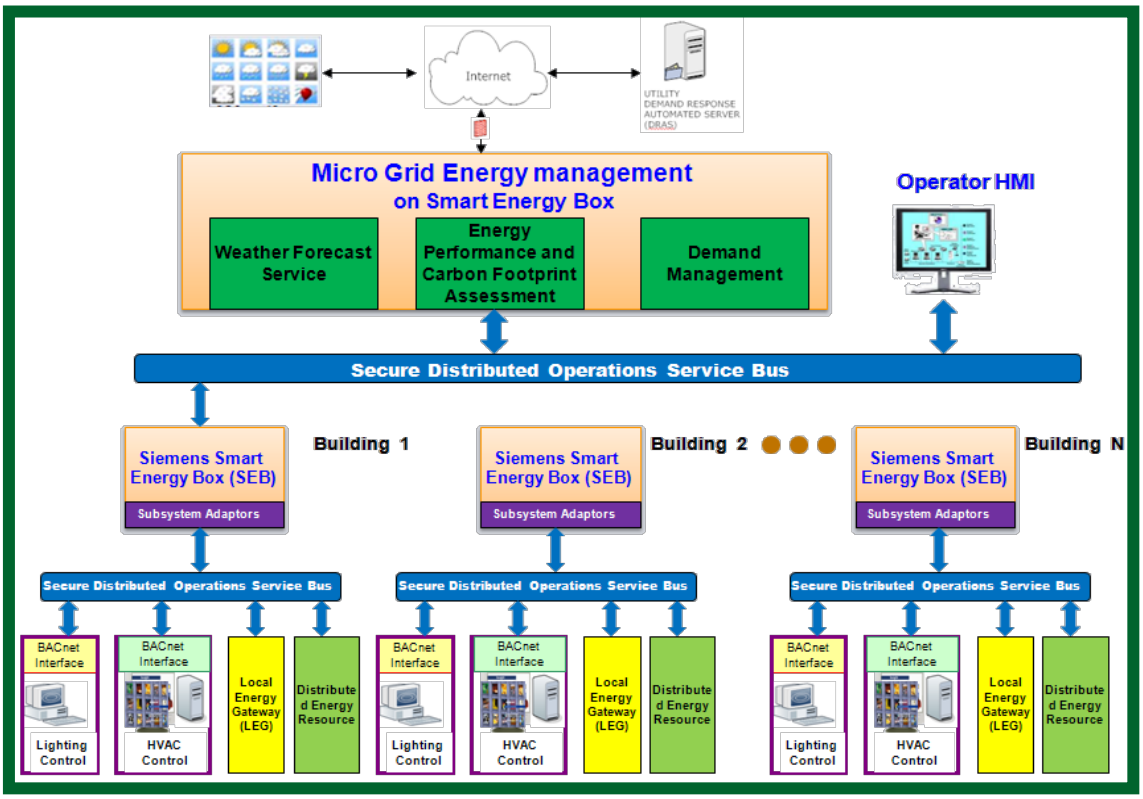
ESTCP
Cost and Performance Report

(EW-201255)



Integrated Control for Building Energy Management at the United States Air Force Academy, Colorado Springs, Colorado

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ESTCP

ENVIRONMENTAL SECURITY
TECHNOLOGY CERTIFICATION PROGRAM

U.S. Department of Defense

COST & PERFORMANCE REPORT
Project: EW-201255

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ACRONYMS AND ABBREVIATIONS

AH	Arnold Hall
AHU	air handling unit
BAS	building automation system
BEUI	building energy use intensity
BMS	building management systems
BTU	British thermal unit
CC	Community Center
CO_2e	carbon dioxide equivalents
CH_4	methane
DIACAP	DoD Information Assurance Certification and Accreditation Process
DoD	Department of Defense
DOE	Department of Energy
DR	demand response
EE	energy efficiency
EISA	Energy Independence and Security Act
EMCS	Energy Management Center System
ESTCP	Environmental Security Technology Certification Program
EUI	energy use intensity
ft^2	square feet
FY	fiscal year
GHG	greenhouse gas
GWP	Global Warming Potential
HMI	human machine interface
HTHW	high temperature hot water
HVAC	heating, ventilation, and air conditioning
iBEMS	Intelligent Building Energy Management System
ICS	Industrial Control System
kBTU	kilo British thermal unit
kW	kilowatt
kWh/ft^2	kilowatt hour per square feet
LCCA	Life Cycle Cost Analysis

MAPE	mean absolute percentage error
MBTU	million BTU
MH	Mitchell Hall
MIT	Massachusetts Institute of Technology
MOU	Memo of Understanding
MTHW	medium temperature hot water
MTPG	medium temperature propylene glycol
N_2O	nitrous oxide
NIST	National Institute of Standards and Technology
OAT	outdoor air temperature
OSB	Operation Service Bus
PO	performance objective
QC	quality control
RDT&E	research, development, test and evaluation
SAT	supply air temperature
SCT	Siemens Corporate Technology
SEB	smart energy box
SSP	static supply pressure
TCP/IP	Transmission Control Protocol/Internet Protocol
UCB	University of California, Berkeley
UI	user interface
USAFA	United States Air Force Academy

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Technical material contained in this report has been approved for public release.
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EXECUTIVE SUMMARY

Moving the United States toward greater energy independence and security, the Department of Defense (DoD) sought ways to reduce energy use intensity, electricity demand, and energy costs in its building portfolio, as required by legislation (Energy Independence and Security Act, 2007) and Executive Orders (72 FR - 39193923 and 74 FR 52117- 52127). To meet this mandate, one approach is to enhance building controls, so that they can a) minimize energy usage in response to occupancy schedules; b) utilize weather forecasts to shift loads in advance of heat waves; and c) increase revenue stream from the utility's demand response (DR) programs. While building automation system (BAS) operators can readily achieve energy and cost savings for a few buildings through changes to the building controls, the task becomes much more onerous when they need to implement the changes across a campus of buildings. Complicating this scenario is that even the state-of-the-art BASs are incapable of coordinating the electricity demand among buildings.

To address the above mentioned issues, Siemens Corporate Technology (SCT), in collaboration with the Boeing Company, DNV KEMA, and the University of California at Berkeley (UCB), deployed and demonstrated an integrated building control system called the Intelligent Building Energy Management System (iBEMS) in four buildings at the United States Air Force Academy (USAFA). In this demonstration, the team's objective was to achieve energy savings using iBEMS to implement advanced, integrated control for building cooling/heating, lighting, ventilation, and plug-load management, while still providing a healthy, productive, and comfortable environment for the building occupants. Additionally, our goal was to demonstrate a dynamic DR approach to shave or shift aggregated building peak load in response to a request from the grid, microgrid, or BAS operator, through iBEMS. Finally, the project team demonstrated the feasibility of a secure integration of individual building controls to a central campus energy management center in a secure network environment. In addition to validating the effectiveness of the technology in improving energy efficiency (EE) and performing adaptive DR, the demonstration allowed the team to determine the system installation costs, identify areas of greatest savings for 1950's-era buildings, and provide a viable transfer plan to DoD sites.

iBEMS is a vendor-independent energy management platform that extends BAS capabilities through the integration of advanced optimization, control, and visualization technologies. These technologies are designed to improve building energy efficiency and the ability to rapidly respond to fluctuations in the grid. In particular, the following innovations were introduced by iBEMS:

- Integrated and coordinated control over heating, ventilation, and air conditioning (HVAC), lighting, on-site generation, and energy storage, with consideration of occupancy dynamics, for the purpose of eliminating some of the shortcomings of the existing stand-alone control strategies.
- The integration of distributed load control or plug-loads control into iBEMS to reduce phantom loads and manage plug loads based on occupancy.
- Dynamic DR capability to achieve maximal load shedding capacity in response to grid or microgrid needs.

- Scalable and optimized configuration of control and prediction functions over multiple controllers governing building clusters with a centralized monitoring and control center.

Several quantitative and qualitative performance objectives (PO) were identified and corresponding metrics were defined, in Table ES1, to assess the performance of iBEMS. To investigate the ability of iBEMS technology to achieve the success criteria for the defined POs, a series of system tests were conducted in four buildings at USAFA to measure the performance of iBEMS with reference to a baseline conditions. The tests were grouped into two test scenarios: an energy efficiency scenario and demand management scenario, and conducted from the perspective of the iBEMS system user who may be the facility manager, a building operator, an energy manager or a base commander. It also became clear that applying an enterprise energy management system to a narrow set of buildings is appropriate for testing purposes but does not yield adequate cost savings to justify implementation. Rather, an enterprise system like the iBEMS has to be deployed at the scale for which it was intended—campuses with building clusters. Therefore, the results for POs 3 and 4 as presented, in Table ES1 reflect the scaled results for a campus of 14 buildings that were chosen from within the USAFA site. The table below provides the summary of the overall achievements, for each PO, during various energy efficiency and demand response tests that were conducted at USAFA.

Table ES1. Demonstration results summary.

Performance Objective	Success Criteria	Performance Assessment
Quantitative Performance Objectives		
PO 1: EE Optimization	20-40% annual reduction in energy usage in Arnold Hall	32% reduction with results scaled using EnergyPlus simulation
PO 2: Demand Reduction	15-30% demand reduction for a cluster of three buildings	11.4% reduction of total building load; 28% reduction of actual controllable loads
PO 3: Greenhouse gas (GHG) Emissions	20% reduction	15% reduction
PO 4: System Economics	15% direct cost saving; simple payback in 5 years	19.2% direct cost saving; simple payback of 3 years for campus wide iBEMS implementation
PO 5: Security/Reliability	Secure communication; no significant effect of latency	Achieved
Qualitative Performance Objectives		
PO 6: Occupant Comfort	Plug-load reduction with up to 50% participation; no substantial complaints by occupants	Site-specific constraints disallowed plug-load controls for EE and DR events; very few complaints
PO 7: System Integration	Ease of use; flexible interface; better load control for DR	Achieved

As is common when designing and implementing control technologies that have a wide range of capabilities, field conditions are not always optimal to fully “test drive” a technology’s controls and algorithms. Due to the site-specific reasons, building lighting and plug-loads, which are a major portion of electrical consumption at USAFA, were not allowed to be controlled for any EE or DR events. Only HVAC loads were allowed to be part of the EE and DR events; even so, among HVAC loads only a subset of air handling units (AHU) in each building were allowed for

participation in EE and DR events. Given these constraints, it can be safely stated that iBEMS performed as expected and was able to achieve most of its POs.

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1.0 INTRODUCTION

This report describes the results of using advanced building controls to save energy consumption, and reduce electricity demand at the U.S. Air Force Academy (USAFA) in Colorado Springs, Colorado. From May 2012 to December 2013, Siemens Corporate Technology (SCT), in collaboration with The Boeing Company, DNV KEMA, and the University of California at Berkeley (UCB), deployed and demonstrated an integrated building control system called the Intelligent Building Energy Management System (iBEMS) in four buildings at the USAFA. In addition to validating the effectiveness of the technology, the demonstration allowed the team to determine the system installation costs, identify areas of greatest savings for 1950's era buildings, and provide a viable transfer plan to Department of Defense (DoD) sites.

The remainder of this section provides background information on the need for intelligent controls technologies, specific objectives of the demonstration project at the USAFA, and a summary of policy drivers that mandate specific decreases in federal and military energy consumption.

1.1 BACKGROUND

DoD's annual energy-related costs for operating and maintaining military facilities are reportedly almost $4 billion (DoD, 2012). As required by legislation (Energy Independence and Security Act [EISA], 2007 [1]) and Executive Orders (72 FR - 39193923 and 74 FR 52117- 52127), the DoD must continue to seek ways to reduce energy intensity, electricity demand, and energy costs in its building portfolio. One approach to achieve the DoD's goals is to enhance building controls so that they can a) respond to occupancy schedules; b) take advantage of utility's demand response (DR) programs; and c) utilize weather forecasts to shift loads in advance of heat waves. While building automation system (BAS) operators are capable of tuning the controls to achieve energy and cost savings for a handful of buildings, the task becomes much more onerous when trying to implement the commands across a campus of buildings. In addition, even state-of-the-art BASs are incapable of coordinating control between demand and supply of electricity within and among buildings. Specifically, current BAS technology suffers from the following shortcomings (D&R International Ltd., 2012):

- Lack of intelligent energy management and control using available information, such as weather forecasts, occupancy forecasts, and energy prices, to improve energy efficiency (EE), save money, and incorporate energy conservation into daily practices.
- Lack of demand management capabilities, an obstacle to future DoD microgrid control, such as DR and islanding. With dynamic demand management in place, DoD buildings can automatically adjust their electricity usage for peak load shedding or load curtailment when electricity prices are high, thereby reducing building operational cost. Additional savings are possible through participation in DR programs offered by local utility or independent system operators once the facility management team has the capability to dynamically shape demand-side loads.
- Lack of control of distributed plug loads for EE and demand management. Plug and process loads in commercial buildings account for almost 35% of total electric consumption, where plug loads account for 11% and process loads account for 24%

(D&R International Ltd., 2012). In this project, the team has considered that plug loads consist of electronics, computers, and cooking (not including refrigeration) loads; and process loads consists of refrigeration and other loads.

The iBEMS is a new and innovative approach to energy management that integrates a variety of technologies and information sources including weather forecasts, building simulations, demand response, optimal algorithms, etc. The iBEMS operates on top of the existing BAS and addresses both the reduction of the total building energy usage as well as the peak demand.

1.2 OBJECTIVE OF THE DEMONSTRATION

The objective of this demonstration is to validate whether iBEMS technology can result in cost effective building EE improvements, enable collaborative building cluster demand management and adaptive DR. and provide secure and reliable communication with existing building management systems (BMS).

Specifically, the team sought 20%-40% building energy savings of a campus building at USAFA, and 30% of aggregated peak load reduction of four buildings through the iBEMS deployment. In addition, the project team will test secured and reliable communication of iBEMS with BMS over Boeing's Operation Service Bus (OSB).

1.3 REGULATORY DRIVERS

The energy saving activities that are part of this demonstration aligns with the legislative mandates of the Energy Policy Act of 2005 (DoD, 2005) and the EISA of 2007 (DoD, 2007). The laws are intended to move the United States toward greater energy independence and security, increase the efficiency of products and buildings, and improve the energy performance of the Federal Government. iBEMS technology also addresses goals set forth in Executive Order 13423, overarching DoD policy and program goals, and goals specific to the Air Force.

1) Legislative Mandates: Energy Policy Act of 2005, EISA of 2007:

This mandate focuses on moving the United States toward greater energy independence and security, increasing the efficiency of products and buildings, and improving the energy performance of the Federal Government. The technology used in this demonstration specifically addresses Title III: Energy Savings Though Improved Standards for Appliance and Lighting, and Title IV: Energy Savings in Buildings and Industry.

2) Executive Order 13423 of January 24, 2007: Strengthening Federal Environmental, Energy, and Transportation Management:

In compliance with this Executive Order, Federal agencies must conduct their environmental, transportation, and energy-related activities in an environmentally, economically, and fiscally sound manner. The technology used in this demonstration specifically addresses two subsections of Section 2 of this Executive Order. The subsections are "(a) improve EE and reduce greenhouse gas (GHG) emissions of the agency, through reduction of energy intensity by (i) 3 percent annually through the end of fiscal year 2015, or

(ii) 30 percent by the end of fiscal year 2015," and "(f) ensure that (i) new construction and major renovation of agency buildings comply with the Guiding Principles for Federal Leadership in High Performance and Sustainable Buildings set forth in the Federal Leadership in High Performance and Sustainable Buildings Memorandum of Understanding (2006), and (ii) 15 percent of the existing Federal capital asset building inventory of the agency as of the end of fiscal year 2015."

3) DoD Policy: Strategic Sustainability Performance Plan, Energy Security Memo of Understanding (MOU) with U.S. Department of Energy (DOE)

This plan directs U.S. military departments to execute their missions in a sustainable manner that attends to energy, environmental, safety, and occupational health considerations. Incorporating sustainability into DoD planning and decision-making ensures current and emerging mission needs are addressed along with future challenges. The technology used in this demonstration specifically addresses Goal 7 of this plan, "Sustainability Practices Become the Norm Sub-Goal 7.2, 15% of Existing Buildings Conform to the Guiding Principles on High Performance and Sustainable Buildings by Fiscal Year (FY) 2015, and Thereafter Through FY 2020."

4) Air Force Energy Plan 2010

This plan builds on a core set of goals, objectives, and metrics designed to provide the platform for continuous improvement in Air Force energy management techniques. Based on 2030 Energy End State Goals discussed in this plan, the technology used in this demonstration specifically addresses the following goals:

- Sustainability strategies are incorporated to aid in GHG mitigation;
- Energy utilization is optimized as a tactical advantage across disciplines; and
- Research, development, test, and evaluation (RDT&E) has delivered the new, cost-effective, energy technologies necessary to substantially reduce demand and increase supply.

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2.0 TECHNOLOGY DESCRIPTION

2.1 TECHNOLOGY OVERVIEW

The proposed iBEMS is a vendor independent energy management platform that extends BAS capabilities by means of integration with advanced optimization, control, and visualization technologies. Figure 1 shows the overall system architecture where the communication between iBEMS and the existing BASs is based on an industry standard, such as BACnet. The core component for the iBEMS is the Siemens smart energy box (SEB) shown in Figure 1, which resides at both campus (microgrid) and building level to oversee a building cluster and subsystems within the buildings, including heating, ventilation, and air conditioning (HVAC) control, lighting control, and local controllers for the on-site energy resources and distributed loads (Auslander, 2013). SEB is a runtime system with several basic function components developed through earlier effort in order to perform HVAC and plug loads demand response control, including a BACnet adaptor, an OpenADR client, a weather service adaptor, an Energy Plus simulation engine and an agent framework for plug load control. Within the scope of iBEMS project, Siemens has extended SEB's capabilities with a rule based energy efficiency implementation, a collaborative and adaptive building cluster demand management, and advanced microgrid energy management human machine interfaces (HMI).

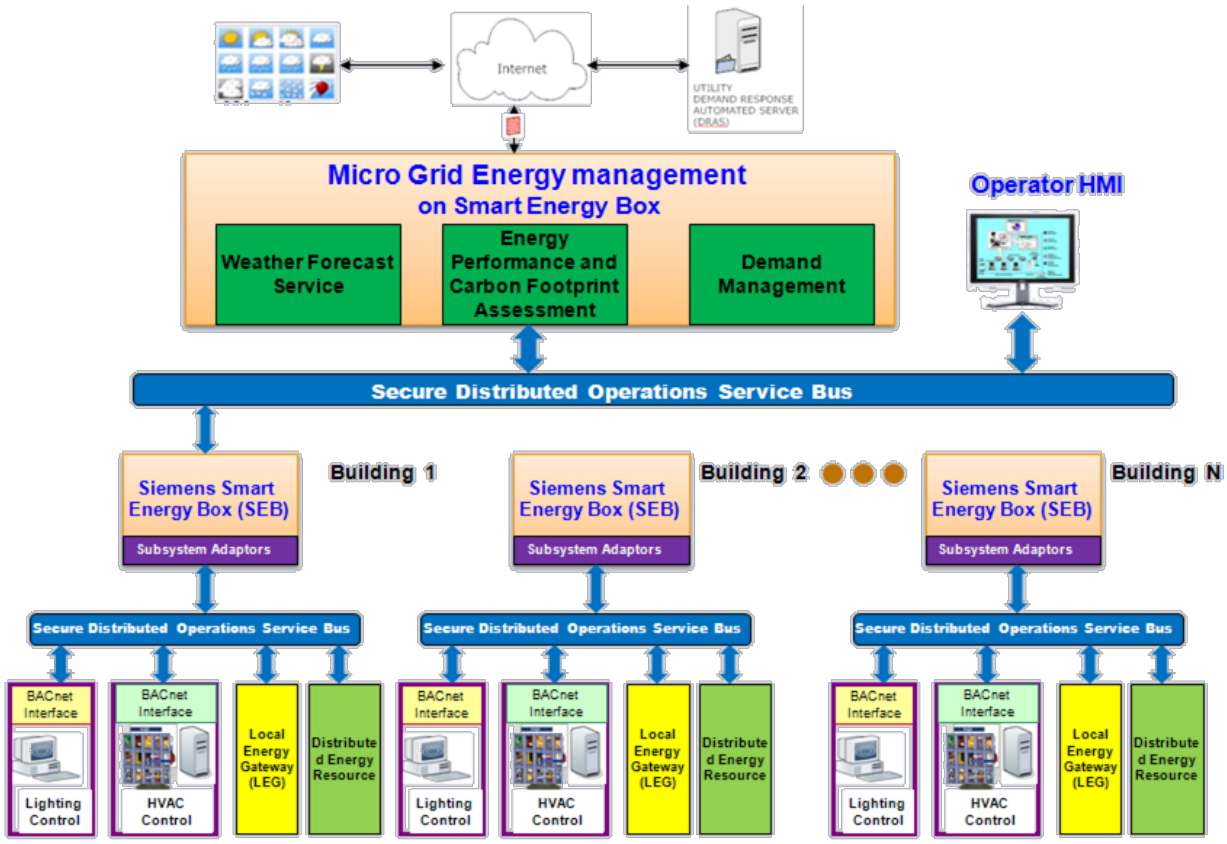

Figure 1. iBEMS architecture.

2.1.1 Rule Based Energy Efficiency Control

SEB EE subsystem works at building level and provides a cost-effective approach to manage energy consumption. In essence, this approach relies on the rule-based EE strategies for HVAC operations. The EE mode is configured and managed through the SEB user interface. The rules of our EE strategies are based on building occupancy and real time weather, which are inputs to the rule-based EE engine. In addition, the EE engine retrieves information about the current weather to define the temperature settings for the zone thermostats that are acceptable in terms of comfort of building occupants while saving energy use. In this demonstration, the activation of the rules is triggered by outside temperature and building occupancy conditions such as "When Activity," "When No Activity – Day Time," and "When No Activity – Night Time." These conditions are taken as a core input in formulation of the rule-based control strategies for EE. For instance, according to facility operation rules at USAFA, the acceptable internal temperature range with occupancy is defined as 68°F–78°F for majority of the buildings. Table 1 depicts the thermostat reset rule defined within the iBEMS EE subsystem.

Table 1. Temperature lookup table for EE thermostat rule.

Outside Temperature (EF)	Thermostat Value (EF)
Heating Season	
0 - 60	68
61 - 70	70
71 - 120	72
Cooling Season	
0 - 60	70
61 - 65	72
66 - 70	74
71 - 75	76
76 - 120	78

2.1.2 Collaborative and Adaptive Demand Management

iBEMS utilizes a multi-agent architecture for buildings to collaborate on demand management. Each building or controllable load/generation is represented by a demand source agent, for example, HVAC agent, Lighting Control agent, etc. A source agent can also be aggregated load or generation, for example building agent. In addition, there is a task agent that receives demand management command from facility operator and is responsible for allocating demand reduction/increase to source agents. The communication among agents is based on a market-like protocol. Upon receiving demand management command, reduction or increase, the task agent sends call-for-load-reduction to sources agents for contribution. The source agents make bids based on their current status (e.g., occupancy) in the format of a utility loss function. Based on this utility loss functions, an optimal load reduction algorithm is used by the task agent to assign demand reduction or increase to each source agent. The negotiation process can be initiated as fast as every 10 minutes to adapt to load or generation status changes. For iBEMS microgrid demand management, the microgrid level SEB implements a task agent, and each building level SEB implements a source agent. For the implementation at USAFA, iBEMS building level

agents perform load reduction based on HVAC related DR actions and generate utility loss functions with the determination of the impact of the DR actions such as the air handling unit's (AHU) supply air temperature (SAT) setback, AHU's supply static pressure (SSP) setback, global temperature setback, etc. After receiving the updated utility loss functions from building agents in SEB, the optimization at SEB is conducted automatically and continuously at the same interval in order to adjust the DR strategy to account for: 1) change in building's occupancy; and 2) building's actual response to the implemented DR actions. Figure 2 shows the entire process.

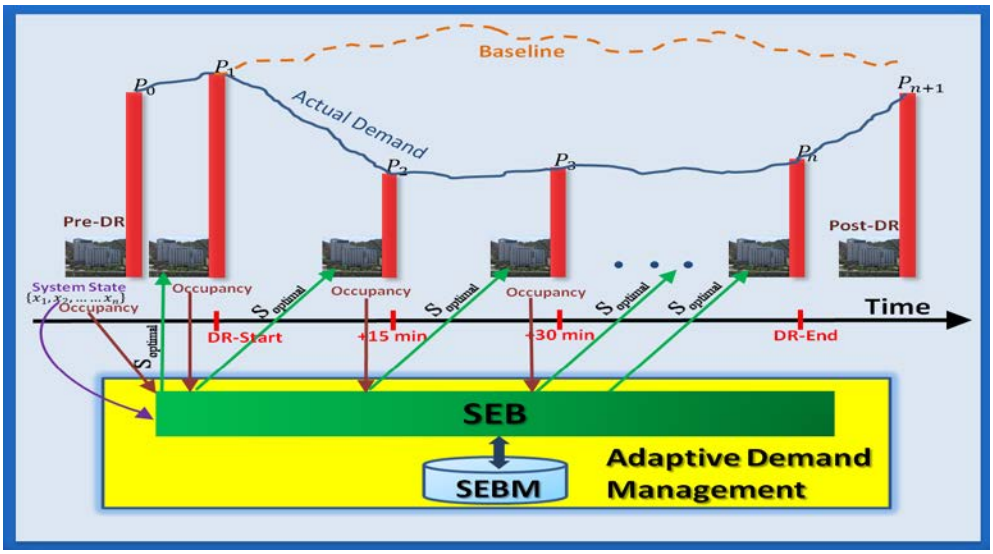

Figure 2. Adjustment of DR strategy based on changes in occupancy.

2.1.3 iBEMS HMI

The iBEMS HMI consists of three main dashboards: Microgrid, Building, and DR view. The Microgrid Dashboard of iBEMS HMI consists of energy monitoring view and the current weather/weather forecast view. It is designed to display and monitor the overall energy consumption of the buildings that are configured and controlled by the iBEMS. The Building Dashboard consists of a Building Info view, a Zone Info view, a Trend Data view, Event Calendar, and a Scheduled Strategies View. Figure 3 shows a screenshot of the Building Dashboard page of the iBEMS HMI. The screenshot depicts monitoring functionality of the Arnold Hall (AH) SEB. The Event Info page consists of the Microgrid Event view, the New DR Event view, and the Building Status view. HMI user can use this page to manage new and existing DR events.

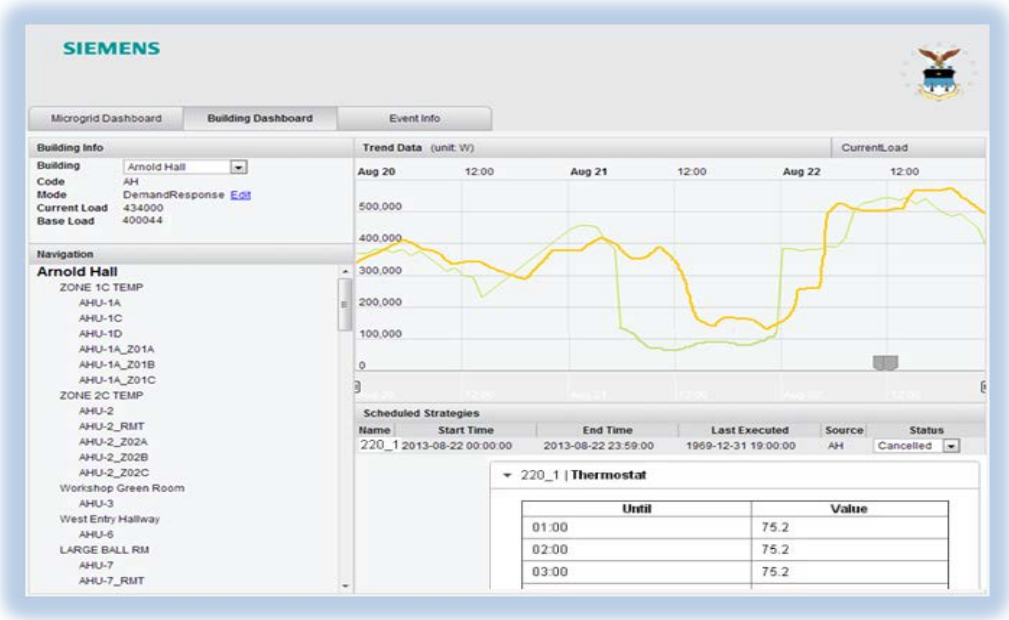

Figure 3. iBEMS HMI – building dashboard.

2.1.4 Communication Infrastructure: Boeing Secure OSB

The iBEMS deployment leveraged Boeing's common OSB as a secure communication platform to increase coordination across different portions of a network based on automated mapping technology and communication standards. The OSB provides: a) the cyber secure network conduit for the aggregation and transport of energy management data from the SEB/BAS representing each building to the various data collection and analytical services on the network; b) an interface to the SEB instances supporting each building and thus provides the linkage for the local data collection and analytic applications at each building site; and c) the required data mediation services for information translation when communicating between the building SEBs.

2.2 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

2.2.1 Performance Advantages

iBEMS implements proactive energy management approach based on weather forecast and occupancy schedules. The overall EE improvement for an office building can reach 30 to 40%. Energy intensity can be dropped from ~100 to ~70 kilo British thermal unit (kBTU) per square foot per year. In addition, the iBEMS is capable of networking and managing unlimited number of facilities, executing collaborative demand management strategies for building clusters based on building dynamic status. This powerful approach provides flexibility for peak load management. Also, the mobile scheduler (a tablet personal computer) of the plug load control subsystem allows flexibility and simplicity in terms of scheduling and prioritizing the plug loads by occupants.

2.2.2 Cost Advantages

As a pure software-based solution, the cost of iBEMS installation and maintenance is much lower in comparison with hardware-based solutions. There are no hard dependencies on any of the existing BAS components because the communication with BAS system is implemented via open protocols. iBEMS is scalable, hence expansion of iBEMS to include additional buildings for control only requires new configurations, which could be done in the order of days.

2.2.3 Performance Limitations

Due to network security concerns, iBEMS cannot retrieve zone/office occupancy information directly from an enterprise system such as Microsoft Outlook Calendar. So for EE improvement, the performance is limited by the availability of occupancy forecast information. For demand management, the performance is limited by the acceptance of the dynamic generated strategies from the building operators/occupants because of the possibility of building utility function loss.

2.2.4 Cost Limitations

The main cost of iBEMS comes from the engineering effort during the commissioning phase. iBEMS also requires an initial effort to develop building models that are used during the runtime phase for demand management strategy generation, and online energy control and optimization.

2.2.5 Social Acceptance

The economic benefit of iBEMS deployment is tremendous. However, the hesitation of building operators and occupants to actively engage in using iBEMS could impair the overall benefits. For regular commercial buildings, iBEMS already provides a social network platform to boost the collaboration among building occupants, building operators, and BASs; however, social network platforms cannot be deployed on DoD sites owing to network security concerns.

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3.0 PERFORMANCE OBJECTIVES

The performance objectives to evaluate the iBEMS technology were based on following goals.

Energy Security: The system demonstrated was the precursor of microgrid controls that will have islanding capability. The technology demonstrated in this work will allow U.S. based military installations to run their microgrids in island mode.

Cost Avoidance: With the performance objectives of up to 40% energy usage reduction and up to 30% peak load shaving, energy cost avoidance will be achieved from both energy savings and demand reductions based on local utility rates.

GHG Reduction: GHG reduction is another performance objective that is covered and resulted from energy savings and demand reduction.

Table 2. Performance objectives.

Performance Objective	Metric	Data Requirements	Success Criteria
Quantitative Performance Objectives			
Building EE optimization reported as building energy use intensity (BEUI)	BEUI kWh/ft^2 or kBtu/ft^2	1. Three years of electricity consumption for AH (2009 to 2011). 2. kW interval meter readings. 3. Equipment trend data recorded by the BASs. 4. BTU savings are estimated by calculating hot water pipe diameters and pump run times during baselines and test periods.	20% to 40% reduction of energy usage compared to baseline level for AH.
Facility peak demand reduction	Peak demand (kW)	1. Interval meter readings (every 15 minutes or less) of load peaks. 2. Response time to grid/microgrid or facility management requests through the iBEMS. 3. Load profiles developed through EnergyPlus models or energy audits of the buildings. 4. Weather data from the three hottest days of the 30 days preceding the summer peak demand tests at MH and the CC.	15% to 30% reduction in aggregated peak demand for four selected buildings. Improvement in dynamic demand management capability.
GHG Emissions	GHG emissions (metric tons)	Estimated release of GHG based on energy baseline, meter readings, historical energy data, or simulations for EE demonstration at AH and DR events at AH, MH, the CC, and Vandenberg Hall.	20% GHG emission reduction.

AH = Arnold Hall
BTU = British thermal unit
CC = Community Center
DR = demand response
kW = kilowatt
kWh/ft^2 = kilowatt hour per square feet
MH = Mitchell Hall

Table 2. Performance objectives (continued).

Performance Objective	Metric	Data Requirements	Success Criteria
System Economics[1*]	• Overall energy cost, including supply cost, demand charge, and potential incentive from Utility DR Program ($). • Return on Investment (year).	1. Utility bill. 2. Integral and interval meter readings. 3. Utility rate structure, DR incentive program tariff. 4. Government incentives programs. 5. Installation costs.	1. Up to 15% direct cost savings. 2. Simple payback in 5 years based on the cost of implementing iBEMS. 3. A favorable life cycle cost that meets DoD's fiscal criteria.
Security/ reliability of the BAS network	• Detect and alert for attempts versus actual unauthorized access. • Successful versus unsuccessful data communication between nodes.	1. Data collection of number and type of intrusion attempts during the demonstration and test. 2. Data collection of successful and unsuccessful communication transactions between nodes. 3. Monitoring of transaction latency due to iBEMS.	1. Secure communication achieved between iBEMS and existing BAS measured by security test (intrusion detection and blocking). 2. No significant effect of latency on the BAS. 3. No negative impact of iBEMS on existing BAS.
Qualitative Performance Objectives			
Occupant behavior/ comfort	• User participation in energy conservation by changing plug-load settings on a regular basis to save energy. • Numbers of complaint calls to USAFA EMCS.	1. Complaint calls to USAFA EMCS prior to EE and DR events. 2. Calls during EE performance period and during or after DR events. 3. Cadet web-based log for active plug-load configuration.	1. User inputs indicate participation in plug-load reduction demonstration up to 50% participation. 2. No substantial complaints experienced by occupants during efficiency mode and peak load reduction period.
System Integration	Usability of aggregated microgrid energy management system (1-10) • Microgrid energy usage and peak load monitoring. • Break down to building and subsystem and zone level. • Synchronization of energy use among buildings to prevent big peak to reduce demand charge. • Microgrid DR enabled. • Microgrid peak load shifting enabled.	Energy manager/building operator survey on the usability of iBEMS. The project team will ask: 1. Do energy managers understand/benefit from microgrid/building energy performance view? 2. Is iBEMS user-friendly and understandable? 3. Is the HMI for plug-load controls user-friendly and understandable?	The iBEMS will provide a web-based HMI to energy managers. Success criteria: 1. Energy managers find iBEMS easy to use. They express desire to continue to use and/or to expand use of system on USAFA campus. 2. Energy managers feel that the system provides a flexible and accessible interface to perform demand management. 3. Facility manager can control the building load or aggregated building load in day-ahead and instant mode. a. System is able to provide instant load shedding. b. System can shape loads to be price responsive.

EMCS = Energy Management Center System

[1] For "System Economics" - Refer to the National Institute of Standards and Technology (NIST) Building Life Cycle Cost program, available on the DOE website: http://www1.eere.energy.gov/femp/information/download_blcc.html#blcc

4.0 FACILITY/SITE DESCRIPTION

The USAFA is a four-year university for future officers of the U.S. Air Force. The Academy was founded in 1954; the current campus dates back to 1958, and is located north of the city of Colorado Springs, Colorado, and east of the Rampart Range of the Rocky Mountains, which is part of the Front Range of the Rockies. The entire campus of USAFA currently covers 18,500 acres, with an altitude of 7258 feet above sea level, while the highest altitude of the nearby Rampart Range Mountains is 9632 feet above sea level. The USAFA community includes over 4,000 cadets (students), and 550 faculty members and support staff. The campus includes laboratories, classrooms, extensive athletic facilities, dormitories, classrooms, a visitors' center, and other military education support facilities.

4.1 FACILITY/SITE LOCATION AND OPERATIONS

Three out of the four buildings selected for the demonstration are located at the Cadet Area, centered around a square quadrant area called The Terrazzo. AH was selected for both the EE and DR demo. MH is a dining facility used for the DR demo. Vandenberg Hall was selected for plug load DR demonstration but its use was limited to the EMCS control room due to network constraints. All the SEBs are also co-located in the EMCS control rooms. The CC, which was part of the DR demonstration, is not co-located at the Terrazzo. All HVAC controllers are connected to the base-wide BAS.

Figure 4. Location of AH and MH.

4.1.1 Arnold Hall

AH, building 2302, is the Cadet Social Center that contains a ballroom, 3000-seat theater/auditorium, game rooms, food court, conference areas, lounge and offices. The construction of the 178,604-square foot facility was completed in 1959. It is generally open from 0600 to 2300 hours on weekdays and 0900 to 2300 hours on weekends. Specific operating hours are listed in the table below. Functions in AH include 23 annual events in the auditorium, and

seven annual formal dances held in the Ballroom, plus numerous other special functions such as briefings, lectures, and commander's calls.[2] An abbreviated operational schedule is provided in Table 3, and a detailed schedule is included in the Appendix B of the Final Report. There are three mechanical rooms in AH located in the west, north and theater areas. High temperature hot water (HTHW) from the central heat plant is converted at AH's heat exchangers for domestic hot water, medium temperature hot water (MTHW), and propylene glycol. The facility is cooled in the summer months by two 450-ton centrifugal chillers located in the west mechanical room that serve both Arnold and Harmon Halls.

Table 3. Specific schedule at AH.

Operational Timeframe	Location
0330 – 2400 (Mon – Sun)	Kitchen
0630 - 2200 (Mon – Sun)	Dining Hall

4.1.2 Mitchell Hall

MH, building 2350, is the central dining facility for 4,000 cadets enrolled at the Academy plus faculty and staff. It also serves as a catering service and supports banquet functions. This facility was constructed in 1958, and had major renovations in 1966, a 1989 addition, and a 1990 upgrade. More recently in 2012, the soffit area around the outside of the building was insulated to seal it off from other building areas. Operating hours are generally from when the cooks arrive at 0330 until 2200, 7 days per week. Specific schedules are presented below in Table 4. This 223,226 square foot facility houses the main dining facility and kitchen areas. Above the cooking area are two mechanical areas that supply heating, ventilation and exhaust for the facility. The entire facility is heated by HTHW (at 400°F) delivered from the central heating plant. The HTHW is converted in heat exchangers to hot water and circulated by variable volume pumps to ten AHUs. All of the AHUs are constant volume with direct evaporative cooling sections. There are a number of refrigerated storage rooms where perishable foods are kept. The rooms are maintained at temperatures ranging from 0°F to 50°F by two 25-ton refrigerant chiller units.

Table 4. Specific schedule at MH.

Operational Timeframe	Location
0330 – 2400 (Mon – Sun)	Kitchen
0630 - 2200 (Mon – Sun)	Dining Hall

4.1.3 Community Center

The CC, building 5136, was constructed in 1958. This multiple use facility includes a pharmacy, barber shop, theater, post office, business offices, beauty shop, education center, library, human resources, services, and several retail stores. It is used daily by active and retired military and visitors. The Services Area is a hub that rents snow skis, camping trailers, and numerous other recreational items. The operation schedule is as shown in Table 5. The CC has 153,657 square

[2] Sain Engineering Associates, Inc.; *Pre-Final Submittal – Energy & Renewable Project Development – United States Air Force Academy*. (2009). Birmingham, Alabama.

feet of floor space is located very far away from the Cadet area and central plants. The building heating is supplied to this facility by HTHW (at 350 - 400°F) from the central heat plant. The HTHW is converted to medium temperature propylene glycol (MTPG) (140°F - 200°F) reset by outside air temperature in the mechanical room heat exchangers, and circulated by pumps to perimeter radiant heat, heating coils at air handlers and unit heaters. Cooling is provided by two 190-ton centrifugal chillers located at the north end of the facility in the upper level mechanical room.[3] Chilled water and MTPG heated water are distributed to three mechanical rooms (A, B, and C) locate at the lower level tunnels.

Table 5. Specific schedule at CC.

Operational Timeframe	Location
0730 – 1700 (Mon – Fri)[4]	Businesses, Military Offices, Government Offices
(Sat – Sun)	Hours vary greatly by business

Figure 5. Location of CC.

4.2 SITE-RELATED PERMITS AND REGULATIONS

The project team complied with a contractor safety, health, and environmental program for any work performed at the USAFA.

- *Regulations:* The Energy Policy Act of 2005 established a number of energy management goals for federal facilities targeted toward decreasing utility costs in federal facilities. The iBEMS demonstration relates to three management requirements from Energy Policy Act of 2005: Metering and Reporting, Energy-Efficient Product Procurement, and Building Performance Standards.

[3] Sain Engineering Associates, Inc.; *Pre-Final Submittal – Energy & Renewable Project Development – United States Air Force Academy*. (2009). Birmingham, Alabama.
[4] The operational schedule varies by business and office.

- *Environmental Permits:* Siemens currently has a valid contractor safety, health, and environmental program in place for any work performed on base.
- *Agreements:* Not Applicable.

5.0 TEST DESIGN

This project is to demonstrate how advanced building controls can be utilized along with available information, such as weather forecasts, occupancy forecasts, and energy prices, to improve building energy efficiency, reduce peak load and eventually reduce energy cost.

5.1 CONCEPTUAL TEST DESIGN

The hypothesis of the demonstration is:

> Employing the iBEMS tool leads to significant reduction of energy consumption in buildings, and supports better mission accomplishment. The amount of energy reductions and improvements depend on the baseline case, physical characteristics of the building and building dynamics. It is expected that these improvements will be optimal when the iBEMS has maximum control over the building assets.

To validate the hypothesis, a series of system tests were designed to measure iBEMS performances, which included the following variables.

Independent variable: For the purpose of iBEMS test design, independent variable is applying iBEMS EE and DR strategies to building operation.

Dependent variable(s): These are response variables to be measured, e.g., kWh consumed, peak demand (kW), GHGs, total electricity costs, measured HVAC changes in static air pressure or supply air temperature, cooling distribution, lighting, ventilation, and plug loads from the BAS sequence of operations.

Controlled variable(s): These variables are to be controlled for fair comparison between baseline and tests, including building physical properties, weather pattern, building occupancy pattern, etc.

To validate the hypothesis, the following tests were conducted by monitoring the dependent variables and tracking the correctness and sufficiency of iBEMS algorithms as well as performance and integrity of the iBEMS design.

- Applying the iBEMS EE Method to AH at USAFA; and
- Applying the iBEMS Demand Management Method to a building cluster of AH, MH, Vandenberg Hall (plug load management only) and CC at USAFA

The results of these tests were analyzed in the context of changes of dependent variables such as energy usage of AH in comparison to its energy consumption baseline; aggregated demand of the group of buildings in comparison to its aggregated demand baseline; and the number of occupancy comfort complaints as a result of the iBEMS test. As changes were made to building operations in response to weather, electricity demand, and occupancy, the team logged and trended the data through the Apogee BAS, the Siemens SEB, and the Boeing OSB. The engineering costs were collected in the application development phase of iBEMS, and the facility

operational cost was calculated using kWh utility rates and kW demand charges from Colorado Springs Utilities.

5.2 BASELINE CHARACTERIZATION

In order to accurately characterize the energy and cost savings resulting from various EE and DR demonstrations, operational baseline for the buildings cluster is required. Based on the extent of information available and collected, two different approaches were developed. For AH, detailed information were available for building equipment, daily operation, and occupancy schedule of the building. EnergyPlus simulation was therefore developed, calibrated and used to establish the baseline for AH. For MH and CC, the lack of detailed information, as well as time/budget constraint, resulted in the use of a weather pattern matching based approach to estimate the baseline. Both the methods are described in detailed below.

Baseline for AH: The project team utilized EnergyPlus software to model the energy performance of AH. This model was then used to compute the baseline during the EE and DR tests. In order to draw conclusion with confidence, the modeling process for AH required special effort to accurately align EnergyPlus model results with historic electric meter data and equipment trend data available for the building. The result of the model calibration to the electric meter data is shown in Figure 6 and Table 6.

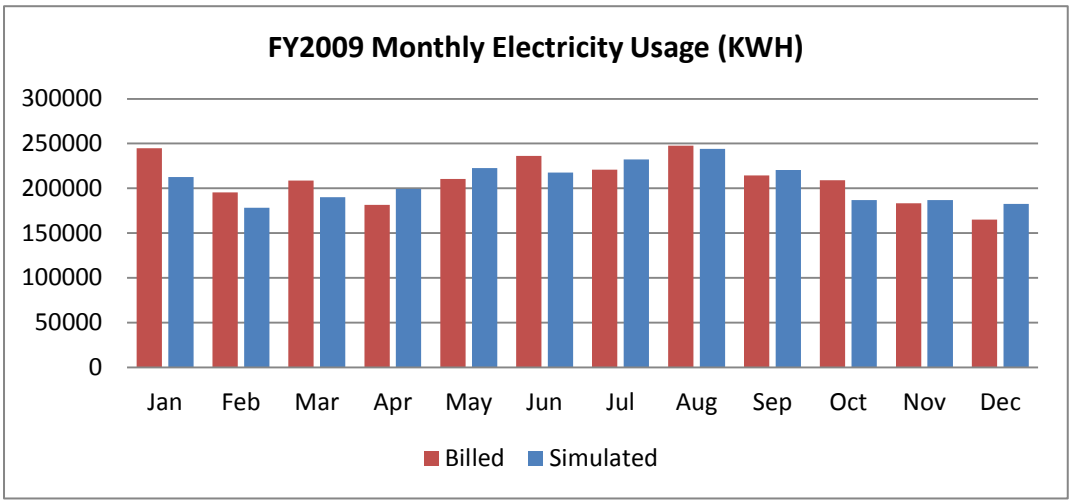

Figure 6. Monthly electricity usage comparison.

Table 6. Simulation model accuracy.

	Measured/Estimated	Simulated	Error	Relative Error
Annual Electric Energy[5]	2,548,618 kWh	2,473,994 kWh	74,624 kWh	2.9%
Annual Heating Energy[6]	83900 Therms	77629 Therms	6,271 Therms	7.5%
Daily Heating Energy[7]	294.2 Therms	207.4 Therms	86.8 Therms	29.5%

[5] FY2009 billed electricity usage
[6] FY2009 heating gas usage estimated by USAFA

Baseline for MH and CC: An analytical approach based on weather pattern matching was utilized to compute the baseline for MH and CC. In this approach, the weather forecast for that day is used along with historical weather (temperature, humidity, and wind speed) and trended electrical load data to determine the electrical load for a future day. The weather forecast of the target day is then compared to obtain "N" closest matches from the historical weather data. Then, the electrical loads of these "N" closest matches are combined to compute the electrical load forecast for the target day. This electrical load forecast can then be used as the baseline consumption for that day. To determine the baseline for DR periods, multiplicative adjustments are also made to the baseline computed using weather pattern matching approach.

Table 7. Average mean absolute percentage error (MAPE) for daily kWh forecast.

	***N*=3**	***N*=5**	***N*=7**	***N*=9**
AH	5.91%	6.23%	6.49%	6.72%
CC	2.64%	2.86%	2.87%	2.91%
MH	6.3%	6.34%	6.37%	6.61%

5.3 DESIGN AND LAYOUT OF TECHNOLOGY COMPONENTS

5.3.1 System Design and Depiction

As a pilot demonstration, only a partial deployment of iBEMS is considered at USAFA for a set of four buildings, AH, MH, the CC, and Vandenberg Hall. Figure 7 shows the as-built system set up of iBEMS at USAFA. All the buildings under consideration are currently controlled through a BAS connected to the USAFA building automation network shown as a blue line (shown in Figure 7). The BAS is linked to the supervisory system: Siemens Apogee building management server residing at Vandenberg Hall building. The entire iBEMS was installed in the server room of Vandenberg Hall at USAFA. Since the iBEMS system is mainly an extension of the BAS, the demonstration layout was designed on top of the existing building controls. In that regard, four building level logical controllers running iBEMS and one Microgrid level logical controller running iBEMS were installed.

Each SEB machine had SEB runtime controller configured to communicate with Siemens Apogee BAS. An HMI station (an LCD monitor) and the Plug Load demonstration equipment (CRT monitor, a laptop and the task light) were mounted and configured side by side with iBEMS hardware. Since USAFA BAS network is isolated from external connection, the access to weather information had to go through USAFA DoD network as shown in Figure 7. There was no definitive agreement with USAFA about the process of making that network connection, therefore, as an alternative it was considered to provide a weather forecast to iBEMS using a weather file via a USB drive. The iBEMS technology leverages the existing building automation and information management systems at the demonstration site. The constituent elements of the iBEMS system were described in Section 2.2.

[7] Daily heating energy estimated based on trend data of November 2012 (hot water temperatures and hot water pump speed)

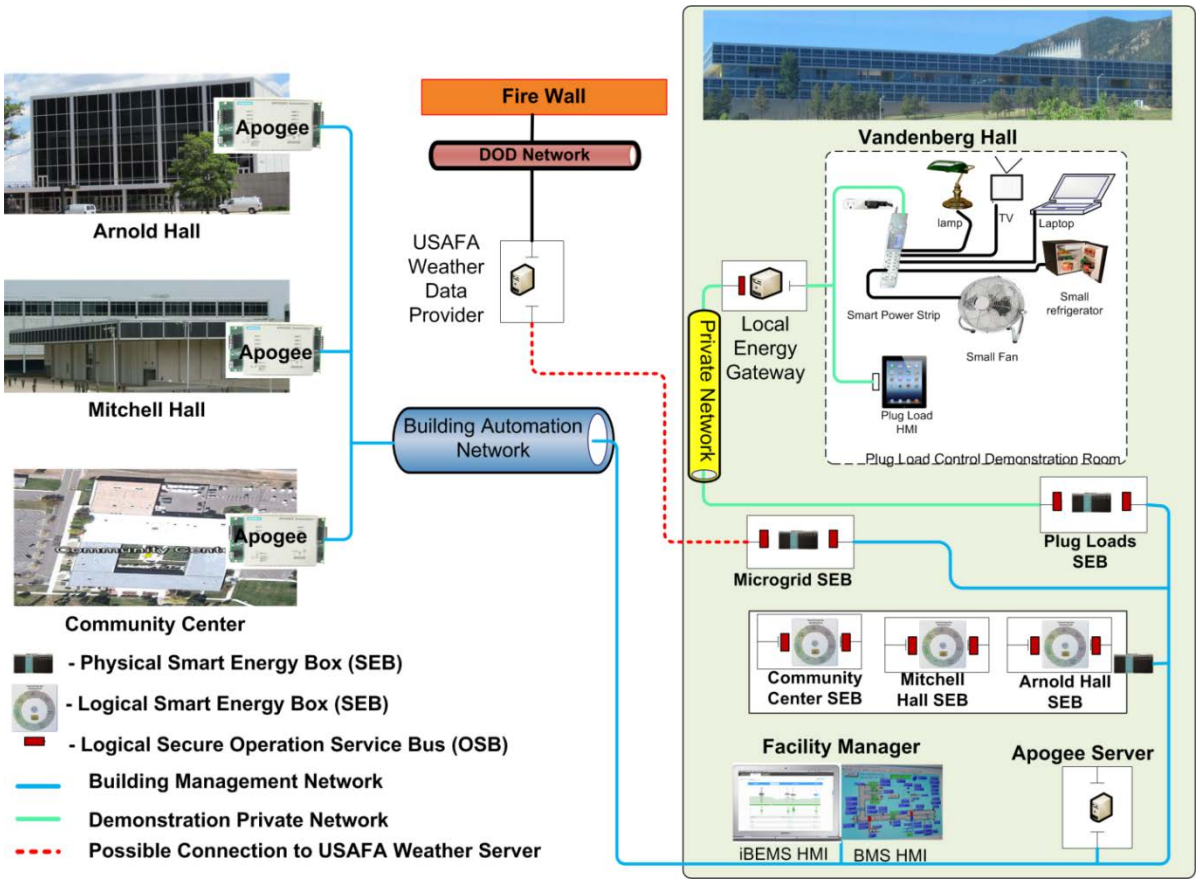

Figure 7. iBEMS demonstration installation layout at USAFA.

5.4 OPERATIONAL TESTING

The operational testing of the iBEMS was based on the following operational scenarios:

- EE Test Scenario (heating season) – EE tests for a single building during the heating season were conducted using AH facilities at USAFA in the months of April and December.
- EE Test Scenario (cooling season) – EE tests for a single building during the cooling season were conducted using AH facilities at USAFA between the months of June and September.
- EE Test Scenario (shoulder season) – EE tests for a single building during the shoulder season was conducted using AH facilities at USAFA in the month of October and the month of November.
- DR Test Scenario (cooling season) – DR tests for AH, MH, and CC were conducted during the cooling season in the month of September.

The EE tests were conducted during 21-24 March, 1-7 April, 18-19 July, 14-19 August, 12-15 September, 16-22 September, 11-14 October, 19-25 November, and 3-9 December. Five DR tests were performed during 23-26 September, 2013.

Siemens Building Technologies is already servicing USAFA and are planning to conduct the technology transfer to the Academy. As for the decommissioning, the control sequence discussed earlier addresses the restoration of the BAS set points when iBEMS demonstration tests are fully completed. There is an ongoing discussion between SBT and USAFA management to extend the iBEMS system with integration of energy storage at USAFA.

5.5 SAMPLING PROTOCOL

Different segments of the demonstration will use different data types and sampling periods. Table 8 summarizes the types as well as the anticipated sampling rates.

Table 8. Sampling protocol table.

Item #	Data Description	Data Collector(s)	Data Recording Method	Frequency	Data Storage and Backup
1	CPU usage	SCR/Boeing	Manual	1h, 6h, 24h, 48h	SVN/GForge
2	Memory usage	SCR/Boeing	Manual	1h, 6h, 24h, 48h	SVN/GForge
3	Latency	SCR/Boeing	Automated	Variable	SVN/GForge
4	Data loss	SCR/Boeing	Automated	Variable	SVN/GForge
5	Security validation	Boeing	Automated	Variable	SVN/GForge
6	Building operation data	SBT	Automated	15 minutes	SVN/GForge
7	Meter data	SBT	Automated	15 minutes	SVN/GForge
8	Occupancy scheduling	SBT	Manual	Variable	SVN/GForge
9	Building Energy Simulation	KEMA	Automated	Variable	SVN/GForge
10	Thermal Comfort Survey	KEMA	Manual	Variable	SVN/GForge
11	iBEMS Usability Survey	SCR	Manual	Variable	SVN/GForge

More detailed information regarding thermal comfort survey and iBEMS usability survey is provided in Sections 6.6, 6.7, and Appendices D and F respectively.

5.6 SAMPLING RESULTS

Quality Assurance Sampling: The KEMA team performed an internal quality control (QC) process of its EnergyPlus models to ensure that data collected is properly represented. They will also describe any planned actions to prevent findings that do not represent the true performance of the demonstrated technology caused by the demonstration process itself, such as variability in the equipment, inadequate data collection time, or uncontrolled variables.

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6.0 PERFORMANCE ASSESSMENT

The main goals of this project are to demonstrate a set of EE measures to save 20-40% energy on DoD buildings, as well the dynamic DR technique provided by iBEMS that can achieve 15-30% demand reduction. Table 9 below provides the summary of the overall achievements of each performance objective based on various EE and DR testes conducted at USAFA.

Table 9. Summary of performance assessment.

Performance Objective	Success Criteria	Performance Assessment
Quantitative Performance Objectives		
Building EE optimization reported as BEUI	20% to 40% reduction of energy usage compared to baseline level for AH.	Achievement: 32.0% of building energy savings for AH, based on the EE tests and the extrapolation using EnergyPlus simulations. BEUI reduction from 26.5 kWh/ft^2 to 17.9 kWh/ft^2
Facility peak demand reduction	15% to 30% reduction in aggregated peak demand for three selected buildings.	Achievement: 11.4% demand reduction of total building load. 32.0 % demand reduction of total controllable loads.
GHG Emissions	20% GHG emission reduction	Achievement: Reduction of 15.0% below the baseline.
System Economics	1) Up to 15% direct cost savings. 2) Simple payback in 5 years based on the cost of implementing iBEMS. 3) A favorable life cycle cost that meets DoD's fiscal criteria.	Achievement: 1) Up to 19.2% direct cost savings for iBEMS implementation for 14 campus buildings. 2) Simple payback of 3 years for campus wide implementation. 3) The net present value of the iBEMS system over a 15 year period is $4,550,053 representing a 5.76 savings-to-investment ratio.
Security/ reliability of the BAS network	1) Secure communication between iBEMS and BAS measured by security test (intrusion detection and blocking). 2) No significant effect of latency on the BAS. 3) No negative impact of iBEMS on existing BAS.	Achievement: Based on the collected data, all objectives were achieved.
Qualitative Performance Objectives		
Occupant behavior/ comfort	1) User inputs indicate participation in plug-load reduction demonstration up to 50% participation; 2) No substantial complaints experienced by occupants during EE and DR tests.	Achievement: 1) Due to site specific constraints, plug-load was not included in the EE or DR demonstration. 2) Survey results show very few complaints by occupants during EE and DR demonstrations.
System Integration	1) Energy managers find iBEMS easy to use. 2) Energy managers feel that the system provides a flexible and accessible interface to perform demand management. 3) Facility manager can control the single or aggregated building load in day-ahead and instant DR mode.	Achievement: 1) Results of usability survey show that the EMCS team is satisfied with the system performance. 2) The EE and Demand Management interfaces were intuitive and easy to use. 3) Day ahead DR events were not conducted.

6.1 BUILDING ENERGY EFFICIENCY OPTIMIZATION

The goal of iBEMS energy efficiency test is to achieve energy savings by integrated and intelligent control of building HVAC, lighting and plug loads. The scope of iBEMS EE measures can be defined as: Implement advanced control strategies to minimize long term energy usage of AH, based on current installation of sensors, HVAC systems and BAS. Within such scope, several additional constraints need to be considered. Those include, but are not limited to, the constraints imposed by site regulations, building functionality and system capability, as well as the availability of detailed information.

6.1.1 EnergyPlus Simulation and Baseline Calibration

The details of EnergyPlus simulation and baseline calibration process has already been provided in Section 5.2.

6.1.2 EE Strategy Design Methodology and Expectation

The new EE measures were designed such that they take into account the existing control sequences as well as constraints imposed by building operational and instrumental limits. The EE measures for AH are detailed as follows:

AHUs: Auditorium AHUs and ballroom AHUs are to be turned ON/OFF depending on whether event has been scheduled and whether it is weekday or weekend. Other AHUs are controlled based on regular office schedule.

Terminal units: Conference room, banquet room, and HAPS lounge are to be switched Day/Night mode based on pre-scheduled occupancy. Other terminal units follow their current Day/Night schedule, which is Day mode during 700~2200 and Night mode, otherwise.

Room Temperature Reset: The room temperature setpoints are to follow the outdoor air temperature (OAT). This method is in line with the adaptive comfort model (Brager and Schiller, 1998). Accordingly, the following lookup table, Table 10, was implemented.

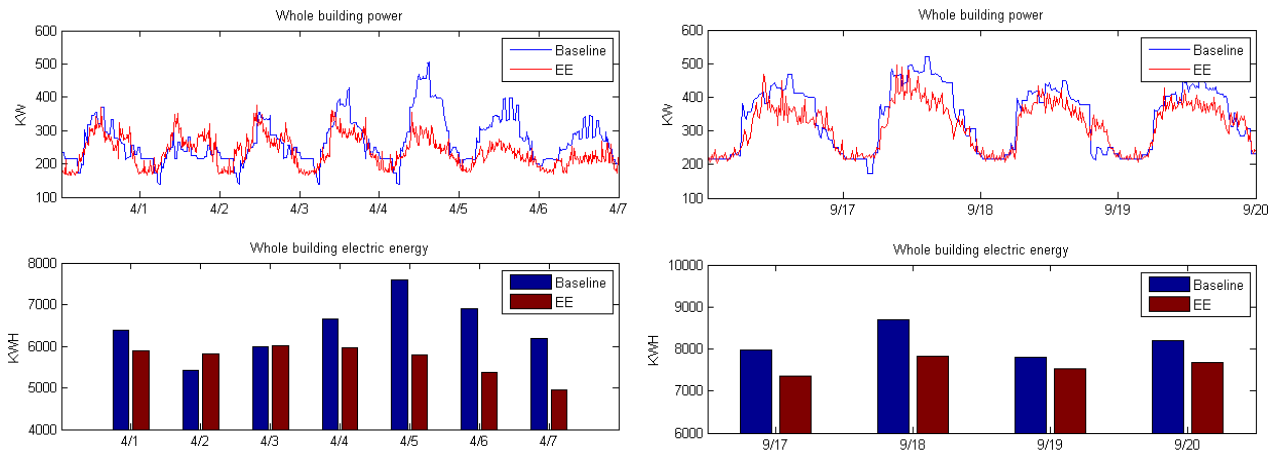
Table 10. Look up table for room temperature setpoint.

Season	OAT (°F)	Room Temperature Setpoint (°F)
Cooling	≤ 60	70
	60~65	72
	65~70	74
	70~75	76
	75~80	78
	>80	80
Heating	≤ 60	68
	60~70	70
	>70	72

Simulation based Experiment: The above EE measures were implemented in EnergyPlus simulation. Calibration of EE enabled EnergyPlus model yields 14.4% error (MAPE) for 15-minute interval building power and 3.3% error for total electric energy consumption. Using this calibrated model, the team was able to estimate the annual energy saving by EE measures.

6.1.3 Result

In total of eight attempts were made to test the above strategies in the field. Unfortunately, for various reasons, no single test has successfully implemented all the strategies. However, we demonstrated our capability of implementing some of the strategies. EE tests have been conducted in both heating and cooling seasons. The following graphs, shown in Figure 8, present the electricity measurement during heating season EE test (April 1-7, 2013) and cooling season test (September 17-20, 2013), in comparison with simulation determined baselines. Total of about 11.7% and 7.0% savings of electric energy were observed in the two periods, respectively.



(a) **(b)**

Figure 8. EE tests electricity results for (a) heating season and (b) cooling season.

6.1.4 Conclusions

Table 11 summarizes both the electricity saving and the natural gas saving obtained in heating/cooling season tests, as well as the projected annual savings. As evident from the table in the section, even though the project achieved only 11.7% saving in heating season test and only 7.0% saving in cooling season test (7.0%), but a 50% reduction in natural gas consumption is significant. The hybrid experiments (field test and simulations for natural gas consumption because there is no interval gas meter available) demonstrate with current EE measures, that the project team was able to save 15.7% electrical energy, and 32.0% of total energy annually, which translates into building energy use intensity reduction from 26.45 kWh/ft^2 (90.25 kBtu/ft^2) to 17.98 kWh/ft^2 (61.35 kBtu/ft^2), suggesting the project goal can be achieved.

Without doubt, if occupancy driven lighting control, demand management on process, and plug loads, chiller optimal control, and pressure optimal control are allowed, even deeper saving can be expected.

Table 11. Energy saving summary.

		Heating Season (4/1~4/7 test)	Cooling Season (9/17~9/20 test)	Annual Estimate (2013, projected)
Electricity (kWh)	Baseline	45,091	32,676	2,512,300
	EE	39,819	30,402	2,117,548
	Saving	5,272	2,275	394,752
	%	11.7%	7.0%	15.7%
Natural Gas (kWh)	Baseline			2,212,377
	EE			1,093,618
	Saving			1,118,759
	%			50.6%
Total Energy (kWh)	Baseline			4,724,677
	EE			3,211,166
	Saving			1,513,511
	%			32.0%

6.2 FACILITY PEAK DEMAND REDUCTION

The aim of this performance objective is to demonstrate the reduction in peak of the aggregated demand for three buildings (AH, MH, and CC). The goal was to achieve a demand reduction of 15% to 30% via a novel DR strategy. The graph below in Figure 9 shows some typical demand curves for MH building for various days. Through examination of such curves for several days, for all three buildings, it was clear that there is no specific time period at which the peak demand occurs. Another observation was that for AH and MH the demand, in general, varies a lot between 9:00am to 7:00pm and these variations do not occur at any specific times, making it impossible to estimate an accurate baseline for these buildings and pinpoint the occurrence and magnitude of the aggregated peak demand. Therefore, the peak demand reduction objective of this project was reformulated as 15-30% reduction of the aggregated electrical demand, at the start of the DR period (pre-DR), and maintained this reduction through the DR duration.

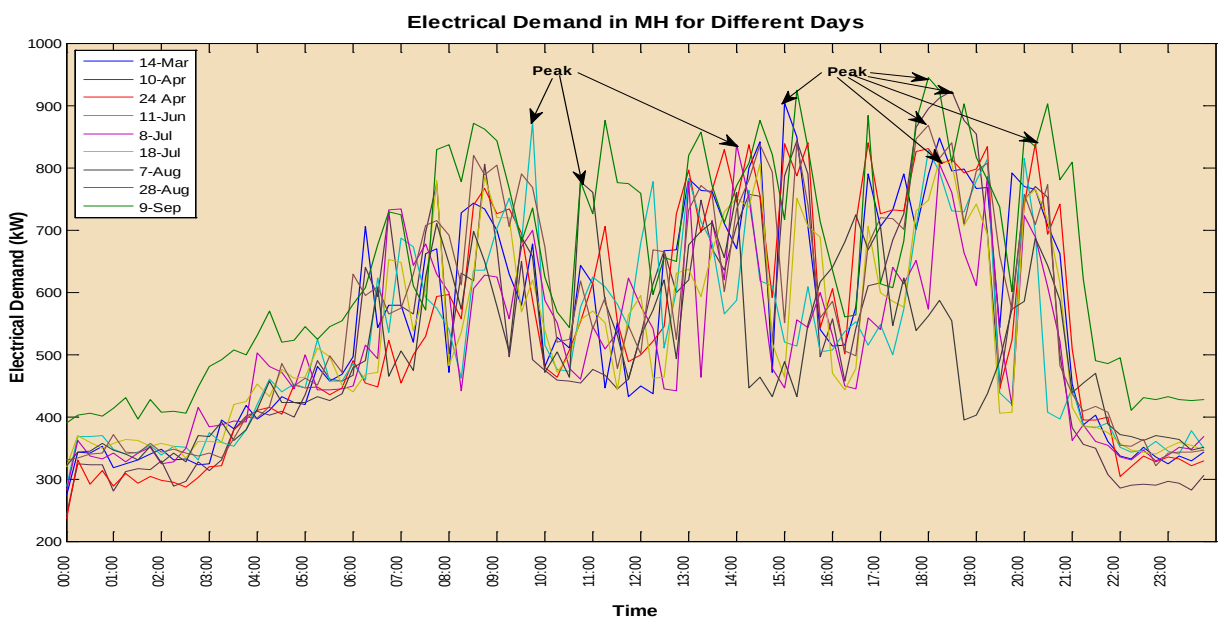


Figure 9. Demand curves for MH.

6.2.1 Baseline Approach

The approaches outlined in Section 5.2 were used to determine the baseline for AH, MH, and CC.

6.2.2 Methodology

The developed adaptive demand management methodology is presented in Section 2.1.2, which was applied to all the three buildings for various DR events, which were conducted during 23-26 September, 2013. There were a total of five different DR events conducted. The DR actions that were considered for dynamic generation during DR events include: a) increase of SAT to 60EF; b) decrease of SSP by 20% with a floor value of 0.8; c) increase of global temperature setpoint to 78EF; d) turning off AHU, if all serving zones are unoccupied; and e) power-cycling of AHUs.

6.2.3 Results Analysis

A DR event period is defined as DR period plus 30 minutes. Difference between DR period saving and DR event saving reflects the energy kickback due to return to pre-DR settings. The result of the DR Test 1 is presented here. Table 12 shows the average kW saving during the period as well as the maximum kW saving that occurred during the DR event. Figure 10 shows the actual meter reading and the baseline during the DR event, where the red area represents the actual electricity consumption and the green area reflects the electrical energy saving from the DR strategies. The overall results of the various DR tests are summarized in Table 13 below.

Table 12. Results summary for DR-1.

Average Aggregate kW Reduction During DR Period	161.76 kW (10.99%)
Maximum Aggregate kW Reduction During DR Period	278.26 kW (18.90%)
Aggregate kWh Savings During DR Period	319.20 kWh (11.56%)
Aggregate kWh Savings During DR Event	341.15 kWh (9.77%)

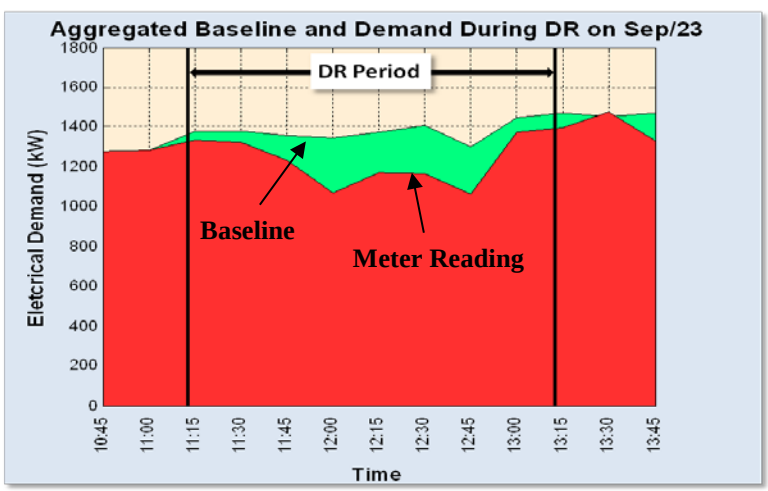


Figure 10. Aggregated baseline and actual demand during DR-1.

Table 13. DR results summary.

	DR1	DR2	DR3	DR4	DR5	Average
Avg. % kW Reduction	11%	8.14%	12.7%	9.56%	15.7%	11.42%
Max. % kW Reduction	18.9%	16.81%	22.38%	17.87%	30.77%	21.35%
% kWh Savings	11.56%	7.59%	13.34%	9.83%	15.48%	11.56%

Only the HVAC equipment are considered for DR testing due to the lack of control on the lighting, plug and process loads from a BAS system, which means that 37.8% of AH loads, 65.1% of CC loads, and 15.4% of MH loads are interruptible during DR. The results presented in the above table are computed based on total building demand, irrespective of controllable or uncontrollable loads. For the true measure of impact of DR strategies, only controllable loads should be considered. For such a case, the modified results are given in Table 14 below.

Table 14. Modified DR results summary for only controllable loads.

	DR1	DR2	DR3	DR4	DR5	Average
Avg. % kW Reduction	30.78%	22.78%	35.54%	26.75%	43.93%	31.95%
Max. % kW Reduction	52.88%	47.04%	62.62%	50.00%	86.10%	59.74%
% kWh Savings	32.35%	21.24%	37.33%	27.51%	43.31%	32.35%

6.2.4 Conclusions

If the total aggregated electrical consumption is considered then the developed DR strategies achieved only 11.42% of demand reduction over five DR events, which failed to meet the goal of 20-30% demand reduction. On the other hand, if only controllable loads are used as references for assessing the performance of DR tests, then the goal of 20-30% demand reduction was achieved, as average demand reduction over five DR events was 31.95% compared to baseline during the DR event period. It is important to make lighting process, and plug loads a part of DR strategy. Also, in buildings with large spaces, the building thermal inertia is very high, therefore, electrical load can be quickly reduced by turning the AHUs off for short durations without affecting the building occupants' comfort.

6.3 GHG EMISSIONS REDUCTION

The estimation of annual electricity and natural gas savings is described later in this report in Section 6.4, and is based on an analysis of the iBEMS system deployment in 14 buildings across campus; comprising greater than 50% of the total square footage of occupied indoor floor space on campus. This section of the report details how the project team translated those energy savings into annual GHG emissions estimates.

6.3.1 Baseline Estimates of Annual GHG Reductions

Total emission reductions from the saving of electricity and natural gas are estimated to be: 5,917 metric tons carbon dioxide equivalents (CO_2e) per year, which is based on a total annual reduction of 1,160,772 kWh/year and 931,464 Therms of natural gas/year. In the case of the electricity and natural gas emission reductions provided in this report, the reduction of CO_2 as

well as methane (CH_4) and nitrous oxide (N_2O) are included in the calculation of the total reduction, provided as CO_2e.

6.3.2 Methodology

The methodology for calculating GHG reductions is taken from *The Federal Greenhouse Gas Accounting and Reporting Guidance, Revision 1: June 4, 2012*, and its accompanying *Technical Support Document*,[8] which is the guidance document used by all federal agencies, including the DoD to annually measure their GHG emissions under Executive Order 13514. To calculate emission reductions from reduced use of electricity and natural gas, the project team used the following simple formula:

Emissions reductions = Activity data * Emissions factor * standard conversion factors * Global Warming Potential (GWP)

6.3.3 Results Analysis

A summary of the expected GHG reductions from electricity decreases and natural gas decreases is shown in Table 15 below. One key factor for the project not meeting GHG reduction goal was that a large portion of the electricity consumption, including lighting, most plug loads, and process loads, was unavailable for reduction using the iBEMS technology because they were considered uncontrollable loads. In addition, some peak time of use EE strategies were not employed to avoid disruption to building functions and occupants.

Table 15. GHG reductions from electricity and natural gas decreases.

	Electricity Emissions (metric tons CO_2e)	Natural Gas Emissions (metric tons CO_2e)	Total Emissions (metric tons CO_2e)
GHG Baseline	28,703	9,847	38,549
iBEMS GHG Reductions	(965)	(4,952)	(5,917)
Totals:	27,737	4,894	32,632
Percentage Reduction	3%	50%	15%

6.3.4 Conclusions

As evident from the table in the section above, the project achieved only a 3% reduction from the baseline electricity consumption and associated emissions, but a 50% reduction in natural gas consumption and associated emissions. These reductions are equivalent to a total savings of 32.1% of energy consumption against the baseline. The reason that natural gas savings are much larger than electricity savings is the current inefficiency of the system used to generate and distribute hot water. Furthermore, the reason that GHG emission reductions are 15% instead of 32% (the total energy reduction) is the difference in the carbon-intensity of electricity consumed in the Colorado Springs area versus the carbon-intensity of natural gas.

[8] See the following website to download the Guidance document and the Technical Support document: http://www.whitehouse.gov/administration/eop/ceq/sustainability/fed-ghg

6.4 SYSTEM ECONOMICS

The team set goals for energy and economic performance objectives of iBEMS that were not necessarily complementary to each other. It also became clear that applying an enterprise energy management system to a narrow set of buildings is appropriate for testing purposes but does not yield adequate cost savings to justify implementation. Rather, an enterprise system like the iBEMS has to be analyzed at the scale for which it was intended – campuses of buildings.

6.4.1 Baseline

The determination of baseline energy consumption is discussed in Section 5.2 for EE and DR. How the project team determined energy and cost savings is discussed in the methodology and results sections below.

6.4.2 Methodology

The methodology for determining the economic performance of the iBEMS is based on the careful analysis of test results for EE measures at AH, and DR measures at AH, MH, and the CC. The life cycle cost methodology is described in greater detail in Section 7, while this section presents results of life cycle cost calculations for electricity and natural gas consumption for a campus using the iBEMS for a 15 year period.

Natural Gas Consumption and Savings: There were no thermal meters installed at the demonstration buildings. So, with the understanding of how heating load/energy use at each building relates back to actual natural gas fuel consumption in the Heating Plant, the natural gas reduction was calculated through the calibrated EnergyPlus energy model. Although calibrated energy models have not been developed for MH or the CC, heating energy savings were estimated by assuming that implementation of EE Measures utilized at AH yielded similar results.

Analysis of Utility Bill Charges: Electricity and natural gas utilities are supplied to the Academy by Colorado Springs Utilities, which is a community-owned municipal utility. Based on review electricity bills from FY09 – FY11, the Academy falls into the large commercial and industrial time of day rates (E8S). The normalized electricity and gas rate was calculated by averaging each of the cost components from the utility bill for the site to get a total blended rate.

Deploying the iBEMS at a Campus Scale: For demonstration purposes, the iBEMS implementation was limited to three buildings, but the intended use of iBEMS is for much larger groupings of buildings. Therefore, the project team completed an exercise to extrapolate the costs and savings of deploying iBEMS at a campus scale, which for this exercise, includes 14 buildings. The details of the extrapolation approach and the various assumptions are given in Section 6.4.2 of Final Report.

6.4.3 Results

The results of the scalability analysis and the projected total energy and cost savings for the 14 buildings on campus are shown below in Table 16. The first table shows potential electricity

savings in kWh and cost savings per building. Utilizing the iBEMS to reduce fan power, cooling demand, and heating demand, and extrapolated to just over 3 million square feet of occupied building space, it is estimated to save annual consumption of 1,610,772 kWh (3,958 million BTU [MBTU]) and 931,464 therms (93,146 MBTU) for a total of 97,104 MBTU. See Table 17 below for baseline consumption as well.

Table 16. Potential electricity, gas, and cost savings per building.

Building	Square Footage (ft^2)	Building Type	Total Building Gas Savings (therms)	Total Gas Cost Savings ($044/therm)	Total Building Electrical Savings (kWh)	Total Electrical Cost Savings ($0.0513/kWh)
Cadet Gym	439,951	Gymnasium	207,441	$146,039	297,274	$15,250
Arnold Hall	178,604	Theater	32,599	$22,950	253,297	$12,994
Sijan Hall	625,272	Dormitory	95,104	$66,953	68,174	$3497
Mitchell Hall	223,226	Dining Hall	22,635	$15,935	248,539	$12,750
Mitchell Hall (Administration)	74,896	Offices/ Storage	3038	$2139	60,628	$3,110
CETF Building	310,334	Classrooms	51,922	$36,553	67,031	$3439
Vandenberg Hall	832,923	Dormitory	126,688	$89,188	121,382	$6227
BOQ	51,401	Hotel	3388	$2385	4449	$228
Golf Course Club House	17,095	Restaurant/ Retail	4334	$3051	23,696	$1216
Base Exchange	45,512	Offices	1846	$1300	97,119	$4982
Youth Center	19,469	Recreational	2961	$2085	62,222	$3192
Community Center	153,657	Retail/ Offices	23,371	$16,453	223,997	$11,491
Family Support Center	10,718	Offices	2717	$1913	15,749	$808
Civil Engineering	52,810	Offices	8836	$6220	67,213	$3448

ft^2 = feet squared

Table 17. Campus wide energy consumption and savings.

	Electricity	Natural Gas[9]	Totals
Site Specific Utility Costs Adjusted to FY2011 Dollars	$0.0513/kWh	$0.44/therm	-
Baseline	34,514,068 kWh	1,852,083 therms	-
Baseline Costs	$1,770,571	$814,917	$2,585,488
iBEMS Reductions	1,610,771 kWh	931,464 therms	-
Savings in Dollars	$82,633	$413,163	$495,795
Percentage Dollar Savings	4.7%	50.7%	**19.2%**
Baseline (Conversion to MBTUs)	117,693 MBTU	185,208 MBTU	302,884 MBTU
iBEMS Reductions (Conversion to MBTUs)	(3958) MBTU	(93,146) MBTU	(97,104) MBTU
Total Consumption After Savings	113,718 MBTU	92,062 MBTU	205,780 MBTU
Percentage Energy Reduced	3.4%	50.3%	32.1%

[9] Natural gas savings take into account an assumed 60% heat loss from fuel combusted at the Central Boiler Plant to the heat available at individual buildings (from Heating Logs provided by CE group). When looking at the campus wide heating energy consumption and savings, the worst case scenario for distribution losses was assumed (58% for CC) as the piping network since associated losses for the entire campus were relatively unknown.

6.4.4 Conclusions

The stated goal of achieving 40% energy savings by implementing iBEMS was ambitious and had to be revised to better reflect conditions at the Academy and the normal physical limitations of any building stock. Important factors that affect the energy savings target were: proper site selection, existing electrical infrastructure, utility rate structure, maintenance of existing equipment, availability of automated controls for lighting, opportunities for plug load controls, and controllability of the HVAC load in the building.

6.5 SECURITY/RELIABILITY OF THE BAS NETWORK

The iBEMS deployment leveraged the Boeing common OSB as a secure communication platform to increase coordination across different portions of a network through a cyber-secure common operating picture based on automated mapping technology and communication standards. The OSB provided the cyber-secure network conduit for the aggregation and transport of energy management data from the SEB/BAS representing each building to the various data collection and analytical services on the network. The OSB provides the required data mediation services for information translation when communicating between the building SEBs. Cyber objectives, like blocking unwanted data and access, successful transactions between iBEMS nodes, and making sure data and commands are received in a consistent and timely manner while not introducing adverse effects were critical.

6.5.1 Baseline

The determination of baseline data was done through discussions with USAFA Industrial Control System (ICS) operations personnel and testing of a representative iBEMS in the Siemens and Boeing laboratories. The USAFA ICS network is an isolated closed network so gathering iBEMS specific baseline data was done in the laboratory environment. Three specific baseline data groups were gathered, existing access (authorized and unauthorized), successful and unsuccessful communications in iBEMS without the OSB and existing latency within iBEMS without the OSB.

6.5.2 Methodology

The methodology the team selected would target data collection and testing on both the USAFA ICS network and a laboratory test network environments. The USAFA ICS network is an existing ICS network that was required to be functional and not be effected by our installation and testing. Remote access and remote data gathering were not available because the USAFA ICS is an isolated network within the campus. Because of the limited nature of this network, the project team developed a more robust test laboratory environment. The laboratory environment included two actual iBEMS SEBs tied into an isolated Transmission Control Protocol/Internet Protocol (TCP/IP) based network. Two other machines with similar architectures and processing capabilities, as the SEB, were incorporated in the network to mirror the USAFA deployment architecture. The computer server was set up to represent multiple number of SEBs, data nodes, and/or non iBEMS related nodes. During the latency test phase we tested 30 SEBs running, communicating and controlling at the same time. The project had three types of data collected to address the success criteria. These include collection of network/node access attempts,

successful/unsuccessful transactions and latency of the data being transmitted. Table 18 outlines the data collected and the analysis to be applied.

Table 18. Data collected and the performed analysis.

Data Collected	Environment	Method of Data Collection	Analysis to be Applied
Existing network access data (authorized/ unauthorized)	USAFA ICS and Lab (lab was configured like USAFA, non iBEMS)	Discussions with USAFA operations personnel on their monitoring data	Successful versus unsuccessful access
Unauthorized access data (with iBEMS)	USAFA ICS and LAB	Log files on SEB nodes and OSB	Successful versus unsuccessful access
Data communication – successful and unsuccessful (with iBEMS)	USAFA ICS and Lab	Packet level monitor at nodes	Data transmission success rate
Data communication – successful and unsuccessful (with iBEMS)	USAFA ICS and Lab	Packet level monitor at nodes	Data transmission success rate; comparison of success with and without OSB
Average packet size and latency of data (without OSB)	Lab	Packet level monitor at nodes; packet level timing	Comparison of latencies with iBEMS requirements
Average packet size and latency of data (with OSB)	Lab	Packet level monitor at nodes; packet level timing	Comparison of latencies (with and without OSB); comparison of latencies with iBEMS requirements

6.5.3 Results

The results for the security and reliability element of the iBEMS demonstration met all the success criteria and the analysis also showed the size of the deployed iBEMS system could be increased without significant impact.

Secure Communications: Secure communications between iBEMS and the existing BAS measured by intrusion and blocking testing. During the intrusion testing, all tests were detected, logged, and a message was sent. In total, over 1000 tests were made with non legitimate access on both the lab and USAFA environments. The only authorized access issues observed were caused by specific node configuration problems. To address this, a simple OSB network status was incorporated for the next round of on-site testing. Packet level spoofing was also tested in the laboratory environment. Packet level injection software attempted to modify and/or spoof packets being passed between iBEMS nodes. In all cases, the modified packets were not detected when the OSB was not running, whereas all attempts to spoof the packet data were caught when the OSB was operational.

Latency Testing: The categorization and testing for latency of communication data was done primarily in the laboratory environment. This was done to allow for testing of communication at rates and packet sizes much larger then would be seen in a real iBEMS environment. Multiple tests were run varying packet size to gather latency data varying. Initial testing was focused on iBEMS without the secure OSB and later testing was done with the secure OSB. Table 19 shows

the average latency in seconds running test client/server with and without the OSB. Given the size of the data being communicated and a requirement of data latency of less than one second, the addition of the secure OSB should have no impact to the iBEMS deployed system.

Table 19. iBEMS latency data.

Message Size (Bytes)	No OSB	No OSB	With OSB	With OSB	OSB Additional Overhead (sec)
	msgs/sec	Average Latency (sec)	msgs/sec	Average Latency (sec)	
2048	1598	0.000625782	409	0.002444988	0.0018192
5000	1278	0.000782473	237	0.004201681	0.0034192
10000	1014	0.000986193	208	0.004807692	0.0038215
15000	852	0.001173709	157	0.006369427	0.0051957

msg = message
sec = second

6.5.4 Conclusions

The overall conclusions regarding the goals and objectives for the security and reliability elements of the demonstration were very good. The results within the security and reliability areas of the demonstration were very good. In all three objective criteria areas, there could be small improvements on results but given the large positive margins between the results and the minimum requirements, trying to achieve better results is not needed. The positive margins would support future increases in scope and number of iBEMS nodes.

6.6 THERMAL COMFORT

The purpose of this performance objective is to determine whether deployment of the iBEMS technology had any detrimental effects on the thermal comfort of building occupants.

6.6.1 Baseline of Building Occupant Thermal Comfort

To create a baseline of indoor thermal comfort, the project team conducted surveys in the CC and MH prior to or at the beginning of the EE and DR demonstrations in September 2013, and also collected complaint logs maintained by Civil Engineering to determine whether any patterns exist for thermal comfort complaints. Surveys were also completed prior to the March 2013 iBEMS tests to gather information on thermal comfort in AH, but a complete survey was not conducted in AH before and after the September demonstration period. Thus, the August survey results are shown in this section, which represent ongoing thermal comfort issues in AH. The pre-demonstration surveys and the complaint logs showed that numerous thermal comfort issues previously existed in the buildings prior to the beginning of the demonstrations in September 2013. Table 20 summarizes key information regarding the initial surveys prior to the tests in August and the demonstrations in September.

Table 20. Thermal comfort survey: summary of baseline results, August 2013.

Building	Number of building occupants surveyed	Number of building occupants with baseline thermal comfort complaints	Percentage of building occupants with baseline thermal comfort complaints	Number of complaints regarding warm temperatures	Number of complaints regarding cool temperatures	Number of complaints regarding temperature fluctuations	Time of Survey
Arnold Hall	3	3	100%	3	3	0	March 2013
	4	4	100%	1	2	1	August 2013
Community Center	8	7	78%	3	2	2	September 2013
Mitchell Hall	2	2	100%	1	0	1	September 2013

6.6.2 Pre-and Post- Demonstration Survey Methodology

The pre-demonstration survey contained a number of questions regarding indoor temperatures and how comfortable or uncomfortable the survey participant felt at the time of the survey. Survey questions also gathered information on the attire of the survey participant, the setting, (i.e., private office, enclosed office area with or without cubicles, or other area such as warehouse or theater), and the amount of electrical equipment located nearby, such as computers, overhead lighting, printers, copiers, etc. A full copy of the survey is provided in Appendix D of Final report. The post-demonstration survey did not repeat questions in which the answers were not likely to change, such as the location of nearby windows and the listing of nearby electrical equipment. Post-demonstration surveys did repeat questions regarding current attire and thermal comfort levels. Survey participants were also asked if they noticed any changes to indoor temperatures during the demonstration period.

6.6.3 Results

Out of the 14 building occupants surveyed in AH, MH, and the CC before and after the demonstration periods in September 2013, only two occupants in the CC and one occupant in AH noticed a difference in thermal comfort during the demonstration periods. The two occupants in the CC noted feeling warmer temperatures during the end of the September demonstration period, and one occupant in AH noted feeling slightly cooler temperatures during the same period. The remaining persons surveyed did not feel anything unusual. However, the three occupants who did note a difference in thermal comfort during the demonstration period may have felt cooler or warmer temperatures due to other reasons. As noted above, all three buildings have a history of HVAC maintenance issues as well as thermal discomfort issues, so these complaints could have been caused by one of the ongoing issues.

6.6.4 Conclusions

Most of the EE and DR strategies included in the iBEMS system are not expected to affect thermal comfort. Shorter strategies, such as the 15-minute DR strategies that are not continued beyond 15 minutes, are considered to have minimal effect on thermal comfort. Longer DR and

EE strategies, such as those 1-3 hours in duration, could have an effect on thermal comfort; these strategies should only be used for unoccupied spaces or should be reduced or curtailed if they start to increase or reduce indoor temperatures beyond established thermal comfort ranges.

6.7 SYSTEM INTEGRATION

6.7.1 Baseline Characterization: BAS Network Survey

Once all the buildings participating in the demonstration were finalized, the survey of the infrastructure and the existing BAS was conducted. During the survey crucial points with respect to the iBEMS integration were also identified. They are as below:

- Location of the deployed iBEMS. The system must be located in a one of the control rooms with access to BAS network.
- Availability of the facility operators. The operator must have a quick and easy access to the iBEMS for the daily management and, if necessary, a prompt shutdown.
- Building security. The iBEMS room must be secured, allowing access to authorized personnel only.
- Daily schedule. The iBEMS room schedule must comply with schedule of the facility management.
- Support of openness of the existing BAS in terms of communication. The BAS system must support extensibility and openness for iBEMS to be integrated.
- Identification of the BAS hardware by types and models. The BAS server must be compatible with iBEMS BACnet or MODBUS client.
- BAS service schedules and its impact on the facility dynamics and vice versa.

6.7.2 Methodology

The entire iBEMS was replicated and commissioned in the test lab of the SCT facility in Princeton, NJ. Some of the system control points were replicated in the local test Apogee system and the entire system ran seven consecutive system tests. The results of all tests were documented and reviewed by the team and all discovered issues were addressed before the on-site commissioning, which occurred in the server room of the Vandenberg Hall in January 2013. The deployment phase was broken down into five work packages: installation, integration, configuration, training, and execution. Details of these work packages are presented in Section 6.7.2 of Final Report. After the installation completion, the iBEMS system runtime test and a 24 hour “dry run” test were performed. This “dry run” included: EE mode test, instantaneous DR test, and day-ahead DR test. Finally, the EMCS staff was trained and qualified to operate the iBEMS.

6.7.3 Result

It was determined that iBEMS is capable of being integrated with an existing BAS in a reasonable amount of time with a minimum “system tailoring” for the demonstration site.

Despite the overall success of integration of iBEMS system with the existing BAS at USAFA, several challenges were observed:

- The installation of the iBEMS system that uses the BACstac windows service does not start the service and does not check if the service is available, as a result the communication with BAS Apogee server could not be established.
- There is no confirmation about success or failure on the connection to Apogee server from the iBEMS WEB User Interface (UI). The connection error information can be obtained from the iBEMS runtime log only.
- Export format of the control points from Apogee does not correspond to the iBEMS data exchange format. The exported data must be manually altered and then imported to SEB controller.
- It has been observed that relinquishing some of the control points didn't change their values and therefore those points must be relinquished manually by the operator on the server side.
- iBEMS system does not notify the user about the control point manipulation on the server side, such modification or deletion
- Some of the control points randomly fail to accept a new value commanded from the iBEMS. The "system-retry" method of iBEMS not always corrects this issue.

The usability survey, presented in Appendix F of Final Report, was conducted after the iBEMS commissioning, during the demonstration and right after the demonstration. The results of the survey show that the building management and EMCS team were satisfied with the system performance and overall usability. However, they also found room for improvement in terms of usability: a) the system should provide more validation capabilities during the configuration (i.e., the control points validation); and b) the system should provide a better runtime response in case of communication or runtime error. Currently, it only provides system logging, no real time feedback is available.

6.7.4 Conclusions

Overall, the iBEMS system performed as expected, without runtime crashes, performance glitches or logic failures; therefore, it can be easily deployed as a part of the EE enhancement solution to DoD sites. However, it still suffers from random communication errors with BAS and requires close supervision. The productized version of iBEMS must address all the issues observed in order to increase its availability and robustness as well as improve its energy performance. Also, it should be possible to control as much building equipment as possible to maximize EE logic and overall energy savings.

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7.0 COST ASSESSMENT

The Life Cycle Cost Analysis (LCCA) presented here is based on standards published by NIST in *Handbook 135*[10] and the *Annual Supplement to Handbook 135*[11]. NIST software, BLCC5[12], or building life cycle cost version 5 was used to compute the LCCA over a 15 year period. The data inputs include duration of life cycle, capital and labor costs, equipment and software replacement costs, recurring maintenance and site specific utility charges for electricity and natural gas.

7.1 COST MODEL

Two different life cycle scenarios were run, one solely on the EE demonstrations results for AH, and the second is an extrapolation of the costs and savings to 14 buildings at the Academy. Table 21 below shows the summary of the AH LCCA inputs and savings, and Table 22 shows the LCCA inputs for the extrapolation of the iBEMS to 14 campus (or campus wide) buildings. Results of the life cycle cost analysis using BLCC5 for AH calculation did not give a payback within the required 6 year period. Implementing iBEMS at just the standalone building level is quite costly due to the equipment, installation and recurring costs to maintain security of the system. iBEMS is significantly more efficient for a singular building if these costs (annual security capital, operation and maintenance costs shown in table below) are removed. Therefore, an energy efficiency alternative for AH was developed, which presents the results when equipment, installation and recurring costs related to security are removed from the single building life cycle cost calculation. In such a case of single building installation, without security costs, net present value of the iBEMS system over a 15 year period is $149,999, representing a 3.38 savings-to-investment ratio and a 4 year simple payback.

Table 21. Cost model for the iBEMS at AH.

Cost Element	Data Tracked During the Demonstration	Estimates
Data Collection and Energy Modeling Costs (one-time cost)	Labor to collect data on building architecture and mechanical systems and to create Energy Plus building energy models	$24,000
Hardware Capital Costs (one-time cost)	Estimates made based on component costs such as computers and networking equipment	$3508
Software Capital Costs (one-time cost)	Estimates of Siemens' SEB software costs and Boeing's OSB software	$481,900
Installation Costs (one-time cost)	Labor to install hardware/software and to commission iBEMS	$68,800
Facility Operational & Maintenance Costs (recurring cost)	Reduction in energy consumed vs. baseline data Maintenance inclusive of software/hardware, labor, and commissioning over 15 year period (net present value)	$9760
Hardware Lifetime	Estimate based on components degradation during demonstration	15 years
Operator Training (one-time cost)	Estimate of training costs	$24,800

Results of the LCCA for the campus wide application, including security costs, were even more rewarding and are presented in Table 22. The net present value of the iBEMS system, for campus

[10] http://fire.nist.gov/bfrlpubs/build96/PDF/b96121.pdf
[11] http://www1.eere.energy.gov/femp/pdfs/ashb13.pdf
[12] http://www1.eere.energy.gov/femp/information/download_blcc.html

wide installation, over a 15 year period is $4,550,053, representing a 5.76 savings-to-investment ratio and a 3 year simple payback.

Table 22. Cost model for campus wide iBEMS at USAFA.

Cost Element	Data Tracked During the Demonstration	Estimates
Data Collection and Energy Modeling Costs (one-time cost)	Labor to collect data on building architecture and mechanical systems and to create Energy Plus building energy models	$201,600
Hardware Capital Costs (one-time cost)	Estimates made based on component costs such as computers and networking equipment	$22,214
Software Capital Costs(one-time cost)	Estimates of Siemens' SEB software costs and Boeing's OSB software	$587,500
Installation Costs (one-time cost)	Labor to install hardware and software and to commission iBEMS system	$152,000
Facility Operational & Maintenance Costs (recurring cost)	Reduction in energy consumed vs. baseline data Maintenance inclusive of software/hardware, labor, and commissioning over 15 year period (net present value)	$21,280
Hardware Lifetime	Estimate based on components degradation during demonstration	15 years
Operator Training (one-time cost)	Estimate of training costs	$24,800

7.2 COST DRIVERS

The most important cost drivers for the iBEMS are the existence of significant heating and/or cooling loads, site-wide BAS, and the costs of utilities at a military base. One cost driver not associated specifically with energy is the need to meet/address security and DoD Information Assurance Certification and Accreditation Process (DIACAP) requirements. Costs typically associated with meeting DIACAP requirements include understanding DIACAP and unique facility requirements; deployment; configuring the system; and testing and documenting to meet the requirements. Another cost driver is the site's BAS network infrastructure. Costs can vary drastically depending on the level of BAS integration among buildings and the level of access to a global network for the remote system operation. At USAFA, the BAS was networked throughout the entire site; however, the fact that security constraints disallowed the iBEMS to be configured and operated remotely via public network drove the cost of system commissioning, servicing and operation.

7.3 COST ANALYSIS AND COMPARISON

One of the great benefits of the iBEMS is its scalability. The system's runtime is, at its core, highly portable and capable being deployed for different platforms including low-scale embedded or even mobile platforms. This means that the iBEMS can be implemented as an add-on software technology that can not only extend the existing BAS systems such as Siemens' Apogee, but introduce another form of mobile energy management using tablets or even smart phones. Depending on the requirements, the iBEMS runtime can also be tightly integrated with that of the BAS server for better performance and more system-native capabilities, such as understanding and acting on internal BAS data models instead of loosely coupled control points. However, the tight integration of iBEMS will require extensive investigation and integration work with the BAS product development team; and that could lead to a costly solution. All of

these options have to be taken into account while productizing and identifying an appropriate cost model for the iBEMS.

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8.0 IMPLEMENTATION ISSUES

The commissioning and demonstration of the iBEMS system at USAFA helped the development team to understand the advantages and constraints of the current iBEMS implementation in the areas of equipment, integration, and communication as well as user experience of the system.

8.1 FACILITY AUDITING

The facility auditing happened to be one of the great challenges of this demonstration. In order to accurately develop a calibrated building model, the project team had to identify the building control sequences and zones that can be controlled by the iBEMS and the building drawings and logical charts had to be obtained manually. Some of the data was outdated and required physical site auditing. The lack of a standard auditing mechanism created difficulty in gathering the physical and the logical building data. This makes the building modeling and calibration one of the most tedious and time-demanding tasks of the iBEMS pre-commissioning phase.

8.2 EQUIPMENT

One of the crucial steps and also a cost driver of the iBEMS commissioning was the installation of the electrical energy sub-meters and data loggers. The existing building automation equipment at USAFA did not provide comprehensive and accurate information about the energy consumption by an individual load. Another constraint of the current BAS at USAFA is a lack of standard mechanism for the energy consumption data collection. A lot of manual work is required to log, retrieve, and exchange any building data including trend data with a third party system like iBEMS.

8.3 INTEGRATION WITH BAS

Because the iBEMS used a loose-coupling approach with the BAS via the BACnet, it was important to test the version of the BACnet at USAFA and its compatibility with a BACstac client library that was used by the iBEMS – SEB runtime platform for the real-time communication with BAS.

The mapping of the BAS control points to iBEMS control point objects was also necessary before the iBEMS startup. The definition and mapping of the control points required manual export of the point defined in Apogee, and manual creation and mapping of the Apogee point attributes in the iBEMS. The manual work was prone to errors and it took several iterations before all the control points were appropriately mapped between the iBEMS and BAS.

Another important aspect of the iBEMS demonstration at USAFA was system availability. The availability requirement drove the decision to dedicate one CPU for each SEB, which in turn is responsible to control one individual building. It also allowed distribution of CPU's over the BAS network in case of not having enough physical space for the entire iBEMS deployment at Vandenberg Hall.

8.4 RUNTIME COMMUNICATION

One of the issues observed during the demonstration was the iBEMS failure to relinquish some of the control points after an event or during operation mode switching. Because this issue was random, it was difficult to do the troubleshooting. This is one of the critical runtime errors that must be addressed in the next iBEMS release.

In addition, the network security constraints made a process of overall iBEMS troubleshooting quite inefficient. It was not possible to access the site remotely and therefore the team had to spend a great deal of time looking into the runtime issues on-site. Finally, the real-time monitoring of EE demonstration was troublesome because it required a person be located on-site. The restriction from a public network access of the iBEMS also created difficulty in obtaining a weather forecast from National Oceanic and Atmospheric Administration public weather service. The forecast had to be manually handled via file transfer, which required an off-site system generating this file specifically for the iBEMS demonstration.

8.5 USER EXPERIENCE

The EMCS team was generally satisfied with the features and functionality for both: engineering and runtime UI. However, some of the obvious issues are discussed below:

iBEMS Configuration Tool:

- The configuration of control points is rather difficult because it requires manual mapping of the point attributes from Apogee to iBEMS;
- The configuration of the rule-based strategies requires a lot of browsing through dialogs;
- The rules creation is not intuitive for the user;
- There is no explicit information for the configured strategies in the configuration tool;
- The information is hidden in the sub-dialog; and
- There is no history of the executed strategies in the tool.

Web HMI:

- There is no secure login to the WEB UI;
- The trending graph does not provide date/time filters and it is difficult to navigate;
- There is no history for the trends in the UI, neither on the Microgrid nor on the building dashboard pages;
- The aggregated energy consumption graph on the Microgrid page is difficult to read;
- The zonal control point list on the building dashboard page does not provide all the information about current point values for each control point; and
- The selected strategy list is not intuitive for the user.

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APPENDIX A

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