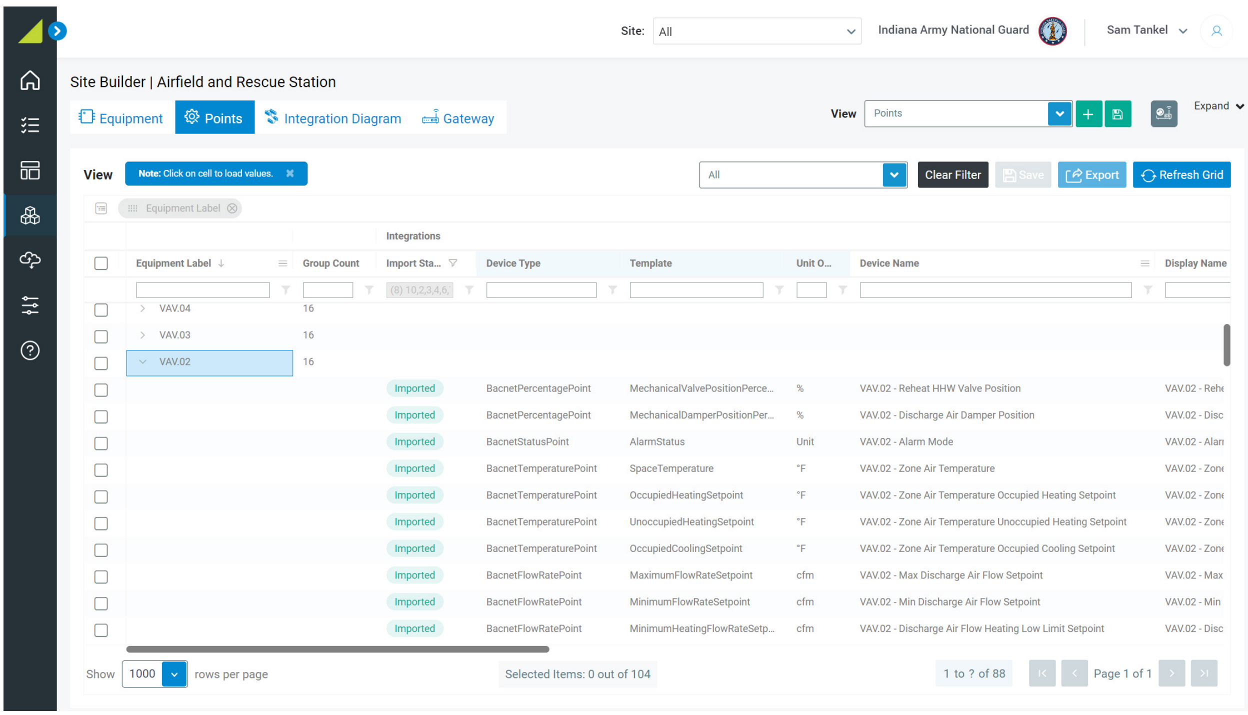


Figure 7. Example of Switch Platform Points Tool

After the point naming process was completed, the incoming data was interrogated using the Alerts Analysis and Site Analysis tools. Alerts Analysis provided in-platform alerts whenever customizable logical rules were triggered, as can be seen in Figure 8 below. Site Analysis allowed users to view the trend data of any point within the platform, seen in Figure 9, which was utilized to confirm the alerts from Alerts Analysis and to identify additional opportunities.

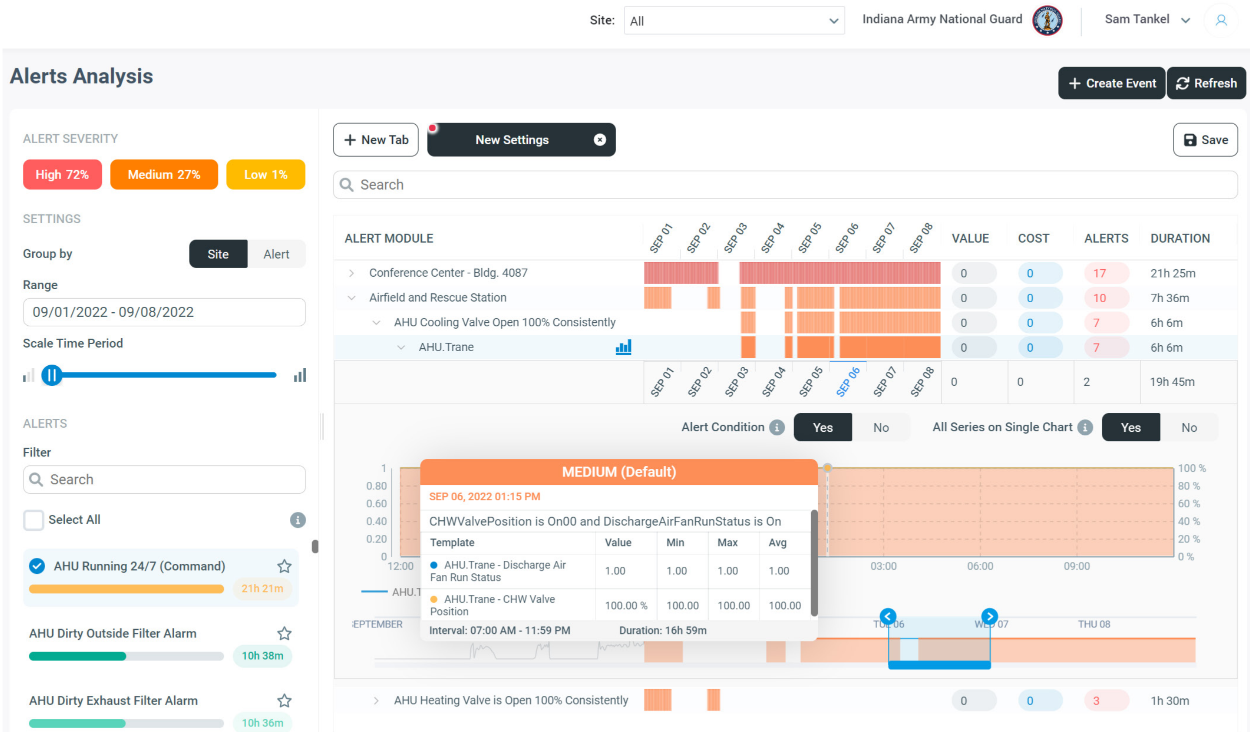


Figure 8. Example of Switch Platform Alerts Analysis Tool

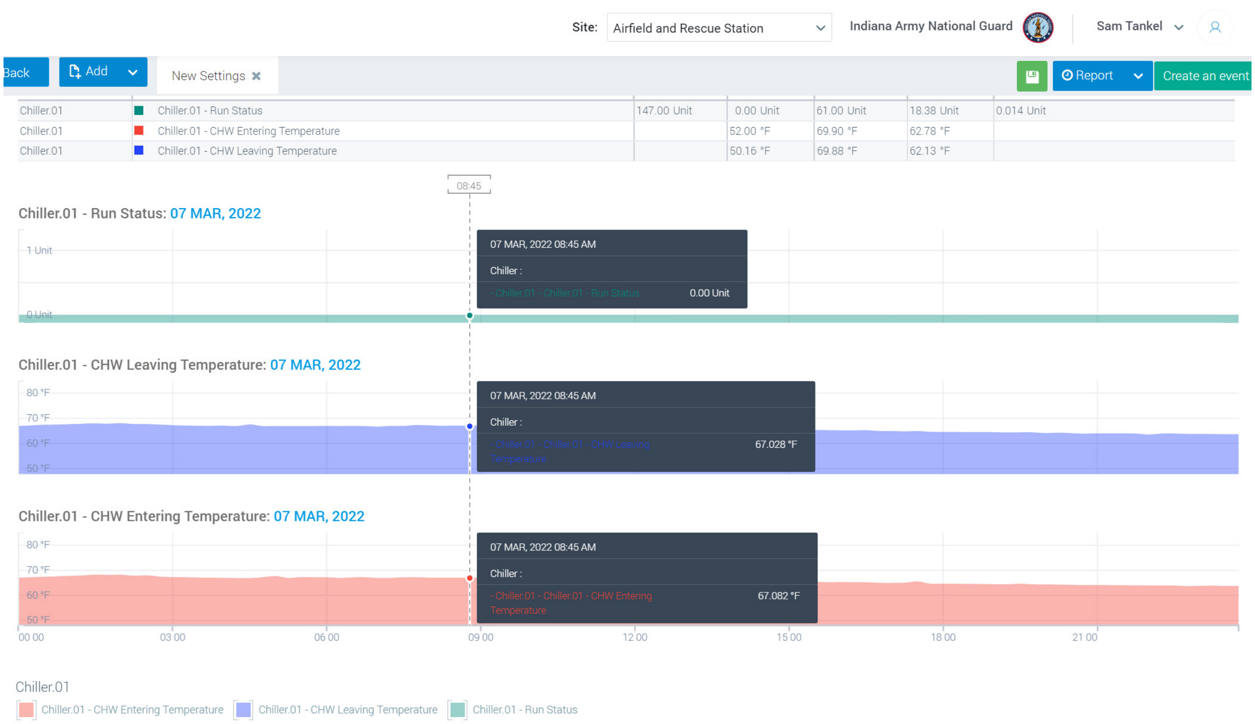


Figure 9. Example of Switch Platform Site Analysis Tool

Additionally, data was visualized using the Workspaces tool to give a quick view into building operations, utility usage, deviations from expected operation, and more. Finally, the insights gained from these tools were used to generate opportunities, called “Events” in the platform. These Events served as repositories for engagement and work around the opportunity, progress tracking, and the data itself. An example of an Event is included in Figure 10 below.

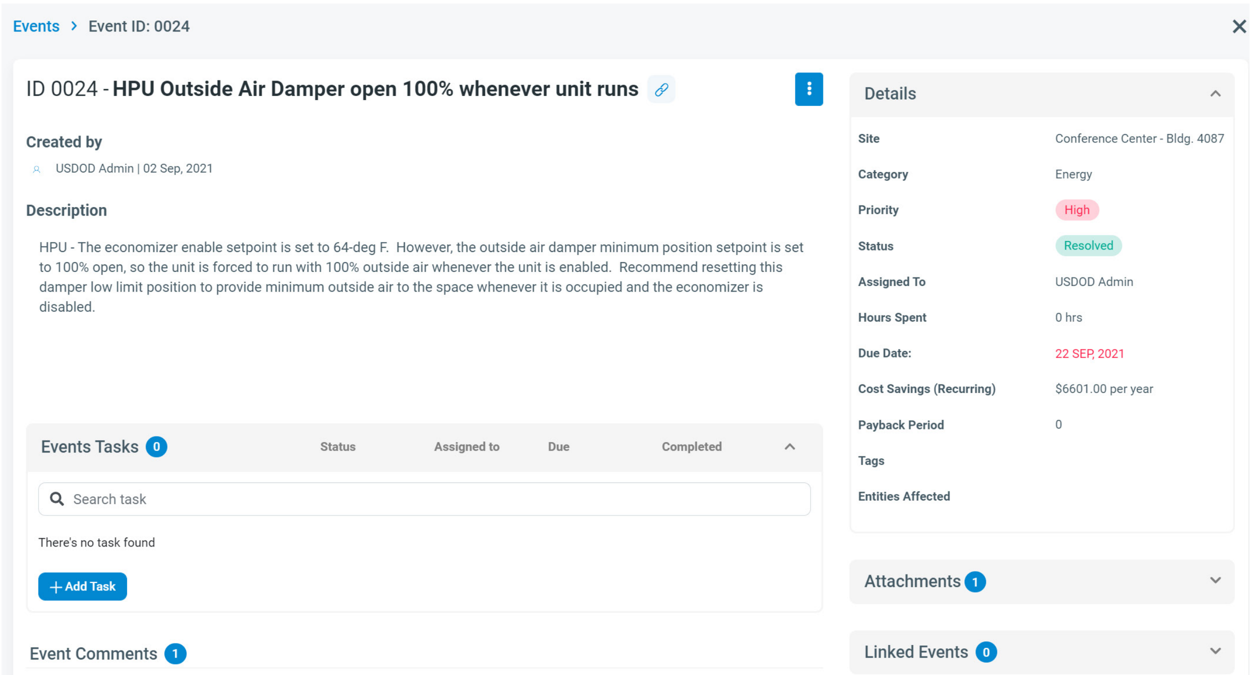


Figure 10. Example of Switch Platform Events Tool

A list of all identified opportunities can be found in Appendix B: Identified Opportunities.

6.0 PERFORMANCE ASSESSMENT

- **Performance Objective Analysis Overview**: Quantitative performance objective assessment procedures reflect the scope of influence for EMIS, and the data made available by integrating such a system.
- **Statistical Methodologies**: To measure the EMIS impact on energy consumption and demand, historical utility data in conjunction with local meter data was used to estimate the associated cost of various systems, then calculated the approximate reduction in usage for each identified Event (opportunity). To create functional models for each pilot site to inform baseline BAS operations, advanced pattern recognition techniques were applied in development of the models.
- **Graphical Methodologies**: The Vendor team used in-platform Graphical User Interface (GUI) tools to visualize data and present pre- and post-EMIS analytics.
- **Sensitivity Analysis**: Regarding electricity demand reduction, the team tested demand sensitivity to different changes in the operating posture, including different pre-cooling strategies and temperature setpoint standards.
- **Industry Standards**: ASHRAE energy modeling standards were used to inform all measurement and verification activities under this demonstration project.
- **Internal & External Validity**: Site selection was critical to promote the integrity and ability to extrapolate the findings. This required sites with different HVAC systems, end-use applications, and climates. Five (5) sites were committed in Indiana and 7 in Maine; however, the Maine sites elected not to continue participation early in the project.

6.1 PO 1 REDUCED ENERGY CONSUMPTION

Calculations were conducted for each raised opportunity that had associated cost and energy savings. Using historical utility data from 2021 for each building and energy end use estimates from the Commercial Buildings Energy Consumption Survey (CBECS), the approximate running cost of each system within the five pilot sites were calculated. By further calculating the percent reduction in energy use for each raised opportunity, a monthly cost savings was attributed. These savings were then converted to kBTUs using the utility rates calculated from the historical utility data. In some cases, enough information was known about the system or equipment to directly calculate the approximate energy reduction.

Using these methods, it was estimated that if all identified opportunities were implemented, there would be a greater than 9% reduction in kBTUs in aggregate for the five(s) demonstration buildings at Camp Atterbury. Savings calculations using the available data, and applying standard practice and presumption of some normal operating conditions associated with each opportunity are represented in Appendix B.

Many of these opportunities did not result in direct savings – energy or otherwise – but instead highlighted malfunctioning sensors or issues that may make occupants of these buildings uncomfortable. These opportunities are proactive rather than reactive, and focused on maintenance and occupant comfort or experience, which meant it was difficult or impossible to associate quantifiable results absent additional data sources (e.g., Work Orders).

6.2 PO 2 REDUCED POWER DEMAND

Peak demand reduction could not quantitatively be calculated due to unforeseen changes in occupancy due to the COVID-19 pandemic and the temporary housing of refugees within the pilot sites, in addition to data connection issues discussed in Section 8. However, it can be qualitatively assumed that peak power demand could have been reduced through identification rectification of plant faults and operational inefficiencies.

The rectification of faults and inefficiencies that cause equipment to operate at higher speed/output will result in reduced power demand. For example, fixing economizers and uncalibrated CO2 sensors to avoid conditioning excess OA, fixing broken pressure and flow sensors so fans operate at lower speeds, and fixing non-operational heat recovery wheels will reduce power demand. The above items were all identified as part of this demonstration.

6.3 PO 3 MECHANICAL EQUIPMENT RUNTIME & OPERATION

Opportunities to reduce equipment runtime and/or incorrect operation were identified for 3 of the 5 pilot sites: the Airfield and Rescue Station, Conference Center, and Dining Facility. Consistent data quality issues did not allow for proper assessment of the two barracks buildings.

The following opportunities relating to equipment runtime and operation were found for the Airfield and Rescue Station:

- **VAV Design Air Flow is not being met:** By comparing design drawings for this site with the actual air flow data gathered during the demonstration, a discrepancy was found between the designed VAV operation and the actual operation. Most VAVs were over-ventilating spaces (though some were under-ventilating), ultimately resulting in cumulative air flow approximately 50% greater than what was described in the design drawings. The site team plans to fix these discrepancies in the near future during a controls replacement.
- **AHU Fan Speed Remains Constant:** The AHU at this site reported a fan speed between 70-80% at all times. The Vendor recommended that this be reduced to approximately 25% during the cooling season, at least. At the time of writing this has not yet been implemented but will reap large benefits when adopted.

The following opportunities relating to equipment runtime and operation were found for the Conference Center:

- **Outside Air Dampers Always Open when AHU/HP Run:** It was discovered that the outside air dampers for this ventilation system opened to 100% whenever the system ran. This was due to the occupancy status being set to "Occupied" whenever the Run Status was "ON". A recommendation for implementing an occupancy schedule so that the unit would not bring in excess outside air when the building was unoccupied, though this has not yet been implemented.

The following opportunities relating to equipment runtime and operation were found for the Dining Facility:

- **Dining RTU OA dampers open 24/7, but building is unoccupied:** During the COVID-19 pandemic, this facility has largely been unoccupied. However, the RTUs were still using outside air 24/7. Like the event for the Conference Center, a recommendation for implementing an occupancy schedule be adopted for this site to prevent unnecessary conditioning of outside air was made, though this has not yet been implemented.

6.4 PO 4 IMPROVED MECHANICAL EQUIPMENT MAINTENANCE VIA WORK

6.4.1 ORDER TRACKING

The INANG site team did not provide Vendor with work order data to determine the success of this Performance Objective.

6.5 PO 5 IMPROVED ANALYTICS & WORKFLOW

The participants of this demonstration logged on to the Switch Platform less than one time per month on average. This login generally coincided with the monthly meetings hosted by the vendor engineering services team to discuss site equipment performance and behavior. While the opportunities identified by the vendor team were taken into consideration and often implemented, self-service of the analytical tools available was not made a priority by the site team. A champion is typically required to drive adoption of the platform outside of the monthly site meeting.

Additional discussion on this performance objective can be found in Section 8.

7.0 COST ASSESSMENT

The solution costing framework takes several factors into consideration to determine the total value invested to deliver product and service. The scope and detail of each project is considered when applying the framework to accurately assess value input against value output, resulting in a tailored "best support model" for each site. These factors include data connection method, API/driver development size of site, complexity of site, required training, and consultative support needed.

7.1 COST MODEL

Table 4. Cost Table

Cost Element	*Data Tracked During Demonstration	*Estimated Costs
Hardware Costs	MSRP for Vendor's IoT gateway is $9,000. Discounts start at 25% and increase depending on volume. A containerized version of the gateway eliminates the hardware component and allows the software stack to be installed on incumbent systems meeting specification.	Large Appliance $2000 (>500,000sqft) Small Appliance $1650 (<500,000sqft) Driver/API Development $10,000-$15,000
Installation Costs	Installation of the Switch hardware takes a minimum of one hour and up to eight hours.	$7,500 if only providing initial set-up and scan; waived if being applied to a larger project with IDL, Analytics, Workspaces, etc.
Implementation	Installation of appliance, point selection, apply analytics, workspaces, and control (if applicable)	$9,150 one-time fee for a site less than 50,000 SqFt. Pricing varies by size of site and complexity.
Facility Operational Costs	Switch Automation's pricing model is designed to reflect the relative size and energy load of the facility being integrated. This is a useful proxy for the cloud computing intensity.	No Charge - Target up to 25% Operational Saving
Maintenance	The only maintenance required relates to the IoT appliance. The hardware typically lasts three to five years before needing to be replaced.	No Charge - Maintenance is included as standard.
Hardware Warranty	Vendor offers a one-year warranty on the gateway appliances.	No Charge
Operator Training	Training is offered as part of a SaaS subscription for $5,000 for up to five operators. Self-service training is offered, as well.	$600/4 hours
Managed Services	Unless investments are made to learn and support the solution, managed services are required to provide maximum value. This is typically negotiated directly with service delivery partners in the market and can range from $400 - $2,400 per facility per month.	Monthly Service $2000/mo Bi-Monthly $1000/mo Increase/decrease based on operator training level.
Software Subscription Costs (SaaS)	As described above, SaaS generally is set never to exceed 5% of facility energy costs. Costs generally hover around $600 per facility per month.	Digital Prescription SaaS Package for a site size of less than 50,000 sqft: $450/mo Increase/decrease based on package selected.

Note - Information in the two columns varies due to circumstance and project objective. "Data tracked during demonstration" highlights project objectives and pricing related to a Proof of Concept/Pilot. Pricing identified in "Estimated Costs "is the standard commercial model pricing for continued service and/or additional projects. Additional price optimization available when using API/Cloud-to-Cloud data ingestion. Packages described above are for edge-based data ingestion.

SaaS subscription costs are designed to remove impacts from large upfront costs while minimizing the impact on ongoing operational expenses. Additionally, ongoing energy cost savings help to offset subscription fees, with a conservatively projected ROI of less than two (2) years after full operation of the platform is implemented.

ROI calculations can be variable based on several common factors. The technology applies a *measure it, manage it* approach to identifying optimization and reduction strategies; however, not all identified opportunities will be adopted. This introduces a variability into the vendor's ROI calculations. Reasons for implementing, or forgoing adoption of optimization or reduction recommendations vary, but are often led by unique operating demands or conditions in the facility/building.

EMIS tools, including those in this demonstration plan, are best implemented where large scale operations that require data normalization, remote access (and supervisory control) as key elements to programmatic objectives (such as operational efficiency, demand-based operations). These tools are not generally cost effective or maximized in single site/building, small building applications, or within assets with closed or proprietary systems that make data sharing difficult or impossible.

7.2 COST DRIVERS

The biggest cost driver will be suitability of the site IP infrastructure to support our data ingestion requirements. If the site does not have the necessary network and infrastructure to support data ingestion requirements, an upgrade would be required.

Additional cost drivers include size of site, complexity of site, driver/API development, enhanced platform features outside of standard package (applications, workspaces, control), increases managed service or training requirements, and customization.

7.3 COST ANALYSIS AND COMPARISON

Basic Site Description Assumed for Cost Analysis:

- Size of Site: 200,000ft^2
- Local BMS not connected to greater BMS, data aggregation, normalization not previously deployed
  - Use Switch IoT Appliance, no additional driver development needed
- Improves on existing technologies
- Monthly Managed Service Required
- Goal: Digitalization & Operating Cost Reduction

In this instance the technology does not fully replace an existing approach, but instead improves on existing technologies. By connecting the local BMS to the greater BMS, data aggregation and normalization is now possible resulting in the ability to identify opportunities for cost savings and avoidance, as well as possible areas for improvements.

Table 5. Cost Analysis

Cost Element	Life Cycle	Description	Estimated Costs
Hardware Costs	30 Days	Small Switch IoT Appliance	$1,650 (one-time)
Implementation	30-90 Days	Installation of appliance, point selection, apply analytics, workspaces, and control (if applicable)	$17,000 (one-time)
Managed Services	Ongoing	Unless investments are made to learn and support the solution, managed services are required to provide maximum value. This is typically negotiated directly with service delivery partners. Includes a monthly meeting to identify opportunities and report progress of implemented changes.	Monthly Service $2000/mo
Software Subscription Costs (SaaS)	Ongoing	SaaS, Cloud Hosting, Support	Digital Prescription SaaS Package $900/mo

8.0 IMPLEMENTATION ISSUES

This demonstration did uncover several implementation issues. Some were known prior to the demonstration but ended up being a larger issue than expected, while others were uncovered as the demonstration progressed:

Site Team Engagement: The most important factor in the Vendor Platform being an effective tool is active engagement and use by the site team. Unfortunately, low engagement limited demonstration effectiveness.

- **Reasons for Lack of Engagement:**
  - Project disruptions due to the COVID-19 pandemic caused several distractions with respect to priorities & availability of site teams.
  - Additionally, site team members present during project kickoff were subsequently deployed and replaced, resulting in a lack of historical knowledge of the project objectives and intent. Stakeholder (and user) buy-in was compromised as a result.
- **Challenges with Lack of Engagement:**
  - The above factors resulted in a lack of platform engagement, which led to low meeting attendance, sub-optimal opportunity resolution, and in some cases a lack of supplementary data provided to the Vendor.
- **Recommendations for Increased Engagement:**
  - Future uses of the Vendor Platform would benefit from a "champion" who can be trained in the analytical tools made available within the platform, prioritize insights, and ensure that internal processes for opportunity resolution are followed. These individuals are then able to engage new DoD users with the technology for continuity of use, and expansion of program objectives and outcomes.

Inconsistent Internet Connectivity: The Switch Appliance pushed data to the cloud via a cellular connection. Often, this connection did not work properly, resulting in a loss of data or data that was improperly aggregated. This is not standard operating procedure for deployment but was necessary in this demonstration for security compliance.

- **Reasons for Internet Connectivity Issues**
  - Cellular/SIM data services were utilized as temporary measure for cyber compliance as approval for hardwired internet was not granted during the project.
- **Challenges with Internet Connectivity Issues**
  - Cellular connections typically have issues maintain consistent connectivity. This can be due to the location of the modem (in a concrete room or near high interference areas) or due to the location of the site (in a remote location). Cellular connections also have cost implications to the project due to cellular carrier fees and data chargers.
  - Due to poor connectivity, it was difficulty baselining utility data and maintaining a transparent view into the five pilot sites at the beginning of the project.
- **Recommendations for Improved Connectivity**

- If SIM cards are required, it is recommended that modems with dual SIM card capabilities are utilized for increased resiliency. Dual modems were installed for this project to mitigate the above challenges faced early in the program.
- If ATO is achieved, internet connectivity issues should decrease significantly as the need for a cellular connection will no longer be present.

9.0 REFERENCES

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APPENDIX A POINTS OF CONTACT

Point of Contact	Organization	Phone & E-mail	Role in Project
Sam Tankel	Switch Automation	(913) 982-6677 stankel@switchautomation.com	Principal Investigator
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APPENDIX B OPPORTUNITIES IDENTIFIED

The table below lists all identified Events during this project, excluding those that only pertained to data quality. Calculations for individual Event savings are available upon request. For Events that discovered a malfunctioning sensor a one-time cost savings was applied to estimate the reduced maintenance associated (fewer truck rolls, targeted labor, etc.).

Table B-1. Estimated Savings from Identified Opportunities

Site Name	Event Name	Status	Estimated Cost Savings*	Estimated kBTU reduction for Portfolio
Airfield and Rescue Station	Boiler System Not Maintaining Setpoint	Resolved	-	-
Airfield and Rescue Station	All VAV dampers and air flow readings are 0	Resolved	-	-
Airfield and Rescue Station	High CHW Temperatures	Resolved	-	-
Airfield and Rescue Station	HHWS Running 24/7	Submitted	$1774/yr	2.06%
Airfield and Rescue Station	Return Air CO2 Sensor is Stagnant	Submitted	$100 (one time)	-
Airfield and Rescue Station	AHU Freezestat in Alarm	Resolved	-	-
Airfield and Rescue Station	VAV.07 High Zone Air Temperature	Resolved	-	-
Airfield and Rescue Station	AHU Mixed Air Temperature Above 90F	Resolved	-	-
Airfield and Rescue Station	VAV.01 in Alarm Mode	Resolved	-	-
Airfield and Rescue Station	Simultaneous Heating and Cooling	Submitted	$1187/yr	1.37%
Airfield and Rescue Station	VAV.05 Space Temperature Maintained Near 80-deg F	In Progress	$155/yr	0.39%
Airfield and Rescue Station	Chilled Water Temperatures Out of Range	Resolved	-	-
Airfield and Rescue Station	VAV Design Air Flow is not being met	Submitted	$1781/yr	2.06%
Airfield and Rescue Station	EF Zone Air Temperature Exceeding Setpoint	Submitted	-	-
Airfield and Rescue Station	Boiler.01 HHW Entering Temp Setpoint Out of Range	Submitted	$150 (one time)	-
Airfield and Rescue Station	Low VAV Space Temperatures	Submitted	-	-
Airfield and Rescue Station	AHU Fan Speed Remains Constant	In Progress	$2623/yr	3.04%

Table B-1. Estimated Savings from Identified Opportunities

Site Name	Event Name	Status	Estimated Cost Savings*	Estimated kBTU reduction for Portfolio
Airfield and Rescue Station	Heat Recovery Wheel Commanded ON, but the Status is OFF	Resolved	-	-
Airfield and Rescue Station	Heat Recovery Wheel Commanded ON, but the Status is OFF	Resolved	-	-
Airfield and Rescue Station	AHU Cooling Valve Open 100% for Long Periods of Time	Resolved	$502/yr	0.58%
Airfield and Rescue Station	Unexpected Boiler Operation / HW Temperatures	Resolved	-	-
Airfield and Rescue Station	AHU Discharge Air Temperature Exceeding Setpoint	Submitted	-	-
Barracks – Bldg. 619	Stagnant Water Meter	In Progress	$600 (one time)	-
Barracks – Bldg. 620	Stagnant Water Meter	In Progress	$600 (one time)	-
Conference Center – Bldg. 4087	HPU Not Maintaining Zone Temperature Setpoint	Resolved	-	-
Conference Center – Bldg. 4087	Zone Air Temperature Below Setpoint	Resolved	-	-
Conference Center – Bldg. 4087	Outside Air Dampers Always Open when AHU/HP Run	In Progress	$4674/yr	2.76%
Conference Center – Bldg. 4087	Occupied/Unoccupied Temperature Setpoints Are Not Being Used	In Progress	$927/yr	0.55%
Conference Center – Bldg. 4087	AHU Missing Economizer Opportunities	Submitted	-	-
Dining Facility – Bldg. 350	MAU Run Status Always 0	In Progress	-	-
Dining Facility – Bldg. 350	EF.15 Status/Command Mismatch	Submitted	-	-
Dining Facility – Bldg. 350	RTU.08 Discharge Air Temp Above Expected Range	Resolved	-	-
Dining Facility – Bldg. 350	RTU.09 Outside Air Temperature Exceeding Normal Range	In Progress	-	-
Dining Facility – Bldg. 350	Dining RTU OA dampers open 24/7, but bldg is unoccupied	In Progress	$1115/yr	1.17%
Dining Facility – Bldg. 350	RTU.06 Zone Temperature Performance	Submitted	-	-
Dining Facility – Bldg. 350	Unusual Spikes in Water Meter Flow	Submitted	-	-
Dining Facility – Bldg. 350	Electricity Meter Reporting High Energy Consumption	Submitted	-	-
Dining Facility – Bldg. 350	EF.10 Status/Command Mismatch	Submitted	-	-
Dining Facility – Bldg. 350	RTUs all Report Null CO2 Values	In Progress	-	-

*see Appendix C for detailed calculations

APPENDIX C SAVINGS CALCULATIONS

CBECS Calculation Table

DoD PROPERTIES OPPORTUNITY TRACKER

Utility Benchmarking

Energy Benchmarking	Airfield and Rescue Station	Barracks Bldg. 619	Barracks Bldg. 620	Conference Center Bldg. 4087	Dining Facility Bldg. 350
% Natural Gas - Heating	95%	95%	95%	0%	95%
% Electric - Space Heating	43%	22%	22%	35%	17%
% Electric - Cooling	8%	5%	5%	10%	7%
% Electric - Ventilation	8%	3%	3%	6%	6%
% Electric - Water Heating	12%	31%	31%	2%	16%
% Electric - Lighting	14%	24%	24%	25%	10%
% Electric - Cooking	1%	3%	3%	0%	25%
% Electric - Refrigeration	2%	2%	2%	3%	16%
% Electric - Office Equipment	1%	0%	0%	3%	0%
% Electric - Computer Use	2%	1%	1%	7%	0%
% Electric - Miscellaneous	10%	7%	7%	10%	4%

Annual Utility Breakdown (from 2021)	Airfield and Rescue Station	Barracks Bldg. 619	Barracks Bldg. 620	Conference Center Bldg. 4087	Dining Facility Bldg. 350
Electric Consumption (kWh)	94,526	53,002	54,661	160960	488,018
Electric Cost	$8,476	$4,715	$4,864	$16,531.29	$44,238
Electric Rate ($/kWh)	$0.09	$0.09	$0.09	$0.10	$0.09
Natural Gas Consumption (Therms)	4302.05	357	427	0	22,219
Natural Gas Cost	$3,066.07	$550.76	$619.61	0	$21,560.11
Natural Gas Rate ($/Therm)	$0.71	$1.54	$1.45	0	$0.97
Total Energy (kBtu)	752,626	216,547	229,233	549,196	3,886,496
Total Cost	$11,542	$5,266	$5,483	$16,531	$65,798
Total Utility Rate ($/kBtu)	$0.02	$0.02	$0.02	$0.03	$0.02

Site Operating Details	Airfield and Rescue Station	Barracks Bldg. 619	Barracks Bldg. 620	Conference Center Bldg. 4087	Dining Facility Bldg. 350
Building Type	Public Order and Safety	Lodging	Lodging	Office	Food Service
Site Area (ft2)	10,626	5,000	5,000	9,893	23,449
Site EUI (kBtu/SF)	71	43	46	56	166
Heating Operating Hours	5,047	5,047	5,047	1,636	1,682
Cooling Operating Hours	1,015	1,015	1,015	752	338
Ventilation Operating Hours	8,760	8,760	8,760	2,920	2,920
Interior Lighting Operating Hours	8,760	8,760	8,760	2,920	2,920
Exterior Lighting Operating Hours	4,380	4,380	4,380	4,380	4,380

Annual System Costs ($/year)	Airfield and Rescue Station	Barracks Bldg. 619	Barracks Bldg. 620	Conference Center Bldg. 4087	Dining Facility Bldg. 350
Heating	$6,557	$1,561	$1,659	$5,786	$28,003
Cooling	$678	$236	$243	$1,653	$3,097
Ventilation	$678	$141	$146	$992	$2,654
Int Ltg	$712	$679	$700	$2,480	$2,654
Ext Ltg	$475	$453	$467	$1,653	$1,770
Heating and Cooling	$7,235	$1,796	$1,902	$7,439	$31,099
Total HVAC	$7,914	$1,938	$2,048	$8,431	$33,753
Total Lighting	$1,187	$1,132	$1,167	$4,133	$4,424
Building HVAC + Ltg	$9,100	$3,069	$3,215	$12,564	$38,177

System Run Rates ($/hr)	Airfield and Rescue Station	Barracks Bldg. 619	Barracks Bldg. 620	Conference Center Bldg. 4087	Dining Facility Bldg. 350
Heating	$1.30	$0.31	$0.33	$3.54	$16.65
Cooling	$0.67	$0.23	$0.24	$2.20	$9.15
Ventilation	$0.08	$0.02	$0.02	$0.34	$0.91
Int Ltg	$0.08	$0.08	$0.08	$0.85	$0.91
Ext Ltg	$0.11	$0.10	$0.11	$0.38	$0.40
Heating and Cooling	$1.97	$0.54	$0.57	$5.73	$25.80
Total HVAC	$2.04	$0.56	$0.58	$6.07	$26.71
Total Lighting	$0.19	$0.18	$0.19	$1.23	$1.31
Building HVAC + Ltg	$2.23	$0.74	$0.77	$7.30	$28.02

Opportunity Tracking Table

Opportunity Overview																	
Site	Status	Issue Description	Issue Type	Cost Savings?	Impacted System(s)	System Annual Cost	System Hourly Operating Cost	System Annual Percent Cost Savings	Building Annual Avoided Cost	1-Month Avoided Cost	Total Avoided Cost	Building Annual Avoided kBtu	1-Month Avoided kBtu	% Reduced kBtu for Building	% Reduced kBtu for Portfolio	Calculation Notes and Key Assumptions	Notes
Airfield and Rescue Station	In-Progress	AHU Fan Speed Remains Constant	Optimization Opportunity	Yes	Ventilation	$678	$0.08	40.0%	$271	$23	$271	17,686	1,474	2.35%	0.31%	See 'Calcs' sheet	
Airfield and Rescue Station	In-Progress	AHU Fan Speed Remains Constant	Optimization Opportunity	Yes	Heating	$6,557	$1.30	40.0%	$2,623	$219	$2,623	171037.56	14253.13	22.73%	3.04%	See 'Calcs' sheet	
Airfield and Rescue Station	Complete	CHW System Control / Missing Points	Control failure	No													
Airfield and Rescue Station	Complete	Verify Heat Recovery Wheel Operation	Equipment failure	No													
Conference Center Bldg. 4087	In-Progress	Occupied / Unoccupied temperature setpoints are note being used	Optimization Opportunity	Yes	Total HVAC	$8,431	$6.07	11.0%	$927	$77	$927	30,810	2,567	5.61%	0.55%	See 'Calcs' sheet	
Conference Center Bldg. 4087	Complete	HPU Outside Air Damper open 100% whenever unit runs	Optimization Opportunity	Yes	Heating and Cooling	$7,439	$5.73	62.8%	$4,674	$390	$4,674	155,284	12,940	28.27%	2.76%	See 'Calcs' sheet	
Conference Center Bldg. 4087	Complete	HPU Not Maintaining Zone Temperature Setpoint	Equipment failure	No													
Airfield and Rescue Station	Complete	Chilled Water Temperatures Out of Range	Equipment failure	No												*$100 One Time*	Labour
Airfield and Rescue Station	In-Progress	VAV-05 Space Temperature Maintained Near 80-deg F	Equipment failure	Yes	Heating	$6,557	$1.30	0.7%	$155	$13	$13	21,803	845	2.90%	0.39%	See 'Calcs' sheet	
Airfield and Rescue Station	In-Progress	Unexpected Boiler Operation / HW Temperatures	Optimization Opportunity	No													
Airfield and Rescue Station	Complete	AHU Cooling Valve Open 100% for Long Periods of Time	Optimization Opportunity	Yes	Cooling	$678	$0.67	74.00%	$502	$42	$502	32,719	2,727	4.35%	0.58%	See 'Calcs' sheet	
Dining Facility Bldg. 350	In-Progress	Dining RTU OA dampers are open 24/7, but bldg is unoccupied	Optimization Opportunity	Yes	Ventilation	$2,654	$0.91	42.0%	$1,115	$93	$1,115	65,848	5,487	1.69%	1.17%	See 'Calcs' sheet	
Airfield and Rescue Station	In-Progress	Simultaneous Heating and Cooling	Sub-optimal Control	Yes	Total HVAC	$7,914	$2.04	15.0%	$1,187	$99	$99	77,404	6,450	10.28%	1.37%	See 'Calcs' sheet	
Dining Facility - Bldg. 350	In-Progress	RTUs all report Null CO2 Values	Equipment failure	No												$200 One time	Labour
Dining Facility - Bldg. 350	In-Progress	RTU.06 Zone Air Temperature Performance	Equipment failure	No												$150 One Time	Sensor + Labour
Airfield and Rescue Station	In-Progress	VAV Design Air Flow is not being met	Optimization Opportunity	Yes	Total HVAC	$7,914	$2.04	22.50%	$1,781	$148	$1,781	116,106	9,675	15.43%	2.06%	See 'Calcs' sheet	
Dining Facility - Bldg. 350	In-Progress	RTU.09 Outside Air Temperature Exceeding Normal Range	Equipment failure	No												$150 One Time	Sensor + Labour
Barracks - Bldg. 620	In-Progress	Barracks - Bldg 620: Stagnant Water Flow Meter	Equipment failure	No												*$600 One Time*	Meter +Labour
Airfield and Rescue Station	In-Progress	Airfield and Rescue: All VAV dampers and air flow readings are 0	Equipment failure	No												$100 One Time	Labour
Airfield and Rescue Station	In-Progress	Airfield and Rescue: Return Air CO2 Sensor is Stagnant	Equipment failure	No												*$100 One Time*	Labour
Airfield and Rescue Station	In-Progress	Boiler.01 HHW Entering Temp Setpoint Out of Range	Equipment failure	No												$150 One Time	Sensor + Labour
Airfield and Rescue Station	In-Progress	HHWS Running 24/7	Control failure	Yes	Heating	$6,557	$1.30	27.1%	$1,774	$148	$148	115,707	9,642	15.37%	2.05%		
								Total:	$13,235	$1,103	$12,005	688,698	56,419		14.28%		

Opportunity Calculations

HPU Outside Air Damper open 100% whenever unit runs

Assumptions

10-ton standard efficiency HPU similar to a Trane Precedent			
2-stage scroll compressor	10.5	hp	75%
EER	11		
indoor fan (variable speed)	2.75	hp	20%
outdoor fan	0.7	hp	5%
Total	13.95	hp	100%
annual building operation (from site team)	8760	hours	
heating annual operating hours (TMY data OSAT<60F, 9am-5pm)	1636	hours	
cooling annual operating hours (TMY data OSAT>76F, 9am-5pm)	752	hours	
ventilation operating hours	8760	hours	

*heating and cooling operation hours were calculated conservatively using TMY data rather than site data due to poor site operations. Actual data shows heating up to OSA temperatures of 66F and cooling down to OSA temperatures of 40F.

annual heating costs (CBECS calculations)	$ 5,786	69%
annual cooling costs (CBECS calculations)	$ 1,653	20%
annual ventilation costs (CBECS calculations)	$ 992	12%
Total HVAC costs (CBECS calculations)	$ 8,431	100%
Percent of HVAC attributed to HPU (AHU: 600cfm, HPU: 4000cfm):	87%	

Method

Compare heating and cooling energy using formula below for condition with OSA damper at 100% open vs OSA damper at recommended 10% open

Q = 1.08 x delta-T x CFM

Q(OSAD=10%) = 1.08 x delta-T x (400 CFM)
Q(OSAD=100%) = 1.08 x delta-T x (4000 CFM)

delta T - does not change
CFM is reduced by 90%

Q(OSAD=10%)=0.1*Q(OSAD=100%)

Results

reduction in heating and cooling loads of the HPU:	90%	
percent of HPU heating and cooling energy impacted - from cut sheet assumptions (total hp-indoor fan hp)	80%	
reduction in annual heating cost (87%*90%*80%):	63%	$ 3,636
reduction in annual cooling cost (87%*90%*80%):	63%	$ 1,039
total reduction in annual cost:	55%	$ 4,674

VAV-05 Space Temperature Maintained Near 80-deg F												
Q = 1.08 x delta-T x CFM												
										q=	4320	BTU/hr
Conservatively…				VAV-05	500 CFM		6.51%	of VAV total CFM		heating hrs	5047	hrs
Setpoint	70.00			All VAVs	4550 CFM		0.67%			Q=	21803.04	Kbtu
Current	78.00			AHU	3741 CFM						218.0825217	therms
							3.84%	of VAV + AHU CFM		utility rate	0.712699262	$/therm
Assuming CFM remains the same							0.39%				$ 155.43	
delta-T	8.00											
	10.26%	in energy for VAV-05										

AHU Fan Speed Remains Constant								
24% for heating		AHU appears stuck at cooling max, heating max is estimated to be 24% (70% reduction in fan speed)					40%	Savings based on heating 57.6% of the year
80% for cooling		This would provide savings in ventilation (reduced CFM, assuming this would also be a 70% reduction) and also heating (less air to heat, not accounted for in this calc)						

Occupied / Unoccupied temperature setpoints are note being used									
From HPU Outside Air Damper event, AHU-South provides 13% of CFM		Night Setback =	2.00	deg (per INARNG request)		Bldg kBTU/yr =	549196.00	
		14 Holidays + 12 hours/day Unocc =	3216.00	hours/year setback		HVAC kBTU/yr =	296565.84	
		Bldg Airflow =	4600.00	cfm			11%	savings from total HVAC energy
		Q = 1.08*CFM*delta-T =	9936.00	BTU/h				
			31954.18	kBTU total saved per year				

HP Simultaneous Heating and Cooling														
Cooling	85.00%					NOTE: Missing heating/cooling system info for this								
heating	74.00%	Assume main heating is 80%, aux heat 20%												
Aux heating	66.00%	Results in weighted heating percent:		72.40%		Estimated								
						120 kBtu cooling		x 85%	=	102.00			Which could be achieved with	
Hrs/Yr	8760.00					225 kBtu heating		x 72.4%	=	162.90			27.06%	of the heating system
Heating Hrs/Yr	5047.00								Net	60.90	kBtus		A 62.6% reduction in kBtus for heating	
Cooling Hrs/Yr	1015.00												A 77% reduction in kBtus for heating and cooling	

VAV Design Air Flow is not being met							
Total Air Flow	4550 CFM						
Designed Air Flow	3525 CFM		Q=	1.08 x Temp x CFM			
				Temperature is constant			
				4550-3525	1025 CFM reduction	22.5%	savings

HHWS Running 24/7			
Assume plant runs 6.5 hours less (with occupancy profile) = 27.1% savings			