ESTCP
Cost and Performance Report

(EW-201406)

Building Performance Optimization while Empowering Occupants Toward Environmentally Sustainable Behavior through Continuous Monitoring and Diagnostics

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The objective of this project was to demonstrate that at least 30% of a Department of Defense (DOD) building's Heating Ventilation and Air Conditioning (HVAC) and plug load annual energy consumption can be saved through continuous diagnostics and controls, while empowering building stakeholders to engage in proactive energy-conservation and sustainable behaviors. The findings and performance assessments from the demonstration provide information that can help the DOD to reevaluate its building operation policies, practices and guidelines, by engaging the whole military installation community, especially building occupants, in energy conservation measures and by engaging facility managers.

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Asset Framework, Air Handling Unit, Building Automation System, Energy Use Intensity, Fault Detection and Diagnostics, Green House Gases, Heating Ventilation and Air Conditioning (HVAC), Indoor Environment Quality, Life Cycle Cost Analysis, Risk Management Framework, Siemens Building Technology, Variable Air Volume

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ACRONYMS AND ABBREVIATIONS

AF	Asset Framework
AHU	Air Handling Unit
ASHRAE	American Society of Heating, Refrigerating and Air Conditioning Engineers
BACnet	Building Automation and Control Networks
BAS	Building Automation System
CMU	Carnegie Mellon University
DOD	Department of Defense
DOE	Department of Energy
EPA	Environmental Protection Agency
ESTCP	Environmental Security Technology Certification Program
EUI	Energy Use Intensity
FDD	Fault Detection and Diagnostics
FEMP	Federal Energy Management Program
FM	Facility Manager
GHG	Green House Gases
HASP	Health and Safety Plan
HVAC	Heating Ventilation and Air Conditioning
ID-C	Intelligent Dashboard for Campus/City Executives
ID-F	Intelligent Dashboard for Facilities Manager
ID-O	Intelligent Dashboard for Occupants
IEQ	Indoor Environment Quality
IPMVP	International Performance Measurement and Verification Protocol
IW	Intelligent Workplace (CMU building research lab)
KPI	Key Performance Indicator
LCCA	Life Cycle Cost Analysis
MOU	Memorandum of Understanding
MS SQL	Microsoft SQL
NEAT	National Environmental Assessment Toolkit
O&M	Operations and Maintenance
OPC	OLE for Process Control

PaANG	Pennsylvania Air National Guard
PC	Personal Computer
PO	Performance Objective
POC	Point of Contact
PI	Principal Investigator
RMF	Risk Management Framework
RMSE	Root Mean Square Error
ROI	Return On Investment
RTU	Roof Top Unit
SBT	Siemens Building Technology
VAV	Variable Air Volume

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EXECUTIVE SUMMARY

OBJECTIVES OF THE DEMONSTRATION

The objective of this project is to demonstrate that at least 30% of a Department of Defense (DOD) building's Heating Ventilation and Air Conditioning (HVAC) and plug load annual energy consumption can be saved through continuous diagnostics and controls, while empowering building stakeholders to engage in proactive energy-conservation and sustainable behaviors. The findings and performance assessments from the demonstration provide information that can help the DOD to reevaluate its building operation policies, practices and guidelines, by engaging the whole military installation community, especially building occupants, in energy conservation measures and by engaging facility managers through user-friendly interfaces that support preventative measures to ensure energy conservation and occupant comfort.

DESCRIPTION OF THE TECHNOLOGY

The team deployed two distinct technologies during this demonstration project. The first technology, Intelligent Dashboard for Facilities Manager (ID-F), targets building facility managers and allows real time diagnostics for BAS systems with features like benchmarking, fault detection, and diagnostic or energy anomaly detection. As an extension of traditional Building Automation System (BAS), ID-F allows a deep performance tracking of building systems. Having a better view of their building's performance, facility managers can avoid system failures, diagnose incorrect sequences of operations, and improve occupants' comfort.

The second technology, Intelligent Dashboard for Occupants (ID-O), targets building occupants, allowing them to manage and control their electrical appliances. Through features like energy feedback, automation, reminder and targeted recommendations, occupants are made aware of their appliances' energy consumption impact and are invited to change their behavior and to engage in more sustainable practices.

RESULTS OF THE DEMONSTRATION

Performance Objectives: To assess the potential for deployment of the technology at military installations in furtherance of DOD energy goals, three sets of parameters were measured in relationship to targeted expectations:

- Energy Savings – Although the success criteria was achievement of more than 30% reduction in annual energy consumption, only 10% reduction in overall energy use was realized. However, since overall energy use had been reduced for part of the test bed during the previous demonstration (EW-201336), this result understates the impact of the technology. While the target for plug-load reduction was also 30%, 24% was actually achieved.
- Greenhouse Gas Reduction – Although the success criteria was achievement of more than 30% reduction in greenhouse gas emissions, only 10% reduction was realized. (Note that the methodology used for measuring greenhouse gases (GHG) is aligned with total energy measurement.)

- User Engagement Toward Sustainable Practices – All of the qualitative objectives of the demonstration were achieved: Occupant engagement was high at 85% participation, sustained positive behavior changes occurred, and satisfaction increased. Facility managers identified enhanced fault detection. And, all participants reported the system was easy to use and beneficial.

OVERALL EVALUATION

The demonstration validated and quantified the effectiveness of the technology in a military environment and confirmed the hypothesis that collaboration between facility managers and occupants in the control of building energy systems can reduce energy waste and increase user satisfaction. Together, the technologies behind the ID-F and ID-O dashboards provided a user-friendly, integrated platform for monitoring, analyzing, and modifying the operation of building systems and their associated energy use both in real time and over time.

The technology succeeded in identifying and exploiting multiple opportunities to adjust the scheduling of operations for building systems to the schedules of building occupants, by optimizing thermostat, air handling, and electrical base load settings during times of low and dynamic occupancy. The technology also succeeded in identifying and correcting system design and operational problems, thereby detecting equipment inefficiencies and faults and empowering predictive rather than reactive repair and maintenance strategies.

Prior to system installation, assessment of the existing BAS infrastructure of meters and data points led to hardware upgrades and equipment re-commissioning. Such improvements are inherently beneficial and should be independently cost-effective; so the process of evaluation should be considered a positive external attribute of the technology adoption process. Nevertheless, expenditure of time and money is required to prepare properly for introduction of the ID-F technology, otherwise deployment will not produce optimal results. Since the extent of required activity cannot be determined in advance, this aspect of technology introduction remains a consideration in overall evaluation.

At scale, for deployments with more than 120 occupants, the ROI for the ID-O technology is projected at 20%, with payback expected in less than 5 years. Because the dashboards are intuitive, training is straightforward, customer support is minimal, and user acceptance is high.

In conclusion, the technology did not meet its energy reduction targets but succeeded in meeting its user satisfaction goals. The savings in energy use and associated cost were substantial, despite being less than anticipated. Overall, the technology performed as designed and accomplished all of its complex missions, although with less impact than hoped for.

1.0 INTRODUCTION

Carnegie Mellon University (CMU)—in collaboration with OSIsoft, Siemens Building Technology (SBT), Energy Efficiency LLC (EEme) and Evolve Foundation, Inc.—demonstrated application of an innovative integrated software platform for the project entitled "Building Performance Optimization while Empowering Occupants toward Environmentally Sustainable Behavior through Continuous Monitoring and Diagnostics." The system was demonstrated at buildings of the 171st Air Refueling Wing of the Pennsylvania Air National Guard (PaANG) located at the Pittsburgh International Airport in Coraopolis, Pennsylvania, using funding provided by the U.S. DOD Environmental Security Technology Certification Program (ESTCP). Within 20 months, the project team demonstrated and validated the base-wide building energy efficiency improvement capability of the integrated systems as well as the beneficial impacts of the systems on increased awareness of energy conservation opportunities and active engagement in workplace energy efficiency enhancement by DOD personnel.

This document describes the work performed and the results achieved during the demonstration of the systems at the PaANG site. In addition to validating and quantifying the effectiveness of the technology, the demonstration allowed the project team to determine the system installation costs, assessed the system's risk management framework and cyber-security acceptance, and provided a viable transfer plan to other DOD sites.

1.1 BACKGROUND

The Pacific Northwest National Laboratory of the DOE (PNNL) reports that the DOD accounts "for roughly 60% of energy use and floor space" for federal buildings [Sec. 2.1.2] but has not been on track to meet the goal of 30% energy intensity reduction by FY 2015 [Sec. 2.2]. In most cases, buildings are managed to provide regulated environmental conditions designed to support high comfort levels for maximum occupancy during periods of time that are longer than necessary, e.g., 6 a.m.–11 p.m. daily, in order to avoid occupant complaints. This management policy leads to substantial energy waste without necessarily delivering occupant satisfaction.

At PaANG, where typical work schedules for National Guard personnel are followed, we found that about 60% of the employees who are assigned to occupy base facilities do so on a limited basis. Furthermore, because the schedules of these "part-time" individuals are subject to change, the BAS is set to air condition the space as if they were "full time" employees. The energy waste due to such persistent, excessive overscheduling, over-ventilation, and over-lighting is significant.

Lack of occupant participation in the control of the building is hypothesized to be the main reason for both energy waste and comfort complaints.

To address these problems, CMU and OSIsoft have developed an innovative, low-cost, integrated software platform that allows interactive communications and actions among occupants, facility managers, and building control systems for both individual building and base-wide applications. CMU has developed "Intelligent Dashboards" at scales for building occupants (ID-O), facility managers (ID-F), and city/campus (ID-C) to provide real-time energy and Indoor Environmental Quality (IEQ) analytics and communications based on sensor and controller information collected and managed by OSIsoft's PI Systems database.

1.2 OBJECTIVES OF THE DEMONSTRATION

The objective of this project is to demonstrate that at least 30% of a DOD building's HVAC and plug load annual energy consumption can be saved through continuous diagnostics and controls, while empowering building stakeholders to engage in proactive energy-conservation and sustainable behaviors.

The team deployed two distinct technologies during this demonstration project. The first technology, 'ID-F,' targets building facility managers and allows real time diagnostics for BAS systems with features like benchmarking, fault detection, and diagnostic or energy anomaly detection. The second technology, 'ID-O,' targets building occupants, allowing them to manage and control their electrical appliances.

Although the success criteria was to reduce annual energy consumption by 30%, only 10% reduction was realized. Overall energy use had been reduced for part of the test bed during the previous demonstration (EW 201336), this result understates the impact of the technology. While the target for plug-load reduction was also 30%, 24% was actually achieved.

1.3 REGULATORY DRIVERS

The energy saving activities of this demonstration are aligned with the following Executive Orders, legislative mandates, federal policy, DOD policy, and the Air Force Energy Strategic Plan.

Executive Order: *EO 13693 of March 25, 2015 (superseding EO 13423 of January 24, 2007) Planning for Federal Sustainability in the Next Decade*:

Legislative Mandates: *Energy Policy Act of 2005, Energy Independence and Security Act of 2007*

Federal Policy: *Federal Leadership in High Performance and Sustainable Buildings MOU 2006*

DOD Policy: *Strategic Sustainability Performance Plan, Energy Security MOU with DOE*

Service Policy: *Air Force Energy Strategic Plan (March 2013)*

2.0 TECHNOLOGY DESCRIPTION

2.1 TECHNOLOGY/METHODOLOGY OVERVIEW

Description:

The Intelligent Data and Dashboard for Facility Managers (ID-F) provides real-time access to the full range of energy metering and BAS system data available on the DOD campus, drawing from a unified database created on a PI Server. The data collection infrastructure is a vendor independent software platform. It supports integration and interoperability since it is compatible with more than 450 different communications protocols, such as BACnet, Modbus, OPC, and others.

The shared data infrastructure allowed us to retrieve data from meters and sub-meters as well as sensors, actuators, and equipment variables tracked by the BAS of the 14 buildings on the PaANG campus. The database supports long term archiving, iterative analysis and customized displays with real-time visualization and analytical interfaces that integrate, monitor and evaluate energy and system performance variables that were developed by the research team. These interfaces were built using a range of client tools to perform analytics and calculations, to generate operator alerts as required, and to visualize the data and the analytical results. This capability delivers significant, immediate value because it allows Facility Managers and decision makers to monitor and compare their system data comprehensively.

The research team also deployed the Intelligent Data and Dashboard for Occupants (ID-O), at eight workstations in Building 205 to support monitoring and control of desktop technology and electrical appliances. Multiple Plugwise™ smart plugs were installed at each workstation to continuously monitor the electricity consumption of key technologies and to support on-line or automated on-off controls for those technologies. This Dashboard provides real time communication, expert feedback, and on-line and automated control for the occupants. Six months of baseline energy use data were recorded before the Intelligent Dashboard was installed.

Within 20 months, the project team demonstrated and validated the base-wide building energy efficiency improvement capability of the integrated systems as well as the beneficial impacts of the systems on increased awareness of energy conservation opportunities and active engagement in workplace energy efficiency enhancement by the DOD personnel.

2.1.1 ID-F Intelligent Dashboards for Facility Managers

Creation of the Base Building Portfolios:

The first step in this research project was the collection and aggregation of data from multiple BAS, online records, and meter sources into a common database. The PI Asset Framework (PI AF) was used to create an object oriented hierarchical model (see Figure 1) in order to capture both facilities' real-time data and relational data (maintenance diagrams and manuals, repair part info, maintenance histories), thereby providing a comprehensive asset management capability.

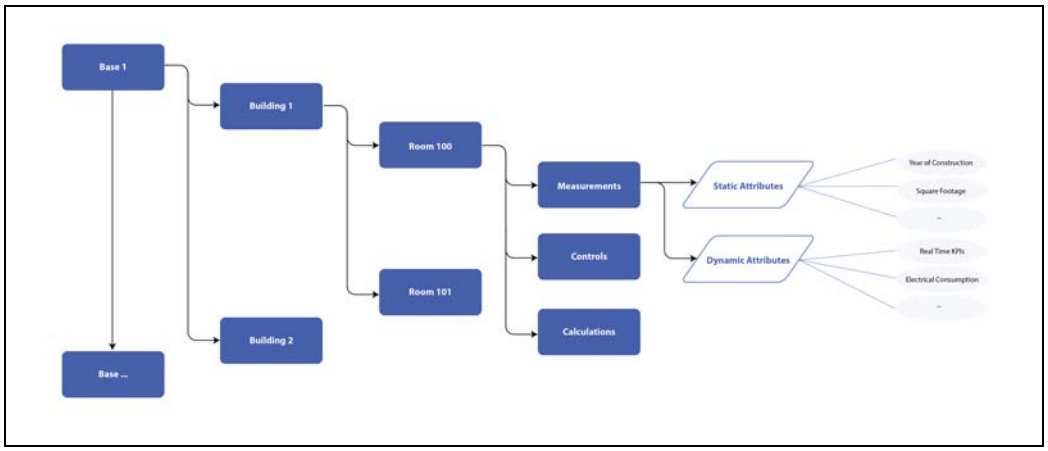

Figure 1. Example of a PI AF Object Oriented Hierarchical Model

Assembled in the PI system, the aggregated data were accessible at any time by the PaANG facilities team. Trends of historical information can be quickly displayed using PI Coresight at multiple time intervals (see Figure 2) as well as provide spatial information (see Figure 3).

Figure 2. Web-based PI Coresight Interface (time interval)

Enabling Continuous Monitoring and Diagnostics

The integrated database provided the following building energy performance assessment tools:

- **Benchmarking:** EUI metrics (kwh/ft^2) were created for comparison with buildings that have similar specification (building type, size, occupancy, year of construction, etc.).
- **Spatial Information Display:** Installation and building-specific energy and BAS data displays were created for easy access to real-time and trended data sets (see Figure 3).

- **Energy Anomaly Detection using simulation of Key Performance Indicators (KPIs):** Boundaries of acceptable energy consumption were defined around the simulation of optimal performance. Using the PI Notification tool, alarm notifications (by email, and on-screen flags) were triggered and delivered to specified users whenever measured data fell outside the KPI boundaries.
- **Quality Control, Fault Detection and Diagnostics:** CMU/OSIsoft developed an automated data quality control that assessed field values for proper range and performed energy balance checks at the component, equipment, and system levels. Alarms were triggered each time that field values were detected outside their proper defined ranges.

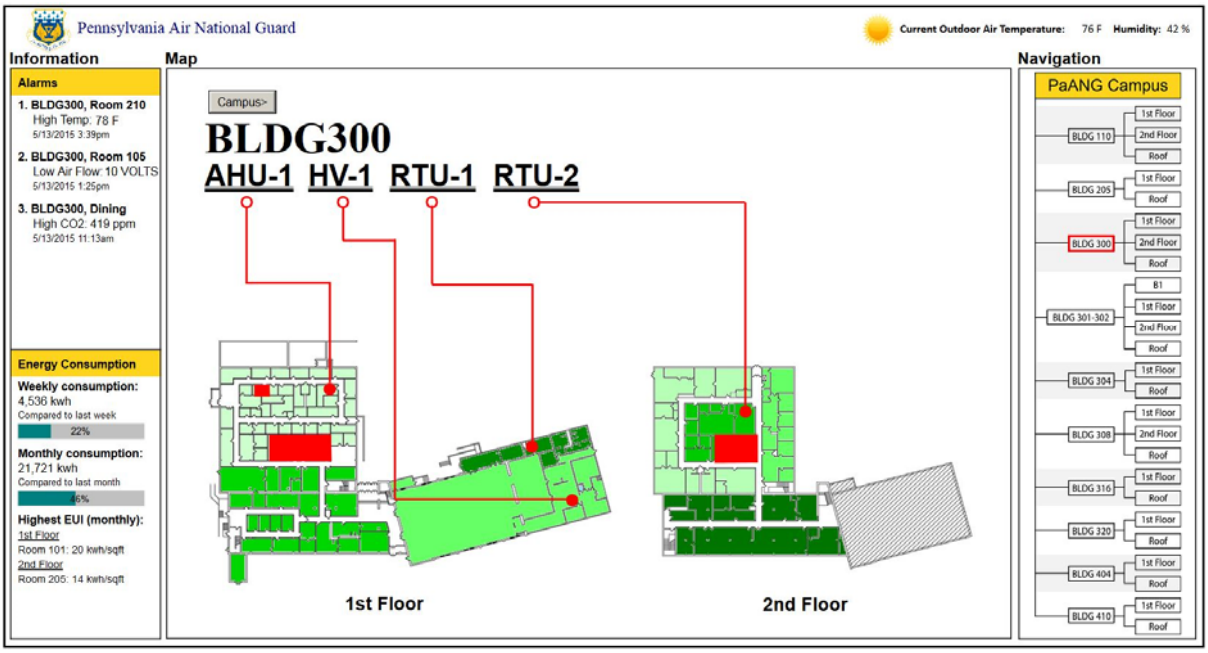

Figure 3. A Floor Plan with Zone Temperature in PI Coresight

2.1.2 ID-O Intelligent Dashboards for Building Occupants

The research team deployed the ID-O interface for eight building occupants in Building 205 to provide real-time information on plug load energy consumption, expert recommendations, and online control. As illustrated in Figure 4, the main features of the Intelligent Dashboard are:

- **Communication:** The self-monitoring interface displays real-time and historic data for each monitored device in the office. The dashboard provides different chart options: daily, weekly and monthly; bar charts and continuous plots; precise energy demands; and comparative use among workgroup peers.
- **Expert Consulting:** Unlike most dashboards that provide only generic advice, the intelligent dashboard recommendations for action are generated on-the-fly, based on actual energy use patterns. The advice can be short-term (e.g., turn off the equipment at night and during weekends) or long-term (e.g., replace the old equipment with an Energy Star™ device).

- **Control:** Most dashboards do not allow occupants to personally control equipment. The dashboard has several control strategies to enable occupants to reduce unnecessary energy uses: clicking a digital on-off button, setting up group controls, and adding calendars and schedules (full automation).

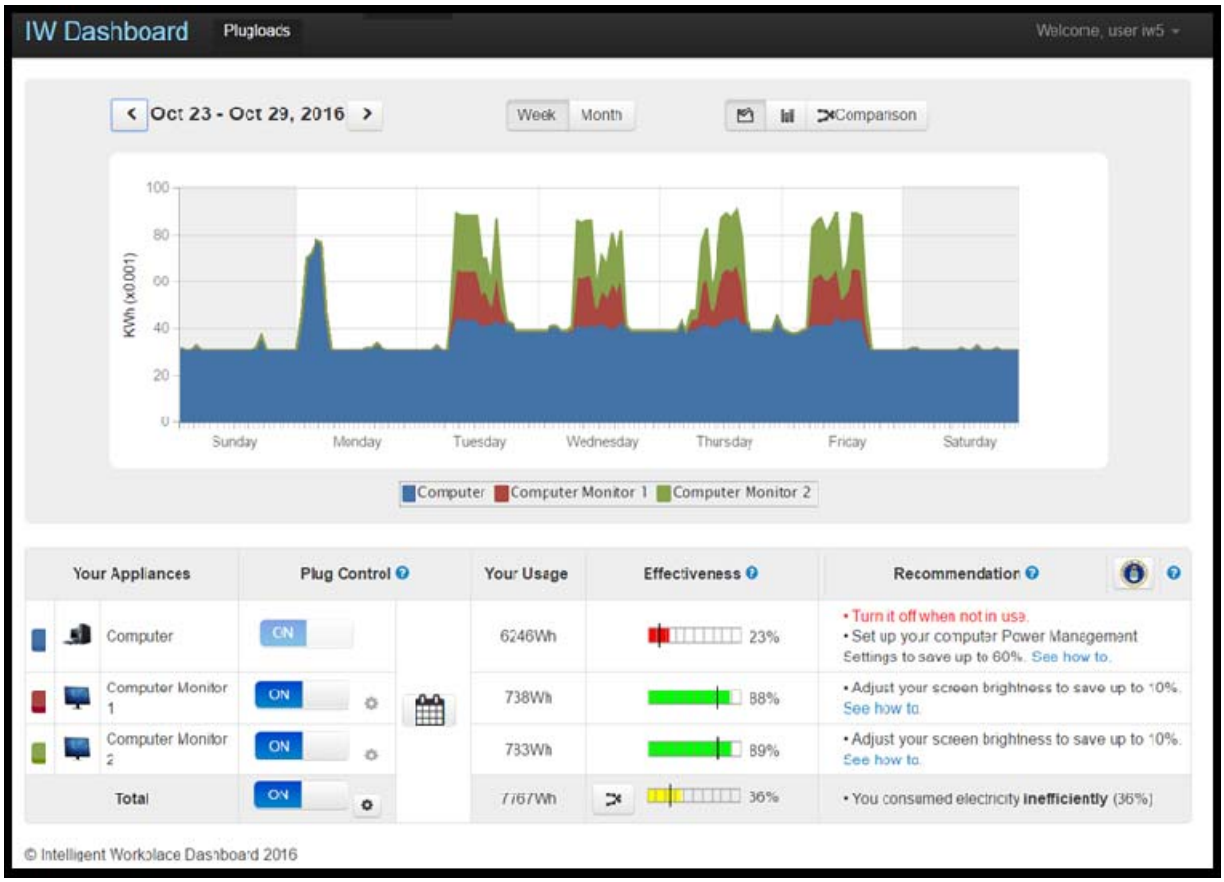

Figure 4. The Plug-load Dashboard Home Screen

2.1.3 Chronological Summary

A chronological summary of the ID-F and ID-O technology development is presented below in Table 1. Although ID-F and ID-O have been developed in tandem and designed to work together, they interface with separate users, facility managers and building occupants; and, therefore, constitute distinct technologies that are integrated within the software platform. "Maturity Level" assessment of the technologies' state of development is assessed on a scale of 1 (conceptual design) to 9 (commercial acceptance in the marketplace). ID-O is currently at Level 8 (complete system qualified through test and demonstration) while ID-F is currently at Level 6 (prototype demonstration in a relevant environment).

Table 1. Chronological Summary of the Technologies Development

	Features	Period	Funding Agency	Maturity Level
ID-O	Cloud-Base ID-O System	2011-2013	DOE	5
	ID-O Deployment at PNC BANK	2013-2014	DOE-CMU	6
	ID-O System architecture redesigned matching DOD requirements	2015-2016	DOD	7
	ID-O Refinement for Local deployment	2016	DOD	7-8
ID-F	Drivers for BAS system	2012-2014	CMU	5
	Front End Interface for Facility Managers	2013-2015	DOE-DOD	6
	Automated Discovery and Mapping of BAS Points	2013-2015	DOE	6

2.1.4 Future Potential and Application for the DOD

The benefits and applications of the integrated building data analytics platform are categorized below for various DOD stakeholders:

1. For *Policy/Decision Makers***,** the information supports data-driven policy-making and assessments, and the planning of prioritized energy conservation measures.
2. For *Facility Managers* and *Building Operators*, the data platform supports proactive operations and maintenance to reduce energy consumption and provide superior IEQ, thereby optimizing building portfolio performance.
3. For *Building Occupants*, the energy and IEQ information creates greater awareness and promotes engagement in energy and resource conservation.
4. The *Public* gains greater access to the environmental footprint of the military installation with verified metrics and key performance indicators.

The ID-F PI-based platform can be installed, as designed, in DOD facilities throughout the world and provide potential dynamic benefits. In addition to collecting and analyzing data, the data platform stores the time-series data indefinitely. Since the historical data is not lost but stored in the facility's internal system, DOD Facility Managers, Building Operators, and other DOD researchers and contractors can use the historical data to further optimize existing building operations, develop applications, algorithms, and customized information presentations to help them support further energy conservation while increasing occupant comfort, satisfaction and performance in their facilities.

2.2 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGIES

Performance Advantages:

The PI system will support long-term data acquisition and storage for the DOD base without overwriting due to space limitations or ongoing fees for data retrieval and trending. The ID-F interface will help the facilities team quickly identify and correct energy waste to reduce overall building energy (electric and gas) consumption by 30%.

Through occupant awareness of the energy use of their desktop technologies, and by using online and automated control, the ID-O is expected to reduce plug load electrical energy consumption by 30%.

Cost Advantages:

Since the PI and ID-F platform is a software-based solution, the primary costs will be attributable to engineering and customization efforts such as the development of an ID-F interface specific to the installation. To help minimize user training costs, the interfaces are designed to be intuitive for the facility team to operate. The Return on Investment (ROI) is expected to be within one year, if the military installation already has a current PI system license and an operational BAS. Without an active PI system license, the return of investment is expected to be within 2–3 years.

Performance Limitations:

The ID-O and ID-F technologies require careful deployment planning to mitigate cybersecurity issues. To reduce potential system hacking and comply with existing DOD standards, the ID-O and ID-F were deployed within the VLAN, separate from the secure NIPRnet and the computers used by base personnel, which could potentially reduce user engagement with the technology. Installation of the ID-O and ID-F dashboards on the computers used for work, instead of a separate laptop, as was provided for the demonstration—and/or installation of the dashboards as a mobile app—would enhance the performance by military personnel to align with the results achieved in a civilian environment. DOD and base-specific policies for IT management may also prevent the optimization of the technologies relative to installations in civilian settings.

Cost Limitations:

The collection and analytics platform relies on operational BAS and sub-metering systems within the military installation. Added cost may be incurred due to faulty and malfunctioning sensors and meters that need to be replaced to ensure robust assessment of the energy and indoor environmental conditions of the facilities. Consequently, re-commissioning of the building is essential for the proper installation of the demonstrated technologies.

Potential Barriers to Acceptance:

The ID-O technology was widely accepted at previous pilot test and demonstration sites, as it provides an easy-to-use interface for building occupants to manage their plug load usage. A potential barrier to acceptance of the ID-O within the DOD is the need to install the technology on a separate tablet instead of on the main computer that the occupant uses for his/her daily tasks. The deployment of the technology on a separate hardware device is necessary to ensure network security (VLAN vs. NIPRnet). However, the separate hardware may reduce the interaction between the building occupant and the plug load management dashboard.

Similarly, the ID-F must be installed on dedicated hardware, thereby eliminating the mobile friendly version of the dashboard for facilities personnel who are moving about the base. The PaANG installation (similar to most military installations) is not equipped with a wireless network.

3.0 PERFORMANCE OBJECTIVES

The technology and economic Performance Objectives (PO) focused the measurement of the technology's contribution to DOD energy goals and demonstrated efficacy of the system for deployment at military installations.

3.1 SUMMARY OF PERFORMANCE OBJECTIVES

Table 2. Performance Objectives

Performance Objective	Metrics	Data Requirements	Success Criteria	Results
Quantitative Objectives				
Reduce Overall Building Energy Consumption (ID-F)	Energy Intensity (MMBTU/^{ft2} kWh/ft^2)	Real-time metered and historical energy data and building square footage	> 30% annual energy savings	**Not Achieved 10% Savings**
Reduce Plug Load Energy Consumption (ID-O)	Energy Intensity (kWh/ft^2)	Energy consumption data from plug load meters, building square footage	> 30% annual plug load energy savings	**Not Achieved 24% Savings**
Reduce Greenhouse Gas Emissions (GHG)	Emissions from fossil fuel (metric tons of eCO_2)	Estimated GHG based on measured or historical energy data	> 30% annual GHG reduction	**Not Achieved 10% Savings**
Favorable System Economics	Simple Payback (years)	Calculated or estimated energy saving in dollars, system first costs	Payoff in < 3 years for ID-F Payoff in < 5 years for ID-O	**Achieved**
Level of Technology Transfer, deployment, and applicability	Number of DOD installations which could use the system	Comparative analysis of Technology applicability at similar military bases using surveys and literature reviews	Technology applicable to more than 25% of DOD bases	**Achieved**
Qualitative Objectives				
Positive Occupant Behavior Change	Active participation in energy conservation	Energy conservation awareness survey data, logged interaction with dashboard	# of recommendations followed by occupants, increased energy conservation awareness	**Achieved 85% of occupants' engagement**
Increase in Occupant Satisfaction	Degree of satisfaction	Occupant survey data	Increased comfort and satisfaction with thermal comfort (pre- versus post-intervention)	**Achieved**
Provide Enhanced Fault Detection	Number of failures detected	Quality control on critical HVAC equipment. Number of failures detected, number of false positives indicated	Reduced number of complaint calls	**Achieved**
Ease of system use by FM and building occupants	Interaction with introduced technology	FM survey data, interaction with dashboard	More than 80% user satisfaction	**Achieved 85% Satisfaction Level for ID-O**

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4.0 SITE DESCRIPTION

The selected facility was the Pennsylvania Air National Guard (PaANG), 171st Air Refueling Wing base in Coraopolis, PA. The PaANG campus is adjacent to the Pittsburgh International Airport, which is approximately 18 miles from downtown Pittsburgh, PA. This site hosted an earlier ESTCP field demonstration project (EW-201366), led by Siemens Corporate Technology, that ended in March 2014.

4.1 FACILITY/SITE LOCATION AND OPERATIONS

The selected PaANG installation is representative of other military installations because they have similar building types (i.e., offices, warehouses/storage and workshops). As an Air Force National Guard installation, it also accommodates hangar buildings and runways.

4.2 FACILITY/SITE CONDITIONS

There are a total of 40 buildings/structures and five major building types within the PaANG installation (see **Error! Reference source not found.**) to include (1) Offices, (2) Hangars, (3) Workshops, (4) Warehouse/Storage Buildings, and (5) Miscellaneous Buildings/Structures that occupy a total area of approximately 400,000 square feet. Hangars have the highest square footage at more than 168,000 square feet, representing 42% of the total building floor space, followed by offices at 108,000 square feet (27%). Information is collected from approximately 4,600 data points (utilities and BAS) at the installation. Most of these points are located in office buildings; they account for more than 70% of the total number of data points on the base.

Table 3. Building Type and Monitored Areas

Function	#	Area		# of data points	
		Sqft	%	Sqft	%
Offices	8	107,579	27.0%	3,254	71.0%
Hangar	4	168,249	42.2%	591	12.9%
Workshop	4	46,266	11.6%	324	7.1%
Warehouse/Storage	7	60,243	15.1%	104	2.3%
Misc. Buildings/Structures	17	16,541	4.1%	310	6.8%
TOTAL	40	398,878		4,583	

The major HVAC equipment types include AHUs, RTUs, boilers, and chillers. There are 8 AHUs, 4 RTUs, 5 boilers and 2 chillers. Most of the mechanical equipment is located in the office and hangar buildings. In addition, the base is equipped with several building-level analog and digital meters for gas, electricity, and water. There are 16 electric sub-meters (5 analog and 11 digital), 9 gas sub-meters (4 analog and 5 digital), and 9 water sub-meters (all analog).

The majority of the buildings (73%) have very few occupants on a regular basis. Approximately 27% of the buildings (offices) house the majority of PaANG's occupants and personnel.

Office buildings were selected as the use type in which to install the majority of the sensors (71%), as data collection in these spaces provides the greatest opportunity for energy savings that will directly impact the personnel. The remaining 29% of the data points were divided among the remaining building use types based on their percentage of energy consumption and personnel occupancy on the base. 70% of all "office" type spaces are housed in two buildings: Building 300 and Building 107. Because these two buildings have the highest occupancies, they also contain the most sensors and data points. The ID-F database and dashboard collected from and communicated with all meters and BAS data for 14 buildings on the base (see building location on base site plan, Figure 5). Early data collection indicates some major anomalies that can be addressed, while longer trended data and data analytics provided more detailed insights.

Location/Site Map:

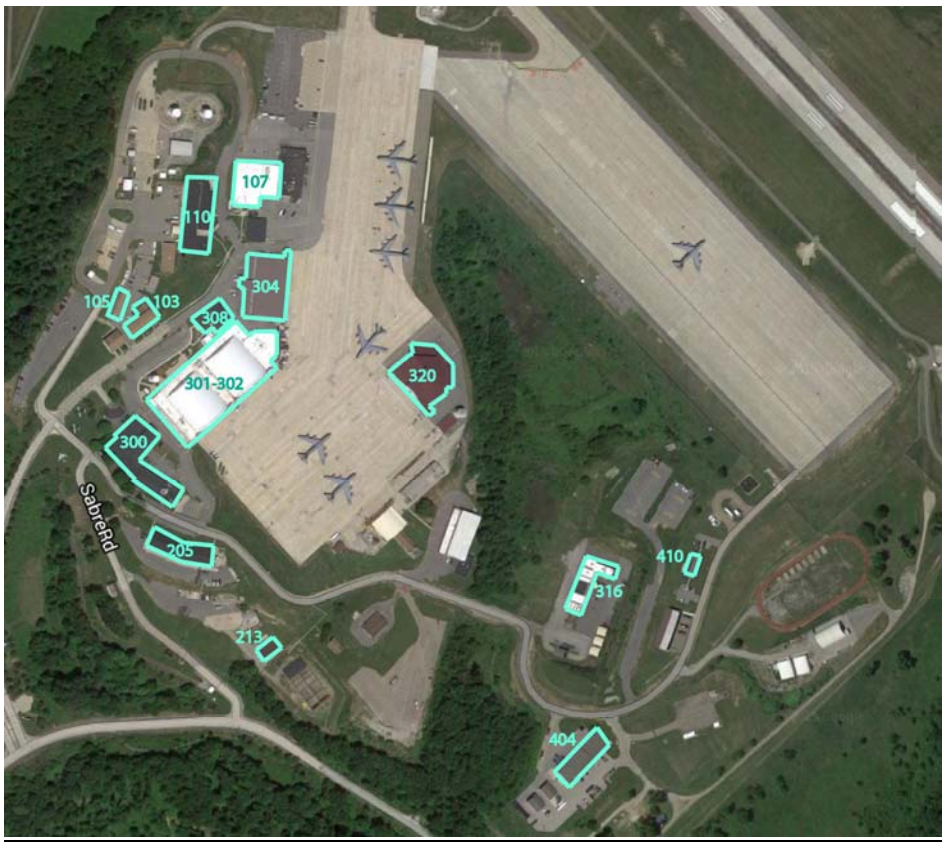


Figure 5. Site Plan of the PaANG Installation, Coraopolis, PA

5.0 TEST DESIGN

Fundamental Problem:

The optimal performance of a building during its lifetime is often compromised due to a lack of monitoring and continuous diagnostics. Drifts or anomalies are not detected, analyzed, and reported. Additionally, various hardware manufacturers produce stand-alone systems and use proprietary communication protocols; and very few robust integrated infrastructure systems are available on the market to integrate them. Furthermore, occupants are not given information regarding their energy consumption and have very little control over their indoor environment. What is more, common building operation practices do not include occupants for feedback and control.

The demonstration aimed to address these shortcomings by implementing an integrated platform solution for monitoring and diagnosing building performances to reduce energy consumption while empowering building occupants toward more energy efficient behavior.

5.1 CONCEPTUAL TEST DESIGN

5.1.1 Hypothesis

To assess the effectiveness of the proposed technology to achieve the performance objectives' success criteria, several tests were designed. The acceptance criteria were:

- 30% reduction in total building energy consumption
- 30% reduction in plug load consumption through user engagement
- Predictive Maintenance through continuous Fault and Diagnostics presentation

5.1.2 Variables

Independent variable(s):

These are the variables manipulated or changed by the facility managers using the ID-F platform and by the building occupants using the ID-O platform.

Dependent variable(s):

These variables were expected to be affected by the proposed technology and were measured (Table 5. Test design summary ID-0

and **Error! Reference source not found.**).

- <u>These Variables were measured:</u> Electrical kWh consumed, peak demand (kW), electricity cost, gas kBtu consumed, greenhouse gas emissions, changes in run times of mechanical systems (air handling units, cooling distribution, ventilation, and boilers), and number of faults detected and resolved.

Controlled variable(s):

These variables were not affected by the proposed solution and, therefore, were held constant between the baseline and the experimental period:

Table 4. Test design summary ID-F

Controlled Variables	Independent Variable	Dependent Variables
• **Building characteristics (size, set points, etc.)** • **Mechanical system main hardware characteristic** • **Weather pattern** • **Occupancy pattern** • **Baseline duration**	• Use of the ID-F technology	• Energy usage for whole building • GHG emissions • Total electricity costs • Occupant comfort • Number of faults detected and fixed

Table 5. Test design summary ID-0

Controlled Variables	Independent Variable	Dependent Variables
• **Building characteristics (size, set points, etc.)** • **Electrical Appliances Specs** • **Weather pattern** • **Occupancy pattern** • **Baseline duration**	• Use of the ID-O technology	• Plug load energy usage • GHG emissions • Occupant satisfaction

5.1.3 Test Design

ID-F Technology:

The ID-F technology provides advance monitoring and analytic capabilities for an existing building or a group of buildings. The real-time monitoring capability of the tool allowed facility managers to detect costly sequences of operation such as:

- inadequate AHU supply air temperature,
- no setback on thermostat during unoccupied hours,
- system failure leading to energy waste (economizer dampers stuck in Open position)
- very high electrical base load during unoccupied hours (nights and weekends)

The energy savings introduced by the ID-F platform was estimated using the ASHRAE Guideline 14-2002 methodology. The Whole Building Performance path was selected to quantify the energy savings induced by the proposed intervention. The Performance path required baseline data collection over the full range of seasonal operation. To match these requirements the baseline was collected for a 10.5-months period, spanning over each season.

ID-O Technology:

The ID-O technology provides insight to building occupants on how to manage their appliances more efficiently by enabling real time energy feedback and automated controls of the office equipment/appliances. Algorithm analyzed users' electrical consumption trends and created personalized feedback and recommendation.

Test Phases:

The main test phases are described below:

- System Installation and baseline data collection: Collection of the buildings' as-built information, occupancy, BAS data, and energy meter data (electrical and gas).
- Baseline Characterization: Statistical analysis was conducted to analyze the baseline energy characteristics and identify the impact energy consumption has on factors not associated by the technology intervention project (i.e., weather, occupancy, etc.).
- ID-O and ID-F user interfaces deployment and BMS commissioning: This phase included hardware upgrades to the existing BAS system, as needed changes were detected by the system.
- Energy savings measurement and estimation: Test result were compared to the baseline and analyzed

5.2 BASELINE CHARACTERIZATION

5.2.1 ID-F Baseline Characterization

Reference Conditions:

The following data was collected for baseline characterization:

- Electrical demand measured from both automatic digital meters and analog meters.
- Gas demand measured from both automatic digital meters and analog meters.
- Boilers' sensors data (supply water temperature, return water temperature and flow, etc.)
- Chiller sensors data (supply water flow and temperature, return water temperature, etc.)
- Ventilation system sensors data (AHUs supply temperature, static pressure, etc.)
- Mechanical system electrical consumption when available (AHUs, RTUs).
- VAV supply air flow and temperature.
- Indoor temperatures and humidity values.
- Weather conditions (temperature, humidity, wind speed, wind direction, and solar radiation).

Baseline Collection Period:

Baseline data collection from the PaANG Base electrical and gas meters and building automation systems started in February, 2015. Ten and one-half months of data collection spanning over all climate seasons (February 2015 to December 2015) was performed.

Existing Baseline Data:

The site utility bill for the years 2012, 2013, and 2014 were used to compare main aggregated building level data and assess energy consumption from the base without any sub-meters.

Following ASHRAE Standard 14-2014, regression models were performed for each building to determinate annualized energy savings. A three-parameter regression model for the electrical consumption (miscellaneous + cooling electrical consumption) of building 205 is presented on Figure 6.

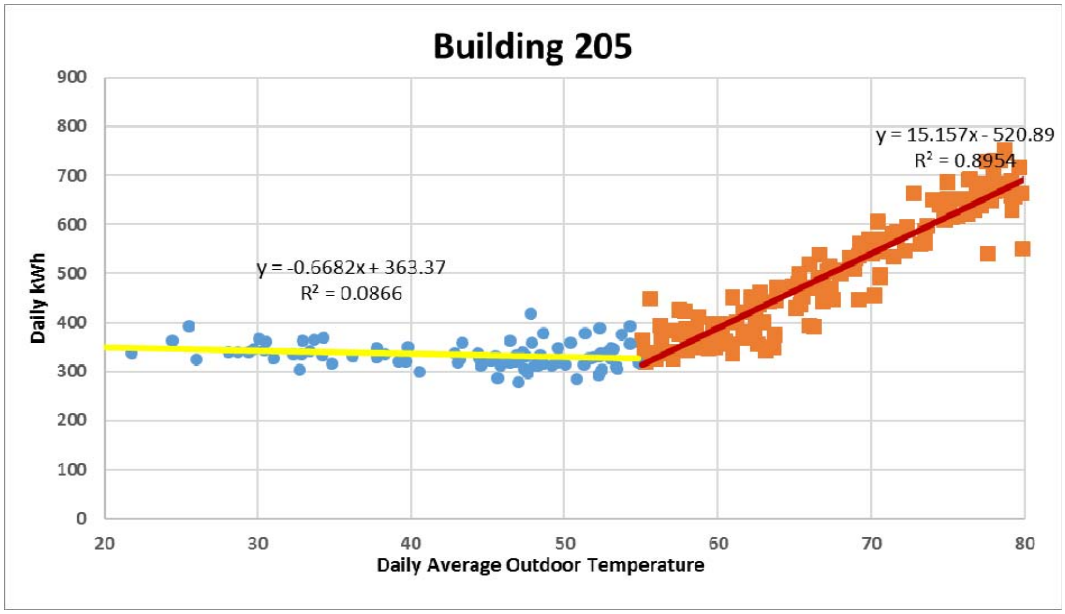


Figure 6. Whole Building Electrical Consumption Regression Model

5.2.2 ID-O: Baseline Characterization

Reference Conditions:

The following data was collected for baseline characterization:

- Individual plug load consumption (wireless sub-meters).
- General Base scheduling (reservist weekend)
- Individual Room Occupancy

Baseline Collection Period:

Baseline data collection started in March 2015, after the wireless plug meters were installed on the occupant appliances. Occupants were informed that the meters would record their appliances' energy consumption and were asked not to change their behavior or how they control their appliances. The occupants didn't have access to any energy data information during the baseline data collection.

The first month of data collected was not incorporated to avoid potential "Hawthorne effect" impacts on the data.

5.3 DESIGN AND LAYOUT OF TECHNOLOGY COMPONENTS

System Design:

The ID-F system is a vendor independent software platform that can integrate, extend, and improve existing BAS capabilities by enabling advanced monitoring and analytic tools and by providing fault detection and diagnostics capabilities.

ID-O provides advanced interfaces with which building occupants can control their indoor environment (plug load, lighting system) when digitally addressable systems are available. In this demonstration project, the ID-O system targeted the management of plug load appliances.

Figure 7 shows the system architecture of the ID-F and ID-O where the communication between the BAS field panels and the system is based on the industry standard BACnet. The BACnet interface (adaptor) translates and saves the BACnet UDP packets information in the Time Series database.

The Plug Load energy data collected by the smart wireless meters are managed by the vendor Plugwise Source software. The data is then collected by 2 databases (SQL Server and PI Server).

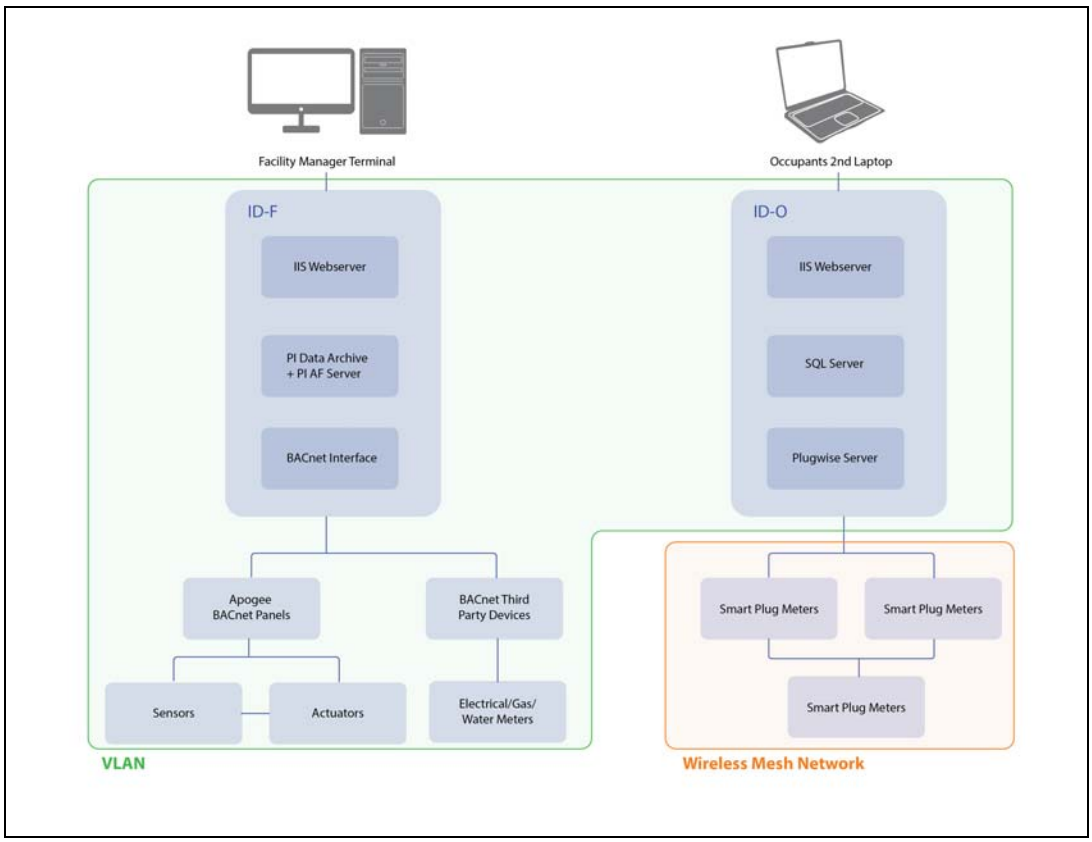


Figure 7. System Layout

Components of the System:

A typical setup of ID-F and ID-O installation requires 2 databases (a Time series data base (PI Server) and a relational database (MS SQL Server)), 2 Webservers (IIS webserver), browser-based Occupant Personal Dashboards, browser-based Occupant Public Dashboards, and browser-based FM Dashboards residing in the same network as the existing Building Automation System.

System Integration:

For the demonstration, ID-F was deployed and collected data for each building that had BAS and/or electrical/gas meters installed. All HVAC equipment in every building at the base is controlled by an existing Siemens Apogee BAS with BACnet interface

The network setup for the system at PaANG is shown in Figure 7. The facility manager (FM) terminal and occupant terminals reside in the same network with the Apogee BAS, all of which is isolated from other IT network devices using a VLAN.

The FM's terminal is located in the control room where the Apogee Insight server is located. The occupant terminals deployed in Building 205 were made accessible from a second laptop directly hardwired to the VLAN. Both the occupant terminals and the FM terminal were unmodified PCs with Windows operating system that had previously been vetted by the base IT office for purposes of assuring military security.

System Controls:

During the demonstration, the occupants using ID-O were able to control their plug load appliances through the dashboard. The tool allowed the following features:

- Automatic calendar control to turn ON/OFF single or a group of appliances
- Manual ON/OFF control of single appliances
- Manual ON/OFF control of a group of appliances
- Appliance-specific recommendations
- Historical individual appliance power consumption
- Anonymized peer-to-peer comparison (you, Average, best, among your peers)
- Effectiveness score

After discussion with the base Facility Managers, it was decided that the ID-F platform would be deployed in a read-only mode. Anomalies and errors detected by the ID-F platform were displayed to the Facility Manager who could then control/adjust settings on the Siemens Apogee system or troubleshoot field devices.

5.4 OPERATIONAL TESTING

The demonstration was composed of several phases that included: Laboratory Integration, Field deployment and the full demonstration execution. The various data collection process in phase are described below in **Error! Reference source not found.**:

Table 6. Operational Testing Design

Phase	Description	Data Collection Process
P1	**Lab Test Integration**	
P1.1	Customization of ID-O technology to DOD IT requirement	CPU Usage, memory usage, data lose, system stability, database performance, system response to user control (latency between command and response)
P1.2	ID-F technology test	CPU Usage, memory usage, data loss, system stability, database performance
P2	**System Installation and Commissioning**	
P2.1	Component and system level testing:	CPU usage, memory usage, latency, data loss
P2.2	System deployment and network installation	% of BACnet points collected and stable, number of data point drops
P3	**Baseline Characterization**	
P3.1	Run the ID-F at PaANG for a 10 months period	Electric meter data, flow meter data, and building automation system trend data, including the sensor and control data for each asset: chiller, air handling unit, VAV box and heat exchangers; occupants survey
P3.2	Run the ID-O at PaANG for a 5 months period	Electrical Appliances data, system stability, Occupancy
P4	**Hypothesis Validation/Demonstration Execution**	
P4.1	Run the ID-F at PaANG for a 6 months period	Electric meter data, flow meter data, and building automation system trend data, including the sensor and control data for each asset: chiller, air handling unit, VAV box and heat exchangers; occupants survey
P4.2	Run the ID-O at PaANG for a 3 months period	Electrical Appliances data, user interaction with ID-O displays

5.5 DATA COLLECTION PROTOCOL

Data Collector(s):

The OSISoft PI Data Archive collects all of the building's time-series data directly from each Apogee BAS field panel and from each individual gas/electrical analog meter. Information from digital meters is manually entered into the system by a field technician with an integrated mobile tool. Facility Managers create routes with a pre-defined list and location of sensors to be collected by the field technician.

For this demonstration project, BAS data was collected using the BACnet protocol, the protocol used by the BAS at PaANG base, but the demonstrated tool is also compatible with other communication protocols such as Modbus and OPC.

Data Description:

Sensor data from the BAS were sampled every 5 minutes. Data from the individual electric/gas meters were sampled each minute.

Data Storage and Backup:

The data collected were stored in the OSIsoft PI System time series database. Full backups of the database were performed weekly on an external hard-drive.

Non-Standard Data:

Building attributes and mechanical attributes were collected at the beginning of the system implementation and saved in a relational database (OSIsoft AF Database running with Microsoft SQL Server) allowing the software to link each sensor's data to specific assets and their related attributes.

5.6 EQUIPMENT CALIBRATION AND DATA QUALITY ISSUES

Equipment Calibration:

All of the installed monitoring equipment was newly purchased and has a manufacturer's calibration valid for at least the duration of the 22-month demonstration period. Data collected from these instruments was sufficient to satisfy demonstration performance objectives and meet QA requirements.

All installed sensor functions were checked in accordance with manufacturers' specifications. Following the installation, source-to-data checks were conducted in the field to verify that the data acquisition properly received incoming signals.

Quality Assurance Sampling:

Received sensor data values were monitored to ensure that computed values were within acceptable ranges. Data points were compared against expected variables, and then they were mapped to identify potential outliers that could alert the project team to possible unforeseen anomalies or values outside a realistic range. All checks were documented and stored as part of project files.

Post-Processing Statistical Analysis:

Received sensor data values and data were organized to ensure that the output was understandable, reliable, and within realistic ranges. Additionally, database attributes and labels were made consistent and easily identifiable to ensure the team was able to interpret the data and locate desired sensor outputs.

6.0 PERFORMANCE ASSESSMENT

Performance of the ID-F and ID-O technology implementation at the PaANG demonstration site was measured against the baseline to determine energy savings. This performance measurement and verification was conducted following industry best practices established by:

- ASHRAE's Guideline 14-2014 for Measurement of Energy and Demand Savings
- FEMP M&V Guidelines: Measurement and Verification for Federal Energy Projects, Version 3.0 (April 2008)

6.1 PO-I: REDUCE OVERALL BUILDING ENERGY CONSUMPTION (ID-F)

Expected Result**:** The project anticipated achieving a 30% energy reduction in total building energy consumption as measured before and after the deployment of the ID-F technology.

Actual Results: The overall energy consumption savings reached 10%, a result significantly below our target savings of 30%. The energy savings per building ranged from 3% up to 23%.

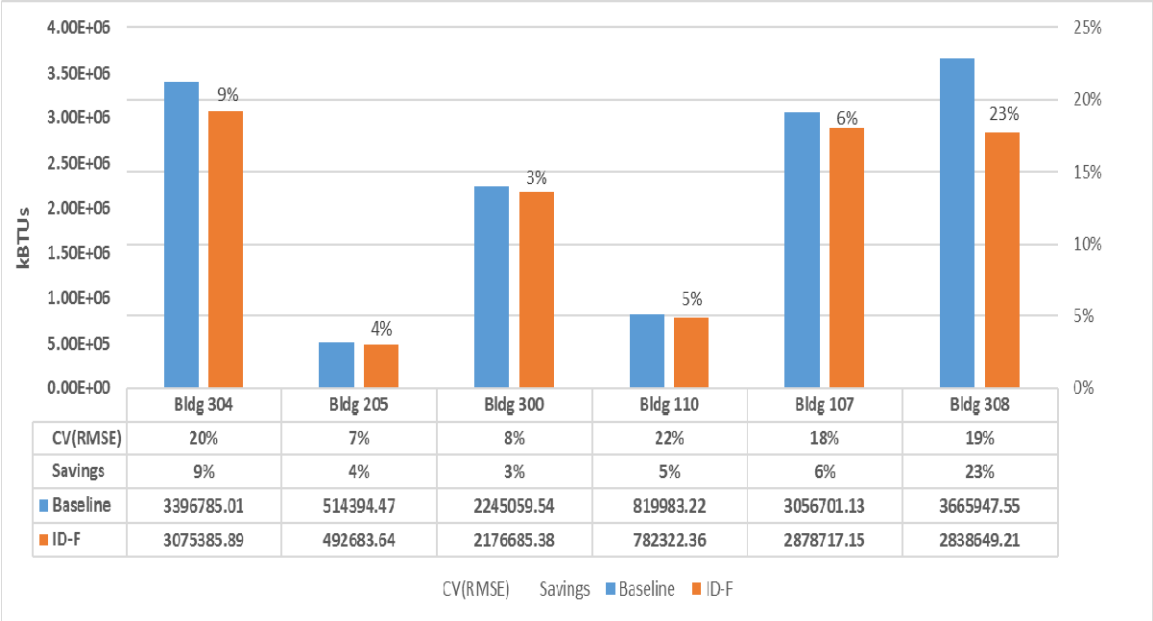


Figure 8. Energy savings per building

Energy savings per energy type are presented on **Error! Reference source not found.**

Table 7. Energy Savings per Energy Type

	Electrical Consumption (kBtu)	Gas Consumption (kBtu)	Overall Consumption
Annualized Baseline	6,197,168	6,743,856	12,941,024
Annualized ID-F	5,866,031	5,747,845	11,613,877
Absolute Savings	**331,136**	**996,010**	**1,327,147**
% Savings	**5%**	**15%**	**10%**

6.2 PO-II: REDUCE PLUG LOAD ENERGY CONSUMPTION (ID-O)

Expected Results: The project anticipated achieving a 30% energy consumption reduction from occupants' electrical appliances as measured before and after deployment of the ID-O technology.

Actual Results: The overall energy consumption savings reached 24%, close to our target savings of 30%. The highest energy savings per occupant was 34%; and the lowest was an overconsumption of 1%, as seen on Figure 9. Seven out of eight participants saved energy compared to their baseline.

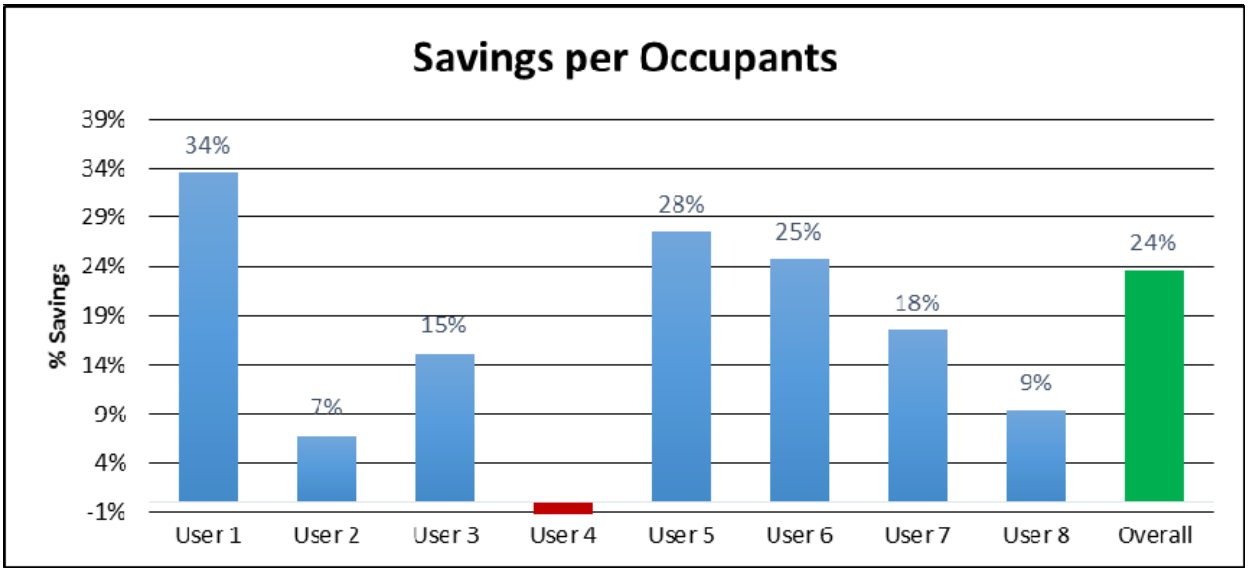


Figure 9. Energy Savings per Occupants

Four main categories of appliances were integrated to the ID-O platform. Median savings per category can be seen on Figure 10. Common appliances (hallway printers, water cooler) had the most energy saving with a median savings of 35%, followed by personal printers (19%), personal monitors (14%) and, finally, personal desktop computers (8%). Personal monitor usage was already efficient at the base because, due to previous training, occupants were correctly managing them. Low savings for personal desktop computers was attributable to a policy that had advised occupants to leave their computers always "ON" in order to be available for automated updates at times when the occupants were absent.

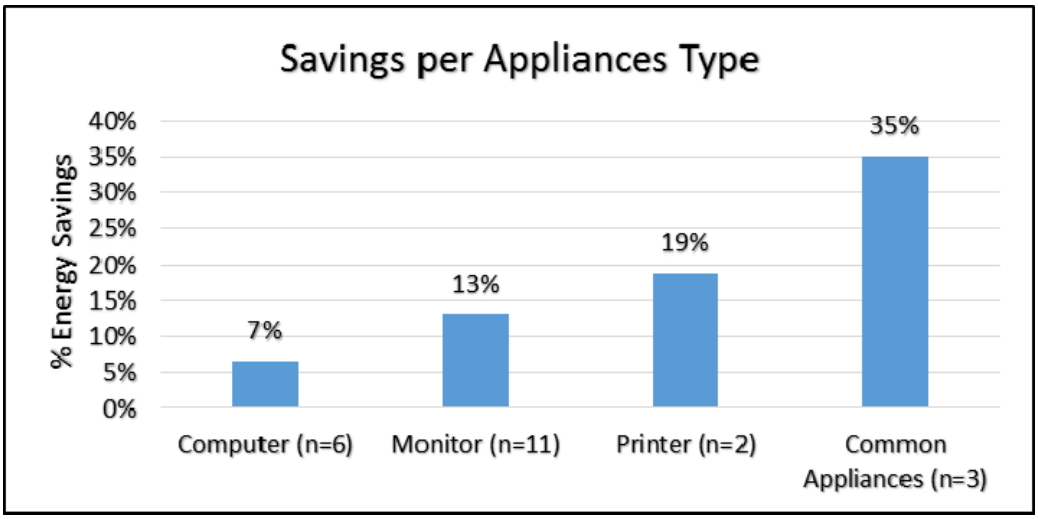


Figure 10. Median Energy Savings per Categories of Appliances

Even though the participants in the study were notified by the base commander that they were allowed to switch off their computers at night, only one of seven occupants changed his behavior and started to turn his computer off during non-work hours on a regular basis (see Figure 11).

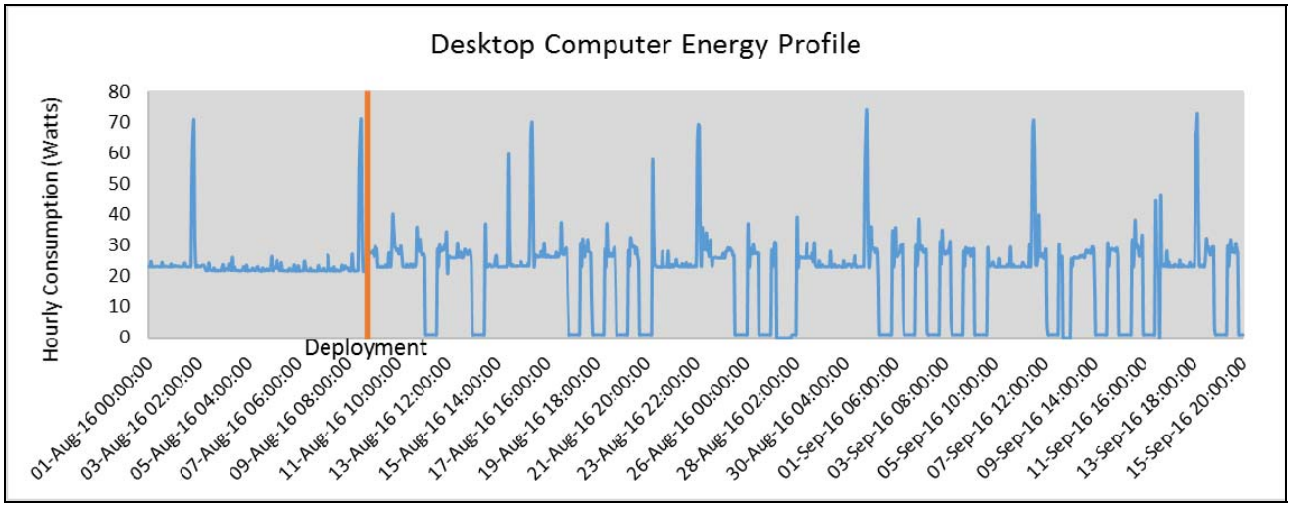


Figure 11. Desktop Computer Energy Profile

As previously explained, a second laptop had to be installed in each office in order to access the ID-O interface running on the base VLAN. Even if the selected installed laptops were energy efficient, it impacted the overall energy savings results. The energy savings decreased six percentage points from 24% to 18% (Figure 12).

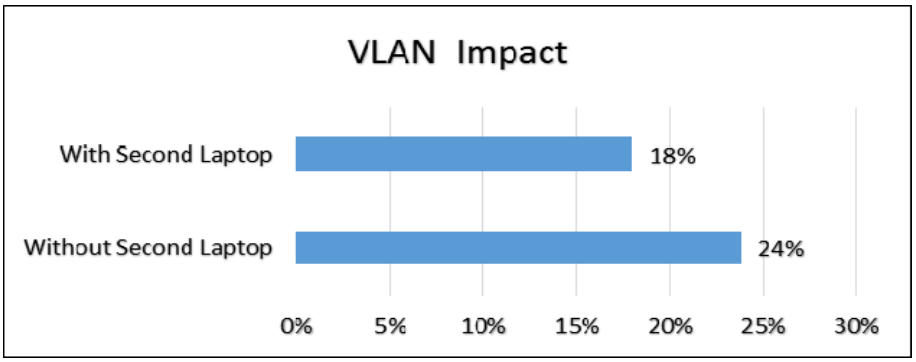


Figure 12. Impact of VLAN Limitation

6.3 PO-III: REDUCE GREENHOUSE GAS (GHG) EMISSIONS

The environmental benefits that are directly linked to electric energy savings relate to the reduction in GHG emissions, particularly CO2 emissions. The emission factor-based methodology, which estimates GHG emissions by multiplying a level of activity data by an emission factor, has been used to calculate the GHG reduction. Activity data is a quantified measure of an activity; in this case, the electricity and natural gas consumption. The emission factors convert activity data into CO_2 emission values and are source-specific (see **Error! Reference source not found.**). The fuel mix of electricity delivered to the PaANG is dominated by coal fired power plants by 58%.

Table 8. CO2 Emission Factor – East Region

	Output Rate (lbs/KBtu)	Data Source	Data Year
Electricity	0.470678	EPA eGRID RFCW	2012
Natural Gas	0.116999	EIA	2014

The CO2 emission reduction per technology is presented below in **Error! Reference source not found.**.

Table 9. Comparison of Emission for ID-O Deployment

	Baseline Emissions (lbs)	After Emissions (lbs)
ID-O	767.25	584.38
ID-F	3,694,849	3,464,211

6.4 PO-IV: FAVORABLE SYSTEM ECONOMICS

6.4.1 ID-O

Table 10. ID-O Savings

Utility Cost	**$0.09 per kWh**
Annualized Baseline Consumption	5,710 kWh
Annualized Baseline Cost	$ 513
Annualized ID-O Consumption	4,231 kWh
ID-O Technology Cost	$1,100

ID-O $ Savings	$140
ROI	12.7%

The low ROI for this demonstration project is due to the scale of the demonstration deployment. With larger deployments, some fixed cost will be significantly reduced. The payback in years as a function of deployment scale is represented in Figure 13. With deployment for more than 120 employees, the expected payback is less than 5 years (20% ROI).

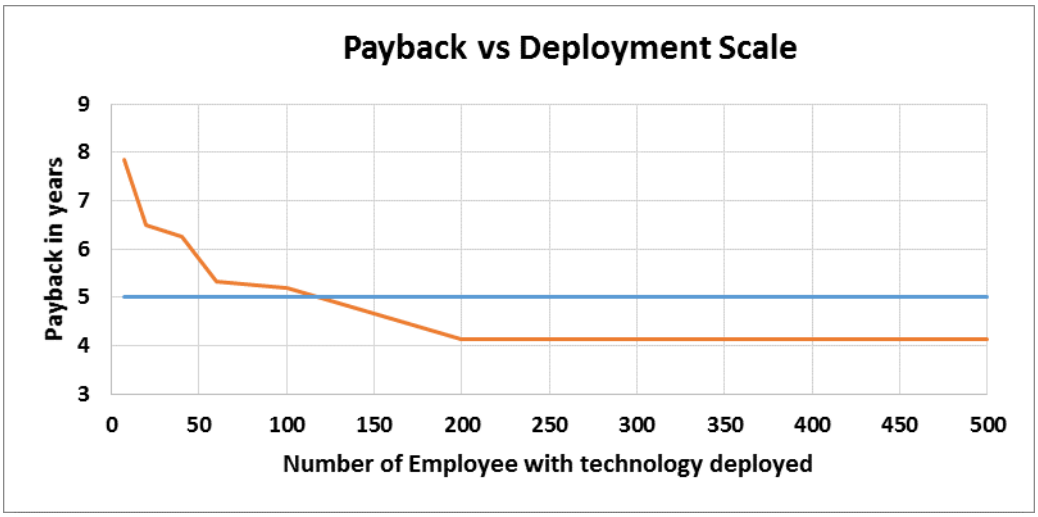


Figure 13. Technology Payback by Deployment Size

6.4.2 ID-F

Table 11. ID-F savings

	Elect. Consumption	Gas Consumption	Total
Utility Cost	0.09 per kWh	8$ CCF	
Annualized Baseline Consumption	1,816,286 kWh	67438 CCF 1,976,511kWh	3,792,797 kWh
Annualized Baseline Cost	$163,465	$51,113	$214,578
Annualized ID-F Consumption	1,719,235 kWh	67438 CCF 1,684,597 kWh	3,403,832 kWh
ID-F Technology Cost	$55,000		
ID-F $ Savings	$8,734	$6,710	$15,444
ROI	28%		

6.5 PO-V: LEVEL OF TECHNOLOGY TRANSFER, DEPLOYMENT AND APPLICABILITY

The ID-F technology can be deployed to any base with BAS from any vendor using an open data communication protocol such as BACnet or providing a front-end API.

The ID-O technology can be deployed to any base with office workers where wireless technology (specifically ZigBee) deployment is possible.

6.6 PO-VI: POSITIVE OCCUPANT BEHAVIOR CHANGE

In order to measure occupant participation level, two variables were tracked during the technology deployment.

- Number of time users logged into the system
- Number time users control the appliances using the ID-O Interface

Active users of the system (2 or more times per week) saved energy ranging from 7% to a maximum of 34%. The only user without any interaction with the system overconsumed by 1% compared to baseline (see Figure 14). Seven out of eight participants actively interact with the ID-O technology throughout the demonstration period (3 months deployment).

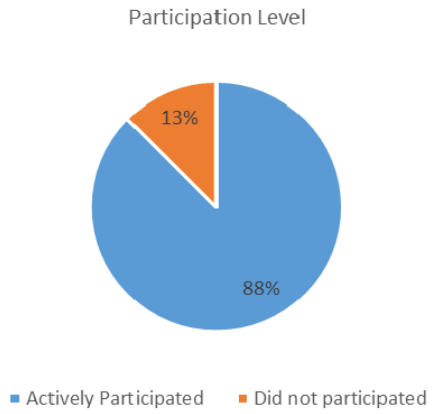
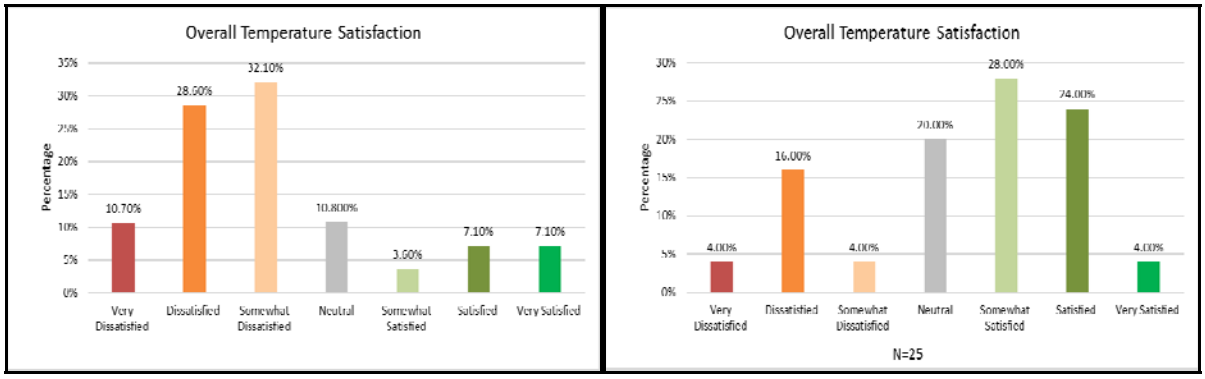


Figure 14. Participation Level

6.7 PO-VII: INCREASE IN OCCUPANT SATISFACTION

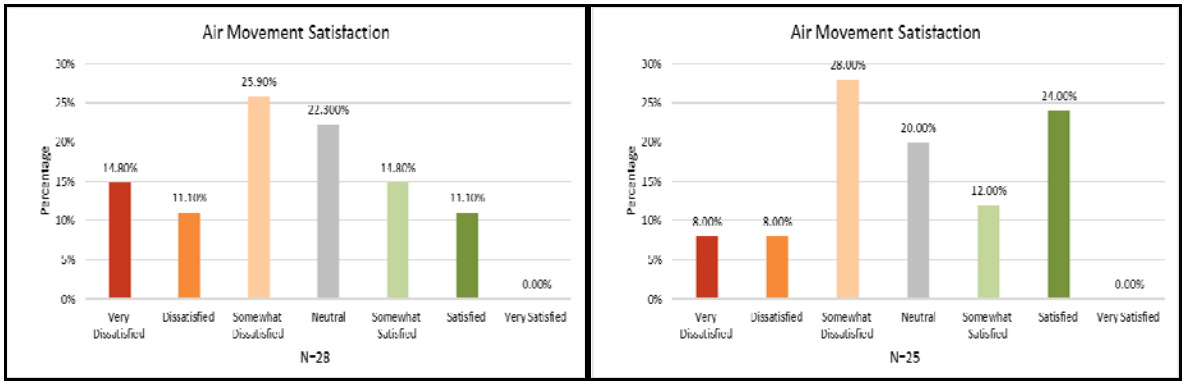
During the deployment period, temperature satisfaction rose from 18% to 56%, a great improvement. Dissatisfaction dropped correspondingly from 61% to 24%, with the remaining employees giving neutral responses (Figure 15). The ID-F system helped the facility operator track temperature conditions in every room on the base, and alarms were triggered when rooms with conditions outside the comfort band were detected.



User Satisfaction Survey (n=28) User Satisfaction Survey (n=25)

Figure 15. Overall User Satisfaction with Temperature on ASHRAE Point Scale

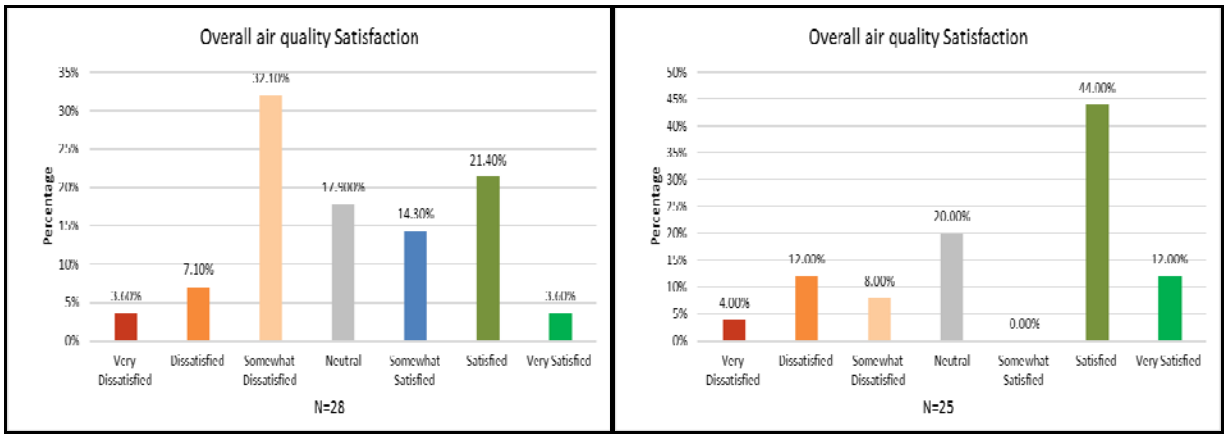
Satisfaction with air movement went from 26% to 36% (Figure 16). The ID-F technology helped the facility operator diagnose the mismatch between the VAVs supply air flow to the current occupancy of the room. The VAVs supply flow rate had been defined during installation for a design occupancy layout that has changed to accommodate different uses over the years.



User Satisfaction Survey (n=28) User Satisfaction Survey (n=25)

Figure 16. Overall User Satisfaction with Air Movement on ASHRAE Point Scale

Overall satisfaction with air quality went from 49% to 56% (Figure 17). This finding correlates to the increase in satisfaction with air movement.



User Satisfaction Survey (n=28) User Satisfaction Survey (n=25)

Figure 17. Overall User Satisfaction with Air Quality on ASHRAE Point Scale

Based on the occupant surveys results it can be concluded that there were improvements in occupant satisfaction after the ID-F installation, compared to the baseline. Hence this PO was achieved.

6.8 PO-VIII: PROVIDE ENHANCED FAULT DETECTION

Before implementation of the ID-F technology, the base had no pro-active fault detection and system optimization strategies, and intervention was driven only by complaint-based reactive triggers (direct phone calls from the occupants). A system would go off or its performance would start to drift and the fault would not be detected until it impacted occupants' comfort (temperature out of comfort range, system off, noise…).

More than 20 faults or incorrect operational sequences were discovered as summarized in **Error! Reference source not found.**.

Table 12. Fault Diagnostic Summary

Type	Class	Action Taken	Numbers Detected	Numbers Fixed
AHU/RTUS ON all the time	Operational	Enable calendar control	7	5
BAS Operator Manual Overrides	Operational	Enable Events in control logic with start and Stop time	10	8
Compressor Short Cycling	Operational	Change control logic PID loop	2	2
Outdoor Lighting on fixed schedule	Operational	Introduce daylight harvesting control	10	10
Incorrect Economizer Control	Operational	Dynamic control of minimum outdoor air intake ratio	3	3
Economizer Damper stuck	Mechanical	N/A, planned in next capital retrofit phase	2	0
Room Temperature out of comfort zone	Operational	Reset automatic set-point, tune VAVs supply air flow	+20	+20

Some examples of faults discovered are presented in the following figures.

A high frequency compressor cycling was discovered on one RTU (Figure 18). Due to a wrong control sequence, the compressor triggered ON/OFF at an alarming rate. The fault was discovered using the building electrical signature collected from the installed sub-meters. A change in the control logic parameters (gain of a PID loop) reduced the cycling of the compressor hence increasing its life expectancy, avoiding potential future replacement capital costs.

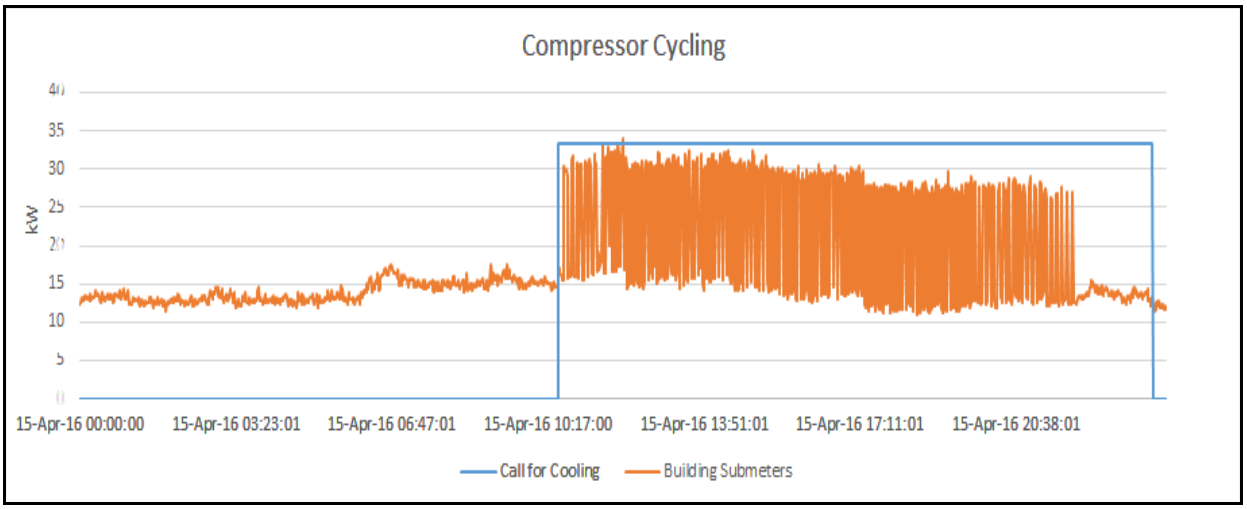


Figure 18. Compressor Short Cycling

A large part of the AHUs controls schedules was overridden manually by an Operator who locked them in the ON position following Drill Weekend events. A new control logic following dynamic scheduling and planned events was created. 2 AHUs had to stay ON as they served 24/7 occupied spaces (Figure 19).

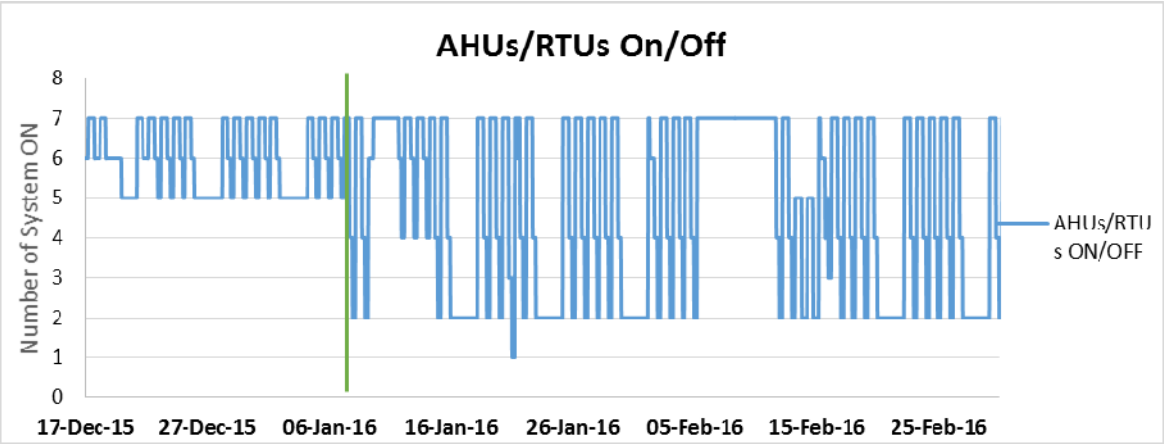


Figure 19. AHUs/RTUs Status

6.9 PO-IX: EASE OF SYSTEM USE BY BUILDING OCCUPANTS

In addition to deploying smart plug-load meters at shared office equipment, we deployed the ID-O dashboard to eight offices within the Civil Engineering building. The deployment was limited to one building to respond to security concerns. Out of eight ID-O installations, only six of the participants responded to the ease-of-system-use survey. All six participants agree that they are able to get the system to do what they want it to do. Only one out of six participants disagreed that learning to operate the system is easy and that the system is easy to use. In general, most of the participants have positive interaction with the system (Figure 20).

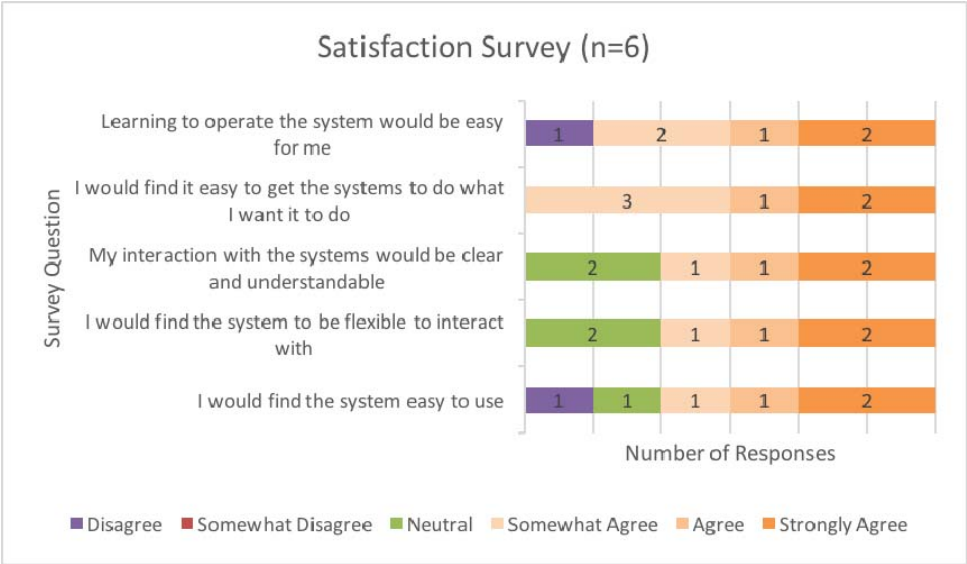


Figure 20. ID-O: Use of System Survey Results

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7.0 COST ASSESSMENT

Building Life Cycle Cost Program:

The team utilized the Building Life Cycle Cost Program (BLCC) model to evaluate the cost (cost of owning, operating, and maintaining the energy efficiency investment) and the benefits of the energy conservation investment at the PaANG installation. In compliance with the NIST handbook's guidelines, the team used the actual energy prices of the buildings based on general economic theory. The cost was determined based on actual fees of the demonstration's hard and soft costs which included the cost of the software, license, and equipment, sensors, and engineering fees associated with the ID-O and ID-F demonstration at the PaANG facility.

The methodology to evaluate the cost and energy benefits of the demonstrated technology is applicable for the current project and also general enough so that it can be replicated in other projects. The methodology includes four main steps: (1) install meters and sensors; (2) collect data and measure the energy consumption, occupant satisfaction, and additional existing parameters; (3) install ID-O and ID-F technologies; and (4) measure and quantify the benefits of the intervention.

NIST Handbook 135:

- The team developed a life cycle cost analysis of the project using rules established in the Life Cycle Costing Manual for the Federal Energy Management Program. For example, the team used the actual energy price and the measured energy consumption at the building site and calculated the Savings-to-Investment ratio and Adjusted Rate of Return in addition to the ROI.

Life Cycle Cost Table:

Table 13. Cost Model of ID-F and ID-O Technologies

Cost Element	Data Tracked During the Demonstration
Hardware capital costs	Acquisition cost of computing equipment as required for the installation; additional sensor and meter installation for asset condition monitoring.
Software costs	Licensing costs of ID-F and ID-O software; software customization costs;
Installation/Commissioning costs	1) Engineering effort of building and asset information gathering 2) Engineering effort of Building Automation System Point configuration and trending. 3) Engineering effort of Network configuration and testing 4) RMF certification process
Facility operational costs	Operational Data Collection (prior and post ID-F installation): 1) Trending data retrieval from building automation system (Siemens Apogee); 2) Interval meter data; 3) Utility rate and bills 4) Manual data entry/data collection for network workaround
Maintenance	1) Engineering effort to resolve BAS trending errors 2) Maintenance cost of ID-F
Hardware lifetime	1) Computer replacement cost 2) Optional cost of meter/sensor performance degradation
Operator/occupant training	Estimate of training time for building operator (ID-F) and building occupants (ID-O)
Salvage Value	Estimate of end-of-life value less removal costs

7.1 COST MODEL

The cost data presented in Table 14 and Table 15 were used to estimate the life cycle cost for a full-scale deployment. Some costs for this demonstration were for experimental purposes only and will not apply to typical deployments. The cost structure for a typical deployment is discussed in Section 7.1.1 and Section 7.1.2.

Table 14. Cost Model for the ID-O Deployment at PaANG

Cost Item	Cost Estimation
Hardware Costs	$12,000
Software Costs	$ 2,300
Installation and Commissioning	$ 1,500
Operator Training	$ 700
TOTAL	**$16,500**

Table 15. Cost Model for the ID-F Deployment at PaANG

Cost Item	Cost Estimation
Software Costs	$30,000
Installation and Commissioning	$ 4,000
Operator Training	$ 2,000
Base ID-F Software Cost	**$36,000**
Hardware Costs	$17,000
Facility operational costs	$ 3,000
Additional Cost based on facility size	**$20,000**
TOTAL	**$56,000**

ID-O costs can be estimated at $85/user—inclusive of hardware, software, training, and commissioning—plus the cost of establishing communications and interface with the BAS infrastructure, which will vary depending on field conditions at a particular installation.

ID-F costs can be estimated at $36,000—for software, operator training, installation, and commissioning—plus the costs of hardware, site preparation, and facility operation, which will vary depending on the number and size of buildings involved and the BAS infrastructure. In conjunction with installation of the system, the DOD installation may also make a prudent investment to upgrade the metering, sensor, and control capacities of its HVAC and electrical systems.

The direct cost of system deployment at a military installation similar in size to the PaANG test bed would therefore by approximately $75,000. Concurrent upgrades that would enhance the

efficacy of the system and be cost effective on their own merits would also be advisable in most circumstances.

7.1.1 ID-O Cost Details

The two major types of cost for a full-scale deployment of the ID-O system are hardware and software cost to install and set up the system. The detailed cost data to fully scale deployment of the ID-O technology is broken down for the following categories.

Hardware Costs:

Considering the ID-O deployment for a base like PaANG with 200 employees, each of whom would be given 2 smart wireless plugs, the total hardware cost for the whole base would be $12,000 (**Error! Reference source not found.**). This include the cost for the wireless plugs and the data collection servers.

Software and Installation/Commissioning costs:

The software cost is calculated to be $2,300. Installation and commissioning can be done at a rate of 8 employees per hour resulting in a total cost of $1,500. The total software and installation cost is estimated to be $3,800.

Operator training:

Simple training is necessary for building occupants to use the ID-O interface to its full capabilities. With group meetings of 15 employees at a time, the total training cost is estimated at $700.

7.1.2 ID-F Cost Details

The two major types of costs for a full-scale deployment of the ID-F system are software and installation/setup costs. The detailed cost data to full-scale deployment of the ID-F technology is broken down for the following categories.

Software Costs:

ID-F deployment for a base of around 10 buildings (with BAS similar to PaANG), including software customization: $30,000.

Hardware Costs:

Additional server and Ethernet cables that are needed to install and run the ID-F technology and collect data from the BAS system, and third party sensors: $2,000. A budget of $15,000 is allocated for the purchase of electrical sub-meters.

Installation and Commissioning:

Installation and initial commissioning estimated at 1 full time week or 40 man/hours: $4,000.

Facility Operation and Maintenance (O&M) Costs:

Operation and maintenance costs for software, hardware, and troubleshooting: $3,000.

Operator training:

1 week of training for building system operators to use the ID-F technology to its full capabilities: $2,000.

7.2 COST DRIVERS

The cost drivers that could affect the cost and economics of the ID-O and ID-F technology are site specific and include the following:

- Financial rebate incentives from electric utilities or other sources
- Bases with antiquated building energy management systems (the cost to upgrade the BMS system will increase the initial capital investment)
- Costs for installing a second network (VLAN) to run the ID-O technology for security purposes.
- Cost to address and meet NIST RMF requirements for the ID-O technology
- Cost of sub-metering sensors (Electric, Gas), to reach minimum viable monitoring state.

7.3 COST ANALYSIS AND COMPARISON

The cost-effectiveness for deployment of ID-O and ID-F systems at DOD installations will be different from civilian settings due to cyber-security considerations. DOD cost will be slightly higher, if VLAN communications are required, as was the case for the demonstration. However, if the systems receive authorization under the Risk Management Framework (RFM) for DOD Information Technology, then ID-O software can be installed on the desktops of building occupants, thereby eliminating the need for separate computer interfaces and communications along with their costs. RFM acceptance will also enhance the effectiveness of the system, since separate login will not be required and the system can be accessed easily from a desktop icon. Nevertheless, unlike civilians, military users will not be able to take advantage of wireless technologies to interface with the systems.

The technology provides new and expanding capabilities; it does not replace an existing approach. Consequently, a cost comparison with an existing technology cannot be made.

The ID-O and ID-F systems enhance a BAS capability and can only be used in conjunction with technology that communicates information about the functioning of building systems that consume energy. Since the ID-O and ID-F systems can therefore be considered extension of the BAS, a cost-effectiveness comparison can be made of the combined ID/BAS relative to the BAS without the enhancement. Such cost comparisons would vary for different BAS vendors rather than climatic conditions or energy costs. Viewed as an improvement on existing BAS technologies, the ID-O and ID-F systems provide the cost savings described at Section 6.4.

8.0 IMPLEMENTATION ISSUES

The deployment, commissioning and demonstration of the ID-O and ID-F technologies at PaANG helped the team better understand the challenges of implementation at large scale throughout DOD installations. The encountered implementation issues are described in the following paragraphs.

8.1 EXECUTIVE ENGAGEMENT

For many organizations, there are no incentives for facilities managers to reduce energy consumption. The most common roles of the facility manager are to ensure the comfort of the building occupants and the smooth operation and maintenance of building equipment. This leads to reactive maintenance practices where systems commissioning is only triggered following occupants' complaints or system failures. The PaANG base is no exception.

By providing real-time analytics, the ID-F technology now enables predictive maintenance to potentially save energy. This technology, coupled with performance incentives for facilities manager from the executive team, can help further reduce energy consumption. Overall energy conservation messaging from the executive team (e.g., base commander) is also needed to help engage the building occupants towards energy conservation.

8.2 USERS ENGAGEMENT

The ID-O interface/dashboard enables the building occupant to view the plug load energy consumption and control the office equipment connected to smart meters. However, the dashboard was installed on separate laptops. Use of separate laptops, connected to the base's VLAN, was necessary to reduce the potential for a security breach into the military's SIPRnet and NIPRnet. The separation of the day-to-day desktop unit from the laptop with the ID-O interface limits the participants' interaction with the ID-O dashboard. The plug-load energy savings and dashboard interaction could potentially be higher if the ID-O interface were integrated to the main desktop.

8.3 SECURITY CONCERNS

The proximity of Building 107, one of our initial sites of the ID-O technology, to the base's communication center precludes its deployment, due to security concerns. The base, as with other military installation, has a protocol of not selecting wireless technology, in order to reduce the risk of a security breach. The ID-O technology relies on ZigBee mesh network, which has a very short range, was tested to ensure that the network was limited to Building 205, the deployment site.

8.4 ISSUE WITH EQUIPMENT

Early findings from the project revealed the existence of electrical smart-meters that were never connected to any data collection platform. The first step was to bring the meters online and collect the data for trending and analytics. In addition new sub-meters were installed at locations with potential high-energy usage. However, the new smart meters had to be hard-wired due to restriction on the Wi-Fi network, which significantly increased the installation cost and deployment time.

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