FINAL REPORT

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

ESTCP Project EW-201255

JUNE 2014

Yan Lu
Sue DeMeo
Dmitriy Okunev
Siemens Corporation

Thomas Hykes
US Air Force Academy

Distribution Statement A

This document has been cleared for public release

TABLE OF CONTENTS

LIST OF FIGURES 3
LIST OF TABLES 5
ACRONYMS 7
ACKNOWLEDGEMENTS 9
EXECUTIVE SUMMARY 10
1.0 INTRODUCTION 12
1.1 BACKGROUND 12
1.2 OBJECTIVE OF THE DEMONSTRATION 13
1.3 REGULATORY DRIVERS 13
2.0 TECHNOLOGY DESCRIPTION 15
2.1 TECHNOLOGY OVERVIEW 15
2.2 TECHNOLOGY DEVELOPMENT 18
2.3 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY 26
3.0 PERFORMANCE OBJECTIVES 30
3.1 SUMMARY OF PERFORMANCE OBJECTIVES 30
3.2 PERFORMANCE OBJECTIVES DESCRIPTIONS 33
4.0 FACILITY/SITE DESCRIPTION 40
4.1 FACILITY/SITE LOCATION AND OPERATIONS 41
4.2 SITE-RELATED PERMITS AND REGULATIONS 55
5.0 TEST DESIGN 56
5.1 CONCEPTUAL TEST DESIGN 57
5.2 BASELINE CHARACTERIZATION 60
5.3 DESIGN AND LAYOUT OF TECHNOLOGY COMPONENTS 73
5.4 OPERATIONAL TESTING 79
5.5 SAMPLING PROTOCOL 83
5.6 SAMPLING RESULTS 84
6.0 PERFORMANCE ASSESSMENT 85
6.1 BUILDING ENERGY EFFICIENCY OPTIMIZATION 87
6.2 FACILITY PEAK DEMAND REDUCTION 103
6.3 GHG EMISSIONS REDUCTION 124
6.4 SYSTEM ECONOMICS 127
6.5 SECURITY/ RELIABILITY OF THE BAS NETWORK 145
6.6 THERMAL COMFORT 156
6.7 SYSTEM INTEGRATION 161
6.8 PROJECT IMPACT ON UTILITY PLANS FOR DEMAND RESPONSE PROGRAMS 170

7.0 COST ASSESSMENT 171
7.1 COST MODEL 171
7.2 COST DRIVERS 176
7.3 COST ANALYSIS AND COMPARISON 178
8.0 IMPLEMENTATION ISSUES 179
8.1 PERTINENT REGULATIONS 179
8.2 END-USER CONCERNS 179
8.3 PROCUREMENT ISSUES 180
8.4 INTEGRATION WITH ICS 180
8.5 RUNTIME COMMUNICATION 181
8.6 USER EXPERIENCE 182
9.0 REFERENCES 183
Appendix A: Points of Contact 184
Appendix B: Operating Schedules and Lists of Controllable Equipment 184
Appendix C: Maintenance and Thermal Comfort Complaint Log 195
Appendix D: Thermal Comfort Survey 200
Appendix E: Implemented DR Strategies during Various DR Events 216
Appendix F: iBEMS Usability Survey 218

LIST OF FIGURES

Figure 1: iBEMS Architecture 15
Figure 2: Smart Energy Box Architecture 16
Figure 3: Configuration of the Rule-based Energy Efficiency Strategies in SEB 19
Figure 4: Adjustment of DR Strategy Based on Change in Occupancy 20
Figure 5: Information Flow for a DR Event Involving Multiple Buildings 21
Figure 6: iBEMS HMI - Microgrid Dashboard 22
Figure 7: iBEMS HMI - Building Dashboard 23
Figure 8: iBEMS HMI – DR Event Info Page 24
Figure 9: Conceptual OSB Integrated Architecture 25
Figure 10: Typical USAFA Electricity Bill Breakdown 40
Figure 11: Location of Arnold and MHs 41
Figure 12: Monthly Electrical Energy Use at AH 43
Figure 13: AH - Electrical Energy Use Breakdown 43
Figure 14: AH - Controllable Electrical Energy Use Breakdown 44
Figure 15: AH - Monthly Electrical Energy Use Breakdown for Controllable and Non-Controllable Loads 45
Figure 16: AH - Monthly Heating Energy for FY11 46
Figure 17: MH - Monthly Electrical Energy Use 47
Figure 18: MH - Monthly Electrical Energy Use 48
Figure 19: MH - Controllable Energy Use Breakdown 49
Figure 20: MH - Monthly Electrical Energy Use Breakdown for Controllable and Non-Controllable Loads 49
Figure 21: MH - Monthly Heating Energy 50
Figure 22: Location of CC 51
Figure 23: CC - Monthly Electrical Energy Use 52
Figure 24: CC - Electrical Energy Use Breakdown 52
Figure 25: CC - Controllable Electrical Energy Use Breakdown 53
Figure 26: CC - Monthly Electrical Energy Use Breakdown for Controllable and Non-Controllable Loads 54
Figure 27: CC - Monthly Heating Energy 55
Figure 28: Overall Installation Architecture of iBEMS at USAFA 56
Figure 29: Building Views from the EnergyPlus 63
Figure 30: Ground Level Floor Plan for AH 64
Figure 31: Step 1 Calibration (Weekday Repeatable Occupancy) 66
Figure 32: Step 2 Calibration (Weekend Repeatable Occupancy) 66
Figure 33: Step 3 Calibration (Event Occupancy) 67
Figure 34: Step 4 Validation 67
Figure 35: Monthly Electricity Usage Comparison 68
Figure 36: Revised Simulation's Results as Compared with Trend Data 69
Figure 37: Forecast Comparison for CC for the Week of 26-30 August 70
Figure 38: Forecast Comparison for CC for 28 August 70
Figure 39: Forecast Comparison for AH for the Week of 24-28 June 71
Figure 40: Forecast Comparison for AH for 25 June 71
Figure 41: Forecast Comparison for MH for the Week of 15-19 July 72
Figure 42: Forecast Comparison for MH for 17 July 72
Figure 43: iBEMS Demonstration Installation Layout at USAFA 74
Figure 44: Simatic Microbox Industrial PC 75
Figure 45: First Level Decomposition of the iBEMS in terms of Runtime Components 76
Figure 46: Integrated System Setup 78
Figure 47: Control Sequence of the iBEMS Demonstration 78
Figure 48: Operational Scenarios of EE Test 80
Figure 49: Step 1 of Operational Sequence of the iBEMS Demand Management 81
Figure 50: Step 2 of Operational Sequence of the iBEMS Demand Management 82
Figure 51: Step 3 of Operational Sequence of the iBEMS Demand Management 82
Figure 52: Performance of Calibrated EnergyPlus Model 91
Figure 53: Comparison of Total Energy Consumption for Calibrated EnergyPlus Model 91

Figure 54: Annual Energy Use Breakdown for Baseline and EE Enabled Models 92
Figure 55: SEB Log for EE Strategy Implementation in C.AHU01....95
Figure 56: SEB Log for EE Strategy Implementation in A.AH07 95
Figure 57: SEB Log for EE strategy Implementation on the HAPS lounge terminal unit – VAV.MB25....96
Figure 58: SEB Log for Room Temperature Setpoints....97
Figure 59: EE Tests Results for Heating Season Test (April 1-7) 98
Figure 60: EE Tests Results for Cooling Season Test (September 17-20) 98
Figure 61: Energy Consumption of Panel DTM29 in Comparison with Baseline....99
Figure 62: Chiller Energy Consumption Compared with Baseline 100
Figure 63: Model Error Histogram (15-minute kWh) 103
Figure 64: Demand Curves for AH....104
Figure 65: Demand Curves for MH....104
Figure 66: Demand Curves for CC....105
Figure 67: Weekday Load Profile: AH....106
Figure 68: Peak Load Profile for AH....106
Figure 69: Weekly Peak Load Profile for AH 107
Figure 70: Peak Load Frequency at Hour Interval for AH 107
Figure 71: Weekday Load Profile: CC 108
Figure 72: Peak Load Profile for CC....108
Figure 73: Weekly Peak Load Profile for CC....109
Figure 74: Peak Load Frequency at Hour Interval for CC....109
Figure 75: Weekday Load Profile: MH 110
Figure 76: Peak Load Profile for MH....110
Figure 77: Weekly Peak Load Profile for MH....111
Figure 78: Peak Load Frequency at Hour Interval for MH....111
Figure 79: Combined Weekday Load Profile 112
Figure 80: Combined Peak Load Profile 112
Figure 81: Combined Weekly Peak Load Profile 113
Figure 82: Peak Load Frequency at Hour Interval at the Aggregated level....113
Figure 83: Aggregated Baseline and Actual Demand During DR-1....115
Figure 84: kW Savings During DR-1 115
Figure 85: Aggregated Baseline and Actual Demand During DR-2....116
Figure 86: kW Savings During DR-2 117
Figure 87: Aggregated Baseline and Actual Demand During DR-3....118
Figure 88: kW Savings During DR-3 118
Figure 89: Aggregated Baseline and Actual Demand During DR-4....119
Figure 90: kW Savings During DR-4 120
Figure 91: Aggregated Baseline and Actual Demand During DR-5....121
Figure 92: kW Savings During DR-5 121
Figure 93: AH - Monthly Heating Energy FY13....129
Figure 94: AH: Monthly EnergyPlus Simulation Calculated Natural Gas Use 129
Figure 95: Real-time Weather versus TMY3 Normalized Weather Data....133
Figure 96: Historical Electrical Data versus Normalized Baseline data for selected buildings on site 134
Figure 97: Process to Calculate the Fan Energy Savings....137
Figure 98: Packet Level Representation with and without the Secure OSB in Place 149
Figure 99: Client/Server Test....150
Figure 100: Test Client and Server Connect to the Secure OSB 150
Figure 101: Example for a Log File and Status Window during Testing 152
Figure 102: Summary of Maintenance Issues and Thermal Comfort Complaints from the EMCS Logs, October 2012 – October 2013 158
Figure 103: iBEMS Deployment Diagram 164
Figure 104: WEB-based iBEMS HMI....165
Figure 105: Rule-based Strategy Setting 166
Figure 106: iBEMS during the “Dry Run” Test at Vandenberg Hall 168

LIST OF TABLES

Table 1: Demonstration Results Summary 11
Table 2: Chronology of iBEMS Development 17
Table 3: Temperature Lookup Table for EE Thermostat Rule 18
Table 4: Performance Objectives....30
Table 5: Specific Schedule at AH....42
Table 6: Specific Schedule at MH 46
Table 7: Specific Schedule at CC 51
Table 8: Test Design Summary 58
Table 9: Calibration Results 66
Table 10: Simulation Model Accuracy....68
Table 11: Average MAPE for Daily kWh Forecast....73
Table 12: Sampling Protocol Table 83
Table 13: Summary of Performance Assessment 85
Table 14: Look Up Table for Room Temperature Setpoint....90
Table 15: Comparison between Yearly Simulation of Baseline and EE Enabled Models....92
Table 16: Rules for Determining SYS and EE Points Using Occupancy Schedule....93
Table 17: Rules for Determining Day/Night Modes Using Occupancy Schedule....93
Table 18: Cooling Season Room Temperature Reset Table 94
Table 19: Heating Season Room Temperature Reset Table 94
Table 20: Operation Time Reduction by Occupancy Based AHU/Terminal Switch (Cooling Season Test) 100
Table 21: Energy Saving Breakdown by Occupancy Based AHU/Terminal Switch (Cooling Season Test)....101
Table 22: Energy Saving Summary....101
Table 23: DR Event Schedule....114
Table 24: Results Summary for DR-1 116
Table 25: Results Summary for DR-2 117
Table 26: Results Summary for DR-3 119
Table 27: Results Summary for DR-4 120
Table 28: Results Summary for DR-5 122
Table 29: DR Results Summary 122
Table 30: Modified DR Results Summary for Only Controllable Loads 122
Table 31: Modified DR Results with Inclusion of Estimated Reduction Due to Plug Loads....123
Table 32: Summary of the Expected GHG Reductions from Electricity and Natural Gas Decreases 126
Table 33: Summary of Findings Related to Heating Energy Usage 130
Table 34: Colorado Springs Utility Electricity Rates 131
Table 35: Colorado Springs Utilities Natural Gas Rates 131
Table 36: Monthly Fan and Cooling savings for AH....139
Table 37: Potential Electricity Savings in kWh and Cost Savings per Building 140
Table 38: Potential Heating and Natural Gas Cost Savings for Each Building 140
Table 39: Campus Wide Energy Consumption and Savings 141
Table 40: Data Collected and the Performed Analysis....148
Table 41: iBEMS Latency Data....153
Table 42: Thermal Comfort Survey: Summary of Baseline Results, August 2013 157
Table 43: Open Maintenance Log Issues or Thermal Comfort Complaints during the iBEMS Demonstration Periods 158
Table 44: Cost Model for the iBEMS at AH 171
Table 45: Cost Model for Campus Wide Intelligent Building Energy Management System at USAFA 172
Table 46: Security Cost Model for AH Intelligent Building Energy Management System at USAFA....174
Table 47: Energy Efficiency Alternative for AH....175
Table 48: Results of the Life Cycle Cost Analysis for 14 Campus Buildings....176
Table 49: Detailed Schedule of Occupancy for AH 184
Table 50: Arnold Hall Controllable Equipment....185
Table 51: Mitchell Hall Controllable Equipment 188
Table 52: Community Center Schedule of Operations 192

Table 53: Community Center Controllable Equipment 193
Table 54: Summary of Relevant Maintenance Log and Thermal Comfort Complaint Log Data for Demonstration Buildings 195
Table 55: Implemented Strategies During DR-1 216
Table 56: Implemented Strategies During DR-2 216
Table 57: Implemented Strategies During DR-3 216
Table 58: Implemented Strategies During DR-4 217
Table 59: Implemented Strategies During DR-5 217

ACRONYMS

AH	Arnold Hall
AHU	Air Handler Units
BAS	Building Automation System
BEUI	Building Energy Use Intensity
CBECS	Commercial Buildings Energy Consumption Survey
CC	Community Center
COTS	Commercial Off the Shelf
CV	Coefficient of Variance
DIACAP	DOD Information Assurance Certification and Accreditation Process
DOD	Department of Defense
DOE	Department of Energy
DR	Demand Response
DRAS	DR Automation Server
E+	EnergyPlus
EE	Energy Efficiency
EISA	Energy Independence and Security Act
EMCS	Energy Management Center System
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 BTU
LBNL	Lawrence Berkeley National Laboratory
LEG	Local Energy Gateway
MAPE	Mean Absolute Percentage Error
MBTU	Million BTU
MH	Mitchell Hall
MOU	Memo of Understanding
MTHW	Medium Temperature Hot Water
MTPG	Medium Temperature Propylene Glycol
NMBE	Normalized Mean Bias Error
NOAA	National Oceanic and Atmospheric Administration
NREL	National Renewable Energy Laboratory
OAT	Outdoor Air Temperature
OSB	Operations Service Bus
PO	Performance Objective
POC	Point of Contact
QC	Quality Control
RMSE	Root Mean Squared Error
SAT	Supply Air Temperature

SCT	Siemens Corporate Technology
SEB	Smart Energy Box
SOA	Service-Oriented Architecture
SSP	Static Supply Pressure
SSTO	Start/Stop Time Optimization
TEC	Terminal Equipment Controllers
UCB	University of California, Berkeley
USAFA	United States Air Force Academy
VAV	Variable Air Volume

ACKNOWLEDGEMENTS

This work is supported by the U.S. Department of Defense ESTCP program under Project 201255. The team would like to thank Dr. Jim Galvin for his leadership during the project execution. We are also very thankful to the technical support provided by Dr. Nicholas Judson from MIT Lincoln Laboratory. The team gratefully acknowledges the support from the staff of United State Air Force Academy who not only provided information and coordination assistance for the project, but also actively participated in the project by evaluating our software.

EXECUTIVE SUMMARY

Moving the U.S. 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 (EISA), 2007 [1]) 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 manual commanding the building control systems, the task becomes much more onerous when they need to manage a campus of buildings. Complicating this scenario is that even the state-of-the-art BASes are incapable of coordinating the electricity demand among buildings.

To address the above mentioned issues, Siemens, in collaboration with the Boeing Company, DNV KEMA, and the University of California at Berkeley, 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 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's) were identified and corresponding metrics were defined, in **Table 1**, to assess iBEMS technology. To investigate the ability of iBEMS to meet the success criteria for the defined PO's, a series of system tests were conducted in four buildings at USAFA to measure the performance of iBEMS with reference to baseline conditions. The tests were grouped into two test scenarios – 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 its implementation. Rather, an enterprise energy management system like the iBEMS has to be deployed at the scale for which it was intended – campuses with building clusters. Therefore the results for PO's 3 and 4, in **Table 1** , 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 based on the analytical results developed from the various energy efficiency and demand response tests that were conducted at USAFA.

Table 1: Demonstration Results Summary

	Success Criteria	**Performance Assessment**
Quantitative Performance Objectives		
PO 1: EE Optimization	20-40% annual reduction in energy usage in AH	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" the 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's) 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 PO's.

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, CO. From May 2012 to December 2013, Siemens Corporation, in collaboration with The Boeing Company, DNV KEMA, and the University of California at Berkeley, 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 [2]. 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 BASes are incapable of coordinating control between demand and supply of electricity within and among buildings. Specifically, current BAS technology suffers from the following shortcomings [3]:

- 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% [3].

In this project, we have considered 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 if iBEMS technology can result in cost effective building energy efficiency (EE) improvements, enable collaborative building cluster demand management and adaptive demand response (DR) and provide secure and reliable communication with existing BMS.

Specifically, we 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 additional, we 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 [4] and the EISA of 2007 [1]. 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, Energy Independence and Security Act 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 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 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.
- Research, development, test, and evaluation (RDT&E) has delivered the new, cost-effective, energy technologies necessary to substantially reduce demand and increase supply.

2.0 TECHNOLOGY DESCRIPTION

2.1 TECHNOLOGY OVERVIEW

The proposed Intelligent Building Energy Management System (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 BASes is based on an industry standard such as BACnet.

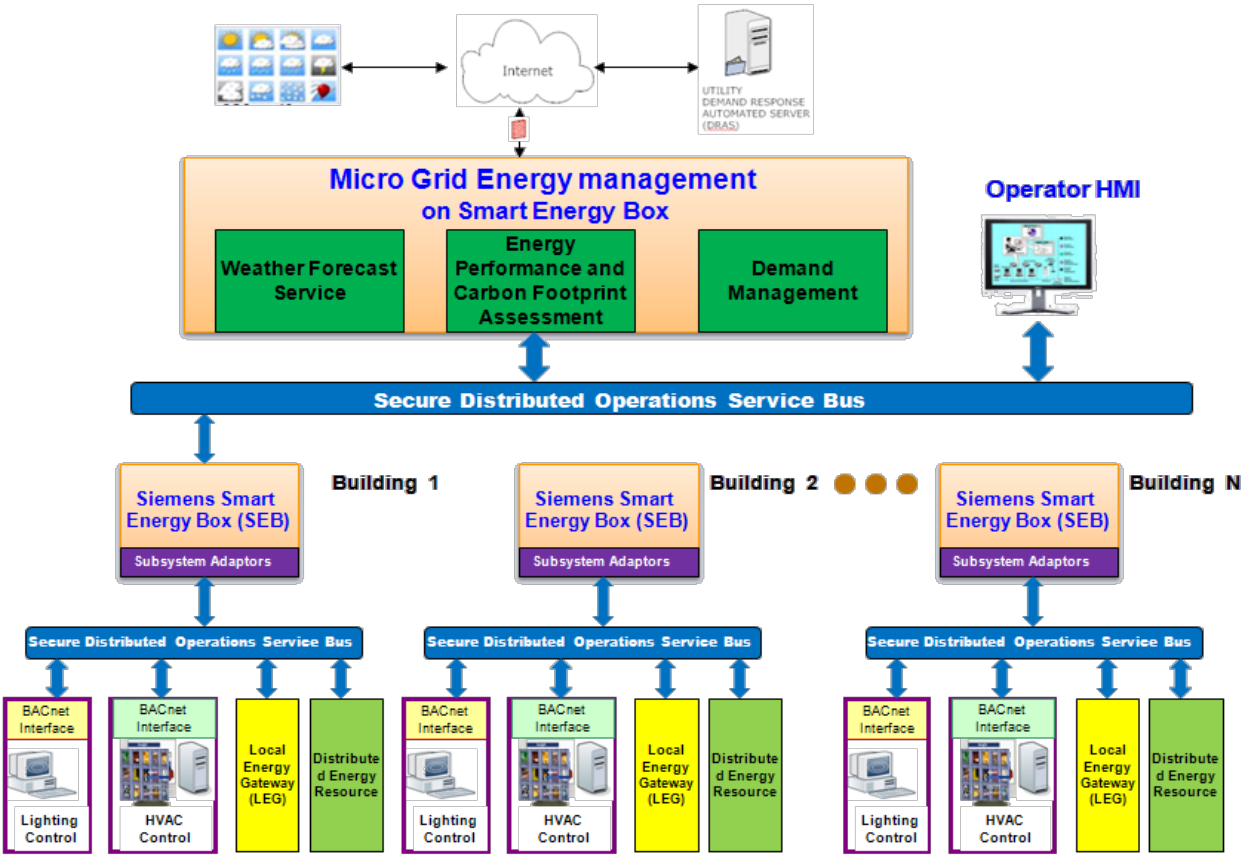


Figure 1: iBEMS Architecture

The core component for the iBEMS is the Siemens smart energy box (SEB), shown in **Figure 2**, which resides at both campus/microgrid and building level to oversee all of the buildings in a cluster and subsystems within the buildings, including HVAC control, lighting control, and local controllers for the on-site energy resources and distributed loads [5]. Specifically, iBEMS offers the following features and capabilities through SEB:

- An integration platform allowing communication among buildings, building subsystems, and building operators to form coordinated demand side load and generation management.

- Implementation of both weather-based proactive energy management and occupancy-based building operations to maximize building energy efficiency and savings while maintaining a comfortable environment for building occupants.
- Dynamic demand management to respond to a grid/microgrid request or an operator's command to perform peak load reduction, load shedding, and load shift and shaping while maintaining building functionalities.
- A gateway to connect to the electricity grid using open standards, such as OpenADR, through which energy prices as well as DR events can be delivered from the local utility to the buildings.
- Implementation of a weather forecast service and an embedded load forecast engine that allows runtime assessment of EE and DR strategy to minimize operational cost.
- Implementation of an advanced human machine interface (HMI) for building operators based on the latest visualization technology. This HMI provides the best transparency of how energy was, is, and will be used, and supports breakdowns among buildings and within buildings down to zone level.

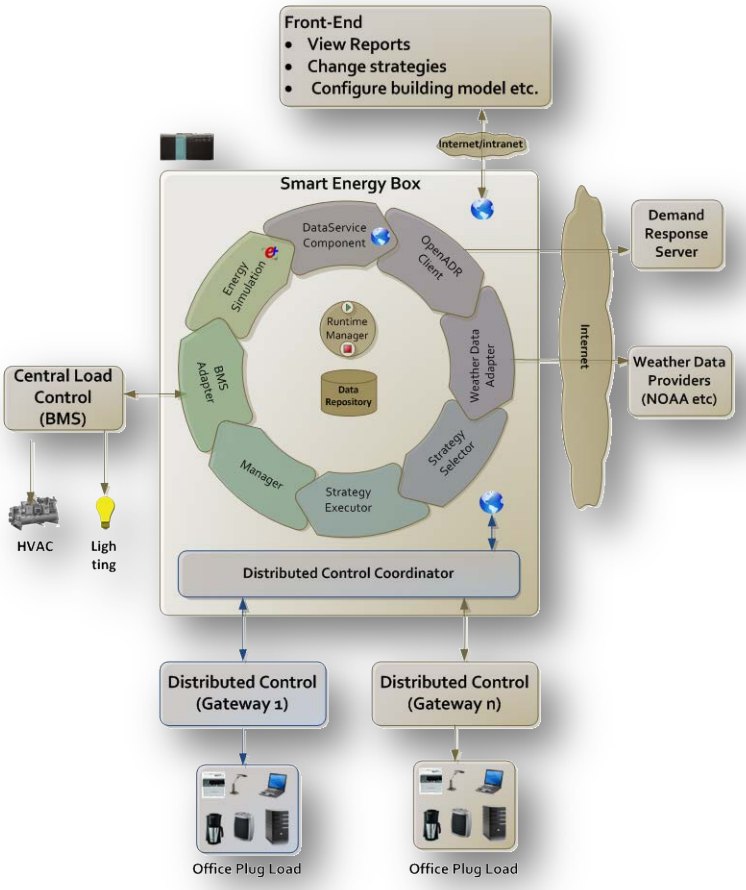


Figure 2: Smart Energy Box Architecture

The SEB has two configurations. The building level implementation (SEB-B) addresses different control features within the building while the microgrid implementation (SEB-M) facilitates the features of communication with the electrical grid and external systems. The SEB at microgrid level implements weather service, grid connection, energy/carbon monitoring, and microgrid demand management, while SEBs at building level implement load forecast and advance controls for EE and building DR optimization. While each building level SEB is capable of containing its own forecasting functions and predictive tools, a more economical solution to SEB scalability is planned. For example, with multiple building facilities, we can host these forecasting and prediction functions on a separate, centralized box. Depending on the application, this box can be located at the microgrid control center or can be localized within the facility. Another unique feature offered by our iBEMS is the control of distributed loads as shown in **Figure 1**. Local energy gateways (LEGs) control plug loads for energy savings based on occupancy and tasks and provide distributed DR capability through communication with the SEB.

2.1.1 Chronological Summary

Table 2 shows the technology development history of iBEMS.

Table 2: Chronology of iBEMS Development

Development Phase	Time Frame	Funding Agency
Local Energy Gateway Version 1	2003 to 2009	California Energy Commission
Open ADR Client and BACnet Building Adaptor	2007 to 2009	Siemens
SEB with embedded E+ engine and integration of weather service	2009 to 2010	Siemens and DOE
Distributed Intelligent Automated Demand Response Management	2010 to 2012	DOE
Local Energy Gateway with agent capability	2010-2012	DOE
Proactive building EE control and management	2010-2012	DOE
Advanced HMI for building energy management	2011 to 2012	DOE
Boeing OSB	2009 to 2011	Boeing

2.1.2 Future Potential for DOD

The iBEMS is a scalable, supervisory level control system that generates consistent and optimal set points to BASes via standard protocols. It works as an extension to all mainstream BASes that support BACnet and Modbus, which makes it applicable to most DOD installations. iBEMS will empower DOD strategic planners, capital budgeters, facilities managers, logistical tacticians, and base commanders to operate clusters of buildings in an energy efficient way. It will also enable them to cut cost through participation in DR programs provided by electrical utilities.

2.2 TECHNOLOGY DEVELOPMENT

During the course of the project SEB functionality was extended by addition of two new function modules and an enhanced HMI. The first new module is for the implementation of a rule-based energy efficiency engine for HVAC operations. The other new module is to implement an adaptive demand response approach in which the DR strategies are dynamically and automatically determined within SEBs, with consideration of occupancy changes. Furthermore, SEB HMI was enhanced to provide holistic campus energy monitoring and control interfaces to building operators or facility managers. In addition, Boeing also enhanced their OSB technology and made a customization for USAFA deployment. The following sections describe the new components of SEB for iBEMS in more detail.

2.2.1 Rule based Energy Management Controller

iBEMS EE subsystem provides a cost effective approach to manage energy consumption. In essence, this approach relies on the rule-based energy efficiency 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. The SEB is programmed with virtual building zones that provide the information about the upcoming events and the overall facility operation schedule. This information is used as an input to the rule-based energy efficiency (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. This rule was used to define the temperature threshold to program the lookup table for the thermostat’s temperature accordingly. **Table 3** depicts the thermostat reset rule defined within the iBEMS EE subsystem.

Table 3: Temperature Lookup Table for EE Thermostat Rule

Outside temperature (F)	Thermostat Value (F)
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

Once the strategies are defined, the corresponding BAS control points are identified for strategy implementation. Whenever a building operation mode in SEB is set to EE, the SEB takes control of the mapped BAS control points and commands appropriate values that are defined by the EE control rules. The EE cycle runs continuously for the duration of the occupancy schedule defined by the iBEMS user. When building operation mode is set back to "None", all the BAS control points managed by the SEB-EE subsystem are relinquished, and the ownership of the points is given back to the BAS system. **Figure 3** depicts the configuration tool for the rule-based strategies in SEB by the iBEMS administrator. Detailed implementation of this approach for AH at USAFA is presented later in Section 6.

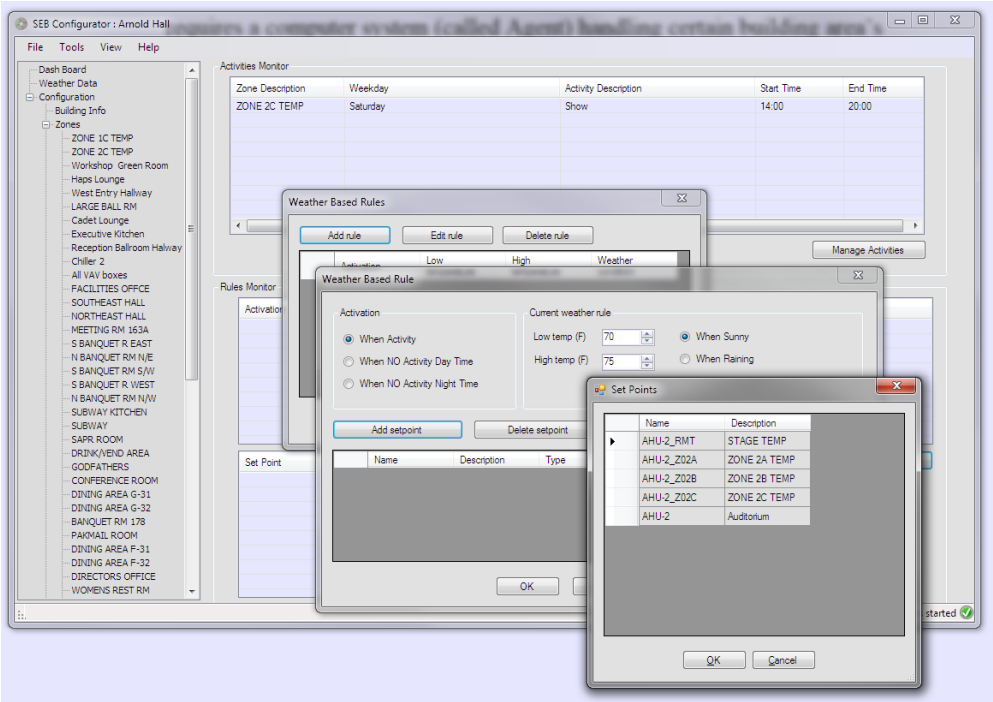


Figure 3: Configuration of the Rule-based Energy Efficiency Strategies in SEB

2.2.2 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, the lighting control agent and energy storage agent etc. A source agent can also be aggregated load or generation, for example building agent. In addition, there is a task agent which receives demand management command from facility operator and is responsible for allocating demand reduction/increase to source agents. In order for the agents to find global feasible DR strategy, the agents must cooperate and coordinate their local actions. 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 a bids based on their current (occupancy) status in the format of a utility loss function. Based on the utility loss functions from the source agents, 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. Building agents generate utility loss functions at a fixed interval with the determination of the impact of the DR actions such as AHU's 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-B, the optimization at SEB-M 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. The entire process is shown in **Figure 4**.

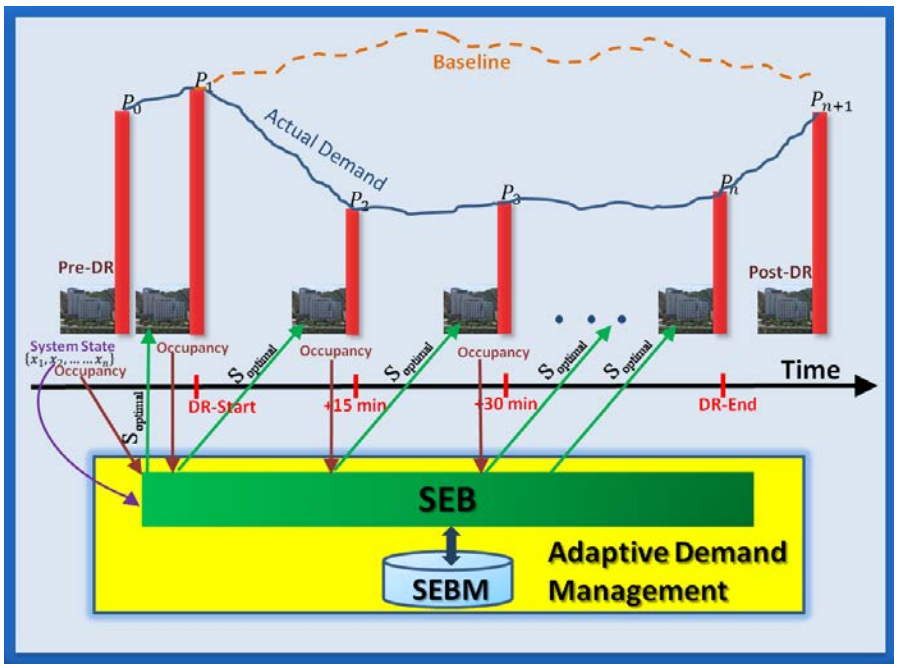


Figure 4: Adjustment of DR Strategy Based on Change in Occupancy

Implemented based on agent technology, the developed approach is highly extensible and distributed in nature. There is no change required of the proposed approach when deployed for multiple buildings which act as a group participating in a DR event. This adaptive DR method for a single building is implemented in a SEB-B. For multiple building, multiple SEB-Bs will then interact with one microgrid level SEB-M that takes as input the various DR strategies from the buildings - amount of possible demand reductions and cost of each strategy as input. Then this SEB-M uses Particle Swarm Optimization (PSO) based approach to determine the optimal strategy for each building such that overall demand reduction target is achieved with the lowest possible cost, as shown in **Figure 5**.

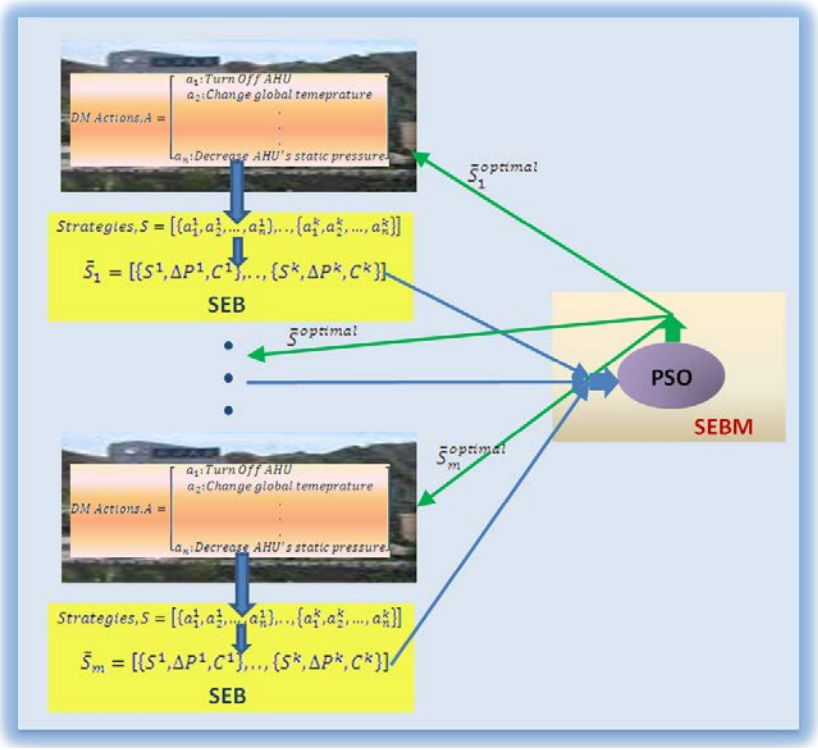


Figure 5: Information Flow for a DR Event Involving Multiple Buildings

2.2.3 iBEMS HMI

The iBEMS system offers three types of HMIs: SEB Configuration Tool for system configuration and general iBEMS administration; a web-based runtime HMI for iBEMS monitoring and energy demand management; and a Local Energy Gateway HMI for the runtime management of the iBEMS plug loads.

The SEB Configuration tool is a Windows based application that is designed for the SEB-B and SEB-M configuration during the commissioning phase. It also supports some of the administrative functions such as User Management, System Restoration etc., as well as runtime diagnostic utilities such as SEB-B runtime status, weather forecast analysis, DR event history analysis, and DR bid negotiation analysis. The iBEMS administrator can also use this tool for configuration and initiation of a Demand Management event or configuration of building operation mode as described in Demand Management section. The views in the tool are dynamic, depending on which SEB the tool is connected to it displays a subset of the corresponding views.

A web (PHP) based HMI is designed to manage the overall status of the iBEMS system at runtime. After the commissioning of the iBEMS system including installation of a PHP server and the PHP configuration on the iBEMS workstation, this iBEMS HMI can be invoked by the user through an internet browser. It fully supports IE8, Chrome and Firefox browsers. At this state the iBEMS HMI is tested with a free version of WAMP PHP server[1] and limited to the PHP

[1] WampServer is a Windows web development environment. It allows you to create web applications with Apache2, PHP and a MySQL database. http://www.wampserver.com/en/

functionality available by the WAMP PHP server. However its functionality is not limited to WAMP and can be configured to be used with other publicly-licensed proprietary PHP servers, as required. The iBEMS HMI consists of three main dashboards: Microgrid, Building and DR View. The iBEMS HMI is scalable and supports a platform-independent architecture. It can be configured to operate on stationary MS Windows-based PCs or UNIX – based systems as well as mobile devices such as tablets. In this demonstration, the web HMI was launched on a laptop dedicated to the demo as well as the SEB-M box for quick diagnostics.

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. **Figure 6** shows a screenshot of the Microgrid Dashboard of the iBEMS HMI. The screenshot depicts an aggregated real time load for three USAFA buildings: AH, MH and CC. The yellow plot displays the calculated base load and the green plot displays the overall energy consumption by three buildings. The information is polled from each SEB-B and aggregated by the SEB-M at the campus level. The iBEMS HMI queries this information from the SEB-M and displays on the web page as illustrated below.

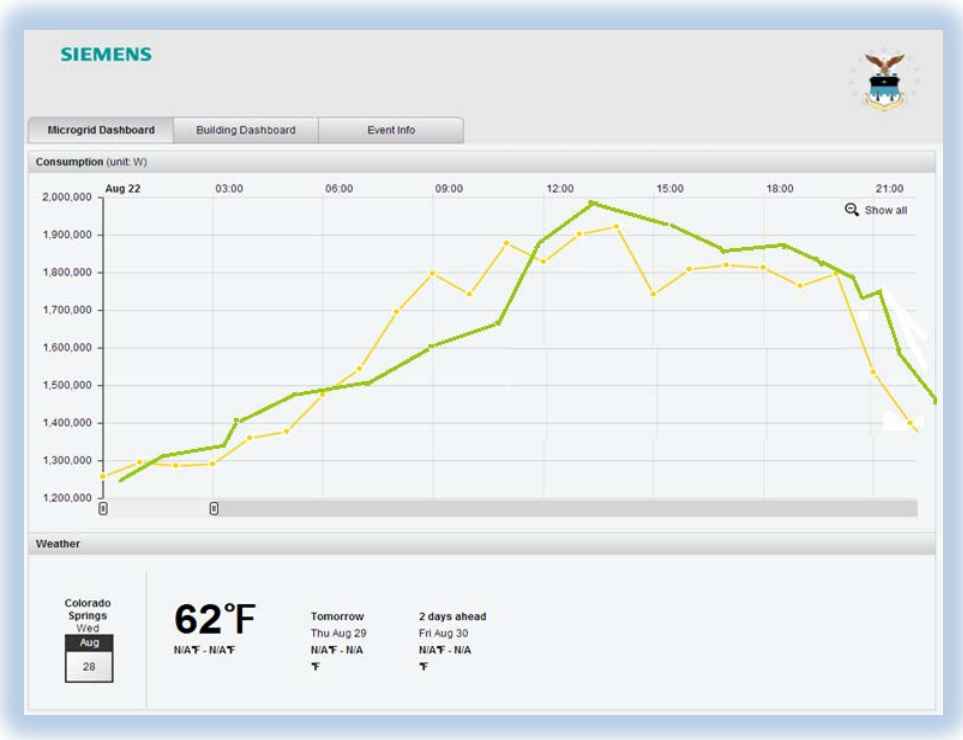


Figure 6: iBEMS HMI - Microgrid Dashboard

The Building Dashboard consists of a Building Info view, a Zone Info view, a Trend Data view, Event Calendar and a Scheduled Strategies View. The iBEMS user can use a selection box to select one of the iBEMS-controlled buildings and work with the following data:

- Building Operation Mode, allowing setting either EE Mode or DR mode.
- Current Load, showing the current load for the entire building. The current load plot view is scalable and can display historical plots as well.

- Base Load, showing the calculated overall base load for the selected building.
- Overall energy trend, allowing monitoring and archiving the trend information for the entire building.
- Zones Information, allowing selection of the individual building zone for monitoring and archiving the consumption on the zone level. Also it is possible to navigate to an individual load of the zone, e.g. Zone thermostat and monitor the current value coming from the corresponding control point.

Scheduled Strategies, allowing analyzing the real time strategies selected by the building's SEB during DR event.

Figure 7 shows a screenshot of the Building Dashboard page of the iBEMS HMI. The screenshot depicts monitoring functionality of the AH SEB. The yellow plot displays the calculated baseline information and the green plot displays the current energy consumption by the AH. The iBEMS HMI queries this information in real time from SEB-AH (Arnold Hall) and displays on the web page as illustrated below.

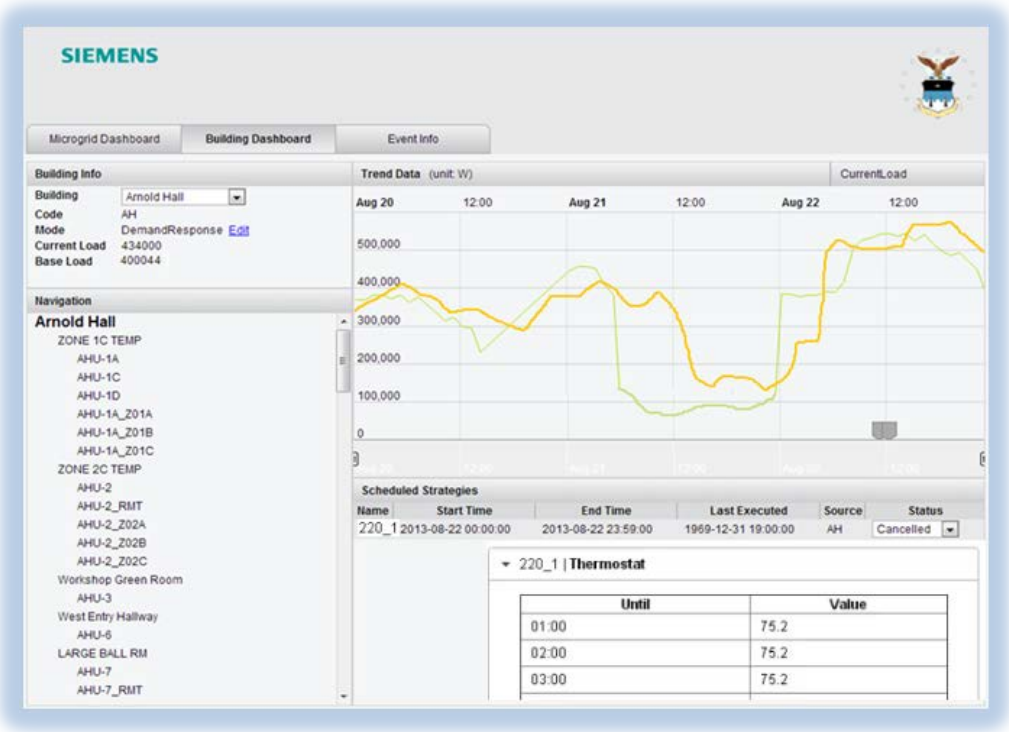


Figure 7: iBEMS HMI - Building Dashboard

The Event Info page consists of the Microgrid Event view the New DR Event view and the Building Status view. iBEMS HMI user can use this page to manage new and existing DR events. In order to issue a new event, the user invokes New DR Event dialog and inputs the information about the event such as event name, the type of event: instantaneous or day-ahead, the event's duration and the energy shedding goal in % or a fixed kW reduction. Once the information of the new event is entered, the event info is listed in the Microgrid Event View with cancellation option. The Building Status view allows monitoring real time information about the

current and a base load for each building participating in the DR event. **Figure 8** shows a screenshot of the DR event page. The iBEMS HMI queries this information from SEB-M and displays on the web page as illustrated below.

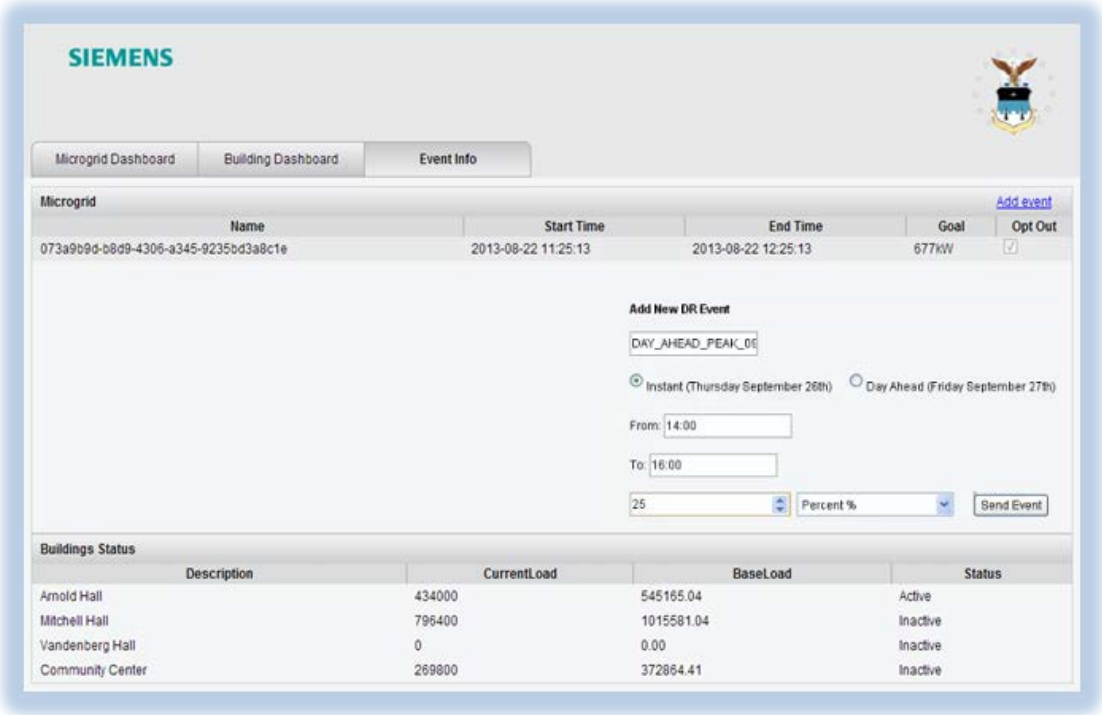


Figure 8: iBEMS HMI – DR Event Info Page

2.2.4 Communication Infrastructure: Boeing Secure Distributed Operations Service Bus (OSB)

The iBEMS deployment will leverage 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 secure distributed OSB connects distributed applications and services with their respective clients in a cyber-secure manner. The OSB is a service-oriented architecture (SOA) solution that supports scalable integration and infrastructure support when integrating standards-based applications, services, and systems. The OSB also provides protocol adaptation for communicating with devices and systems via legacy-based translators and energy industry standard communications protocols. OSB was enhanced to support BACnet and SEB communication protocols under this project.

The OSB is designed and implemented to facilitate reliable communications over persistent and non-persistent networks on which host nodes may become unreachable owing to disruptions to the physical network, plugging or unplugging of devices, or cyber-attacks of non-protected elements. This functionality, securely effecting communications in an ad-hoc highly distributed network environment, gives the OSB a tactical networking capability that differentiates it from traditional enterprise solutions. The OSB communication functions provide a range of features to ensure cyber security. Authentication, authorization, role-based access control, protected

transports, and encryption methods are selectively available to the range of communications styles. Cyber security elements of the OSB are designed into the product to take full advantage of other service capabilities in the OSB. This differs from other enterprise type infrastructure solutions in which cyber elements are typically added on.

As shown in **Figure 9**, the OSB provides 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 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. The OSB provides the required data mediation services for information translation when communicating between the building SEBs.

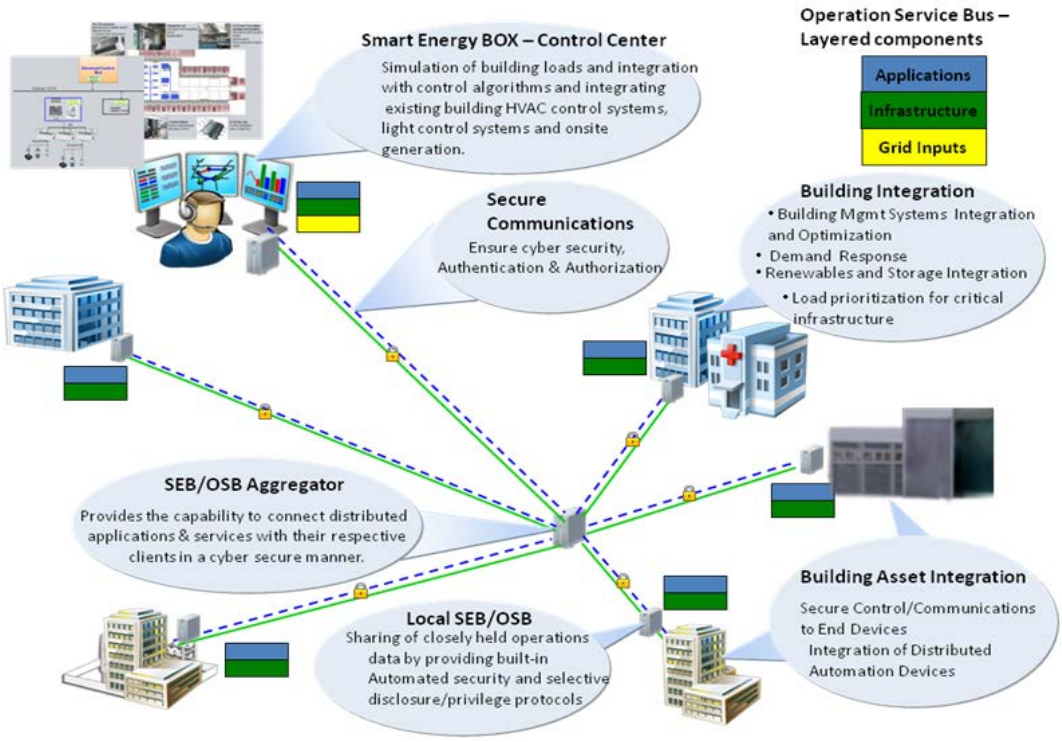


Figure 9: Conceptual OSB Integrated Architecture

2.2.7 Comparison to Existing Technology

Today's BASes provide building customers with various control strategies to satisfy energy demand and consumption targets and to meet building operation goals while maintaining comfort, life safety, security, and productivity of the building occupants, including economizer, scheduling, night setback, peak demand limiting, supply air/chilled water reset, and demand-based ventilation. As stated in the background section, the state-of-art building energy management strategies are limited in the following aspects:

- The buildings are operated in silos and the strategies listed above are also running individually while there is a lack of an integral view.

- Most of the strategies programmed are static without consideration of actual physical properties or building model, weather and occupancy changes.
- Some of the strategies work well in terms of EE, but are not cost-effective, e.g., demand-based ventilation requiring CO_2 sensor installation and yearly maintenance.
- No dynamic load management in response to a microgrid's price-sensitive operations.
- No plug-load control capabilities to improve EE.
- Lack of holistic control among different loads and energy resources
- Lack of direct control over the distributed loads

As described in section 2.1, the main advantage of the iBEMS technology compared with existing technologies is that it provides integrated demand management optimization algorithms based on weather and occupancy forecasts for building clusters. In addition, the iBEMS:

- Has a scalable, component-based architecture that enables various configurations for different applications.
- Has a central data repository for data exchange among runtime components and services.
- Provides an open architecture for extensibility with custom 3rd party runtime services.
- Is capable to accommodate a variety of communication protocols for communication with BASes and DR programs.
- Provides real-time building control for central loads, distributed loads, and on-site energy resources.
- Provides and open ODATA restful web services to communicate with other runtime services in the network.
- Provides web-based HMI capabilities for energy management using stationary HMI systems as well as mobile devices such as tablets and mobile phones.

2.3 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

2.3.1 Performance Advantages

On top of state-of-the-art instantaneous building energy management strategies in response to a grid/microgrid request, iBEMS implements proactive energy management approach based on weather forecast and occupancy schedules. Building operation modes are not limited to the cooling/heating/swing seasons. Chilled water, supply air temperature, and duct static pressure can be further optimized based on the current weather and occupancy demand to achieve maximum mechanic system efficiency. Most importantly, zone minimum ventilation will be re-assessed and dynamic occupancy schedule are integrated into the system to eliminate energy waste. The overall EE improvement for an office building can reach 30 to 40%. Energy intensity can be dropped from ~100 to ~70 kBTU per square foot per year.

In addition, the iBEMS is capable of networking and managing unlimited number of facilities, executing energy management strategies for each individual building based on the building's energy demand. The iBEMS also supports simultaneous execution of EE one building and instantaneous DR for a subset of the buildings at the same time. This powerful approach provides flexibility in terms of what energy savings methods are appropriate for each individual building. Also, the mobile scheduler (a tablet pc) of the plug load control subsystem allows flexibility and simplicity in terms of scheduling and prioritizing the plug loads by occupants.

2.3.2 Cost Advantages

Since our solution is software based, the cost is much lower in comparison with hardware-based solutions. The cost of iBEMS mainly comes from engineering effort during the commissioning phase. After commissioning, very little maintenance is required in contrast with hardware-based systems, e.g.CO_2 sensor-based ventilation control requiring yearly calibration of CO_2 sensors. The integration of iBEMS with BAS is very cost effective. There are no hard dependencies on any of the existing BAS components. The communication with BAS system is implemented via open protocol such as BACnet or Modbus and provides a loosely coupled interface via communication client service that is explicitly configured for the SEB. In essence, the iBEMS is designed to discover and command values for existing BAS control points only, without modifying or optimizing the internal BAS architecture. In addition, the advanced web HMI provides enhanced visualization enabling iBEMS operators to monitor and command control building energy usage with flexibility in terms of HMI device selection and physical location. Also, the simple, intuitive WEB UI requires very little training to operate. Furthermore, the scalability of the system allows it to coordinate DR among all buildings to achieve greater load reduction and participation in utility incentive offerings.

Secure communication leveraging the OSB will also support scalability and wider distribution in a cost effective manner. With the onetime non-recurring engineering of integration with iBEMS complete, expanding the system would incur minimal cost for the OSB element. Increasing the size of the existing system and / or deploying the system into other facilities should only require software installation and configuration for the specifics of that ICS. Expanding at the USAFA would require a simple update of the configuration files and testing that the changes worked. Time required to do this kind of update would be in the order of days.

2.3.3 Performance Limitations

For EE improvement, the performance is mainly limited by the availability of occupancy forecast information. Due to network security concerns, iBEMS cannot retrieve zone/office occupancy information directly from an enterprise system such as Microsoft Outlook Calendar. Instead, iBEMS comes with an HMI with which building operators can set the weekly schedules of individual zones. The static schedule file is used by iBEMS to apply occupancy-based control. Hence, the performance improvement heavily depends on the active engagement of the building operator and the availability of schedule information on each zone.

Besides the availability of accurate occupancy information, iBEMS EE control also depends on the actual controllable assets in the field. The demonstration site did not permit iBEMS to control site's lighting, mechanical cooling (chiller) and plug loads. These posed constraints to EE and DR strategy design. Even though the iBEMS is capable of controlling central lighting, the

facility management prohibited the iBEMS to do so. That, in turn had drastically affected overall energy savings results of the demonstration and inability to fully test iBEMS control logic of the central lighting system.

For demand management performance, iBEMS is limited by the acceptance of the dynamic generated strategies from the building operators and occupants because of the possibility of building utility function loss. The same concerns exist for plug-load control where the least impact is expected on occupant's daily work. In this demonstration the iBEMS experienced the constraints of controllability of some of the important loads.

The security constraints at USAFA disallow iBEMS from the direct access to public networks, such as public NOAA web service for weather forecasting. This limited the ability to fully test the real-time weather based strategies provided by the iBEMS. Instead, the iBEMS was using a file-based approach by importing the forecast into the system via statically generated file.

The iBEMS support for notification and diagnosis of BAS failures is limited. There are no real time alarms that are currently handled by iBEMS. The iBEMS system logging and trend data logging are the only way to analyze and identify failures of points commanding or communication with BAS.

2.3.4 Cost Limitations

The main cost of iBEMS comes from the engineering effort during the commissioning phase. Also iBEMS requires an initial effort to develop building energy models that are used during the runtime phase for detailed energy control, demand management strategy generation, and online energy optimization. Developing detailed models, in software like EnergyPlus, can be time consuming and is heavily dependent on building information availability and meter data for calibration. However, once the building model is established, it benefits the whole building life cycle for energy management, control, and monitoring.

There is no automatic point discovery functionality in iBEMS. The development of the control point lists is manual and requires a lot communication effort with BAS service team. This is a cost-ineffective, lengthy procedure that can be optimized.

The absence of the real-time failure notification mechanism in iBEMS constrains user from quickly troubleshooting the issues, especially during building's EE operation. To analyze the trended or logging data is time consuming.

2.3.5 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 benefits of the advanced energy management system. For regular commercial buildings, iBEMS already provides a social network platform to boost the collaboration among building occupants,

building operators, and BASes; however, social network platforms cannot be deployed on DOD sites owing to network security concerns.

Instead, we used different approaches with iBEMS designs to acquire end-user acceptance of the system deployment. We actively collected special requirements from the installation site and converted the fully automatic iBEMS controls into man-in-the-middle controls. Whenever there is an intelligent load reduction decision made by iBEMS, it requires confirmation from building operators before commands are sent to the BASes. The HMI is customized with complete transparency to the operators and occupants with displays of the potential impact of each optimized control sequence. In addition, the building operator and occupants can opt out of the iBEMS controls anytime during the operation.

During the demonstration, the active engagement in energy conservation from both the facility management team and the occupant was observed. This specifically addresses DOD Strategic Sustainability Performance Plan, Energy Security MOU with DOE-Goal 7: Sustainability Practices Become the Norm.

3.0 PERFORMANCE OBJECTIVES

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

Energy Security: The system we are demonstrating is the precursor of microgrid controls that will have islanding capability. Future versions of the SEBs, operating in the secure environment of the OSB, will provide autonomous control of on-site generation, load curtailment, peak load shifting, and energy storage at the microgrid level. The technology demonstrated in this work will allow U.S. based military installations to run their microgrids in island mode if DOD desires.

Cost Avoidance: With the performance objectives of up to 40% energy usage reduction at AH and up to 30% demand reduction at AH, MH and the CC, the team will determine the cost avoidance from energy savings and electric 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 reductions.

3.1 SUMMARY OF PERFORMANCE OBJECTIVES

Investigators collected data before and during iBEMS operation to evaluate the technical and financial objectives of the demonstration. These objectives are summarized below in **Table 4**.

Table 4: 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 Arnold Hall (2009 to 2011). 2. kW interval meter readings. 3. Equipment trend data recorded by the BASes. 4. BTU savings will be 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 Arnold Hall.
Facility peak demand reduction	Peak demand (kW)	1. Interval meter readings (every 15 minutes or less) of load peaks. 2. Response time to	15% to 30% reduction in aggregated peak demand for four selected buildings. Improvement in dynamic

		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 Mitchell Hall and the Community Center.	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 Arnold Hall and DR events at Arnold Hall, Mitchell Hall, the Community Center, and Vandenberg Hall.	20% GHG emission reduction
System Economics[2*]	• 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 vs. actual unauthorized access. • Successful vs. 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.	Provides reliable and secure communication to connect various Siemens SEBs, Energy Gateways, web services, web browsers, and Windows Communication Foundation clients distributed over the building automation network (BAN).

[2] 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

			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	Energy manager/building operator survey on the usability of iBEMS. We will ask: 1. Whether 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

	enabled. • Microgrid peak load shifting enabled.		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.

3.2 PERFORMANCE OBJECTIVES DESCRIPTIONS

3.2.1 Building Energy Efficiency Optimization

AH is selected for the EE demonstration. The building has very dynamic occupancy and a lot of energy is wasted on unoccupied space. This type of building will reap the greatest benefit through the fusion of information technology with building automation.

Purpose: Optimized building EE will reduce energy consumption and demand, thereby reducing the site's vulnerability to power grid disruptions. The performance target is to achieve up to 40% energy saving by demonstrating an advanced, integrated control for building cooling/heating, lighting, ventilation, and plug-load management on the site. The goal is to meet this energy savings target while still provide a healthy, productive, and comfortable environment for the building occupants with reduced operating and equipment costs for the building owners.

Metric: The metric is reported in electricity and gas usage of the building (kWh, therms, or MBTU).

Data: Data collected from the building's energy baseline (including meter readings of energy used by installation and/or utility consumption recorded by BASes) will be required to perform the analysis for optimized building energy efficiency.

Analytical Methodology: The iBEMS has an advanced and integrated optimization control strategy to determine the best control to maximize building EE and load-shaping capability. The building modeling will be performed in EnergyPlus software and the output data will be integrated into the control algorithms of the Siemens' SEB. Certain control signals will be developed to achieve maximal EE. The results of actual savings resulting from few days of EE strategies implementation at USAFA site can be extrapolated to a year using EnergyPlus model and statistical approach in order to estimate the annual EE savings for AH.

Success Criteria: 20%-40% EE improvement. The percentage improvement of the proposed design is calculated with the following formula:

Percentage improvement = 100 x (Baseline building performance – Proposed building performance)/ (Baseline building performance)

3.2.2 Facility Peak Demand Reduction

Three buildings on the USAFA campus were analyzed and tested for DR potential. The buildings synchronized with each other on the level of energy use during demand response period to avoid high peak load.

Purpose: The purpose is to enable the aggregation of buildings to achieve at least 30 % of peak load shedding capability and to respond to the grid/microgrid through the integrated intelligent building control system. Implementing DR strategies promotes energy savings, increases operational control of the building systems, and improves power system reliability.

Metric: The metric used to measure demand reduction is the measurement of power demand on the site (kW) at a pre-defined period of time.

Data: The data required to conduct the DR analysis consists of 15-minute interval meter readings of electricity, cooling, and heating energy used in the building as well as lighting and mechanical systems' rated electrical load recorded by onsite BASes.

Analytical Methodology: The iBEMS enables integrated operation of individually controlled building subsystems. The building modeling for AH was performed in EnergyPlus software to determine baseline. Baselines for MH and CC were determined through a new weather-forecast based approach. Several DR events were then conducted to estimate the average DR savings.

Success Criteria: 15-30% of demand reduction. Quantified demand savings (kW) representing selected load profiles for the building during a certain peak demand period (i.e., total building load, mechanical fans, and chiller). Analysis of combined load profiles of the three buildings showed variation in both the peak load values as well as peak load times. This was due to random nature of certain loads in AH and MH. This made the accurate determination or prediction of peak load for a given time period very difficult. To address this, the success criterion was adjusted from 10-30% peak load reduction to 10-30% reduction of the pre-DR combined load of all three buildings.

3.2.3 Direct GHG Emissions

Carbon dioxide emissions from electricity consumption on-site at the building facilities and from natural gas consumption at the Central Boiler Plant were calculated to determine the GHG reductions that can be attributed to the demonstration.

Purpose: The concentrations of GHG emissions in the atmosphere are increasing due to human activity, causing serious climate changes that are degrading the environment and natural resources across the globe. If optimizing building EE and reducing facility demand are achieved, a reduction of GHG emissions will result.

Metric: Emissions are reported in metric tons of carbon-dioxide equivalents (CO_2e).

Data: Measured or estimated reduction of GHG emissions are based on emission factors that take into account the fuel mix of electricity in Colorado region, and are also based on standard emission factors for natural gas. To quantify the emissions from these sources, data was collected from the Academy's building energy baseline (including electric meter readings and trend data recorded by the onsite Apogee BAS); this data formed the baseline for GHG emissions. The U.S. EPA publishes a database called "eGrid" that displays the GHG's emitted by electricity generation by geographic region and allows customers to see emission profiles for their region. The team employed this database and standard emission factors for natural gas to determine the GHG baseline and the GHG reductions for the Air Force Academy demonstration.

Analytical Methodology: The methodology for determining savings involved development of EnergyPlus models and extrapolating performance results to other campus buildings, which is described in greater detail in the next section and in the report. The analytical methodology for determining CO_2 equivalent emissions involved applying emission factors to the electricity and natural gas savings. Using the emission factors, GHG emissions were calculated for CO_2, CH_4, and N_2O and these three GHGs were then normalized to CO_2e using standard Global Warming Potentials. The same methodology is used to calculate GHG emissions from baseline levels of electricity and natural gas consumption, and the GHG savings are compared against the baseline GHG emissions to determine if the reduction target was achieved.

Success Criteria: 20% reduction of GHG emission from energy consumption reduction.

3.2.4 System Economics

It is estimated that DOD spends ~$4 billion annually on energy-related costs for its facilities. iBEMS is an approach that will apply intelligent operational strategies to save electricity and fuel consumption. Cost of equipment, installation, training, operating, and maintaining iBEMS must meet the payback criteria of the DOD to move from demonstration status to implementation at multiple sites.

Purpose: If investment in iBEMS outweighs the savings benefits, then the technology and strategy will not be adopted by the DOD.

Metric: MBTU/kWh and MBTU/kW saved and converted into cost savings; return on investment.

Data: The data required to complete the analysis of the iBEMS will include calculated baseline and peak savings, utility/fuel costs, estimates of market-ready equipment, and estimates of installation, training, operational, and maintenance costs.

Analytical Methodology: In order to determine the impact of gas and electricity savings on a campus-wide scale, the savings from AH, derived from careful calibration of EnergyPlus models with metered electricity data and 10 year normalized weather data, were extrapolated to 13 other buildings on site. The team developed simple paybacks as

well as life-cycle costs based on NIST's *Life-Cycle Costing Manual for the Federal Energy Management Program.*

Success Criteria: iBEMS enables at least 15% energy cost savings with simple payback in 5 years based on the cost of implementation.

3.2.5 Security / Reliability

The iBEMS is designed to enable seamless and integrated operation of individually controlled building subsystems. The Boeing OSB is able to integrate new and legacy data systems into iBEMS through the application of translation services to a common data model. OSB, with its multi-tiered, distributed architecture provides scalability, interoperability, and high availability by pushing intelligence to the periphery of the network. Once the OSB is deployed, nodes can be added incrementally with configuration and other operational changes propagating automatically across the system. Consequently, communications, data flow, and decision-making bottlenecks are minimal resulting in a highly scalable and manageable system.

While the OSB enables a very reliable and scalable system, the need for security for the iBEMS is paramount. As a networked system that collects data outside of its own network, for example for DR and weather data, the system must be solidly protected from tampering and cyber-attacks. Addressing DOD's security protocols in this demonstration will enhance the attractiveness of iBEMS at other DOD installations and reduce barriers to implementation.

Purpose: The Boeing secure distributed OSB provides the capability to connect distributed applications and services with their respective clients in a cyber-secure manner. The OSB is a service-oriented architecture solution for direct or adapted utilization that provides flexibility of architectural choice for best-fit solutions when integrating existing applications, services, and systems. The OSB also provides protocol adaptation and data mediation services for communicating with devices and systems via energy industry standard communications protocols, such as DNP3 and Modbus.

- The OSB facilitates reliable communications over non-continuous networks in which host nodes may become unreachable due to disruptions to the physical aspects of the network, devices plugging into or out of the network, or cyber-attack of non-protected elements. This functionality, securely effecting communications in an ad-hoc, highly distributed network environment, gives the OSB a tactical networking capability that differentiates it from that of traditional enterprise solutions.
- The OSB communication functions provide a range of features to ensure cyber security. Authentication, authorization, role-based access control, protected transports, and encryption methods are selectively available to the range of communications styles.

Metric: To measure the level of reliability between iBEMS, OSB, and the existing infrastructure data communication between all system nodes in the iBEMS network will be assessed. To determine the degree of conflicts or synergies caused by interaction with

other systems, data collection of successful, unsuccessful, and attempted communication transactions for all communication nodes within the iBEMS network will be recorded.

Security metrics will be used to discern the effectiveness of various components of the iBEMS security system to identify the level of risk and provide guidance in prioritizing corrective actions. Metrics such as detect and alert for attempts vs. actual unauthorized accesses, average number of vulnerabilities detected, change in number of vulnerabilities, and detected virus alerts issued are used to assess the security system for the iBEMS network.

Data: Reliability data will be focused on the number of successful and unsuccessful communication attempts during operation of the system. This data will be gathered through testing and system operations with and without the OSB operational. Latency data will also be collected throughout the test and demonstration process.

Security data will target the number and type of intrusion attempts during the demonstration and test are recorded and used to assess the iBEMS security system.

Analytical Methodology: OSB has the capability of recording and reporting interactions between the subsystems within the iBEMS network to ensure translation of the interface into another interface. The OSB can also generate logs in sufficient detail to create historical audit trails of individual user account access activities. The system will also support automated tools and processes to monitor system events related to cyber security. OSB will initiate granting access to critical cyber assets. Critical cyber assets will be defined within the iBEMS network.

Success Criteria: The success criteria for OSB will be to provide the capability to securely connect various SEB web services, web browsers, and Windows Communication Foundation clients that are distributed over the BAN. Along with reliable connectivity, it is important the system will ensure cyber security by providing security monitoring processes that detect and alert attempts and/or actual unauthorized accesses and, where feasible, provide appropriate notification to designated response entities.

3.2.7 Occupant Behavior/ Comfort (Qualitative)

Occupant behavior is the interaction between occupants and systems in the building in terms of controlling the energy demand and consumption of an entire facility and its individual components.

Purpose: Occupant behavior has a significant impact on building energy use. Meeting the thermal and visual comfort needs of the building occupants is what drives the design of the building envelope, lighting, and mechanical and process systems. If the EE and DR events do not change behavior in terms of causing occupants to call the EMCS staff to complain, then the team has found strategies that, if anything, have a neutral effect on occupant behavior.

Metric: To determine occupant behavior at other facilities in the demonstration we interviewed the EMCS staff to determine whether they had a higher frequency of complaint calls during EE and DR events. We also spoke to facility managers for each building to determine whether they detected any discomfort among occupants or they, themselves, had experienced discomfort.

Data: Interviews with EMCS staff and facility managers.

Analytical Methodology: The team asked the facility staff to record complaint calls on demonstration buildings for a period equal to the demonstration period prior to the start of the demonstrations. For DR, the period may be the day of or potentially the day before the demonstration. We then asked staff to count complaint calls and share the content of the calls during the demonstration period.

Success Criteria: If EMCS staff reports as many or fewer complaints than during the baseline period, and the content of the complaints is not about occupant comfort or not solely about comfort then success will have been achieved for this category.

3.2.8 System Integration

For this demonstration, our hypothesis was that the iBEMS will provide an improved microgrid/campus energy management system for facility management with:

- Enhanced transparency of microgrid energy usage, peak load monitoring, and clear breakdowns at building, subsystem, and zone levels.
- Synchronization of energy use among buildings preventing big peaks and thereby reducing demand charges.
- Microgrid DR enabled.
- Microgrid peak load shifting enabled.

Purpose: The purpose of this performance objective is to validate the hypothesis.

Metric: Acceptance level of iBEMS.

Data: Energy manager/building operator survey on the usability of iBEMS. We will ask:

- Whether energy managers understand and benefit from microgrid/building energy performance view.
- How user-friendly and understandable the iBEMS is to run.
- How user-friendly and understandable the HMI is for plug-load controls.

Analytical Methodology: N/A.

Success Criteria: This demonstration will be successful if

- Energy managers find the system easy to use.
- Energy managers express desire to continue to use and/or expand use of system on USAFA campus).
- Energy managers find the system flexible and accessible for demand management activities.
- Facility manager can control the building load or aggregated building load in day-ahead and instant mode.
  - System is able to provide instant load shedding.
  - System can shape loads to be price responsive.

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 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 7,258 feet above sea level, while the highest altitude of the nearby Rampart Range Mountains is 9,632 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.

A brief survey of the USAFA site and the preliminary energy audit conducted earlier in this demonstration indicate several energy, cost, and water savings opportunities. In particular, the following situations were identified:

- For all the buildings, the heating, ventilation, and air conditioning (HVAC), lighting system, and other load controls are run independently from each other. None of the buildings is operated under consideration of the occupancy dynamics, and the BASes are running on a separate network without access to weather forecast service data. Hence, no predictive thermal/ventilation control is possible.
- There is a separate interval meter system installed at the site to record building load profiles; however, the information is not used for building operation. Some USAFA utility bills (**Figure 10**) show that up to 46% of electricity costs come from demand charges, but peak load control is not part of the existing energy management system.

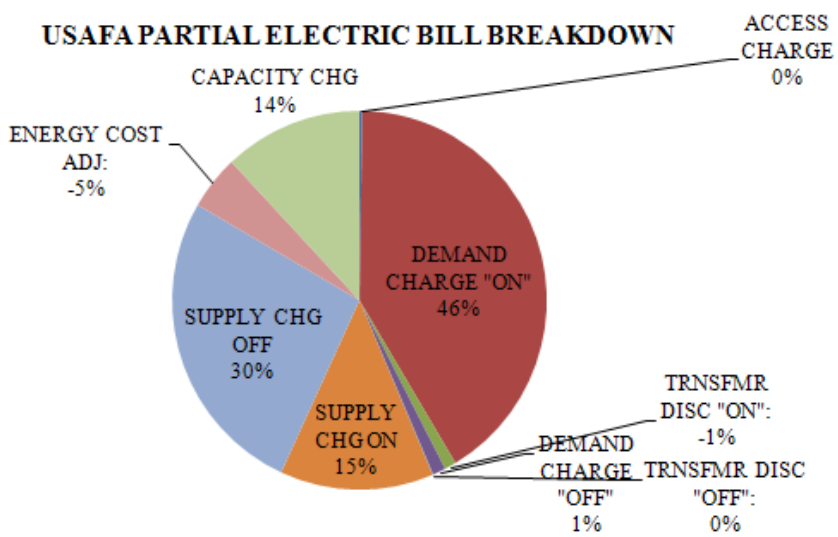


Figure 10: Typical USAFA Electricity Bill Breakdown

- HVAC systems operate on static schedules in open loops; occupancy plays little to no role in guiding building operations. Comfort complaints are dealt with sporadically, while

overheating and overcooling are not monitored. For example, in one of the buildings, the chillers and air handler units (AHUs) run continuously 24 hours-a-day even though the building is not occupied from 11:00 p.m. to 6:00 a.m.

- There is lack of transparency in how energy is used beyond total energy consumption and capacity. No tools are available that allow the campus BAS operators to visualize the real-time energy usage breakdown within and among buildings. These sources of energy include electricity, hot water, and chilled water.
- Plug loads are neither monitored nor controlled for office buildings and dormitories.

4.1 FACILITY/SITE LOCATION AND OPERATIONS

The map below shows the main part of the campus - the Cadet Area, centered on a square quadrant area called The Terrazzo. Mitchell Hall (AH) is located on the Terrazzo, and Arnold Hall (AH) is located just off the Terrazzo. Vandenberg Hall was selected for plug load demonstration but its use was limited to only the EMCS control room due to the network constraints. All the SEBs are also co-located in the EMCS control rooms. The Community Center (CC) which was also part of the demonstration is not co-located at the Terrazzo. The buildings will be described in more detail later in this section.

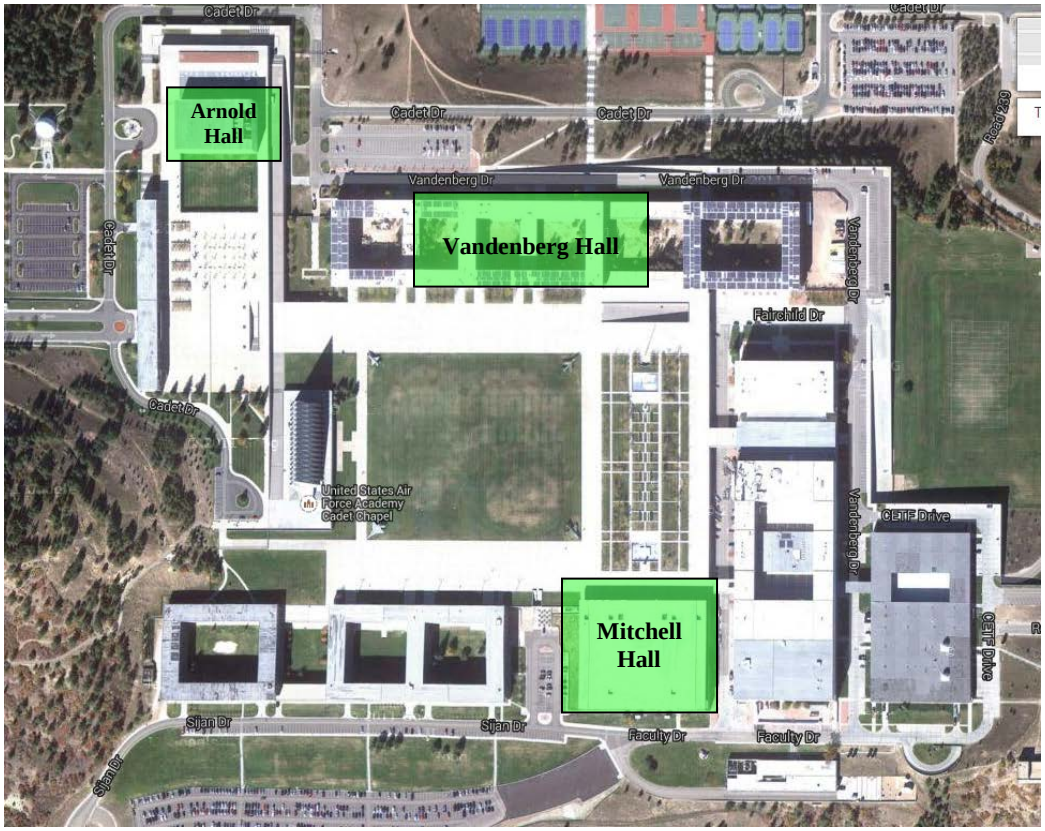


Figure 11: Location of Arnold and MHs

4.1.1 Arnold Hall

Arnold Hall, 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. Specifics 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[3]. An abbreviated schedule is provided below, in **Table 5**, and a more detailed schedule of occupancy is included in the appendix B.

Table 5: Specific Schedule at AH

Operational Timeframe	Location
0600 – 2300 (Mon – Fri)	AH
0900 - 2300 (Sat- Sun)	AH

There are three mechanical rooms in AH located in the west, north and theater areas. All HVAC controllers are connected to the base-wide BAS. 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. 13 supply fans[4] provide forced air heating and cooling while 25 exhaust and return fans provide fresh air and pressure balance for the building. All mechanical systems are controlled and monitored by the Academy-wide BAS.

Electrical Energy Use

Based on AH sub metered data available between October of 2008 and June of 2012, the average annual electrical energy use[5] at AH sums to 2,492 MWh with a monthly breakdown as shown in **Figure 12**[6].

[3] Sain Engineering Associates, Inc.; *Pre-Final Submittal – Energy & Renewable Project Development – United States Air Force Academy*. (2009). Birmingham, Alabama.
[4] AHU-4 & AHU-5 were recently removed from the facility.
[5] At this time a breakdown of the hot water use from the central plant for local space heating is not available and under further investigation (all buildings).
[6] Energy use values taken from "USAFA-EnergySmartBox-ElectricalConsumption.xslx" spreadsheet (all buildings) from USAFA's Civil Engineering group.

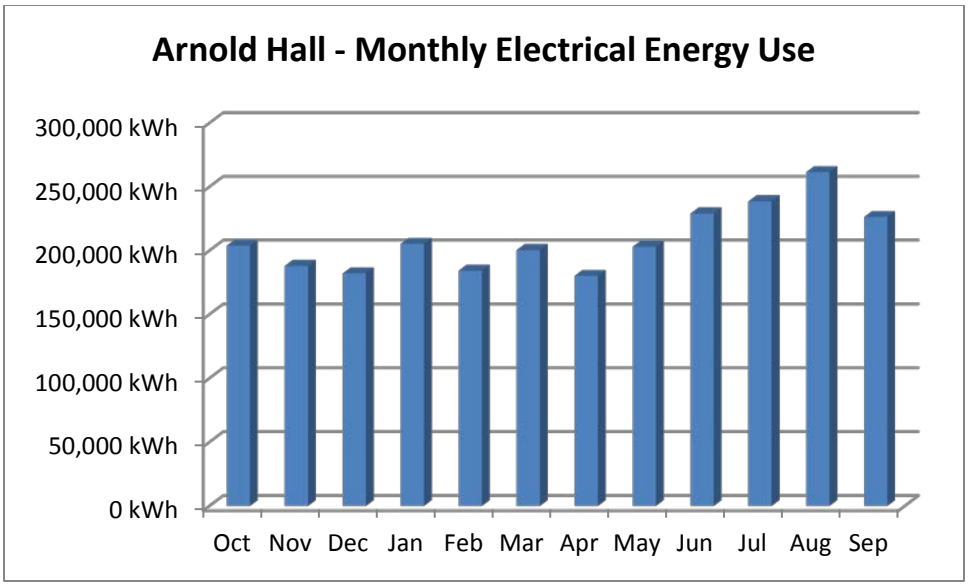


Figure 12: Monthly Electrical Energy Use at AH

Alternatively, the annual electrical energy use can be illustrated broken down per building end use category[7], as shown below in **Figure 13**.

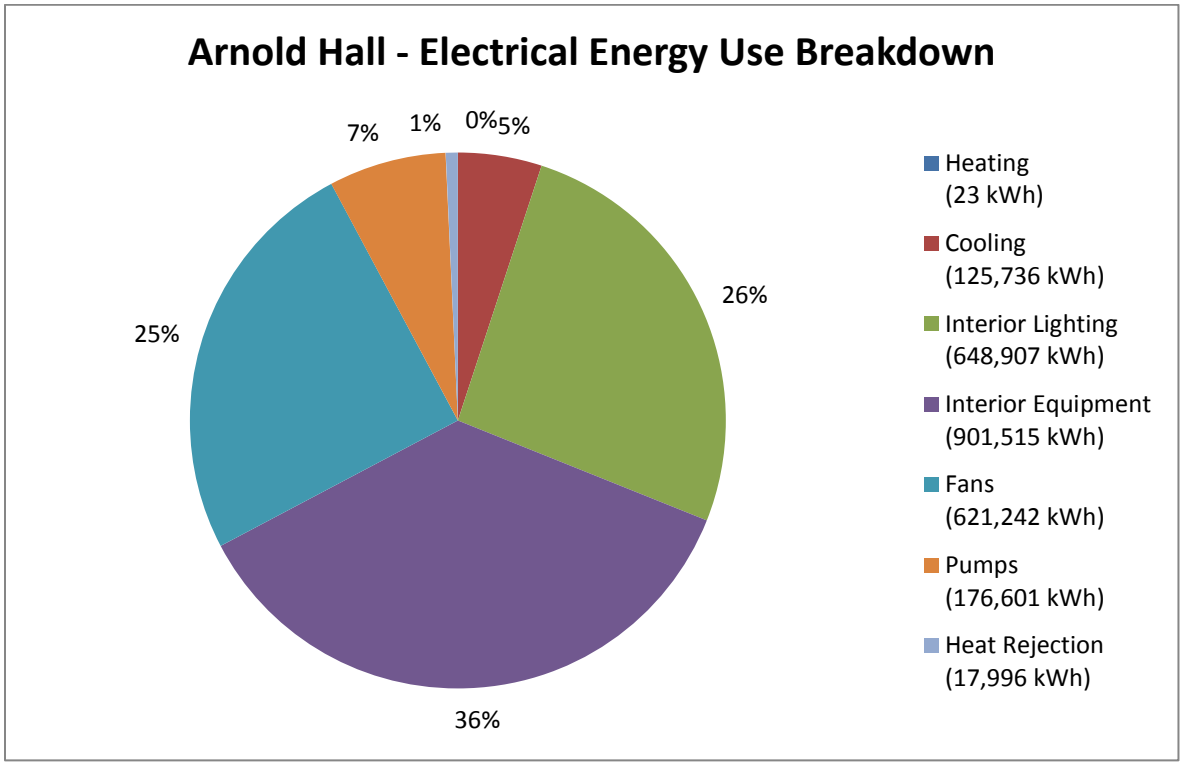


Figure 13: AH - Electrical Energy Use Breakdown

[7] End use breakdowns calculated as per calibrated EnergyPlus model results (Arnold Hall & Community Center).

Of these end uses, only the HVAC end uses are considered controllable for the purpose of testing as the interior lighting, process and plug loads are not controlled by the BAS system. Removing the non-controllable end uses, it can be calculated that 37.8% of the building's electrical energy use can be controlled, accounting for 942 MWh of electrical energy use annually. A breakdown of the controllable end uses, as a percentage of total controllable end uses, is characterized in **Figure 14**.

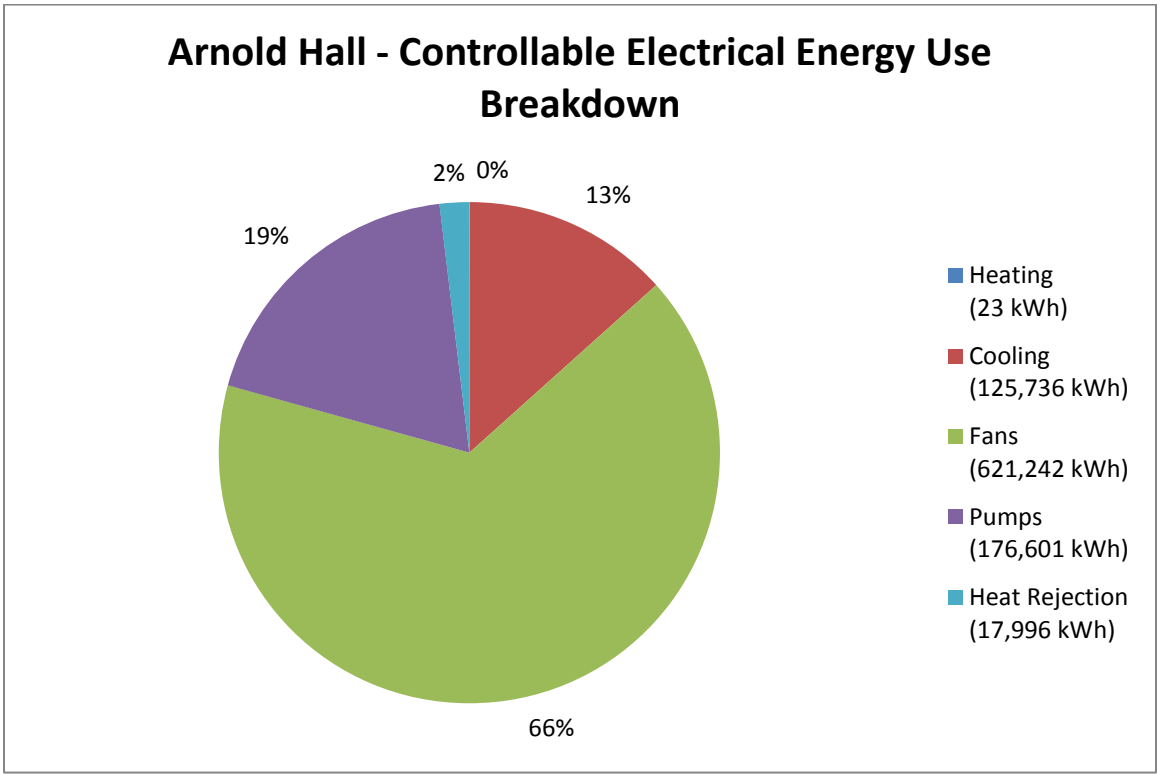


Figure 14: AH - Controllable Electrical Energy Use Breakdown

Regarding the installed controllable equipment, the Appendix B provides a listing of HVAC equipment and its rated power based on a preliminary site audit. Based on the demand listed in the AH equipment table and the assumed load curtailment potentials, a maximum instantaneous controllable electrical load for the facility can be calculated as 589 kW with a possible instantaneous flexible load of 104 kW, resulting in an average instantaneous flexible load of 18%.

The remaining end uses are all non-controllable, including the interior lighting, process and plug loads. These end uses account for approximately 62.2% of the total electrical load, or 1,550 MWh of annual electrical energy use. As the non-controllable loads are based on non-weather dependent occupant usage patterns, it is assumed that these non-controllable end uses do not vary per season. In contrast, all the controllable loads are the HVAC loads, and vary by season due to weather influences. The following chart, in **Figure 15**, identifies the controllable and non-controllable end uses per month.

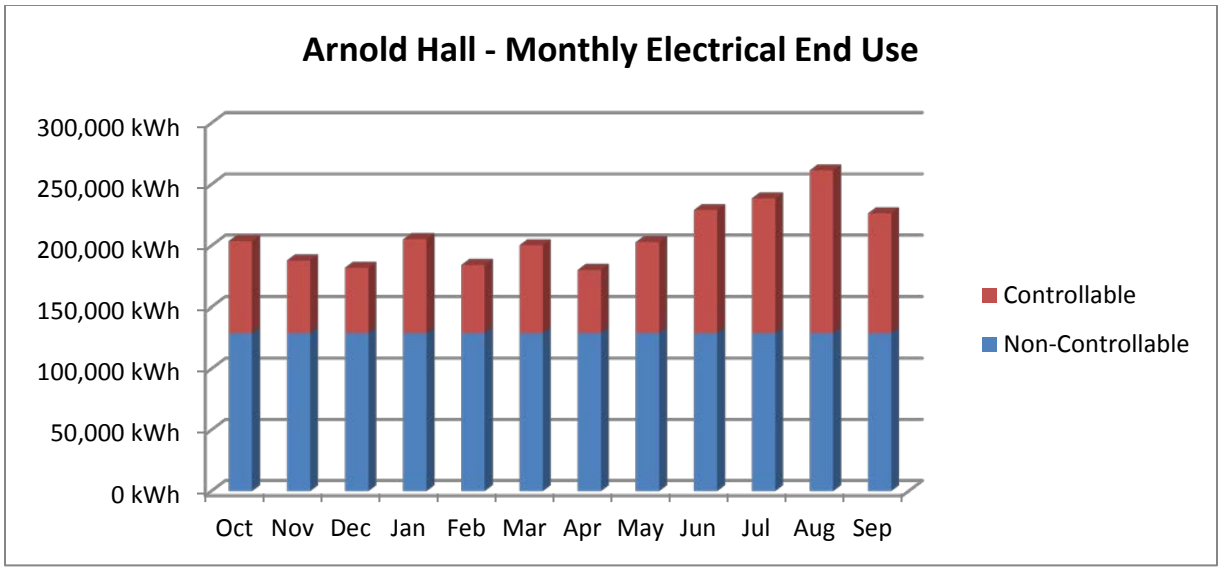


Figure 15: AH - Monthly Electrical Energy Use Breakdown for Controllable and Non-Controllable Loads

Natural Gas Energy Use

All space and domestic hot water heating is provided to AH as HTHW from the campus' central HTHW Boiler Plant. This HTHW is then downgraded through heat exchangers to provide the medium temperature hot water needs of the facility. Although the exact distribution of HTHW to each of the building's in the Academic Area of the campus is not available, it has been estimated that 3.8% of the HTHW delivered to the Academic Area is used by AH. Based on 2009 data[8], the HTHW plant is calculated to operate at a total efficiency of 63.2% considering equipment efficiencies and plant equipment. Further, although there is generally negligible loss associated with distribution of natural gas, as this system is based on the distribution of HTHW; approximately 5.2% of the total heating energy distributed to the Academic Area is lost through piping heating losses. In general terms, for every MBTU of heating energy that is needed at AH, the HTHW Boiler Plant needs to consume 1.7 MBTU of natural gas.

For Fiscal Year 2011, it is calculated that AH had a combined domestic hot water and space heating load of 7,412 MBTU and caused the HTHW Boiler Plant to consume 12,371 MBTU of natural gas. The following graph, in **Figure 16**, illustrates the monthly gas heating energy use for Fiscal Year 2011 based on the information noted above.

[8] Source: "USAFABuildingEnergyUsage2009.xls"

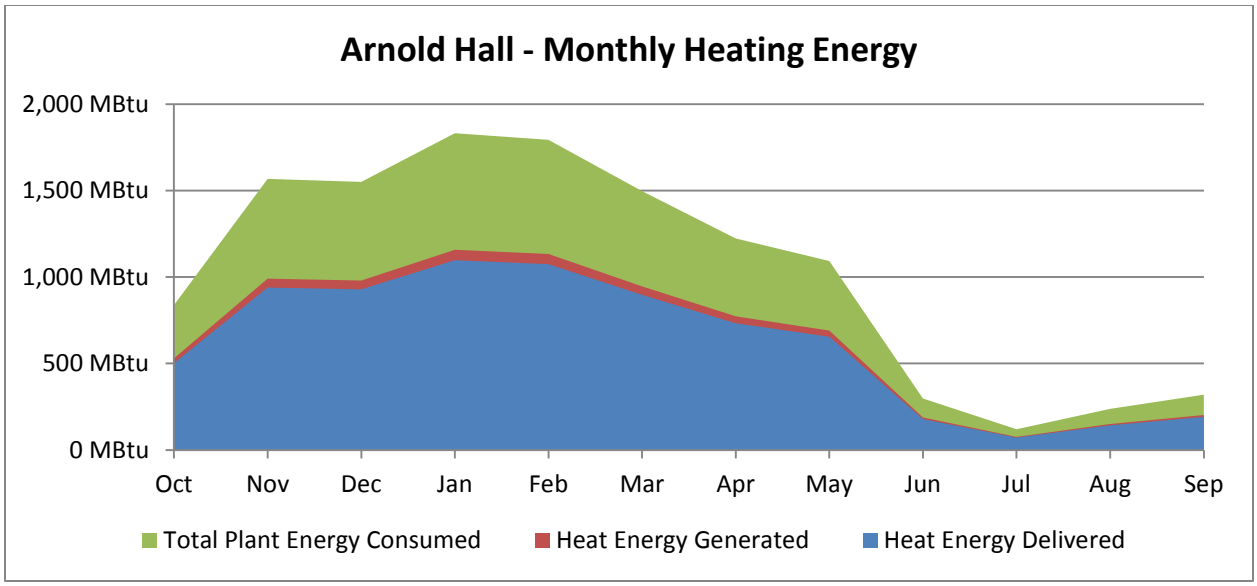


Figure 16: AH - Monthly Heating Energy for FY11

Occupancy Summary

Occupancy behavior is a source of a lot of uncertainty in energy modeling. Variation in this single parameter alone can significantly impact model results. As AH is the social center of the Academy that consists of a theater, ballroom, various game rooms, lounges and conference rooms, the occupancy fluctuates quite substantially on a daily basis. Apart from the office areas, the rest of the spaces in the building do not have a set occupancy schedule. There are seven formal dances held in the ballroom annually and twelve Broadway style shows at the theater. Aside from these scheduled events, the ballroom and theater spaces are used when needed for large gatherings, such as Air Force briefings, on a random basis. The conference and lounges are also used intermittently throughout the day. As a result, the energy profile of the building is unlike a typical commercial office building.

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 as given below in **Table 6**.

Table 6: Specific Schedule at MH

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

This 223,226 square foot facility houses the main dining facility and kitchen areas. The south side of the building at street level has receiving docks and freight elevators to deliver food and equipment to cold storage, freezers and various food processing and preparation areas. The dining and kitchen areas are located on the main floor at the Terrazzo level. Above the cooking area are two mechanical areas that supply heating, ventilation and exhaust for the facility.

The entire facility is heated by HTHW (@400°F) delivered from the central heating plant. The HTHW is converted in heat exchangers to hot water with 20% propylene glycol (MTPG@145°F) and circulated by variable volume pumps to ten air-handling units. All of the air-handling units are constant volume with direct evaporative cooling sections. Two of the large air-handling units serve the cadet east and west dining areas. There are 46 exhaust fans serving the kitchen, dining, toilets, warehouse, service lockers, staff tower and other areas. 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. All HVAC controllers are connected to the base-wide Apogee BAS.

Electrical Energy Use

Based on sub metered data for MH available between October of 2008 and June of 2012, the average annual electrical energy use[9] at MH sums to 3,603 MWh with a monthly breakdown as shown in **Figure 17**.

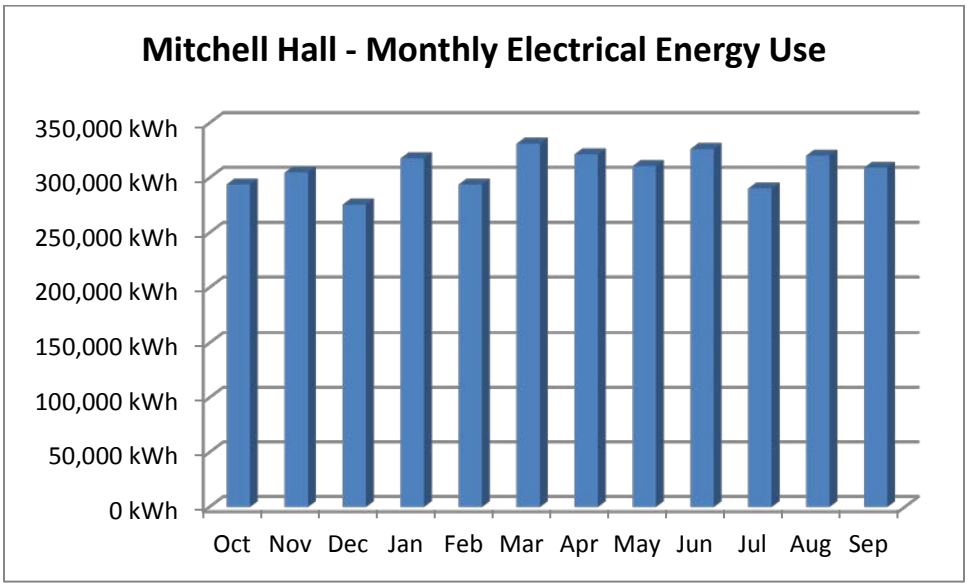


Figure 17: MH - Monthly Electrical Energy Use

Alternatively, the annual electrical energy use can be illustrated broken down per building end use category[10], as shown in **Figure 18**.

[9] At this time a breakdown of the hot water use from the central plant for local space heating is not available and under further investigation.

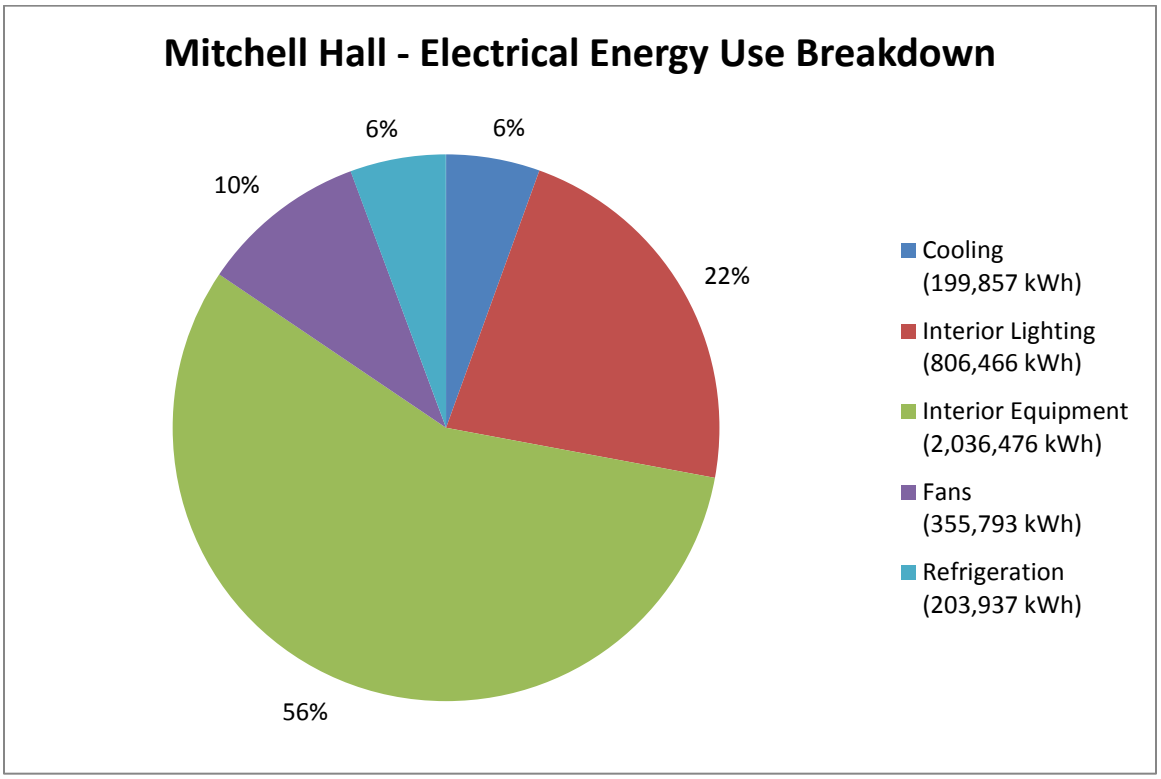


Figure 18: MH - Monthly Electrical Energy Use

Of these end uses, only the HVAC end uses are considered as controllable for the purpose of testing as the interior lighting process, and plug loads are not controlled by the BAS system. Removing the non-controllable end uses, it can be calculated that 15.4% of the building's electrical energy use can be controlled, accounting for 555.7 kWh of electrical energy use annually. A breakdown of the controllable end uses, as a percentage of total controllable end uses, is as shown in **Figure 19**.

Regarding the installed controllable equipment, the full table of controllable equipment and its rated power is provided in the appendix B. Based on the power ratings listed in the equipment table, a maximum instantaneous controllable electrical load for the facility can be calculated as 448 kW with a possible instantaneous flexible load of 189 kW, resulting in an average instantaneous flexible load of 24%.

[10] Energy breakdown by End Use for Mitchell Hall based on benchmark EnergyPlus file created by the U.S. DOE for a Full-Service Restaurant located in ASHRAE Climate Zone 5b (http://www1.eere.energy.gov/buildings/commercial/ref_buildings.html)

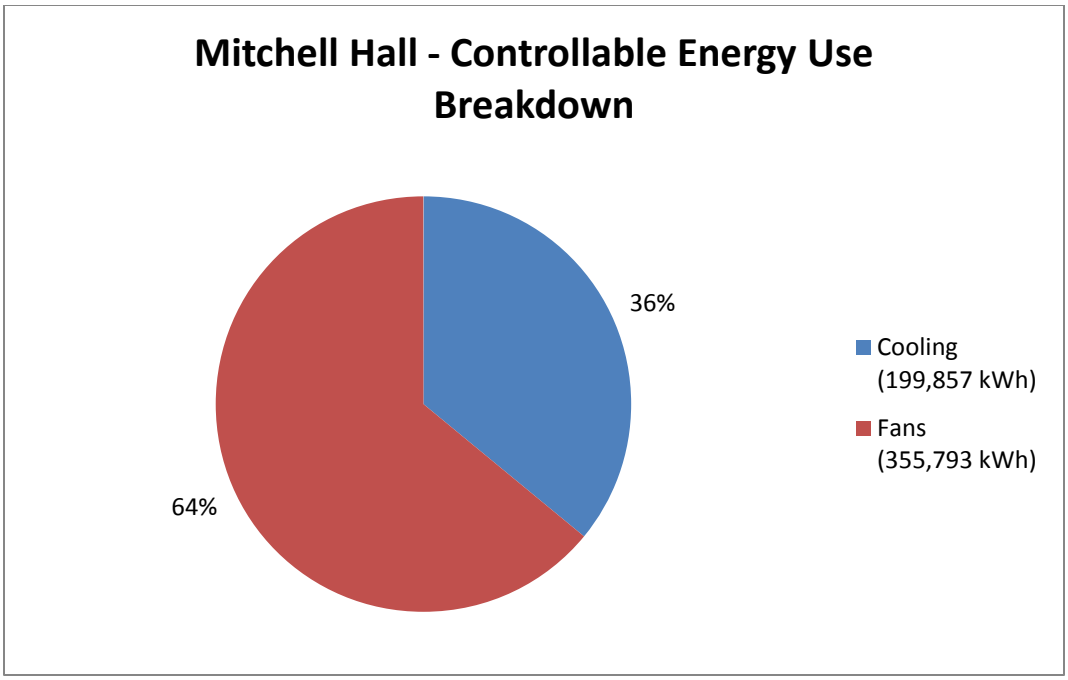


Figure 19: MH - Controllable Energy Use Breakdown

The remaining end uses are all non-controllable and include the interior lighting, process and plug loads. These end uses account for 84.6% of the total electrical load, or 3,047 MWh of annual electrical energy use. As the non-controllable loads are based on non-weather dependent occupant usage patterns, it is assumed that these non-controllable end uses do not vary per season. In contrast, all the controllable loads are the HVAC loads, and vary by season due to weather influences. The following chart, in **Figure 20**, identifies the controllable and non-controllable end uses per month.

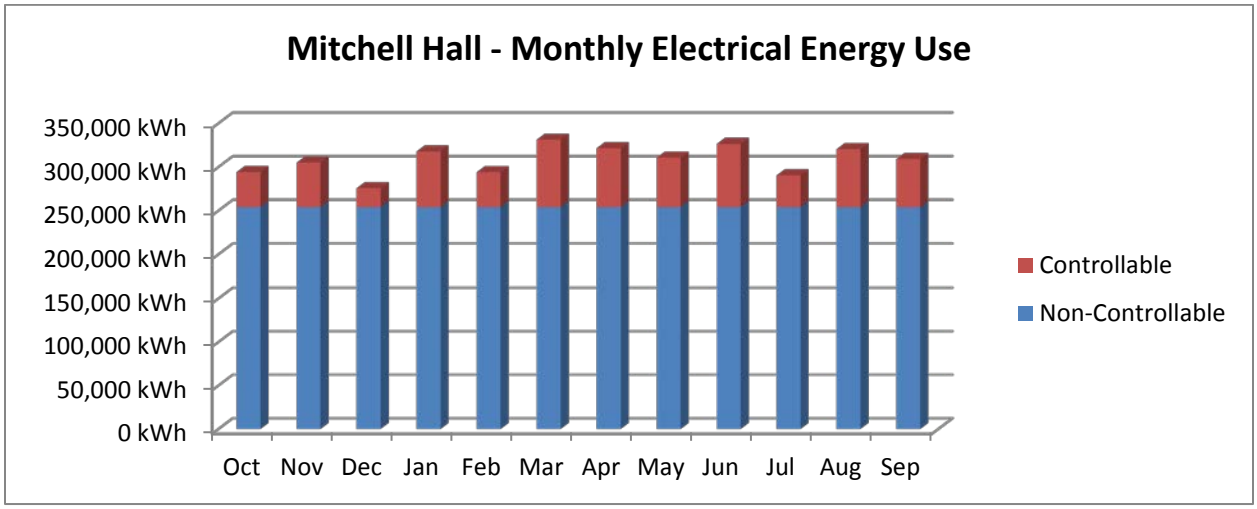


Figure 20: MH - Monthly Electrical Energy Use Breakdown for Controllable and Non-Controllable Loads

Natural Gas Energy Use

All space heating in MH is provided as HTHW from the campus' central HTHW Boiler Plant. This HTHW is then downgraded through heat exchangers to provide the lower temperature hot water needs of the facility. Although the exact distribution of HTHW to each of the building's in the Academic Area of the campus, it have been estimated that 4.0% of the HTHW delivered to the Academic Area is used by MH. Based on 2009 data[11], the HTHW plant is calculated to operate at a total efficiency of 63.2% considering equipment efficiencies and plant equipment. Further, although there is generally negligible loss associated with distribution of natural gas, as this system is based on the distribution of HTHW; approximately 5.2% of the total heating energy distributed to the Academic Area is lost through piping heating losses. In general terms, for every MBTU of heating energy that is needed at MH, the HTHW Boiler Plant needs to consume 1.7 MBTU of natural gas.

For Fiscal Year 2011, it is calculated that MH had a heating load of 7,802 MBTU and caused the HTHW Boiler Plant to consume 13,022 MBTU of natural gas. The following graph, in **Figure 21**, illustrates the monthly gas heating energy use for Fiscal Year 2011 based on the information noted above.

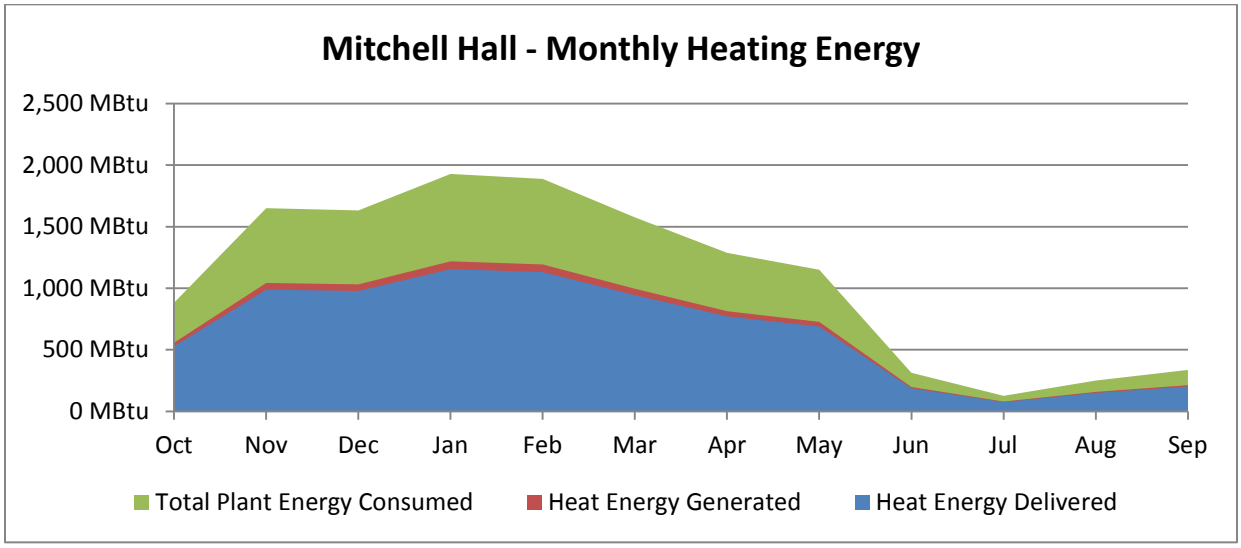


Figure 21: MH - Monthly Heating Energy

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 7**. For a detailed operational schedule for the CC, please see the appendix B.

[11] Source: "USAFABuildingEnergyUsage2009.xls" provided by USAFA's Civil Engineering group.

Table 7: Specific Schedule at CC

Operational Timeframe	Location
0730 – 1700 (Mon – Fri)[12]	Businesses, Military Offices, Government Offices
(Sat – Sun)	Hours vary greatly by business

The CC has 153,657 square feet of floor space. The facility has two stories with a utility tunnel at the lower level that encircles the building complex. Two maps showing the location of the CC are shown in **Figure 22** below.

Figure 22: Location of CC

The building heating is supplied to this facility by HTHW (@ 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[13]. The cooling tower for chiller condenser water is directly outside behind an enclosed brick wall and open roof addition. Chilled water and MTPG heated water are distributed to three mechanical rooms (A, B, and C) locate at the lower level tunnels.

Electrical Energy Use

Based on locally metered data available between October of 2008 and June of 2012, the average annual electrical energy use[14] at CC sums to 2,318 MWh with a monthly breakdown as shown in **Figure 23**.

[12] The operational schedule varies by business and office.
[13] Sain Engineering Associates, Inc.; *Pre-Final Submittal – Energy & Renewable Project Development – United States Air Force Academy*. (2009). Birmingham, Alabama.
[14] At this time a breakdown of the hot water use from the central plant for local space heating is not available and under further investigation.

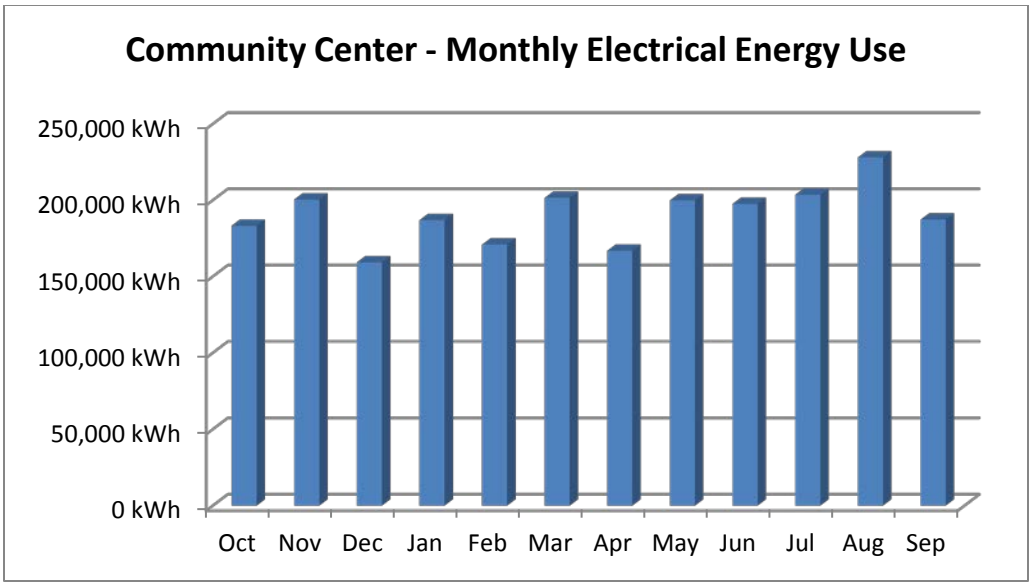


Figure 23: CC - Monthly Electrical Energy Use

Alternatively, the annual electrical energy use can be broken down per building end use category as illustrated below in **Figure 24**.

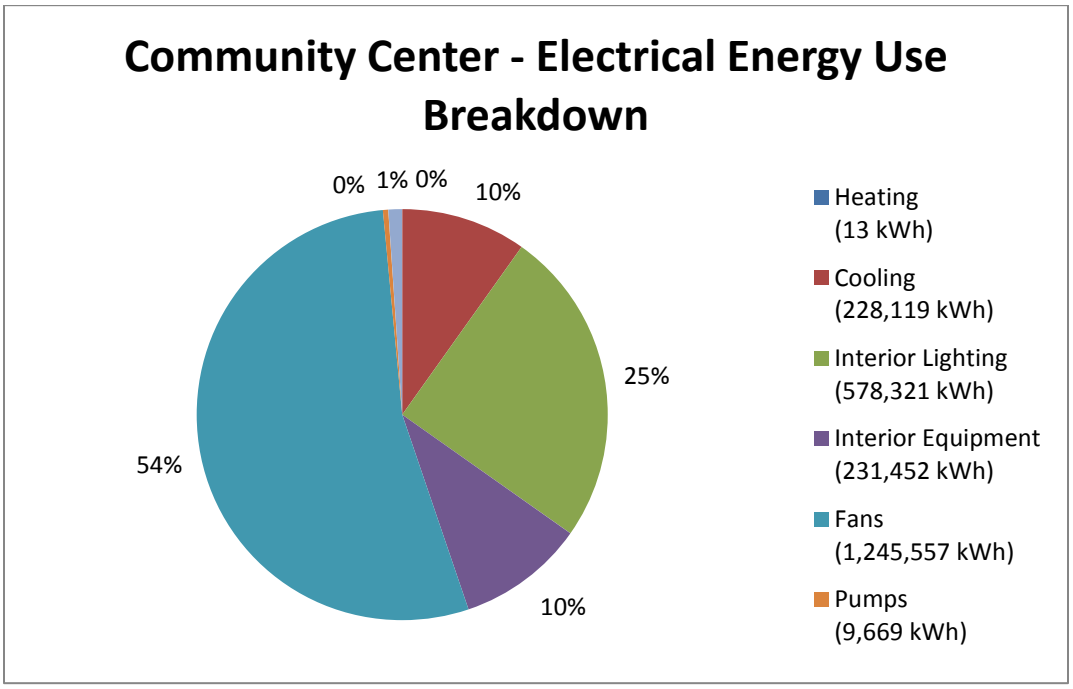


Figure 24: CC - Electrical Energy Use Breakdown

Of these end uses, only the HVAC end uses are considered as controllable for the purpose of testing as the interior lighting, process, and plug loads are not controlled by the BAS system. Removing the non-controllable end uses, it can be calculated that 65.1% of the building's electrical

energy use can be controlled, accounting for 1,509 MWh of electrical energy use annually. A breakdown of the controllable end uses, as a percentage of total controllable end uses, is as shown in **Figure 25** below.

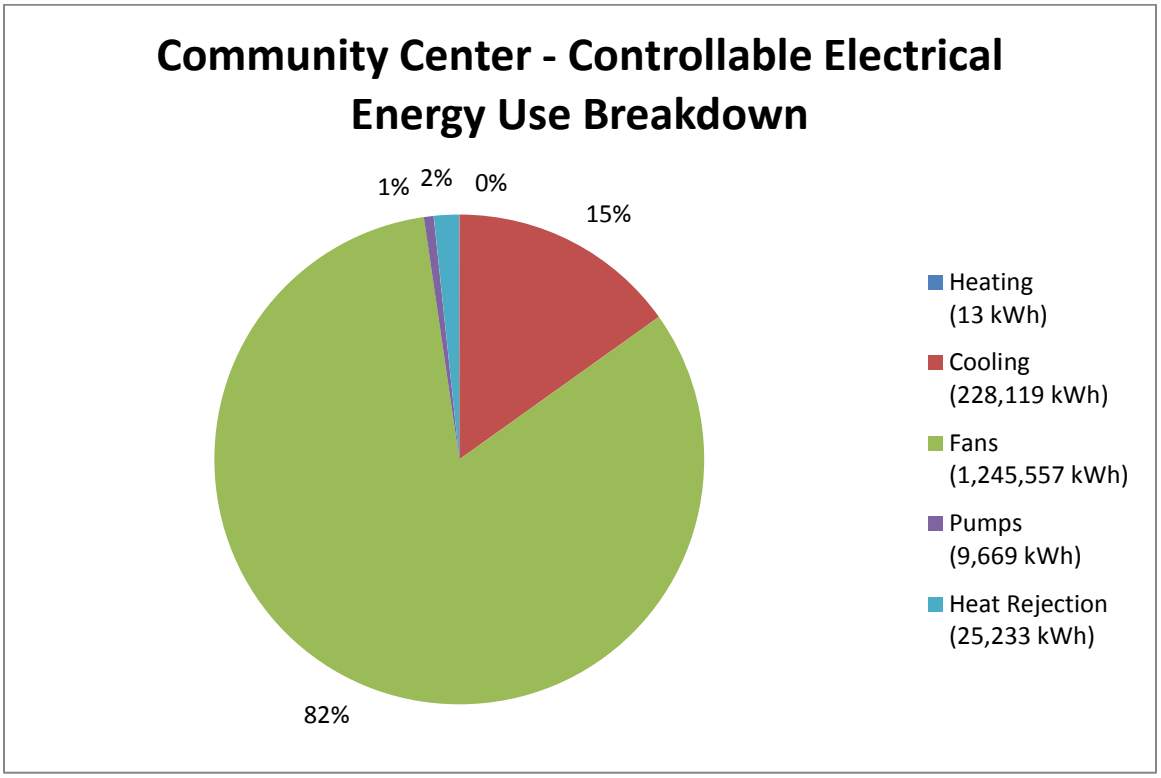


Figure 25: CC - Controllable Electrical Energy Use Breakdown

Regarding the installed controllable equipment, a detailed table is provided in the appendix. Based on the power ratings listed in the table, a maximum instantaneous controllable electrical load for the facility can be calculated as 392 kW with a possible instantaneous flexible load of 78 kW, resulting in an average instantaneous flexible load of 20%.

The remaining end uses are all non-controllable and include the interior lighting, process, and plug loads. These end uses account for 34.9% of the total electrical load, or 809.7 kWh of annual electrical energy use. As the non-controllable loads are based on non-weather dependent occupant usage patterns, it is assumed that these non-controllable end uses do not vary per season. In contrast, all the controllable loads are the HVAC loads, and vary by season due to weather influences. The following chart, in **Figure 26**, identifies the controllable and non-controllable end uses per month.

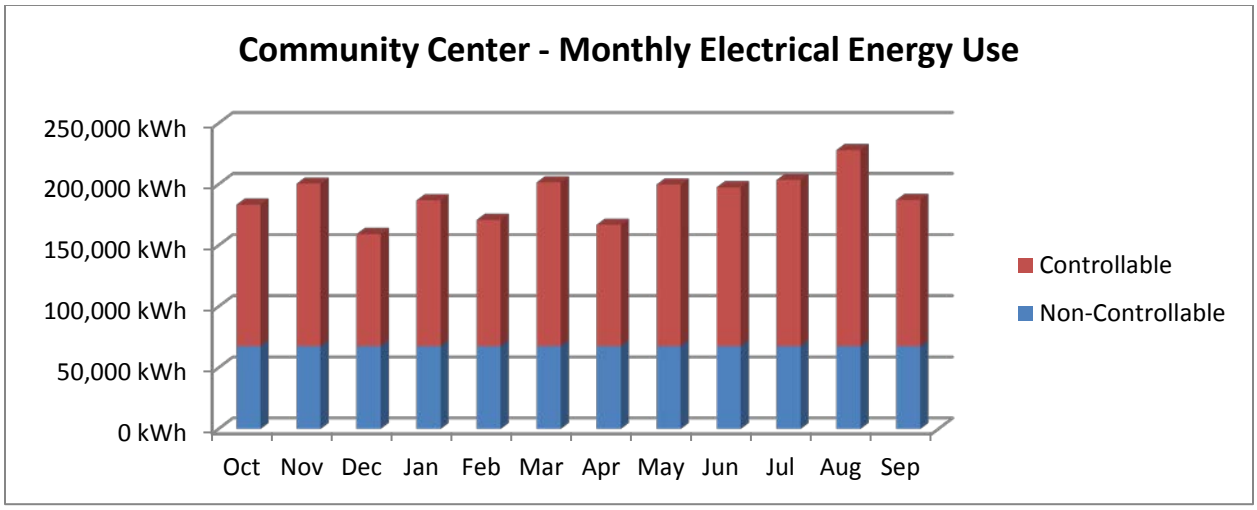


Figure 26: CC - Monthly Electrical Energy Use Breakdown for Controllable and Non-Controllable Loads

Natural Gas Energy Use

All space heating in the CC is provided as HTHW from the campus' central HTHW Boiler Plant. This HTHW is then downgraded through heat exchangers to provide the lower temperature hot water needs of the facility. It has been estimated that 10.6% of the total HTHW produced by the Boiler Plant is delivered to the CC. Based on 2009 data[15], the HTHW plant is calculated to operate at a total efficiency of 63.2% considering equipment efficiencies and plant equipment. Further, although there is generally negligible loss associated with distribution of natural gas, as this system is based on the distribution of HTHW through nearly 2 miles of piping; approximately 58% of the total heating energy distributed to the CC is lost through piping heating and water losses. In general terms, for every MBTU of heating energy that is needed at the CC, the HTHW Boiler Plant needs to consume 3.7 MBTU of natural gas.

For Fiscal Year 2011, it is calculated that the CC had a heating load of 19,477 MBTU and caused the HTHW Boiler Plant to consume 73,030 MBTU of natural gas. The following graph in **Figure 27** illustrates the monthly gas heating energy use for Fiscal Year 2011 based on the information noted above.

[15] Source: "USAFABuildingEnergyUsage2009.xls" from USAFA's Civil Engineering group.

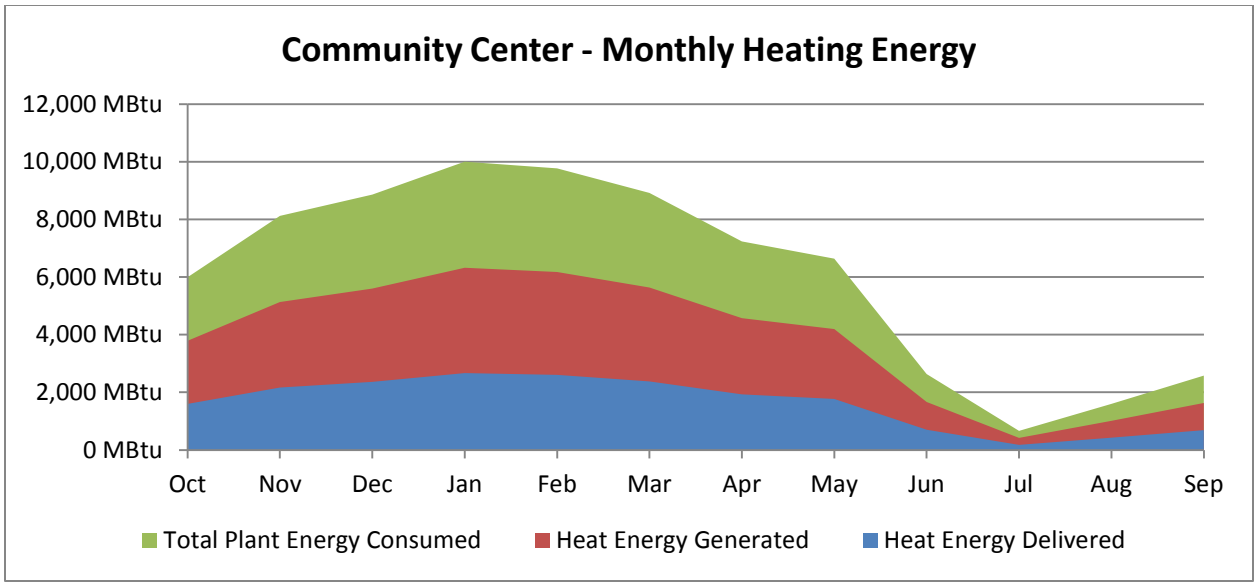


Figure 27: CC - Monthly Heating Energy

4.2 SITE-RELATED PERMITS AND REGULATIONS

We 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 EPAct 2005: Metering and Reporting, Energy-Efficient Product Procurement, and Building Performance Standards.

- Environmental Permits: Siemens currently has a valid contractor safety, health, and environmental program in place for any work performed on base.

- Agreements: N/A.

5.0 TEST DESIGN

Military facilities across the United States are suffering from low EE, energy waste, and high energy costs at peak loads because of the lack of integrated energy intelligence. By deploying a low-cost solution—iBEMS, greater amounts of facility operational costs can be saved while enhancing site energy security beyond what today's run-as-silos BASes can provide. Moreover, iBEMS, which combines Siemens' SEB with the Boeing OSB, offers the type of advanced controls and data security needed to develop stand-alone microgrids at military facilities. To show how iBEMS can effectively solve DOD's high energy cost problem, we conducted iBEMS demonstration at USAFA. We examined the economic and technical feasibility of implementing iBEMS at a building cluster located at USAFA. **Figure 28** depicts the overall installation architecture of iBEMS at USAFA for campus wide energy management. Specifically, we demonstrated deep energy savings for AH, targeting up to 40%, and several scenarios of coordinated demand management among the three buildings (AH, CC, and MH) to achieve up to 30% peak load reduction.

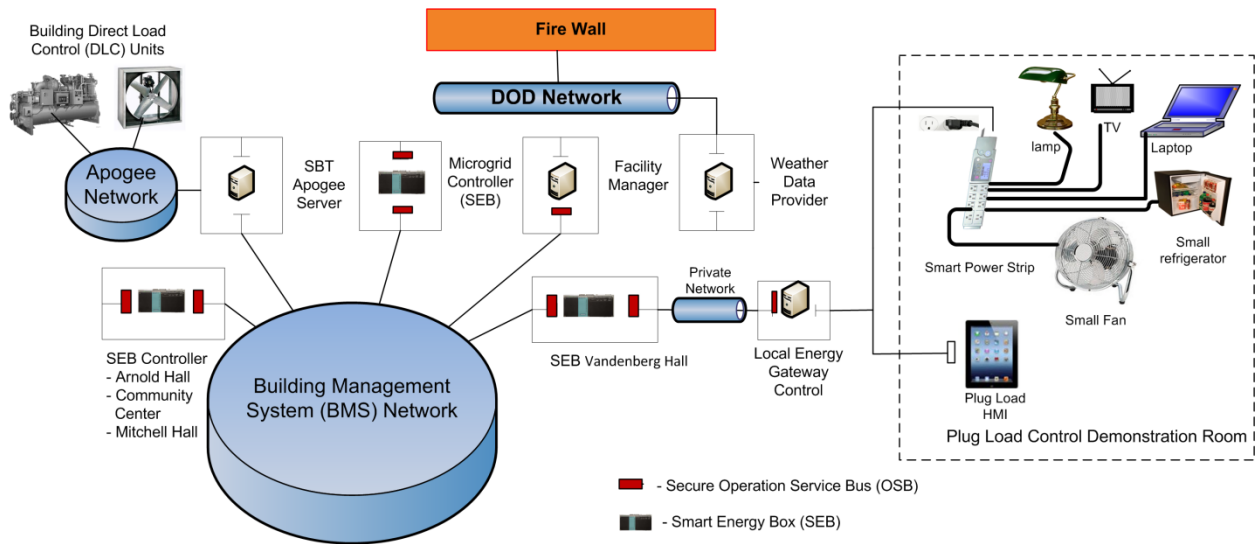


Figure 28: Overall Installation Architecture of iBEMS at USAFA

<u>Fundamental Problem:</u>
How can advanced building controls be utilized along with available information, such as weather forecasts, occupancy forecasts, and energy prices, to improve EE, demand reduction, save money, and incorporate energy conservation into daily practices, while keep building missions fulfilled?

<u>Demonstration Question:</u>

- Can iBEMS reduce the annual building energy usage by 20-40% through implementation of advanced EE strategies?
- Is iBEMS able to facilitate 10-30% electric load shedding within a 15 minute response time through a fast DR?

- Can iBEMS achieve 20% GHG emission reduction?
- Is iBEMS able to improve occupant's satisfaction, after installation, as compared to a baseline based on occupant surveys?
- There will be other secondary questions that will be answered by the iBEMS demonstration. For example, how easy to use did the occupants and facility managers find the system? Or, did USAFA personnel express a desire to continue using the iBEMS technology?

To show how iBEMS can effectively solve DOD's high energy cost problem, we conducted an iBEMS demonstration at USAFA. This demonstration helped answer the questions listed above.

5.1 CONCEPTUAL TEST DESIGN

To investigate the ability of the iBEMS technology to meet the success criteria for the defined performance objectives, a series of system tests have been designed to measure iBEMS performances with reference to a baseline conditions based on both field data and simulations.

The tests were grouped into two test scenarios – Energy Efficiency and Demand Response, and conducted from the perspective of the user of the iBEMS system who may be a building operator, an energy manager , a strategic planner or a base commander. For these tests following variables were defined:

Independent variable: These are the variables that can be manipulated or changed by or on behalf of the user. For the purpose of this conceptual test design, independent variable is applying iBEMS EE and DR strategies to building operation (**Table 8**).

- Configurable Variables: These variables can be set and/or changed by the user during the iBEMS configuration phase (programming of SEB), e.g. EE control rules.
- Manipulated Variables: These variables can be changed and controlled by the user during the actual iBEMS runtime, e.g. schedules of the building activities and demand reduction target.

Dependent variable(s): These variables are expected to be changed implicitly based upon the use of the iBEMS (**Table 8**). These are response variables to be measured, e.g.: kWh consumed, peak demand (kW), greenhouse gases, 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 the iBEMS triggers for experimental test cases that influence dependent variables, shown in **Table 8**.

- Static Variables: These variables are physical properties that are static. Example – area of a control Zone, baseline electricity data (i.e., data not altered by building renovations, equipment upgrades, or changes to control sequences

- Dynamic Variables: These variables change dynamically e.g. building occupancy or a weather pattern

Note that patterns of weather and occupancy are variables that are inherently uncontrollable by the user. For purposes of **Table 8**, however, these patterns are considered "controlled variables," meaning that they will be used as inputs in the simulations for both baseline and iBEMS tests.

Table 8: Test Design Summary

Controlled Variables	Independent Variables	Dependent Variables
a. Building characteristics (size, set points, etc. b. Weather pattern c. Occupancy pattern d. Peak demand event e. Baseline electricity data (i.e., data not altered by building renovations, equipment upgrades, or changes to control sequences) f. Duration of baseline, and the demonstration periods. g. Existing equipment and distribution systems.	Use of iBEMS control algorithms vs. no use of iBEMS control algorithms	a. kWh consumed. b. Peak demand (kW). c. Greenhouse gases. d. Total electricity costs. e. Changes in run times of AHUs. f. Cooling distribution, lighting, ventilation, and plug loads from the BAS sequence of operations.

Hypothesis:

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

The acceptance criteria for the above hypothesis are:

- The iBEMS optimal operation shows at least 20%-40% reduction in energy consumption during building operation in EE mode and at least 15%-20% of peak load reduction in Demand Management mode. In all other cases, iBEMS should identify the opportunity for improvement.
- The number of the comfort complaints by the building occupants during iBEMS operations should be minimal and not exceed the threshold of comfort complaints during normal building operations

Test Design: To validate the hypothesis, we conducted the following tests 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
- 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.

Test Phases: The following test phases were defined and implemented:

- Pretest preparation: For AH, MH, the CC, and Vandenberg Hall, building design and operational data were collected from two walkthroughs, interviews with USAFA facility team, the BAS trending system, occupancy logs, plug-load surveys of a select number of cadets, and an electric metering system. Additionally for AH, this data was then used to build building energy model, and for the calibration of the model in EnergyPlus software. At the same time, Siemens and Boeing worked on iBEMS customization to meet DOD special needs.
- Baseline characterization: In order to accurately predict the building dynamics and establish a realistic baseline of the building, the iBEMS used two different approaches. First approach was based on detailed EnergyPlus modeling and simulation which was applied to AH only. For MH and CC a weather pattern match based forecasting algorithm was developed to compute the baselines for DR events. These two approaches are described in detail in the next section. The baseline characterization process included a runtime data collection for all four buildings. Building modeling and calibration was performed specifically for AH, because the precision of the building baseline is particularly important for the EE test that was conducted in AH.
- Simulation-based system test of iBEMS: The integrity of the iBEMS hardware and software as well as runtime logic of EE, instantaneous DR, day-ahead DR and plug load management was tested in simulation environment at SCT's Princeton facilities.
- Design of experiment and testing EE hypotheses: This step involved running the design of experiments to accept or reject the EE hypothesis that was formulated earlier in this chapter.
- Design of experiment and testing Demand Management hypotheses – This step involved running the design of experiments to accept or reject the demand management hypothesis that was formulated earlier in this chapter.

5.2 BASELINE CHARACTERIZATION

5.2.1 Data Collection Equipment

Annual and monthly energy data was collected from the utility side power meters associated with each building. The trended data from the Apogee building control system provide detailed information on the operation of the heating and cooling systems. Sensors are located at various positions on the air- and water-side systems and record data from the chillers, fans (AHU, exhaust, etc.), pumps, and heat exchangers (converters). Furthermore, we installed 10 additional submeters to monitor AH and CC HVAC loads.

5.2.2 Reference Conditions

Reference conditions were collected for AH, MH, and the CC, including a collection of the following variables: building zone temperatures, energy consumption of separate end-uses (heating equipment, cooling equipment, lighting, receptacle, and other miscellaneous process loads), instantaneous demand of these separate end-uses, heating and cooling equipment (chiller, supply fans, pumps etc.) operating conditions (supply air temperature setpoints, chilled water setpoints and duct pressure setpoints etc.), time of operation for the process, lighting, and receptacle loads.

5.2.3 Baseline Estimation

DR energy regimes in buildings, as well as efficiency measures, require a baseline for comparison. Unlike so many other areas, there is no realistic possibility for a “control” so that definitive conclusions can be reached about the effects of an experiment. In the classic case of medical trials, the use of large groups of people and placebos establishes a statistically rigorous control against which a drug or other medical procedure can be measured. Buildings, particularly commercial buildings, unfortunately rarely come in large groups in the same climate area. A “baseline” is a calculation of what a building would have done in the absence of efficient control strategies. It is based on past information on building performance, weather information, occupancy, and any other known conditions that would affect the outcome. For DR events, the baseline needs to cover the period of the event, typically no more than six hours. EE baselines are harder to develop, unless the efficiency measures are periodically undone to determine the performance of the unmodified building. This is because efficiency measures are normally applied in perpetuity. For this demonstration, DR involves reducing electrical load by a specified amount to mimic times when the electricity grid is stressed in some way.

In order to accurately characterize the energy and cost savings resulting from various EE and DR demonstration 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 due to lack of detailed information as well as time/budget constraint, a weather pattern matching based approach was developed 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. 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 process of calibrating the model to the electric meter data is described in this section.

Model Development

Data on the building's properties and internal loads (although limited) was collected from architectural drawings and site surveys. The HVAC system equipment and operational data were obtained from the mechanical drawings, site observations, interviews and trending data from the BAS. There were some gaps in the data collection as there weren't always complete building drawings available. Most of the data used was from retrofit drawings that show removal and replacement of mechanical equipment over the last 20 years or more. In areas of doubt, site visits were conducted to verify the location of the actual equipment and their operation sequence. There were also some assumptions made for the heating equipment as the building's hot water was provided by a district heating plant with no monitoring of the heating distributed at the building level. The hot water circulation pumps located in the building were included in the model and it was noted that further calibration on the heating side will still be needed.

The input parameters for the building can be broken into four main groups: *program*, *form*, *fabric* and *equipment*. These categories were created based on methodology presented in a technical report from the National Renewable Energy Laboratory (NREL) [6]. This methodology is recognized and used commonly in the modeling industry. The *program* group refers to the building's use and the occupancy's activity inside (e.g. climate, plug and process loads, ventilation requirements and occupancy). The *form* refers to the geometry of the building components (e.g. floor-to-floor height, window-wall ratio). The *fabric* group refers to the envelope of the building and each element's construction (e.g. insulation type, wall thickness). And the *equipment* group refers to the internal loads such as lighting and HVAC systems installed.

Program

Defining the *program* of an existing building is a relatively easy task, however, at the beginning of the project the building selected was missing some important information that made this step a little difficult. The weather, geographical site and building's usage and service were known but a detailed occupancy schedule for the building was not. Assumptions based on room activity type were made to create an approximate occupancy density and profile with the intent of these inputs being improved as the project progressed and more details became available.

Form

AutoDesk's Revit software [7] was used to create the geometry of the building by importing and tracing over the latest drawing files available (for each of the five floor plans) to form the footprint for the building. The geometry built in Revit consisted of the floor, exterior and interior walls, windows and roof plane. The HVAC zones were then defined in Revit to match the most recent mechanical floor plans available for the building. Once the zones were defined, the model was

exported into Design Builder. Design Builder is a graphical interface for EnergyPlus and is commonly used in the modeling community to define thermal zones and basic system components.

Fabric

Once the model was brought into EnergyPlus, details on its building components such as envelope construction and materials were added. As there were very few drawings showing the wall and roof assemblies available for AH, a site visit was paramount to compiling the envelope constructions (layer by layer) in the models.

Equipment

The lighting power density was set using a combination of the building's lighting plans and fixture counts during the site visit. Mechanical systems were assigned to the appropriate zones in the building and the zone terminal VAV boxes were created for each zone. The Design Builder model was then imported into EnergyPlus so that more detail on all the system components could be provided. Performance characteristics of the HVAC equipment such as the power draw and efficiency were modeled from name plate data photographed during the site visit and the most recent mechanical drawings.

Real time weather data used in the initial stages of modeling came from two sources: NOAA Colorado Springs weather station output and the USAFA weather station on site. Once the calibration of the model began, the USAFA weather file was considered to be more accurate and used for all future modeling runs. **Figure 29** shows the building views from the EnergyPlus model. And **Figure 30** shows the zoning of the ground floor of simulated building.

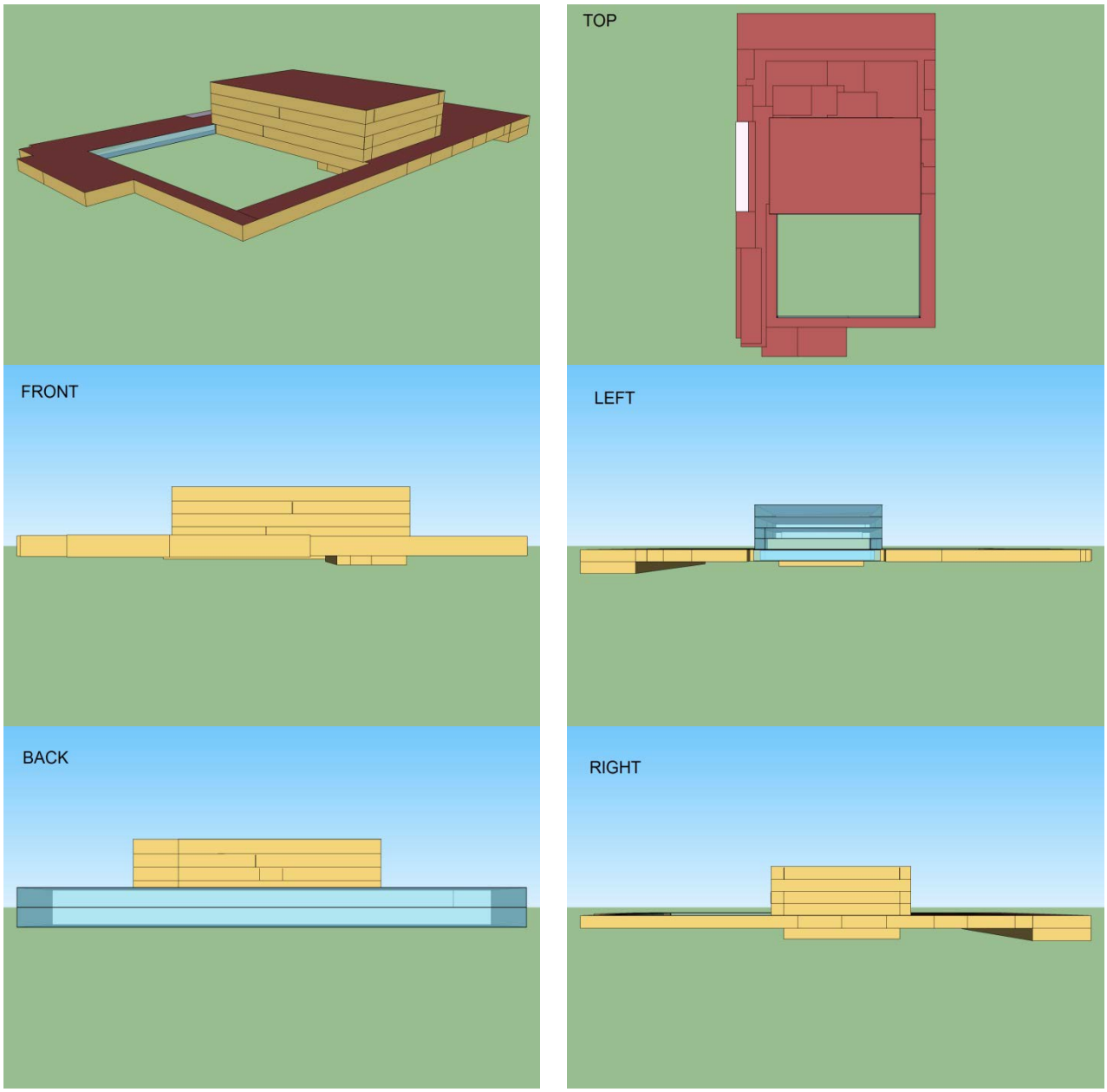


Figure 29: Building Views from the EnergyPlus

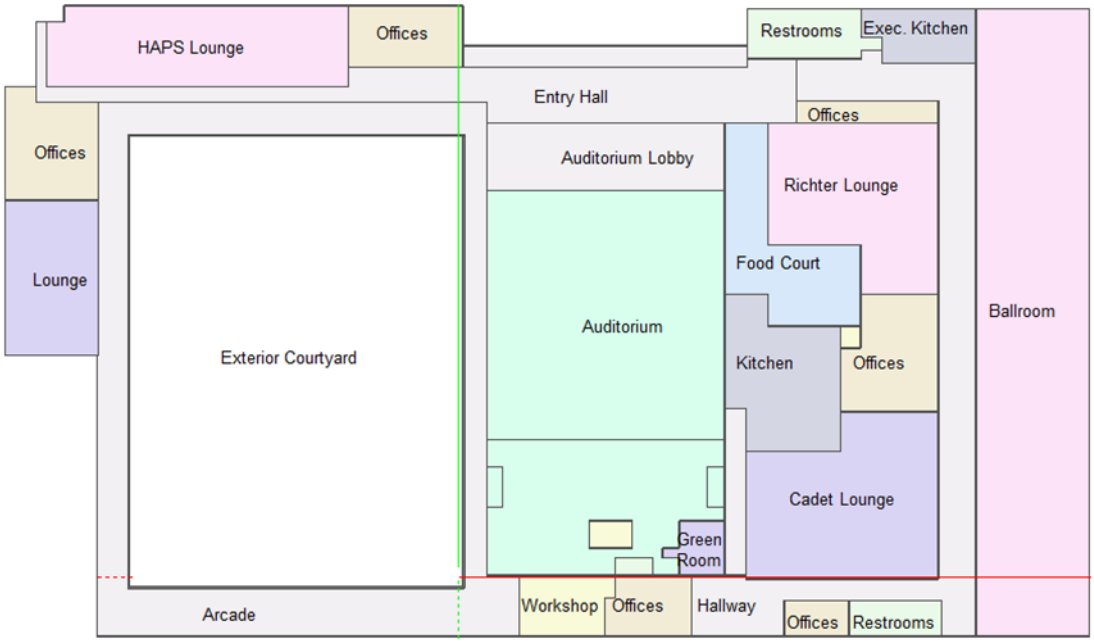


Figure 30: Ground Level Floor Plan for AH

Model calibration

Simulation models are considered useful only when they are calibrated. The calibration criteria vary based on the use of the simulation. In the domain of building energy system, if simulation is used in design phase, a roughly calibrated model would be sufficient. If simulation is employed in mechanical system control, a model calibrated to component level consumption and temperature and/or humidity with granular resolution on both spatial and temporal aspects will be necessary. ASHRAE sets up a guideline for calibrating simulation model (ASHRAE Guideline 14-2002). However, the availability of reliable measurement data and manpower are also important constraint while considering about calibration criteria. The following facts are considered in calibrating AH model for iBEMS project:

- The model is used to establish baseline for EE and DR.
- EE strategies will be tested on the model, and annual energy saving estimate will be obtained by simulation.
- Monthly and annual electric energy bills are available for the last few years.
- Annual heating gas consumption estimate is available for year 2009; no additional information is available about heating gas consumption.
- 15-minute interval submeter reading is trended for whole building, but breaking down consumption according to end uses or zones/systems is not possible.
- Room temperature trending is available for limited number of spaces, and is not reliable.

- AH consumption is very volatile, and is heavily influenced by both weather and occupancy, but accurate occupancy information is not available.

Due to the lack of information, following two assumptions were made:

- 2009 annual gas usage estimation is accurate. It reflects the true usage information that can be extrapolated to other years;
- Our baseline simulation, developed with EnergyPlus default settings and calibrated to 2009 estimation, captures the system characteristics. It is capable of predicting gas usage under both baseline and EE scenarios.

According to ASHRAE Guideline 14-2002 [8], coefficient of variance of the root mean squared error (CV-RMSE) within 30% and normalized mean bias error (NMBE) within 10% of whole building hourly consumption will be considered acceptable. However, these two metrics both involve normalization operation by mean measured values. They may not be appropriate for simulation that spans long period of time (e.g. a whole year), if the subject building switches its operation mode. An alternative metric called mean absolute percentage error (MAPE) defined by the following formula is adopted in calibration of AH model:

$$MAPE = \frac{1}{N}\sum_{i=1}^{N}\left|\frac{M_i - S_i}{M_i}\right| \times 100\%$$

where M_i and S_i are measured and predicted values of sample i, and N is the sample size. And the calibration is targeting MAPE of 15-minute interval whole building electric power below 15%.

Since occupancy is known to have significant impact on the subject building, but the information is very limited, occupancy profile was chosen as a subject of tuning in calibration. Also considered that AH has large spaces of offices which may have moderately routine daily occupancy pattern, but occupancy of large spaces such as auditorium and ballroom is correlated with event, rather than office routine, the team decided to separate occupancy tuning into two parts: (1) repeatable occupancy patterns for weekdays and weekends, and (2) additional occupancy due to events. The calibration is carried out according to the following steps:

Step 1: Tuning hourly occupancy profile for weekdays without event (weekday repeatable occupancy). Continue to Step 2 when MAPE<15%;

Step 2: Tuning hourly occupancy profile for weekends without event (weekend repeatable occupancy). Continue to Step 3 when MAPE<15%;

Step 3: Applying weekday/weekend repeatable occupancy and tuning additional occupancy level due to ballroom and auditorium events (event occupancy). Continue to Step 4 when MAPE<15%;

Step 4: Validate results of Step 1-3 using a longer period that includes weekdays, weekends and events. Calibration stops when MAPE<15%, otherwise goes to Step 1, again.

Note that, when tuning repeatable occupancy (Step 1 and 2), periods with no event were selected. Occupancy in ballroom and auditorium were made zero during the periods, while same hourly occupancy profile applies to all the other zones over all weekdays (another profile applies over weekends). And while tuning event occupancy (Step 3), repeatable weekday and weekend occupancy were applied as "base profile" to other zones. And occupancy of ballroom and auditorium was tuned based on site provided event registration calendar (showing space and time period of each event). The occupancy during event period was assumed to be the same. Thus only three parameters need to be adjusted – occupancy level during events, number of hours before event begins that spaces start seeing occupants and number of hours after event ends that spaces close. The 4-Step calibration goes iteratively and in a cyclic manner, until criteria is met in all 4 steps. **Table 9** and **Figure 31-Figure 34** present the final result of all the steps.

Table 9: Calibration Results

Step	Period	MAPE
1	2013-07-22 to 2013-07-24	11.8%
2	2013-07-20 to 2013-07-21	12.0%
3	2013-08-20 to 2013-08-23	12.6%
4	2013-07-25 to 2013-08-08	11.0%

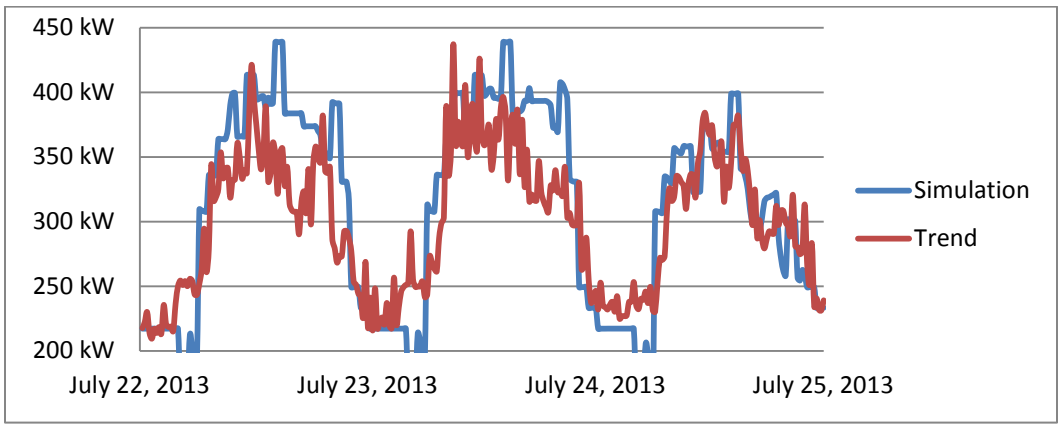


Figure 31: Step 1 Calibration (Weekday Repeatable Occupancy)

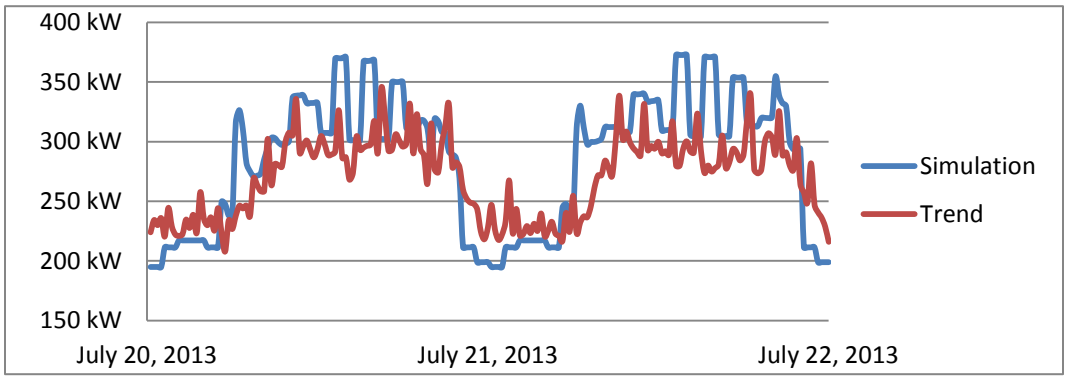


Figure 32: Step 2 Calibration (Weekend Repeatable Occupancy)

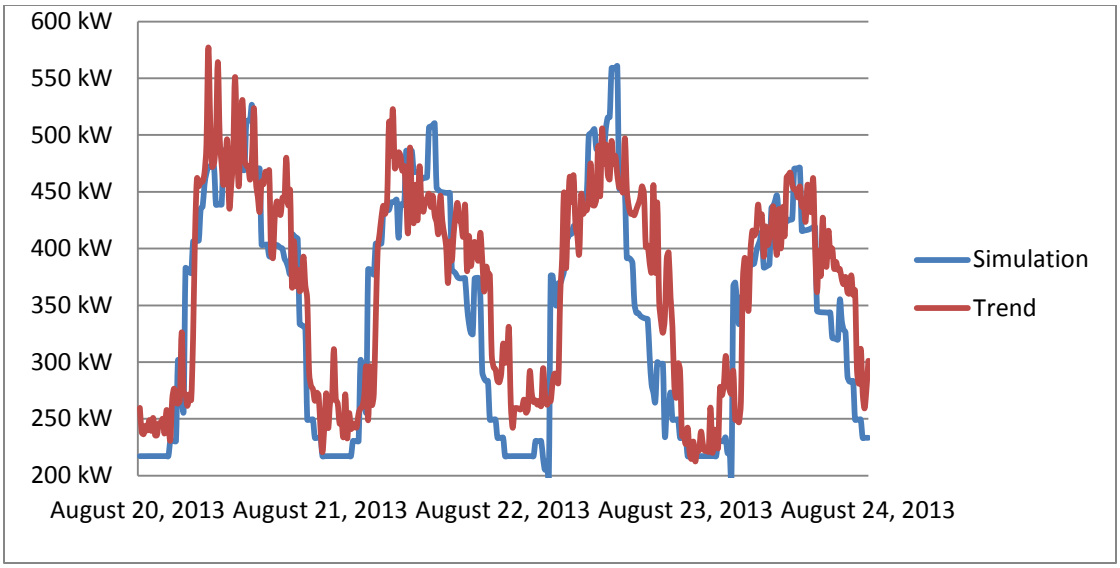


Figure 33: Step 3 Calibration (Event Occupancy)

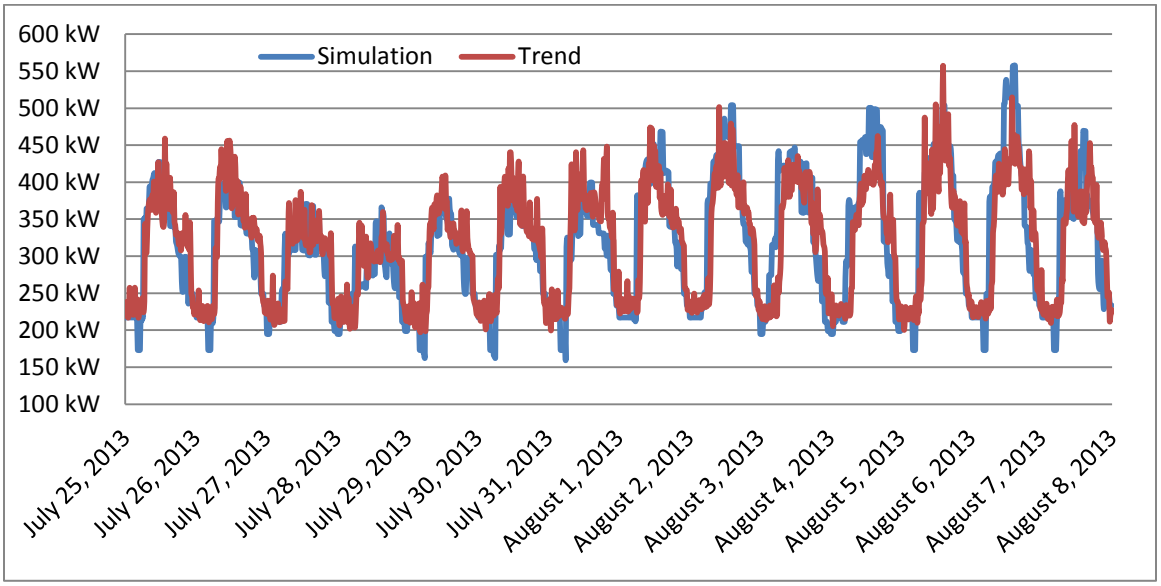


Figure 34: Step 4 Validation

Figure 35 shows the monthly electricity usage comparison. Error < 13.2%, and average error is 7.2%. **Table 10** shows the accuracy of simulation measured by other items.

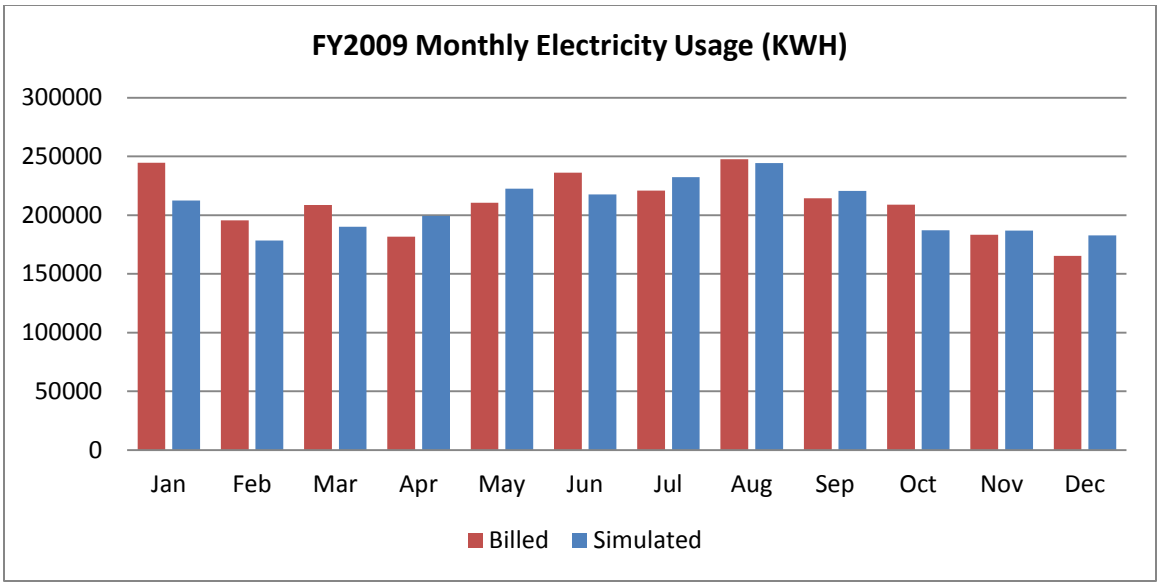


Figure 35: Monthly Electricity Usage Comparison

Table 10: Simulation Model Accuracy

	Measured/Estimated	**Simulated**	**Error**	**Relative Error**
Annual Electric Energy[16]	2,548,618 kWh	2,473,994kWh	74,624 kWh	2.9%
Annual Heating Energy[17]	83900 Therms	77629 Therms	6,271 Therms	7.5%
Daily Heating Energy[18]	294.2 Therms	207.4 Therms	86.8 Therms	29.5%

Calibration of the Simulation for Implemented EE Measures

Calibrated with the baseline energy data detailed previously, the EnergyPlus model was further developed to calculate the EE measures implemented during the test week in September. Using the time period of September 17th through to September 29th, a revised fan schedule was included in the simulation that turned off the appropriate AHU fans during periods when their relative spaces were unoccupied. The result of the analysis yielded the following curves with a MAPE of 14.4%.

[16] FY2009 billed electricity usage
[17] FY2009 heating gas usage estimated by USAFA
[18] Daily heating energy estimated based on trend data of November 2012 (hot water temperatures and hot water pump speed)

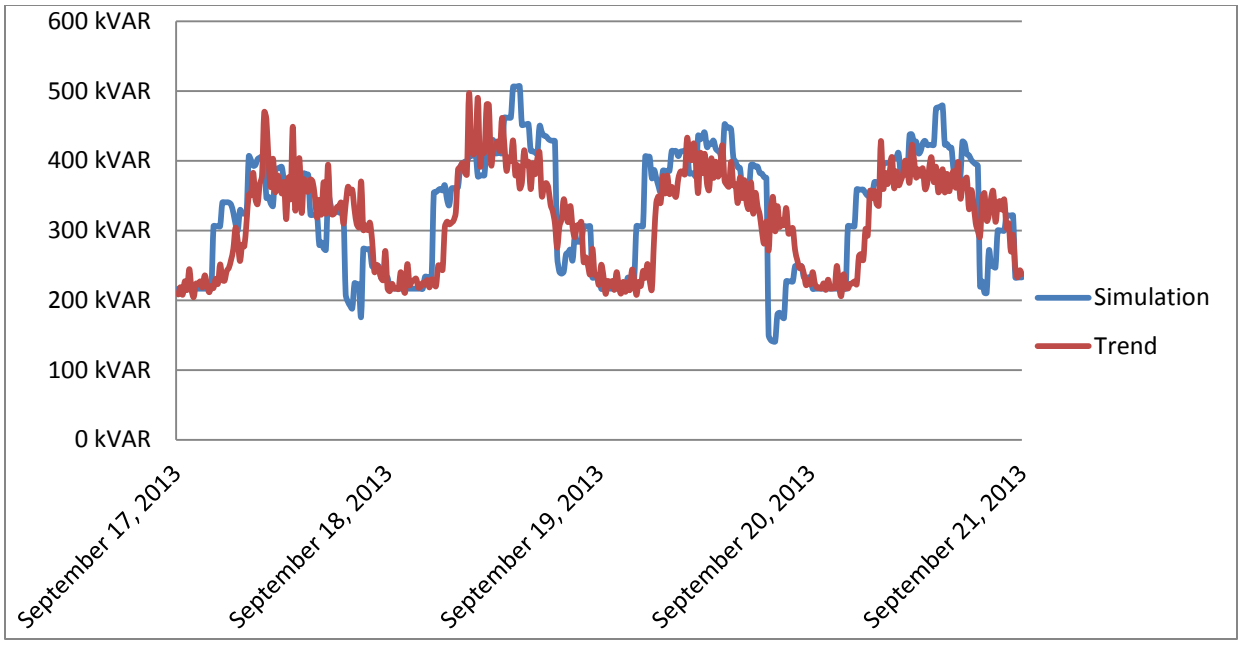


Figure 36: Revised Simulation's Results as Compared with Trend Data

With the confirmation that the calibrated model accurately reflects the metered energy use from the EE events, the model is now ready to be used to predict annual energy savings based on the selected EE measures.

Baseline for MH and CC

As explained in the previous section, due to the lack of detailed information an analytical approach based on weather pattern matching was utilized to compute the baseline for MH and CC. In this approach, in order to determine the electrical load for a future day the weather forecast for that day is used along with historical weather (temperature, humidity, and wind speed) and trended electrical load data. 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*" closes 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.

<u>Results for Weather Pattern Matching based Electrical Load Forecast</u>

The developed baseline approach was then tested for all three buildings. For AH and MH meter readings between 2/1-5/9 and 6/10-9/29 and for CC meter readings between 7/17-9/29 were used for assessing the performance of the developed algorithm for predicting the electrical load for these buildings. For performance assessment period, forecast for each week day was made using historical data and then compared with the actual meter reading for those days. Days on which EE and DR tests were conducted and holidays were excluded from this performance assessment. Three different metric were used for performance assessment – MAPE, Theil's U, and R Squared. The forecast were performed with varying "*N*" (number of similar weather pattern) values.

Figure 37 shows the results for a comparison between the forecast load and actual meter reading for the week of 26-30 August for the CC building. The comparison plot for a given day – 28th August is shown in **Figure 38**. Similar plots are shown for AH and MH in **Figure 39**-**Figure 42**. In these plots *N* – number of similar weather pattern – used was 7.

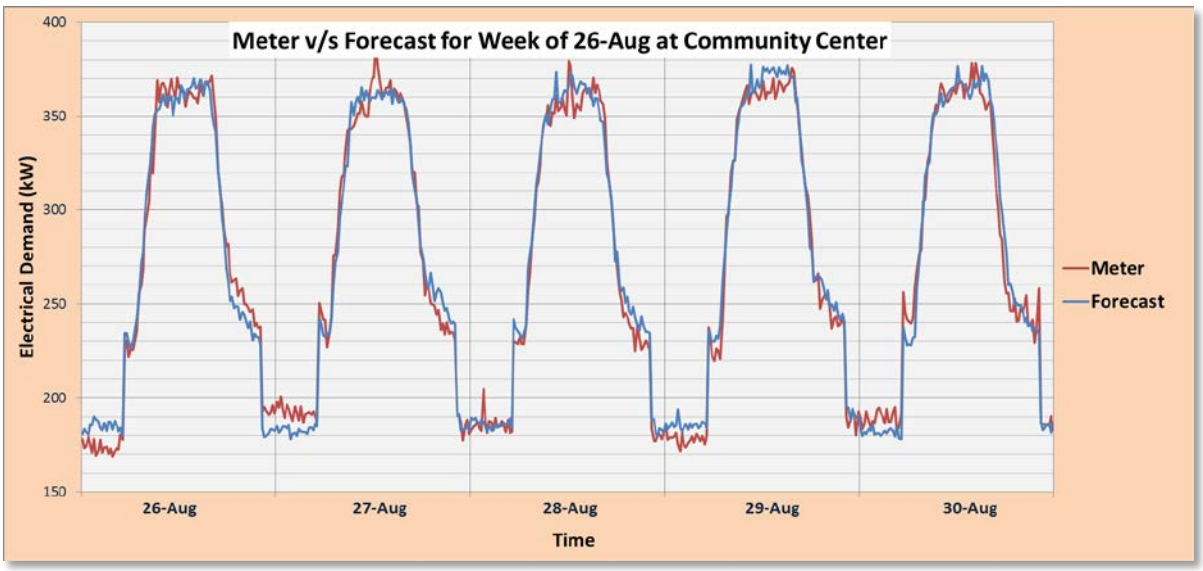


Figure 37: Forecast Comparison for CC for the Week of 26-30 August

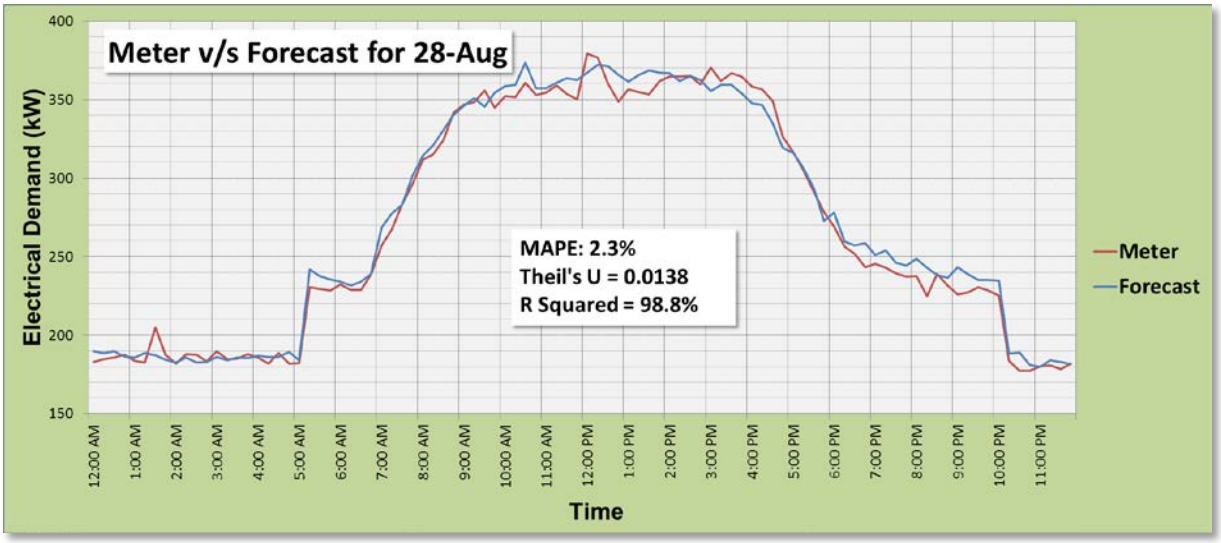


Figure 38: Forecast Comparison for CC for 28 August

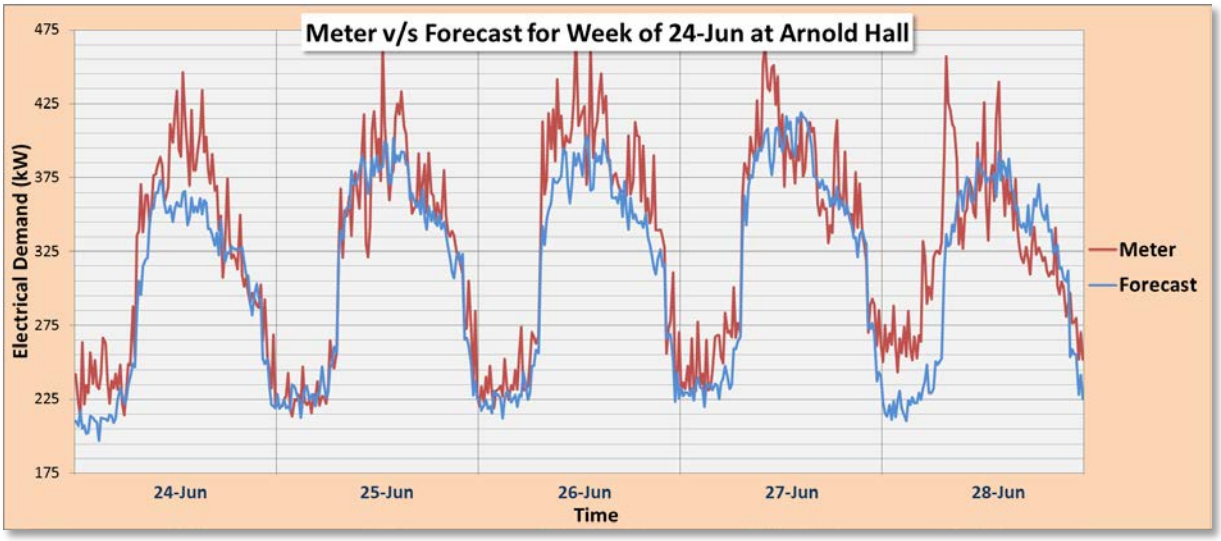


Figure 39: Forecast Comparison for AH for the Week of 24-28 June

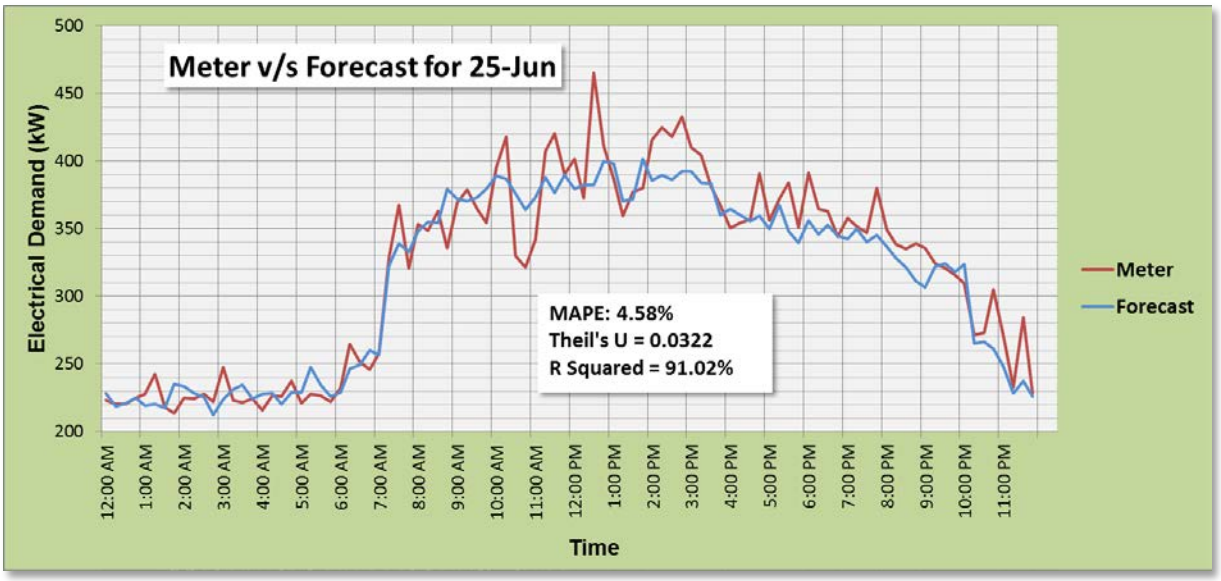


Figure 40: Forecast Comparison for AH for 25 June

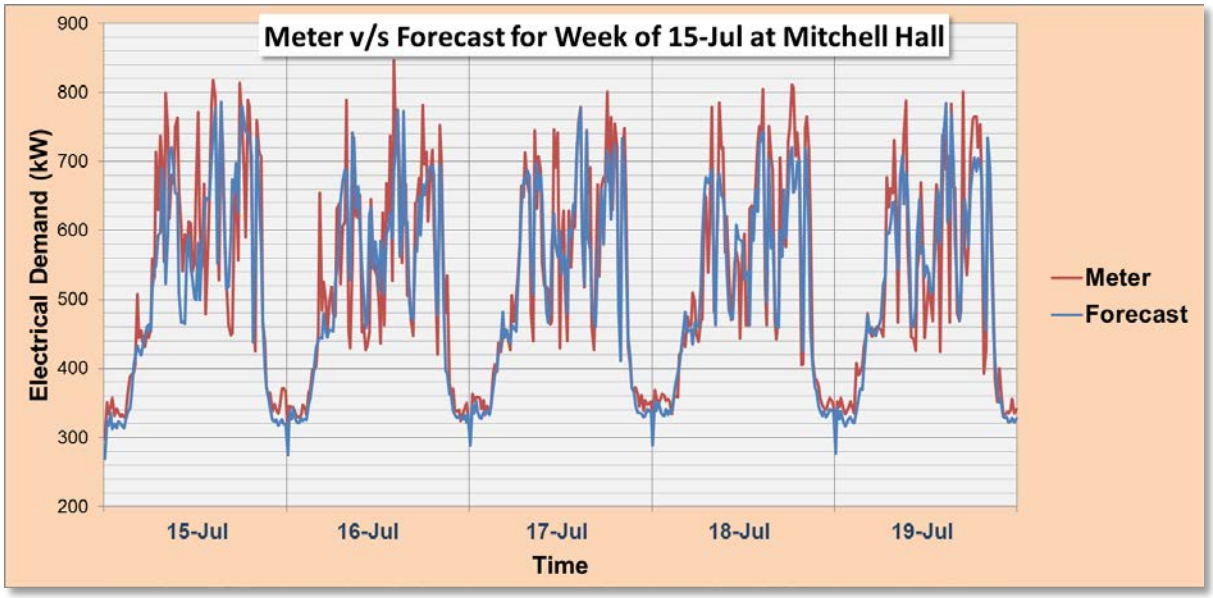


Figure 41: Forecast Comparison for MH for the Week of 15-19 July

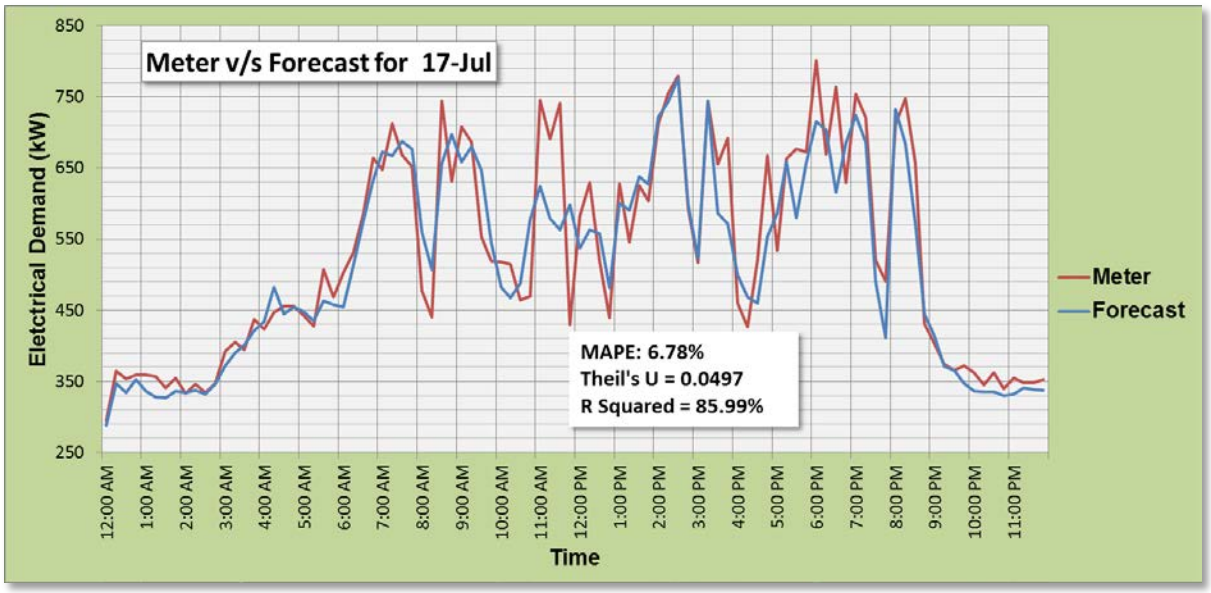


Figure 42: Forecast Comparison for MH for 17 July

Table 11 shows the average MAPE for the forecast of daily energy consumption for each of the three buildings with different values of "*N*". It can be concluded from this table that forecasting accuracy decreases with the increase in value of "*N*" after 3. This conclusion is as expected because as we add more days (more "*N*"), with similar weather pattern but with deceasing similarity (higher individual MAPE for weather comparison) with forecasted weather of selected

day, it may first cause in decrease the overall daily kWh MAPE but will eventually lead to its increase.

Table 11: Average 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 43** 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 in the picture below. 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 43**. Since there was no definitive agreement with USAFA about the procedure of making that network connection, 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.

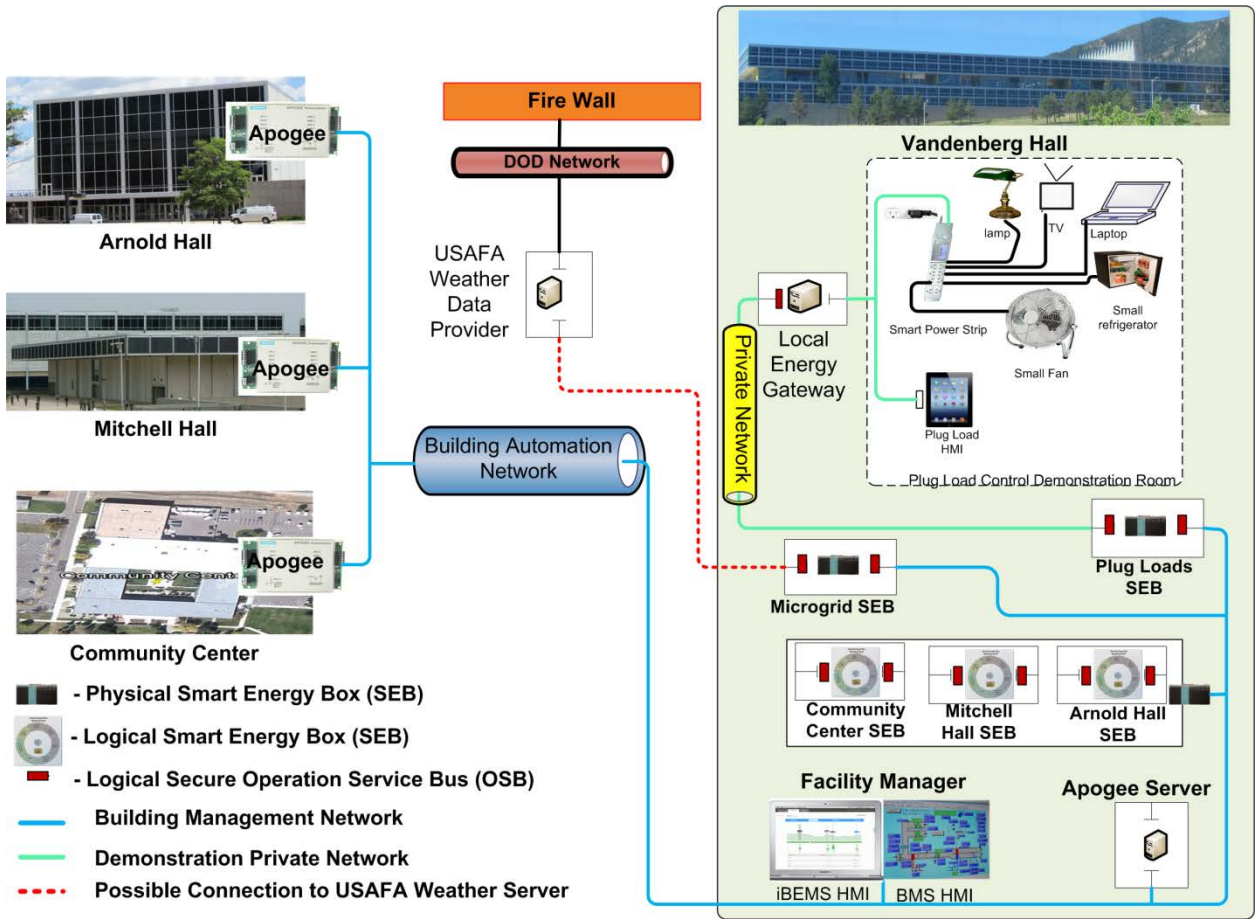


Figure 43: iBEMS Demonstration Installation Layout at USAFA

5.3.2 System Components

iBEMS SEB

iBEMS SEB is a stand -alone software that enables a totally integrated building/Microgrid energy management system. It provides a control platform to integrate HVAC, lighting systems, onsite distributed energy resources, and distributed loads based on common communication standards. The SEB optimizes total building energy savings based on weather forecasts, occupancy detection, and energy simulation. It also provides building-to-grid/Microgrid connections and enables the buildings to respond to grid commands. The typical host of SEB is Siemens Simatic Microbox**,** a small, form-factor industrial PC. This hardware is commercially available from Siemens.

The iBEMS hardware included 4 Siemens SIMATIC Microbox PCs, an HMI station and plug load controllers. The hardware hosting SEB controllers are Siemens SIMATIC Microbox PCs (**Figure 44**).

- One Siemens SIMATIC Microbox PC to host SEB instances layered on top of the building controllers of MH and the CC.

- One Siemens SIMATIC Microbox PC to host a SEB instance layered on top of the building controllers of AH (separated for the purpose of a stand-alone EE demonstration)
- One Siemens SIMATIC Microbox PC hosting the instance of SEB running the microgrid energy management.
- One Siemens SIMATIC Microbox PC hosting the instance of SEB controlling the Vandenberg Hall plug loads.

Although the iBEMS HMI is a web based application and could run on any system, to avoid any unforeseen HMI runtime constraints such as reconfiguration or upgrade, the HMI system was installed on SEB-M microbox PC that also runs an SEB-M controller.

Figure 44: Simatic Microbox Industrial PC

iBEMS HMI

iBEMS HMI is a web-based user interface that provides the capability of starting/stopping, managing and monitoring the iBEMS runtime, initiating EE and DR control modes as well as restoring the Apogee runtime state to a non-iBEMS. Details of iBEMS HMI has been provided in section 2.2.

LEG for Plug Loads

LEG is a subsystem of iBEMS that manages the control over common plug-load devices and appliances that would be found in and around occupant work areas. Plug loads are great sources for demand management because most of them are interruptible. However, deep engagement from occupants is required to apply load control for demand management. For this demonstration, the actual plug loads of the buildings were not allowed to be a part of the EE or DR events. Some external small scale plug loads, such as a laptop, CRT monitor and a task light were deployed

onsite in Vandenberg Hall for a concept demonstration. These plug loads are managed by the LEG to validate the SEB's plug load management functionality. One of the main components of plug load subsystem is a smart switch. It is used by the LEG software to obtain information about the current power consumption of all plugged equipment, obtain the list of active equipment and finally to command the selected equipment ON or OFF depending on the LEG bidding logics. In addition, the LEG is capable of monitor the occupant environment (temperature, humidity, light level, occupancy), and communicating with the SEB for negotiation of load management goals, and hosting a user interface or web server for the tablet HMI.

Figure 45 depicts the first level decomposition of the iBEMS system in terms of runtime components.

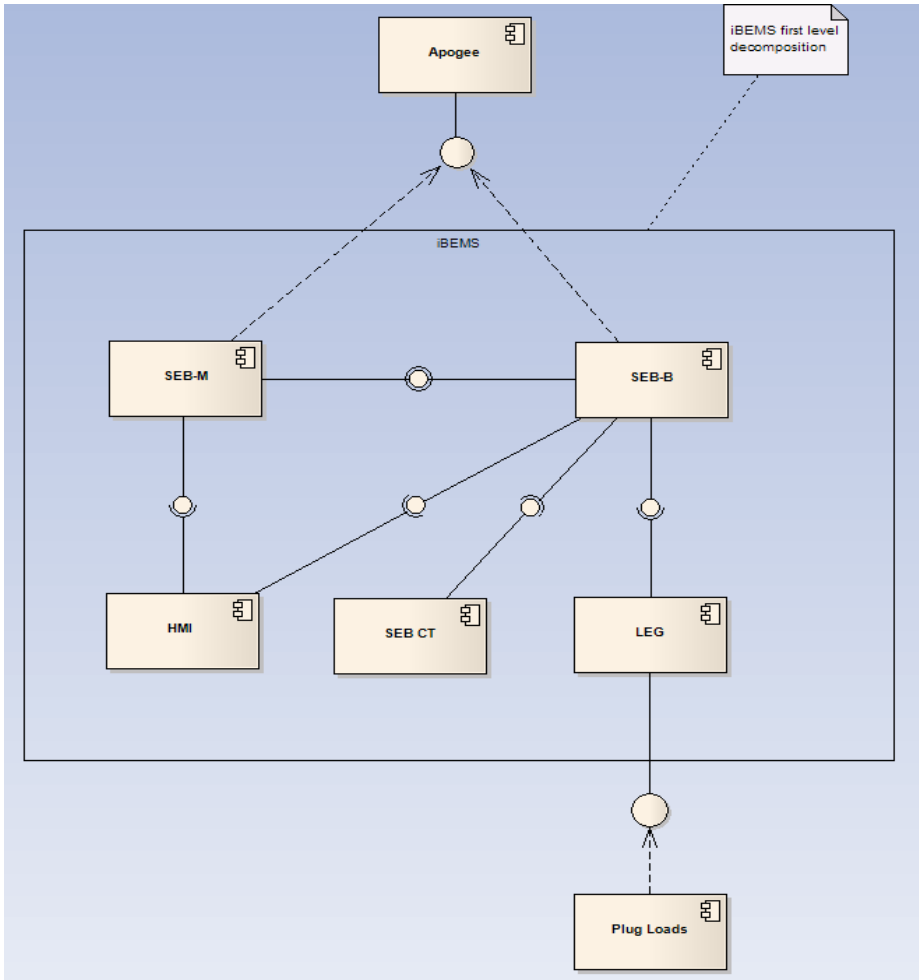


Figure 45: First Level Decomposition of the iBEMS in terms of Runtime Components

5.3.3 Network Security: Boeing's Secure Distributed OSB

To secure the communication in our private network, the secured distributed OSB was developed and deployed by the project sub-team from Boeing. The OSB integrates new and legacy data systems into an intelligent building energy management system through the application of

translation services to a common data model. OSB, with its multi-tiered, distributed architecture provides scalability, interoperability, and high availability by pushing intelligence to the periphery of the network. Once the OSB is deployed, nodes can be added incrementally with configuration and other operational changes propagating automatically across the system. Consequently, communications, data flow, and decision-making bottlenecks are minimal resulting in a highly scalable and manageable system.

5.3.4 System Integration

As shown in Figure 1, iBEMS is a vendor-independent energy management platform that extends BASes by means of integration with advanced optimization and control and visualization technology. It doesn't require additional mechanical equipment or changes to the existing BASes except a few sensors, power meters, or BTU meters, if necessary. The communication between SEBs and existing BASes is based on industry standards such as BACnet, which is already provided by the Siemens Apogee system installed at USAFA.

The LEG part of the demonstration at Vandenberg Hall required additional hardware system installation. The LEGs sit in parallel to the existing building control systems on a separate private network and pose no negative impact on the existing systems. The plug-load control can be opted-out by simply unplugging all appliances from the smart switch.

Overall, the iBEMS is designed as an extension of existing BASes. It does not modify files or archives of the existing BAS. In case of catastrophic failure of the iBEMS, it can simply be disconnected from the network and the BAS settings can be restored using its archived configuration files. The iBEMS makes a runtime copy of the existing BAS control points before it changes their values. In case of malfunction or failure, the iBEMS has a routine built-in to relinquish the control points and set BAS to its original state.

Figure 46 shows the overall system integration setup.

5.3.5 System Controls

Two types of control were generated from iBEMS, including applying changes to building set points via the BAS and applying commands to the building plug loads via LEG during demand response event. The recovery for later demonstration is straightforward. If the participant no longer wants a plug load to be controlled by the LEG, it can be unplugged from the smart switch and plugged into a standard switch. For the EE and DR demonstrations, the set points were applied to the buildings from the SEB via BACnet. As indicated in the previous System Integration section, all set points affected by this demonstration will be backed up first. When the demonstration is aborted or completed, the set points are relinquished to its previous values and the control is taken over back by the BAS. **Figure 47** shows a control sequence of the demonstration in the case of EE and DR. The first step of the demonstration is to back up the current BAS setpoints that will be affected by the demonstration. If the backup fails, the demonstration is aborted. In this first scenario, the restore will not be necessary because BAS setpoints have not been changed.

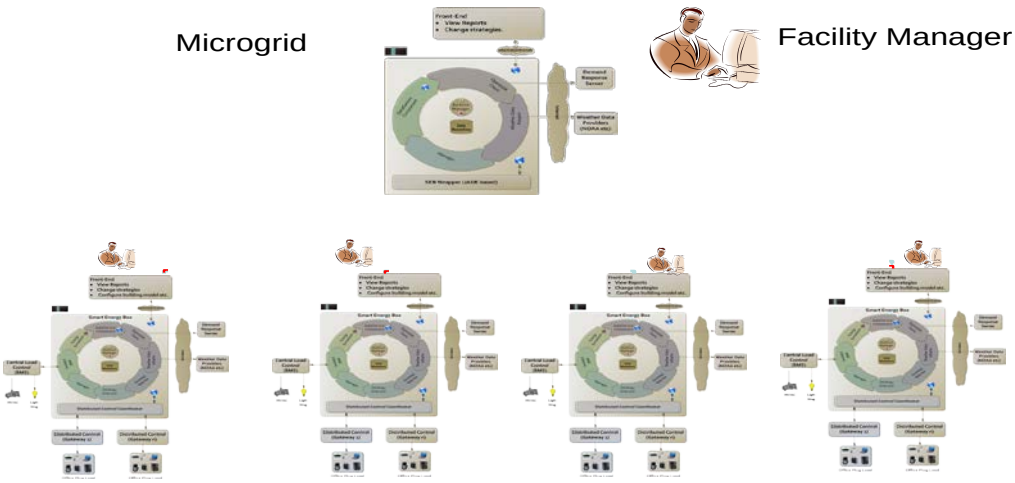


Figure 46: Integrated System Setup

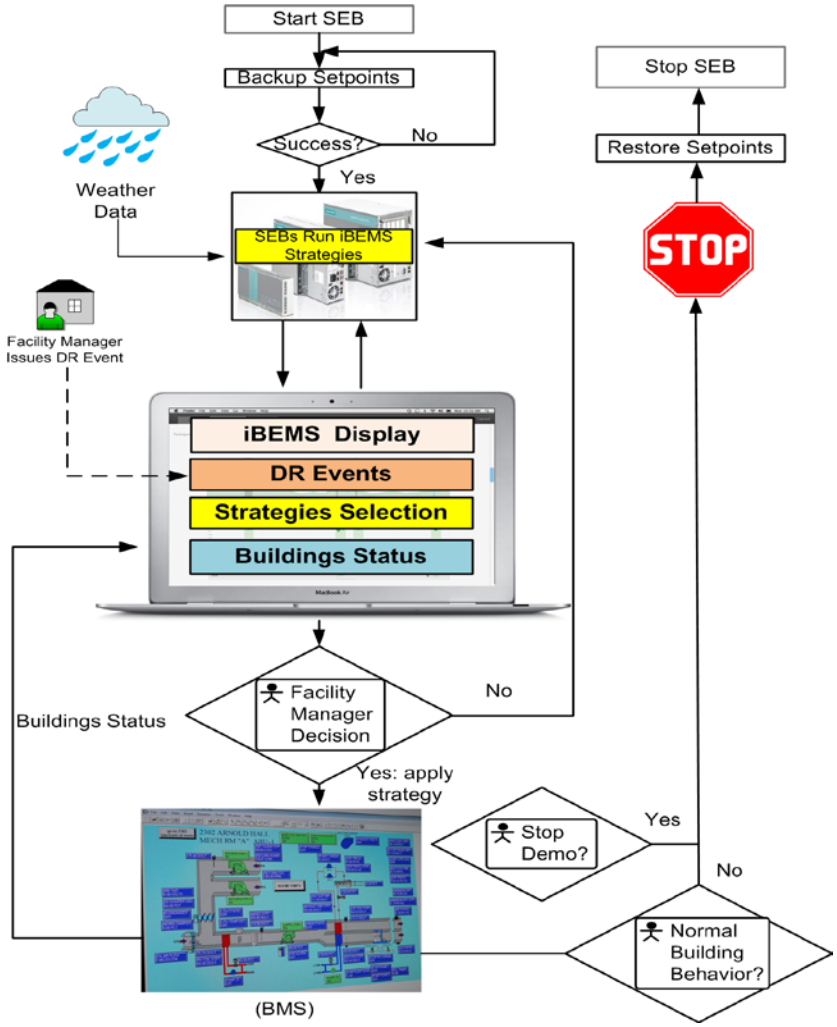


Figure 47: Control Sequence of the iBEMS Demonstration

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 month of April and the month of December.
- EE Test Scenario (cooling season) – EE tests for a single building during the cooling season were conducted using AH facilities at USAFA in between the months of June to 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.

5.4.1 EE Test Scenario

Building: AH

Duration: 1 week

Configuration: SEB-AH configured with rule-based EE strategies for the AH automation zones based on the occupancy schedule and current weather conditions

Requirements of a facility manager:

- Provided weekly up-to-date events calendar of the building.
- Provided current weather control point for trending by SEB-M

Facility manager control access:

- Can switch the building from normal operation to EE operation (weather and occupancy-based control strategy adopted).
- Can monitor zone setting (temperature set points); AHU setting (On/Off), and analyze the changes from a normal operation.
- Can relinquish the Apogee control points back to normal operations at the end of the test or for unforeseen events

Figure 48 shows the operational scenarios of the iBEMS EE tests at USAFA.

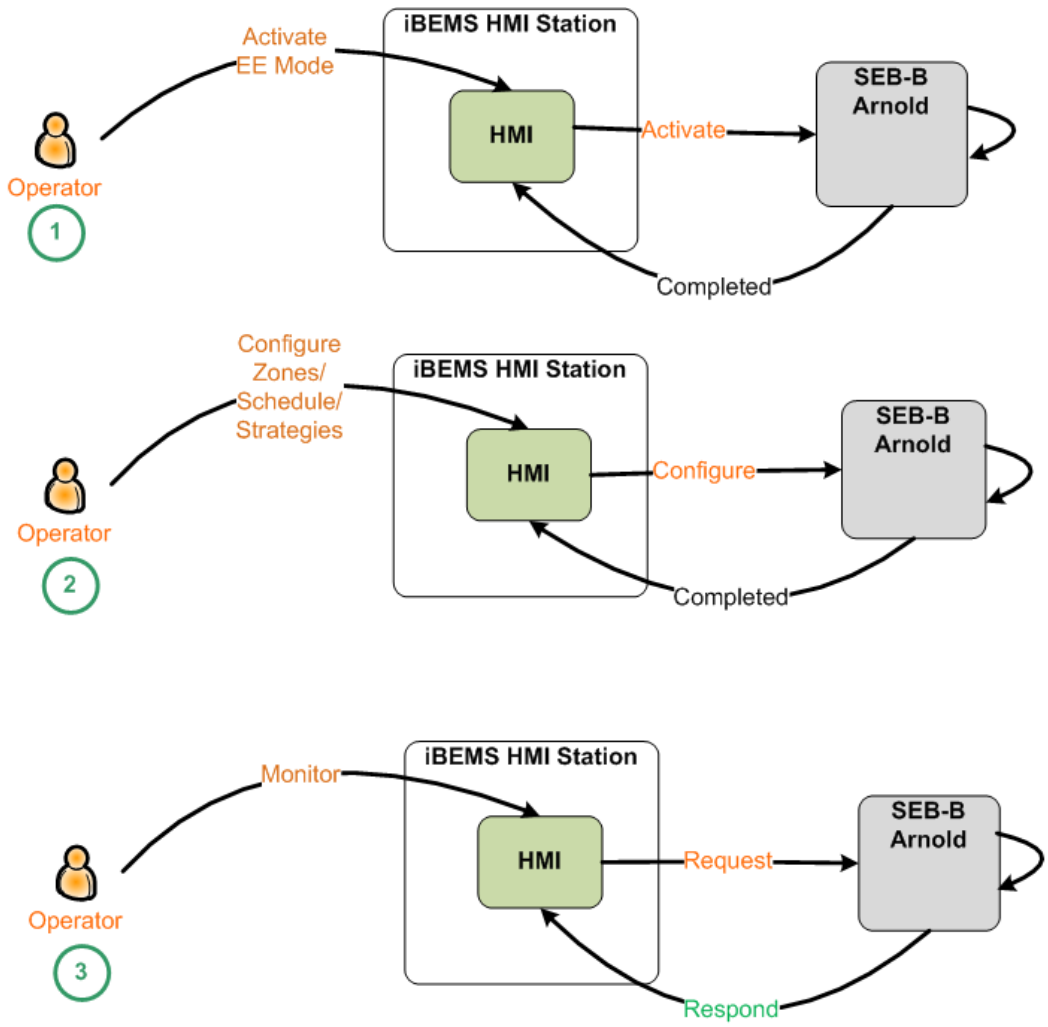


Figure 48: Operational Scenarios of EE Test

5.4.2 DR Test Scenarios

Building: AH, MH, CC, Vandenberg Hall (plug loads)

Duration: 2 hours

Configuration: Instantaneous DR: SEB-AH, SEB-MH, SEB-CC configured with instantaneous strategies for the automation zones based on the peak load demand goal and the base line characterization.
Day-ahead DR: SEB-AH, SEB-MH, SEB-CC configured with day-ahead strategies for the automation zones based on the weather forecast, peak load demand goal and the base line characterization.

Requirements of a facility manager:

- Provide maximum asset availability (HVAC, Zone thermostats, Central Lighting) for the duration of the test

Facility manager control access:

- Can switch the building from normal operation to DR operation (instantaneously, or for the day-ahead event).
- Can monitor zone setting (temperature set points); AHU setting (SAT, SSP), and analyze the changes from a normal operation.
- Can relinquish the Apogee control points back to normal operations at the end of the test or for unforeseen events

Figure 49-**Figure 51** depicts three steps of operational sequence of the iBEMS DR event.

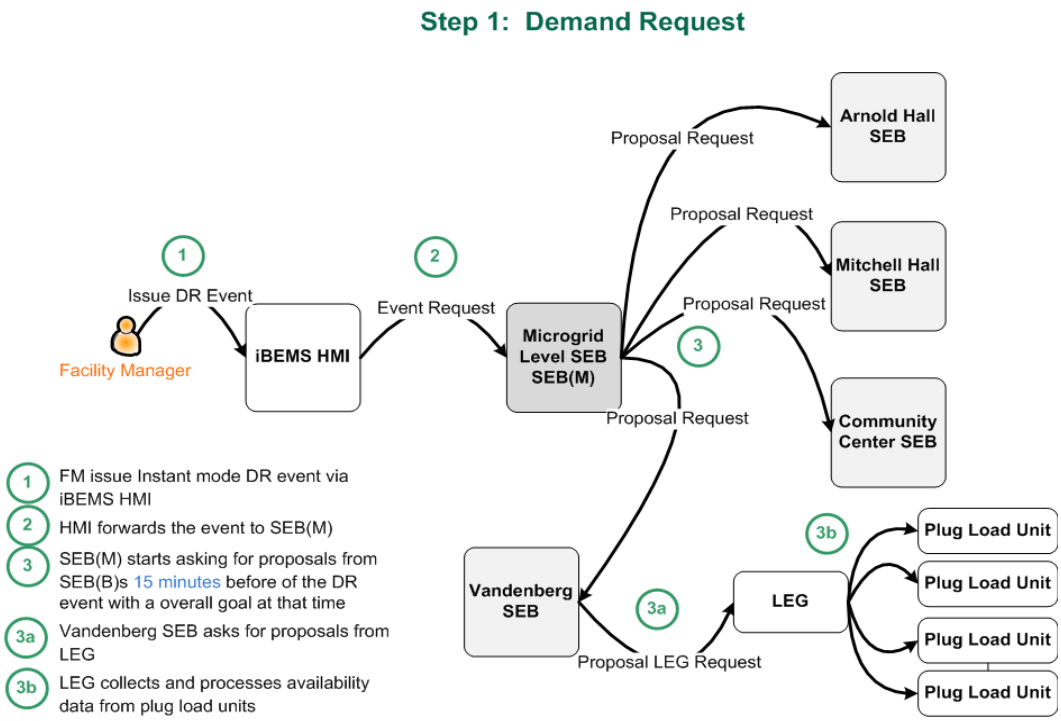


Figure 49: Step 1 of Operational Sequence of the iBEMS Demand Management

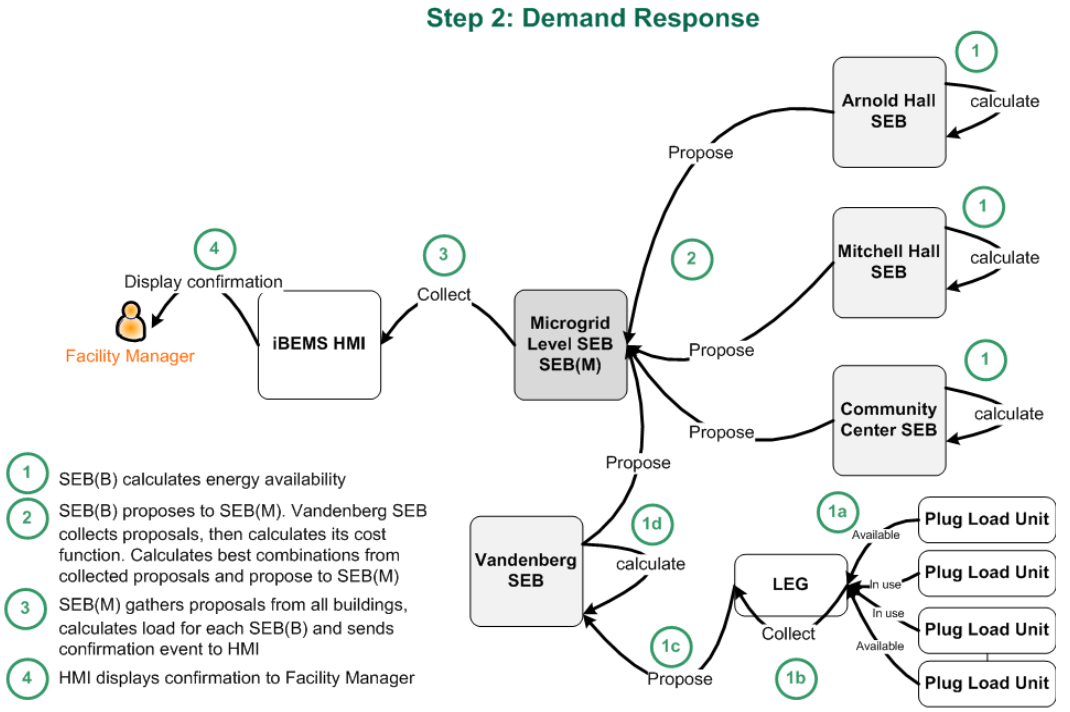


Figure 50: Step 2 of Operational Sequence of the iBEMS Demand Management

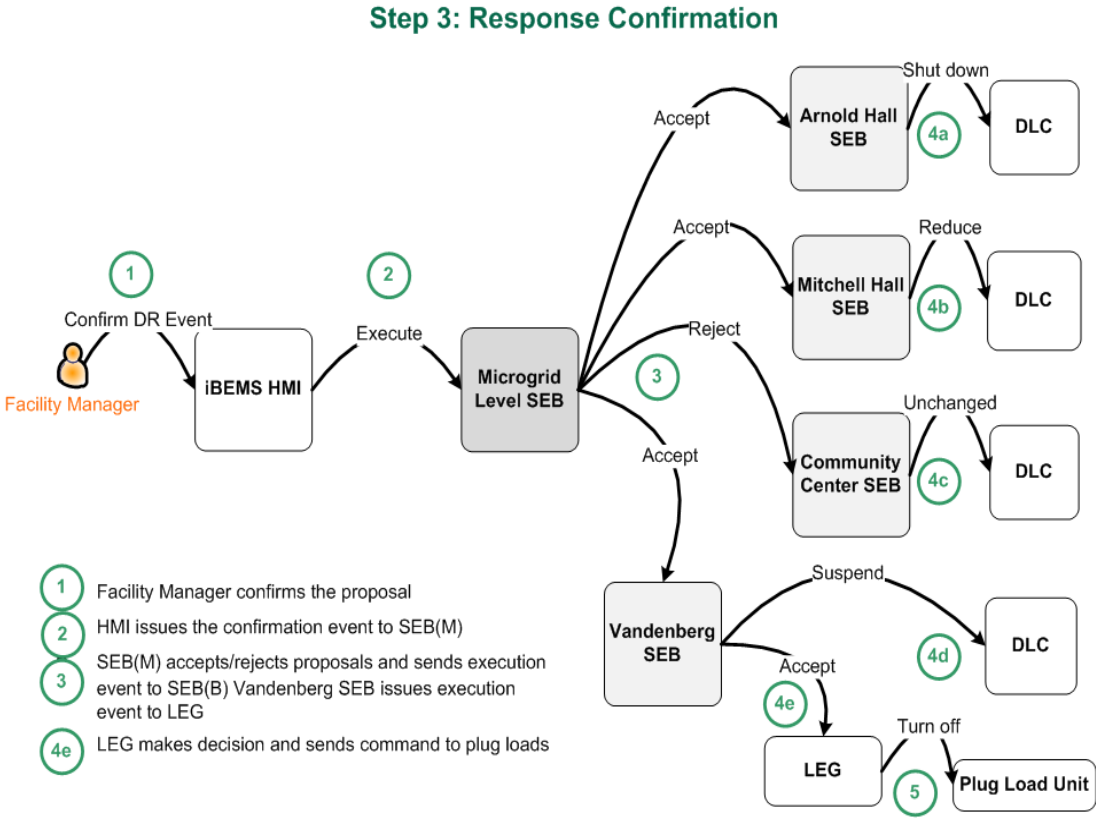


Figure 51: Step 3 of Operational Sequence of the iBEMS Demand Management

5.4.3 Modeling and Simulation

The demonstration team employed EnergyPlus to establish demonstration baseline and to assess EE and DM strategies in the simulation environment. The models allowed the team to analyze how different control strategies, such as lowering lighting, changing set points for walk-in freezers and coolers, and reducing fan speed will affect overall building consumption and room temperatures. For AH, the model helped establish the baseline energy conditions to determine the savings during the demonstration period.

5.4.4 Timeline

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 of September, 2013.

5.4.5 Technology Transfer or Decommissioning

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 12** summarizes the types as well as the anticipated sampling rates.

Table 12: 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

Equipment Calibration: N/A

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.

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. The iBEMS technology is based on Siemens' SEB, which includes functions like - external information acquisition (weather and occupancy), optimal decision making (for both DR and EE purposes) and interoperation with existing BASes. Furthermore, SEB works with Boeing's OSB and extends its energy management capability to a microgrid level.

Four buildings on USAFA campus at Colorado Spring, CO, were selected for demonstration – AH, CC, MH and Vandenberg Hall (plug load control only). Instant DR strategy selection and real-time DR control were tested on all four buildings, and EE measures were designed and tested on AH only. This section of the report covers the performance assessment of the performance objectives defined in Section 3. **Table 13** below provides the summary of the overall achievements of each performance objective based on various EE and DR testes conducted at USAFA.

Table 13: Summary of Performance Assessment

Performance Objective	**Success Criteria**	**Performance Assessment**
Quantitative Performance Objectives		
Building EE optimization reported as building energy use intensity (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 the campus consisting of 14 buildings. 2) Simple payback of 3 years for campus wide iBEMS 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 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.	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 efficiency mode and peak load reduction period	Achievement: 1) Due to USAFA site specific constraints, plug-load were not included in the EE or DR demonstration. 2) The survey results show that there were very few complaints by occupants during EE and DR demonstrations.
System Integration	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 DR mode. — System is able to provide instant load shedding. — System can shape loads to be price responsive.	Achievement: 1) The results of usability survey show that the building management and EMCS team are satisfied with the system performance and overall usability. 2) The EE and Demand Management interfaces were intuitive and easy to use. However, the more explicit strategy implementation information would be beneficial. 3) Day ahead DR events were not conducted. The instant DR events showed that the system is able to provide instant load shedding and can shape loads.

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. Therefore, some conventional energy conservation measures are not involved in the project. For example, installation of energy efficient HVAC equipment (e.g., variable frequency drives) is not considered. Any measures that include building renovation are not considered, such as LED lamps, pipe insulation and window films. Faults in building operation may be identified and corrected during the project, however, they are not considered as EE measures. Consequently, 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 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

Current EE Measures

The mechanical system in AH is equipped with Siemens Apogee BAS with Terminal Equipment Controllers (TECs). Localized and component level optimal controls have been implemented. System level optimizations have also been conducted through several projects. According to a report prepared by Sain Engineering Associates, Inc., in June, 2009:

> "*the lighting throughout AH was upgraded to energy efficient lighting during base-wide lighting projects in 1992 and 1997. The projects replaced existing T-12 fixtures and magnetic ballasts were with T-8 and electronic ballasts in conjunction with occupancy sensor switches by zoned areas. An Energy Conservation and Investment Project (ECIP) was completed in 2006 that: replaced motors over 1 horsepower with energy efficient motors; programmed EMCS start/stop of fans and pumps; reset variable fan static pressure based on damper position; installed CO_2 demand control using CO_2 space sensors for the theatre and ballroom air handlers; and installed wet bulb optimization for the cooling tower.*"

By analyzing the HVAC control programs, we discovered that the following control sequences have been implemented:

- AHUs, except A.AH01, are scheduled for operation from 6:00 to 22:00. A.AH01 is scheduled for 6:00~ 23:00. During nonoperational period, AHUs are turned off – there will be no air conditioning or ventilation.

- A.AH01 implemented Siemens Start/Stop Time Optimization (SSTO) technology. The optimization learns from the history of space thermal dynamics. It adaptively changes the time in advance to turn on AHU before occupancy starts, and to turn it off before occupancy ends.
- A.AH01 has both cooling coil and evaporative unit in cold air duct. When cooling demand is low, the AHU can rely solely on evaporative unit to provide cooling. And when cooling demand is high, it can turn on cooling coil, and use cooling provided by chiller. The switching is done manually.
- When AHUs are in operation, the setpoint for supply air temperature in all AHUs (including cold/hot deck temperature in A.AH01) are changing adaptively based on measured temperature of the space.
- The outdoor air damper control considers about space fresh air requirement (CO_2 based) and use of free cooling (air side economizer). However, it was discovered from trend data that CO_2 based outdoor air control is not functioning well, possibly caused by faulty CO_2 sensors.
- C.AH03 implemented Siemens VAVPlus technology. This technology optimizes fan outlet static pressure setting based on damper positions at variable air volume (VAV) terminal units. The energy consumption by AHU fans is minimized.
- In most zones, air temperature setpoints are 70-74 °F.

Design Constraints

Some constraints were imposed by building operational and instrumental limits, when we designed EE measures.

Hot water system

AH heating is provided by centralized hot water plant. HTHW from the central plant is converted at heat exchangers for domestic hot water, MTHW, and propylene glycol. The hot water volume flow rate and supply/return temperature are either unavailable or unreliable. For this reason, it is very difficult to obtain accurate heating energy consumption. An annual estimate of 8,390 MBTU/year provided by campus facility was used as the baseline heating energy to calibrate simulation model.

Chilled Water System

The building is cooled by two 450 ton centrifugal chillers. However, in the past few years, only one chiller (CH01) was in operation. The chilled water is shared with Harmon Hall, but chilled water flow and supply/return temperature are not available. So it is difficult to estimate AH usage of mechanical cooling. Due to some operational concerns, any change on chilled water system control is prohibited by the site.

Lighting and Plug Load Controls

The power feeds to lighting and plug loads are mixed with those to HVAC components. Therefore, it is difficult to isolate lighting and plug loads from whole building load. During the development

of simulation model, lighting was estimated from designed luminance level and square footage, and plug load level is based on rough survey of total installed power. These data are incorporated in the simulation. Due to some operational concerns, lighting and plug loads are out of scope for participation in this project.

Building Occupancy

The office area in AH has regular occupancy pattern. However, there are large spaces such as ballroom, auditorium and conference room – the occupancy of these spaces is related to events, and does not follow set schedules. These spaces also have considerable thermal inertia, so extensive pre-cooling/pre-heating period is required before each event, to ensure the space temperature at desirable level throughout the event. Although many zones are equipped with occupancy sensors, they are not accessible from BAS. The event calendar became the only source of occupancy information for these spaces. As a result, any occupancy-based control would be based on pre-scheduled occupancy information.

AHU Static Pressure

Static pressure of VAV air handler is set both to ensure adequate air supply and to keep certain building pressure. Reducing static pressure setting of individual air handler is not recommended, because building pressurization change could result in unexpected door sealing.

New EE Measures

Due the above constraints, EE measures that can be tested in addition to the current system will be limited to (a) pre-scheduled occupancy-based shut down of AHUs; (b) pre-scheduled occupancy-based Day/Night mode switch of air distribution terminal units; and (c) room temperature reset. The philosophy behind (a) and (b) is to eliminate unnecessary HVAC load, when the zones are not being used. And (c) is to minimize heating/cooling demand while maintaining a healthy thermal comfort standard. The EE measures for AH are detailed as follows:

AHUs

Auditorium AHUs (C.AH01, C.AH02, C.AH03 and D.AH01) and ballroom AHUs (A.AH07 and A.AH08) are to be turned ON/OFF depending on whether event has been scheduled and whether it is weekday or weekend.

- Event: ON during event plus 2 hours before the first event of the day; OFF, otherwise;
- Non-event weekday: ON 9:00~10:00 (for ventilation); OFF, otherwise;
- Non-event weekend: OFF the whole day.

Other AHUs (A.AH01, A.AH06, A.AH08, A.AH09 and A.AH10) are controlled based on regular office schedule.

- Weekday: ON, 6:00~17:00; OFF, otherwise;
- Weekend: OFF the whole day.

Terminal units

Conference room, banquet room and HAPS lounge (VAVs MB15, 18, 22 and 25~28) are to be switched Day/Night mode based on pre-scheduled occupancy.

- Occupied: Day mode;
- Unoccupied: Night mode;

Other terminal units follow their current Day/Night schedule, which is Day mode during 7:00~22:00 and Night mode, otherwise.

Room Temperature Reset

Instead of aggressive reset toward the upper bound of comfort zone, the room temperature setpoints are to follow the outdoor air temperature (OAT). This method is in line with the adaptive comfort model [9]. Accordingly, the following lookup table, **Table 14**, was implemented.

Table 14: 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 Experiments

The above EE measures are 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, over the period of September 17-20, 2013 (see the **Figure 52-Figure 53**).

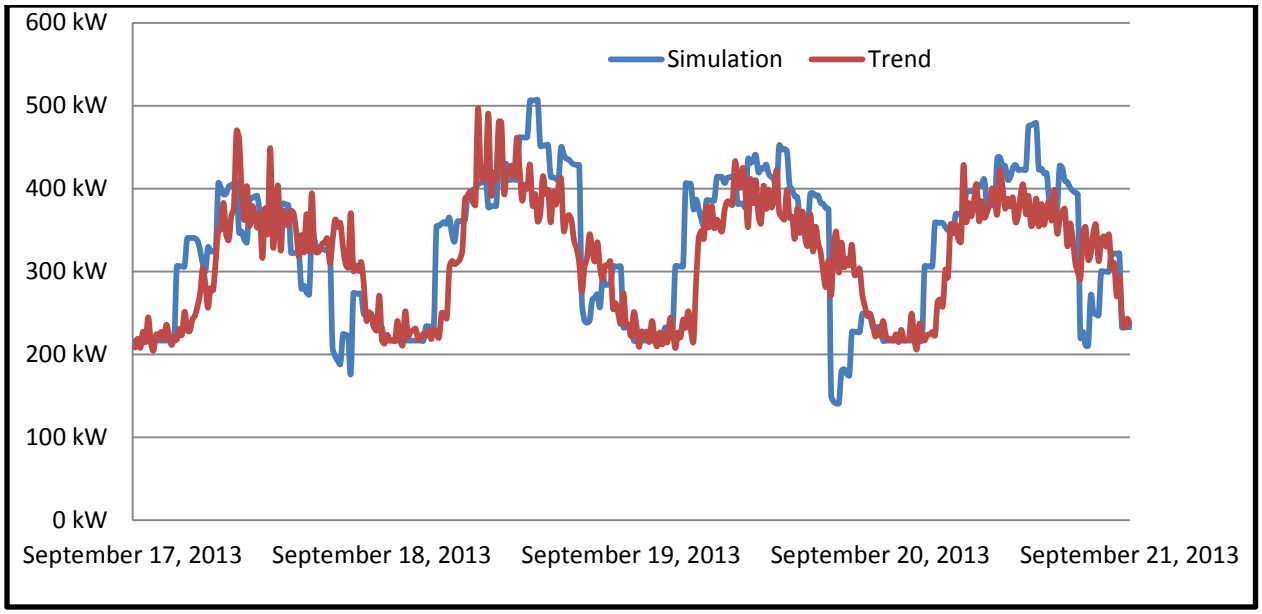


Figure 52: Performance of Calibrated EnergyPlus Model

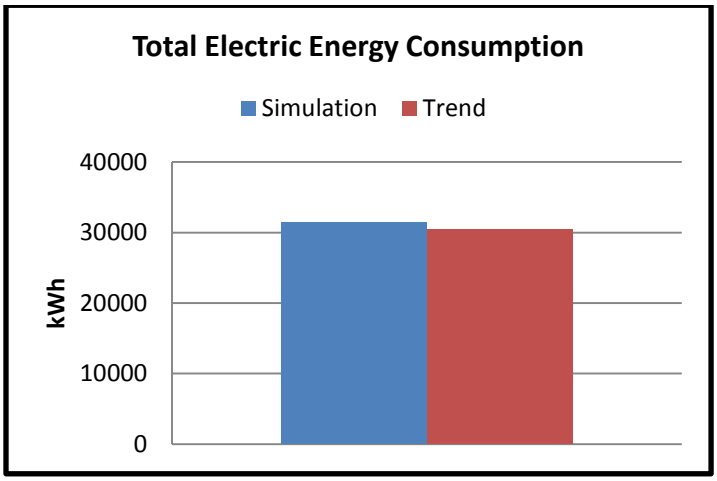


Figure 53: Comparison of Total Energy Consumption for Calibrated EnergyPlus Model

Based on such result, it is concluded that EnergyPlus simulation is able to predict the energy consumption with EE measures implemented. Given the calibrated model that can predict building baseline consumptions, we are able to estimate the annual energy saving by EE measures. We used the recorded weather (NOAA) of the period from January 1, 2013 to November 09, 2013, with average weather (TMY3) of the period from November 10 to December 31, to create the weather input for annual simulation. And information about ballroom and auditorium events through the year of 2013 is extracted from actual event registration calendar. The comparisons between yearly simulations of baseline and EE enabled models, shown below in **Table 15**, estimate that iBEMS EE controls can reduce about 15.7% of electrical energy and 50.6% of heating gas energy. That translates to 32.0% saving of total energy consumption. Considering that the simulation model

predicts annual electricity and heating gas consumption with 2.9% and 7.5%, accuracy respectively, the projected saving is significant.

Table 15: Comparison between Yearly Simulation of Baseline and EE Enabled Models

	Baseline	EE	Savings	% Savings
Electrical	2,512,300 kWh	2,117,548 kWh	394,752 kWh	15.7%
Heating Gas	75,489 Therms	37,316 Therms	38,174 Therms	50.6%
Total	4,724,677 kWh	3,211,166 kWh	1,513,512 kWh	32.0%

Further break down by end uses shows the largest saving is achieved by reduced fan energy and heating energy (see the plot shown in **Figure 54**).

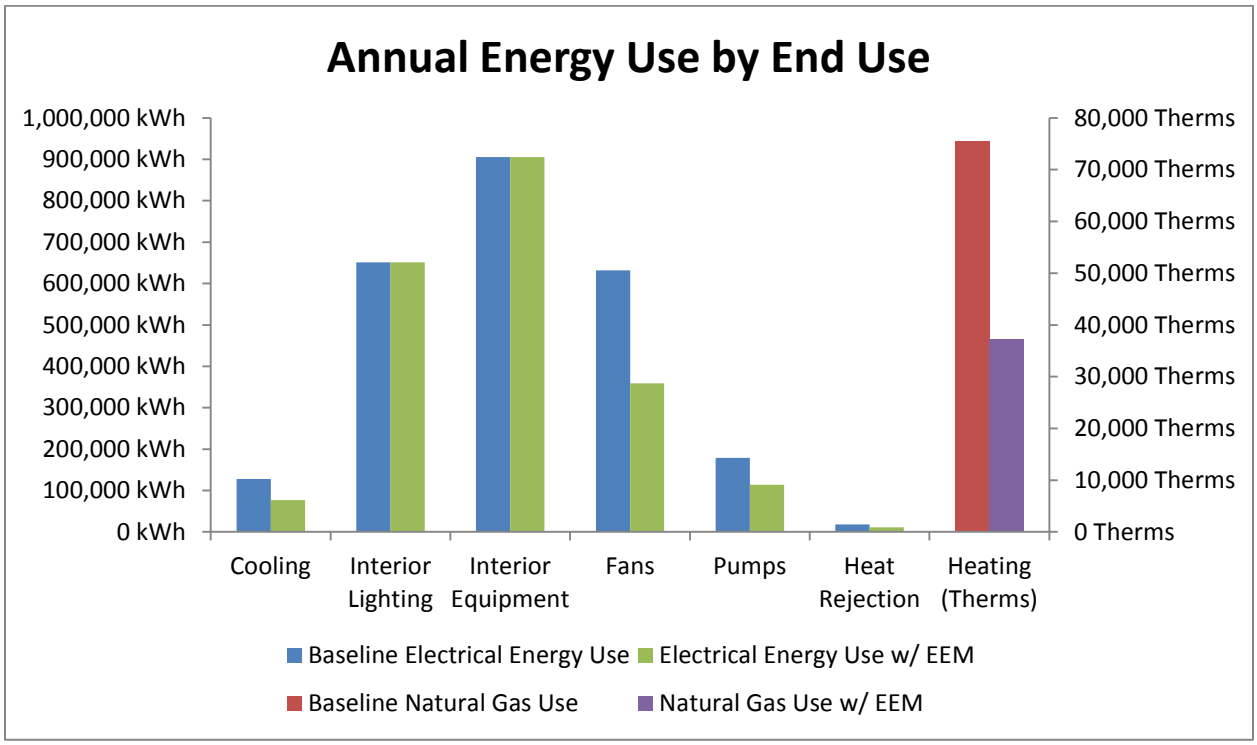


Figure 54: Annual Energy Use Breakdown for Baseline and EE Enabled Models

6.1.3 EE Tests and Result Analysis

Implementation Details

The EE strategies were implemented in SEB at AH and were tested for both heating and cooling seasons.

AHUs

To implement EE strategies for AHUs, two new control points were introduced for each AHU, i.e. SYS point and EE point, and new control logics were added to the control panels. The new control logics will:

- When EE = 1, suspend SEB control, and reinstate original control for AHU ON/OFF
- When EE = 2, suspend original control, and let SEB control AHU ON/OFF
  - When SYS = 1, SEB turns AHU (fans) ON;
  - When SYS = 2, SEB turns AHU (fans) OFF;

The values of SYS and EE points are commanded from SEB, according to occupancy schedule. The rules are summarized below in **Table 16**.

Table 16: Rules for Determining SYS and EE Points Using Occupancy Schedule

Point	During Event	Day/Night	OAT_{min}	OAT_{max}	Value
EE	Yes	-	0	120	2
	No	Day	0	120	2
	No	Night	0	120	1
SYS	Yes	-	0	120	2
	No	Day	0	120	1
	No	Night	0	120	1

Terminal units

SEB directly commands on Day/Night mode control points on VAV boxes MB15, 18, 22 and 25~28. The rules are based on occupancy schedule, as shown below in **Table 17**.

Table 17: Rules for Determining Day/Night Modes Using Occupancy Schedule

Point	During Event	Day/Night	OAT_{min}	OAT_{max}	Value
DAY.NIGHT	Yes	-	0	120	0
	No	-	0	120	1

Room Temperature Reset

The room temperature is controlled by many room temperature setpoints, each of which controls one or more zones. Instead of commanding all setpoints separately, a new global room temperature control point is introduced, i.e., VAV.CTL.STPT. New control logic is programmed in Siemens Apogee BAS to propagate the value of VAV.CTL.STPT to all room temperature setpoints. **Table 18-Table 19** show the settings for this point for cooling and heating seasons, respectively.

Table 18: Cooling Season Room Temperature Reset Table

Point	During Event	Day/Night	OAT_{min}	OAT_{max}	Value
VAV.CTL.STPT	-	-	0	60	70
	-	-	60	65	72
	-	-	65	70	74
	-	-	70	75	76
	-	-	75	80	78
	-	-	80	120	80

Table 19: Heating Season Room Temperature Reset Table

Point	During Event	Day/Night	OAT_{min}	OAT_{max}	Value
VAV.CTL.STPT	-	-	-100	10	68
	-	-	10	20	68.5
	-	-	20	30	69
	-	-	30	40	69.5
	-	-	40	50	70
	-	-	50	60	71
	-	-	60	120	72

Test Result - Implementation

In total 8 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.

AHUs

During the tests, SEB operation was recorded by internal logging system. The values that were commanded, as well as timestamps of the commands can be retrieved in post analysis. SEB log can also be double verified by Apogee trend data. The following two figures, **Figure 55-Figure 56**, show the EE strategy implementation on auditorium and ball room AHUs – C.AHU01 and A.AH07, respectively.

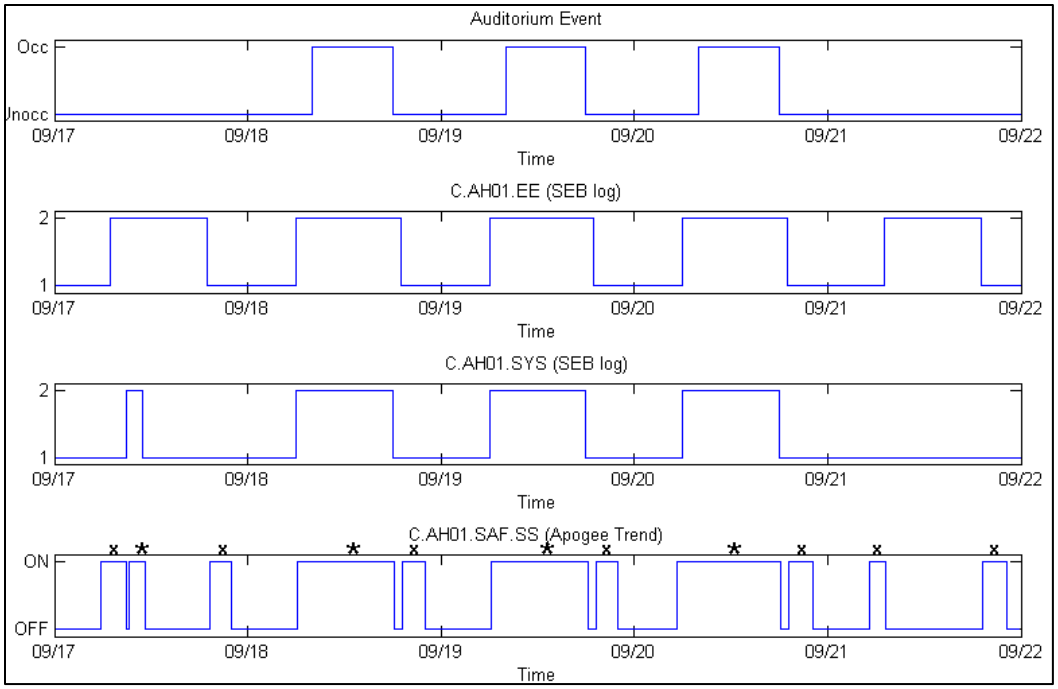


Figure 55: SEB Log for EE Strategy Implementation in C.AHU01

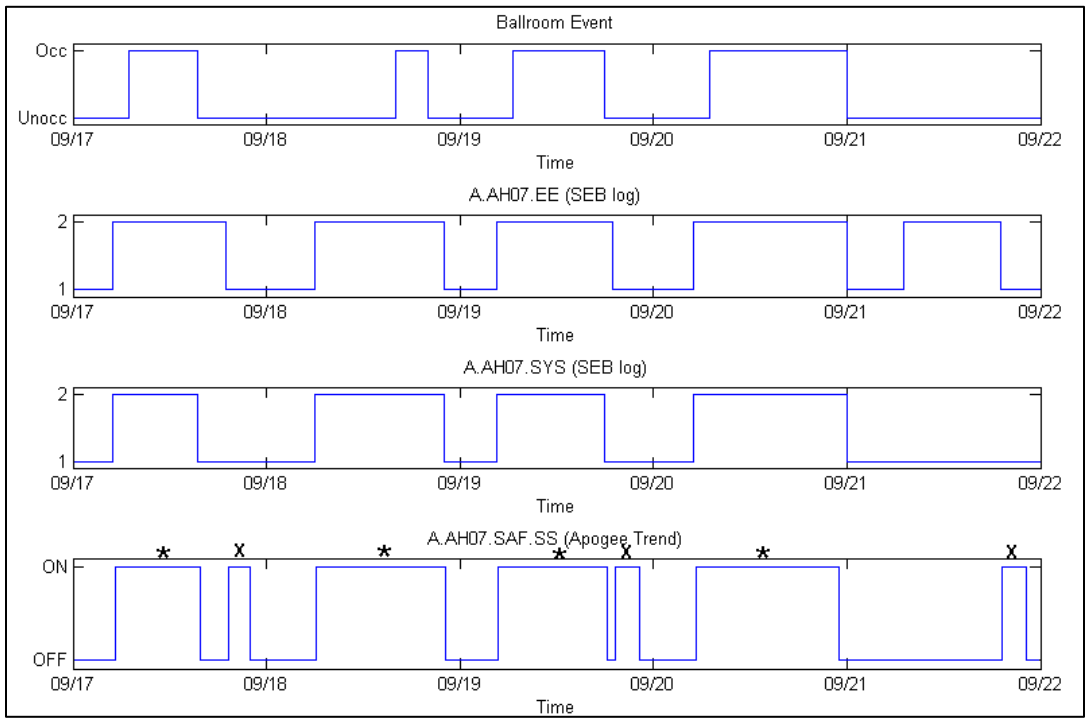


Figure 56: SEB Log for EE Strategy Implementation in A.AH07

SEB log shows that SYS=2 commands were issued 2 hours before each event, and SYS=1 commands were sent right after each event – as expected. Apogee trend data proves that those commands went through and successfully turned AHUs ON or OFF (marked by "*" sign in the figures). Two things need to be pointed out: (1) auditorium did not have event in 09/17. The EE

strategy is to turn AHU ON for two hours in the morning, to keep air fresh. This goal was achieved according to Apogee trend. (2) AHUs were turned on early in the mornings and turned off late in the evenings (marked by "x" sign in the figures). This was because SEB defines Night starting from 19:00, however, current control logic switches to Night mode at 22:00. If there is no event going after 19:00, SEB will reinstate current control logics (set EE=1) at 19:00. Current control logics will keep AHUs ON until 22:00. Similarly in the morning, SEB defines Day starting from 7:00 but current logic switches to Day mode at 6:00. Due to time constraint, we were unable to test with correct Day/Night definition. Simple estimate can be conducted – assume SEB Day/Night definition agrees with Apogee's definition, then when there is no event, ballroom and auditorium AHUs will be OFF during 6:00 – 7:00 and 19:00 – 22:00. It translates to reduction of 58.8 kW loads for additional 4 hours each day, which is a significant saving of energy.

It is also evidenced that, in 09/21, which was weekend and there was no event in auditorium and ballroom, AHUs were turned off most of time. In contrast, they should have been ON during the day, according to the current control logic.

Terminal Units

The **Figure 57** figure shows the EE strategy implementation on the HAPS lounge terminal unit – VAV.MB25. HAPS lounge had events 17:00~23:00 every weekday. EE strategy turned the terminals to Day mode during the events and kept Night mode otherwise. The current control logic would have kept terminals in Day mode 6:00~23:00 every weekday.

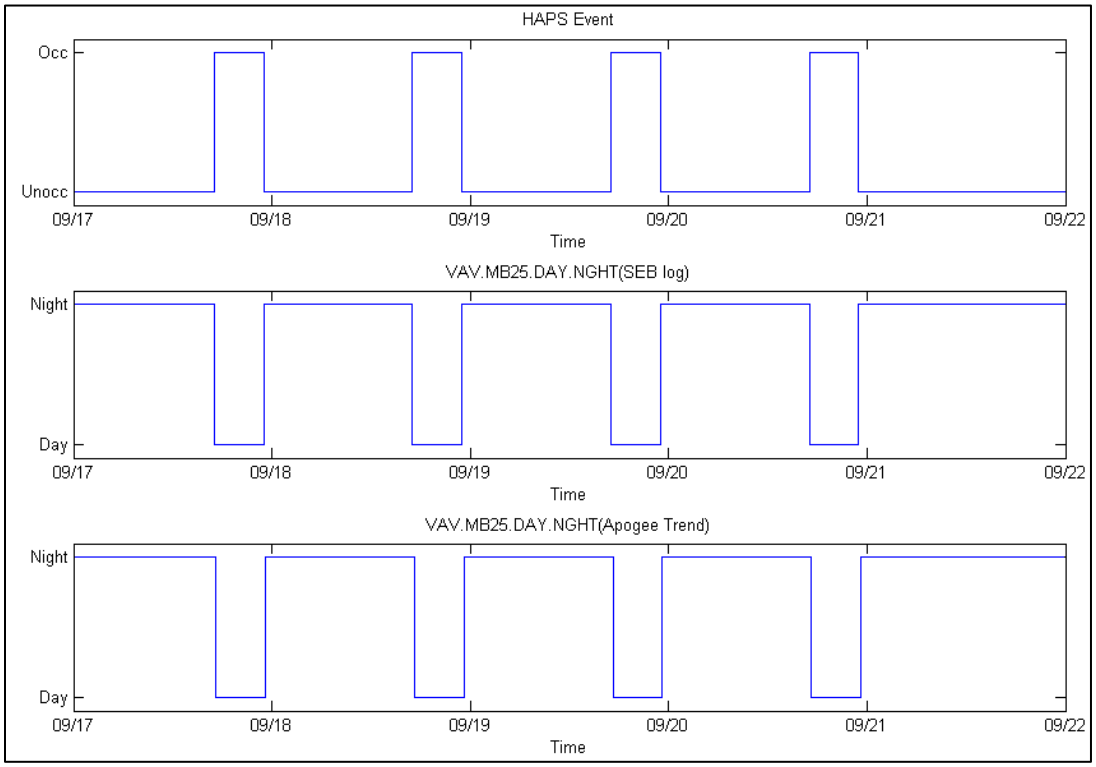


Figure 57: SEB Log for EE strategy Implementation on the HAPS lounge terminal unit – VAV.MB25

Room Temperature Reset

In two attempts, we tried to implement weather based room temperature reset. The following graph, in **Figure 58**, presents the value commanded by SEB on room temperature setpoints versus the outdoor temperature at the time. Apparently, the setpoint value follows the intended rule. However, Apogee trending revealed that SEB command did not reach each terminal unit. It was discovered that the program that is responsible for propagating the SEB command to terminal units was compromised by another ongoing project. Unfortunately, due to time constraints, we were unable to conduct another test.

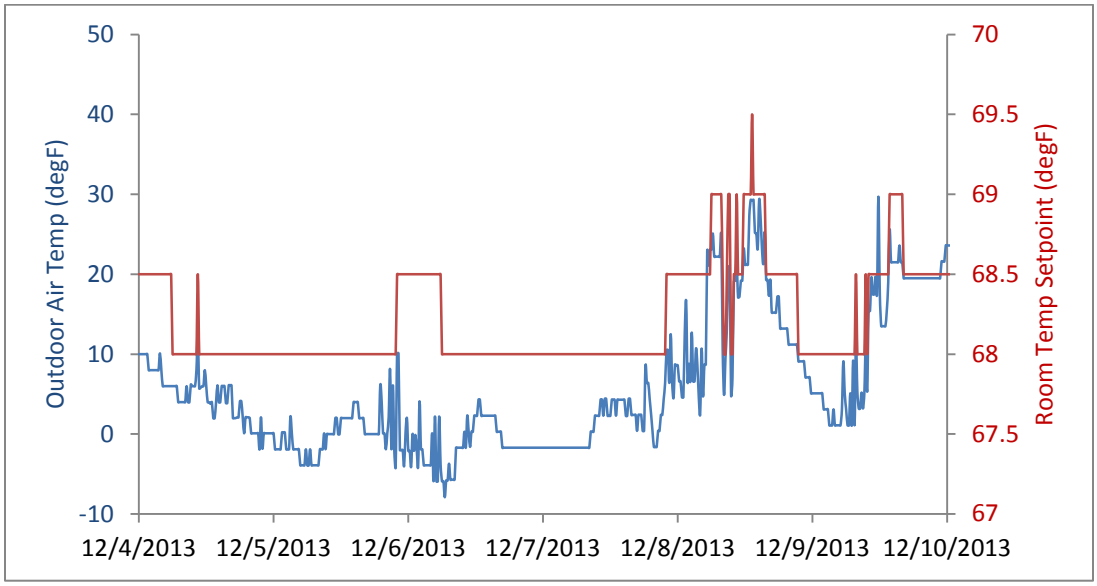


Figure 58: SEB Log for Room Temperature Setpoints

Test Result – Energy Usage

Submeter Reading

EE tests have been conducted in both heating and cooling seasons. The following graphs, in **Figure 59**-**Figure 60**, present the submeter measurement during heating season EE test (Apr. 1-7, 2013) and cooling season test (Sep. 17-20, 2013), in comparison with simulation determined baselines. Total of about 4% and 7% savings of electric energy were observed in the two periods, respectively.

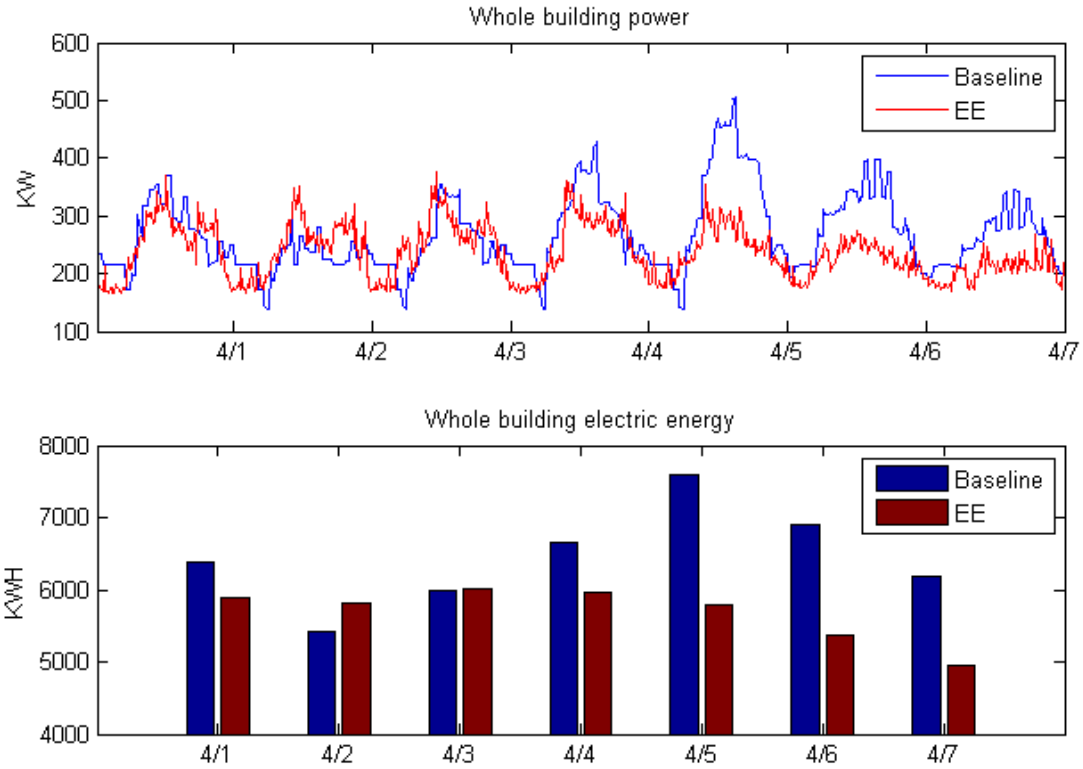


Figure 59: EE Tests Results for Heating Season Test (April 1-7)

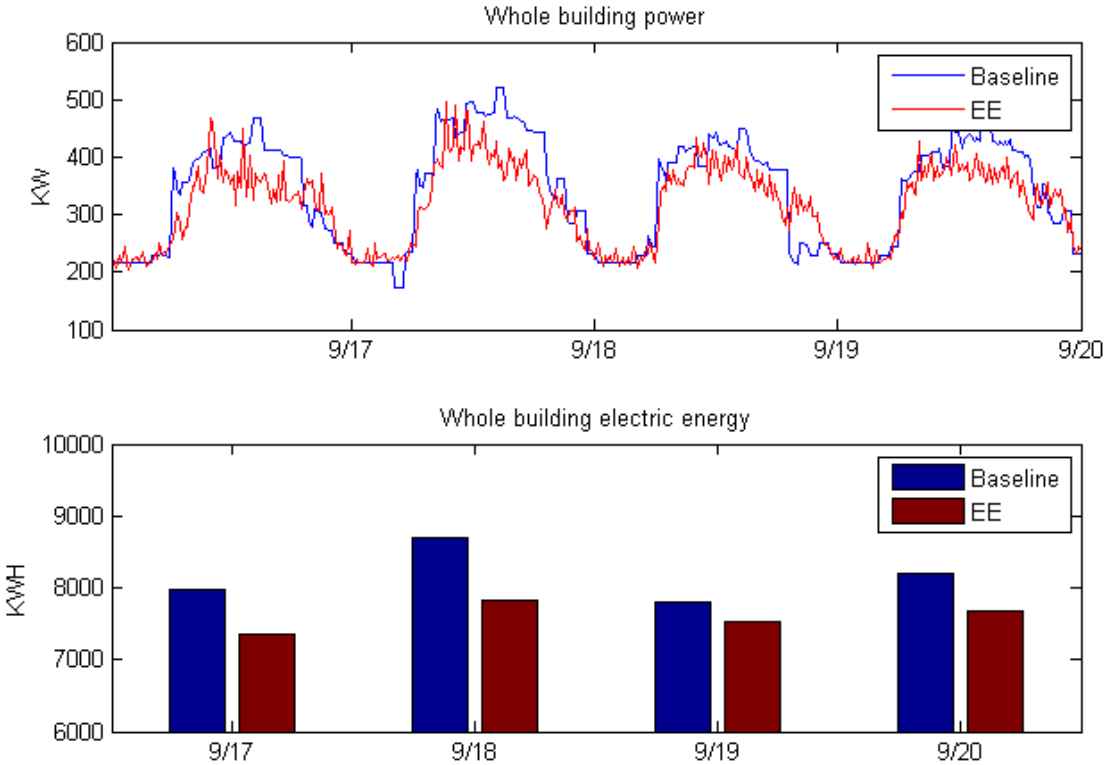


Figure 60: EE Tests Results for Cooling Season Test (September 17-20)

Data logger

The project team installed data loggers to record the energy draws by individual feed panels. The **Figure 61** below compares the energy consumption of panel DTM29 in test period with baseline. Panel DTM29 provides electricity to auditorium AHUs (i.e., AHU1C and 2C), together with some other uses. The baseline is determined by averaging the consumption over the weeks before and after the test. Margin of error is also marked in the chart. Clear 230~300kWh reduction was observed for each day. This reduction agreed very well with the duration and magnitude of auditorium AHU turning off, commanded by iBEMS EE mechanism.

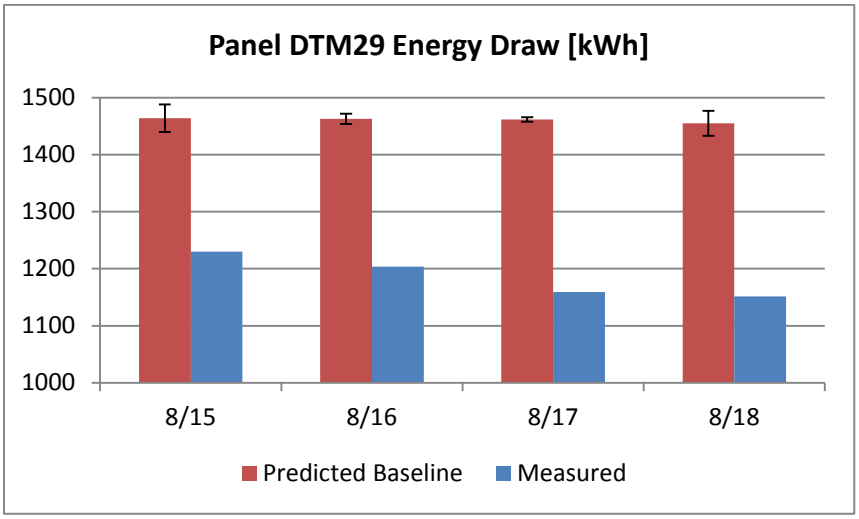


Figure 61: Energy Consumption of Panel DTM29 in Comparison with Baseline

Chiller Energy Consumption

We were able to measure chiller energy consumption. The blue bars in the graph below in **Figure 62** show the chiller energy consumption during each day of test (cooling season). And the red bars are consumptions predicted by a simple regression model, which considers chiller consumption as a polynomial function of daily average air temperature. The margin of error is also marked. This result shows that chiller energy was reduced by SEB EE measures, especially in the first two days of test. It agrees very well with the conclusion made by comparing measured whole building energy with simulated value.

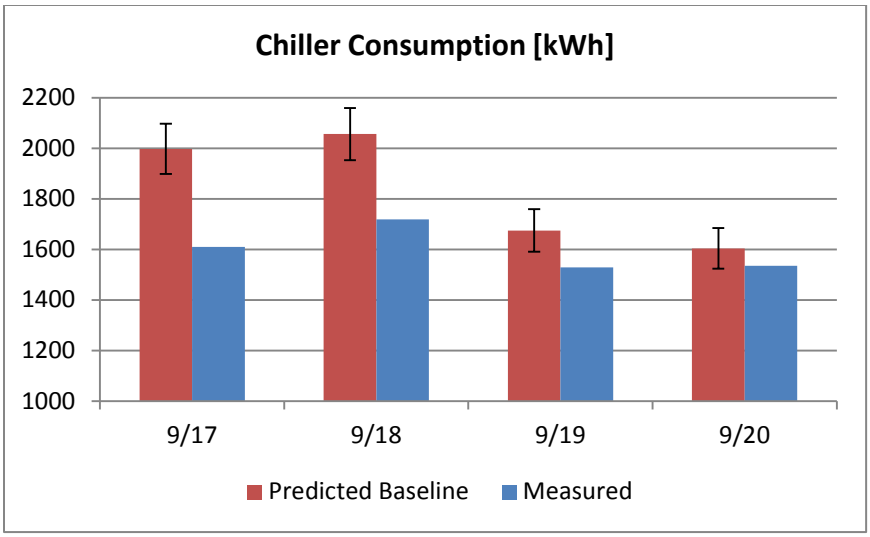


Figure 62: Chiller Energy Consumption Compared with Baseline

6.1.4 Discussion and Conclusion

For various reasons, the implementation tests of EE measures did not achieve complete success. However, based on the analysis on test records, the occupancy driven switching has reduced the operation hours of auditorium, ballroom AHUs and some large space terminal units. The following **Table 20** summarizes the operation time reduction in the cooling season test (September 17-20). Although, due to the Day/Night definition issue mentioned previously, we did not reach the reduction target, shown in **Table 21**, it was evidenced that fan energy and chiller energy were reduced significantly (see section 6.1.3, "Data logger" and "Chiller energy consumption"). Fan energy saving were achieved by reducing air volume demand, and chiller energy saving were achieved by reducing cooling demand. It is reasonable to believe that if the Day/Night definition issue was resolved (which would be technically easy), even greater energy savings can be expected from the fans and chillers.

Table 20: Operation Time Reduction by Occupancy Based AHU/Terminal Switch (Cooling Season Test)

		Operation Time (hours)			**Fan Energy Saving (kWh)**	
		Current	Target	Observation	Target	Observation
AHU	Auditorium	80	38	55	1688	1005
	Ballroom	82	61.5	67.5	381	270
Terminal	HAPS Lounge	68	24	24		
	Conference Room	64	14.5	30.5		
	Banquet Room	64	50	62		

The breakdown of energy saving into component levels is given by the following table:

Table 21: Energy Saving Breakdown by Occupancy Based AHU/Terminal Switch (Cooling Season Test)

Component	Observed Saving (kWh)	Target Saving (kWh)
Auditorium AHU	1005	1688
Ballroom AHU	270	381
Chiller	941	941
Miscellaneous	59	59
Total	**2275**	**3069**

In **Table 21**, miscellaneous items include pumps and AHU-1A fan. The AHU-1A fan energy was affected by occupancy driven terminal unit switching. The measurements of these two (pumps and AHU-1A fan) savings are not available; therefore observed saving for miscellaneous items was obtained by subtracting the Auditorium AHU, Ballroom AHU, and Chiller savings from total savings. Target savings were obtained by replacing the observed AHU savings with the target AHU savings that were obtained assuming no Day/Night definition issue. The **Table 22** below summarizes the energy saving obtained in heating/cooling season tests, as well as the projected annual savings.

Table 22: 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%

Note that the baseline electricity usages in the above table were obtained by simulation whose monthly prediction error is 7.2% and annual prediction error is 2.9%. We can only conclude that saving in heating season test (11.7%) was significant, whilst the one in cooling season test (7.0%) was not significant. If target value, rather than observed one, is used, then the saving will be 9.4%, which is significant. The above table does not include gas calculation for the two tests, and no total energy calculation, either because the accurate measurement of natural gas consumption during tests was not available.

It is necessary to emphasize that the savings we achieved in both heating and cooling season tests were lower than the projected annual saving. One reason could be because both tests did not successfully implement the full set of EE measures, as has been discussed before. And another

explanation could be the weather and occupancy profiles during the tests were not typical. This is true, as the presented two tests were conducted close to the end of heating season and cooling season. The heating and cooling demands were low compared to typical days in each season. Also May, June and July are summer recession periods of USAFA. The campus sees less cadet activities during these months. iBEM's occupancy driven measures would have achieved more saving during the period, however, the cooling season test presented here was not conducted in summer recession time.

Although, due to time constraints and various issues in field tests, we did not reach the energy saving targets in the tests, our results show that it is not far away from resolving all the issues and meeting the goal. The simulation experiment demonstrates with current EE measures, we are able to save 15.7% electrical energy and 32.0% of total energy annually, which translates into building EUI 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. Furthermore, the baseline consumption of the subject building has already been optimized by previous projects (EE measures currently in place have been discussed in Section 4.2); plus constraints imposed by the site prohibit several common energy saving strategies (discussed in Section 4.3). 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.

Confidence Interval of Annual Electrical Energy Saving Estimate

iBEMS project adopts two simulation models to estimate the saving of electrical energy. The two models are the baseline (BL) model and the EE model. Models are calibrated towards MAPE<15% of 15-minute interval metered building power consumption, for some periods (calibration periods). For BL model, for calibration period from July 25 to August 13, the 15-minute MAPE was 11.0% and daily MAPE was 3.7%. For EE model, for calibration period from September 17 to September 20, the 15-minute MAPE was 13.9% and daily MAPE was 4.8%. The annual energy saving is calculated by comparing annual consumptions predicted by the models. As shown in **Table 22**, the total electrical saving was 15.7% or 394,752 kWh.

Assume that, for both simulation models, prediction error is identical and independently distributed with normal distribution $\mathbf{N}(0,\sigma_k^2)$, where k={BL, EE}. This can be validated by error histograms shown in **Figure 63**. For these normal distributions of model error, the mean μ and standard deviation σ for BL model are 0.6 kWh and 11.5 kWh, respectively. Similar values for EE model are -3.6 kWh and 14.2 kWh.

Using simulation models, annual consumption, *Y*, can be obtained as:

$$Y = \sum_T y_i = \sum_T (\hat{y}_i + e_i) = \sum_T \hat{y}_i + \sum_T e_i = \hat{Y} + \sum_T e_i$$

where, y_i and $\hat{y}_i$ are the 15-Minute consumption and its estimated value. $\hat{Y}$ is the annual consumption predicted by the simulation. Note that, based on "identical and independently distributed" assumption of error, the summed error term $E = \sum e_i \sim \mathbf{N}(0, N\sigma_k^2)$, where N=8760*4=35040. Therefore, the σ of annual consumption error is 2161 kWh and 2660 kWh for BL and EE model respectively.

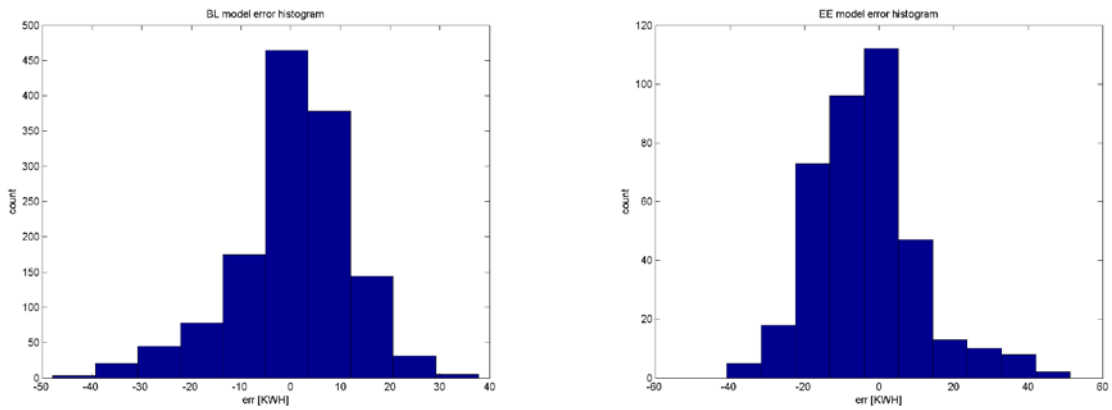


Figure 63: Model Error Histogram (15-minute kWh)

Annual saving Z is calculated as:

$$Z = Y_{BL} - Y_{EE} = (\hat{Y}_{BL} - \hat{Y}_{EE}) + (E_{BL} - E_{EE})$$

The error term $E_Z = E_{BL}$-E_{EE} ~ **N**(0,Nσ_{BL}^2+ Nσ_{EE}^2). Then the standard error of annual kWh saving is 3,427 kWh. The confidence interval of Z is obtained by:

$$\hat{Z} \pm tS.E.(Z)$$

where, t is the critical value. For 95% confidence, t = 1.96.

Hence, $tS.E.(Z)$=1.96*3,427 kWh=6,717 kWh. Therefore, 95% confidence interval of annual saving is 394,752±6,717 kWh (i.e., 15.7±0.3%).

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 graphs below in **Figure 64** to **Figure 66** show some typical demand curves for the three buildings 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. For e.g. for AH and MH the peak demand can occur at any time between 8:00am to 10:00pm. Similarly for CC the peak demand can occur anytime between 9:00am to 3:30pm. Hence, there is no fixed peak load time at the aggregated level either, as shown in Figure 79. Another observation is 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. This is due to the randomness nature of the high percentage process load in these buildings. The demand variations make it impossible to estimate an accurate baseline for these buildings and pinpoint the occurrence and magnitude of the aggregated peak demand. Thereafter the peak demand reduction objective of this project was reformulated as reduction of the aggregated demand with reference to the demand at 15 minutes prior to the start of the DR period. The DR strategies were designed to reduce the aggregated

electrical demand at the start of the DR period (pre-DR) by 15-30% and maintain the reduction through the DR duration.

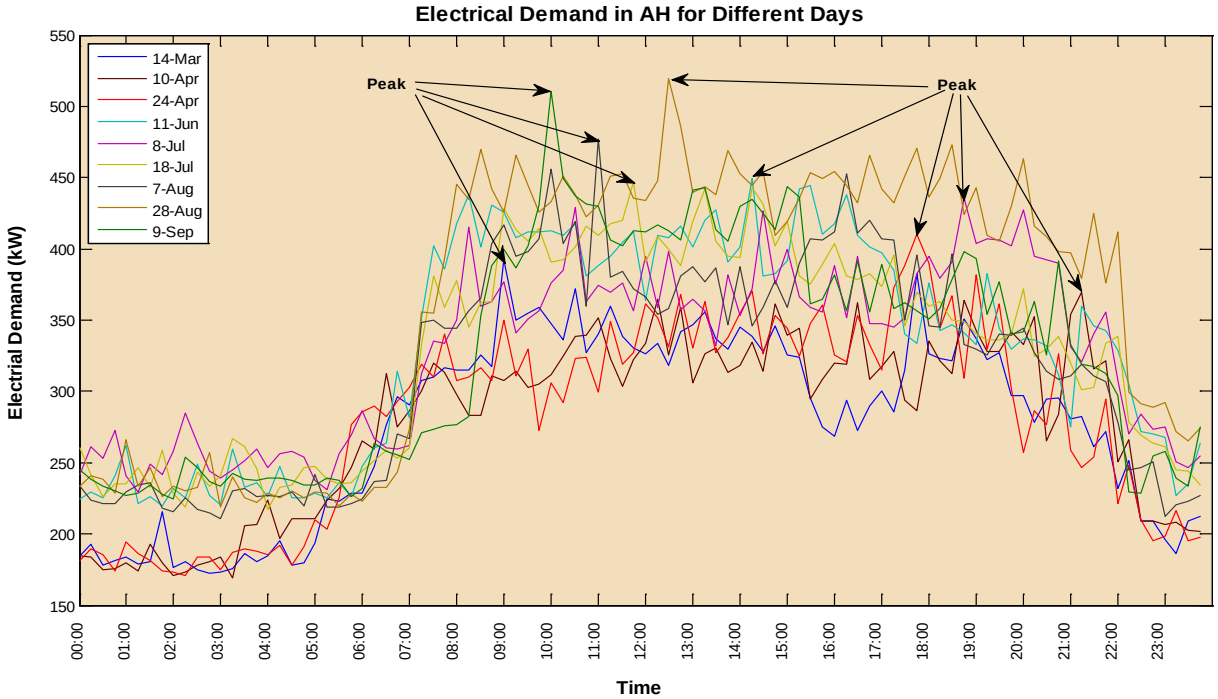


Figure 64: Demand Curves for AH

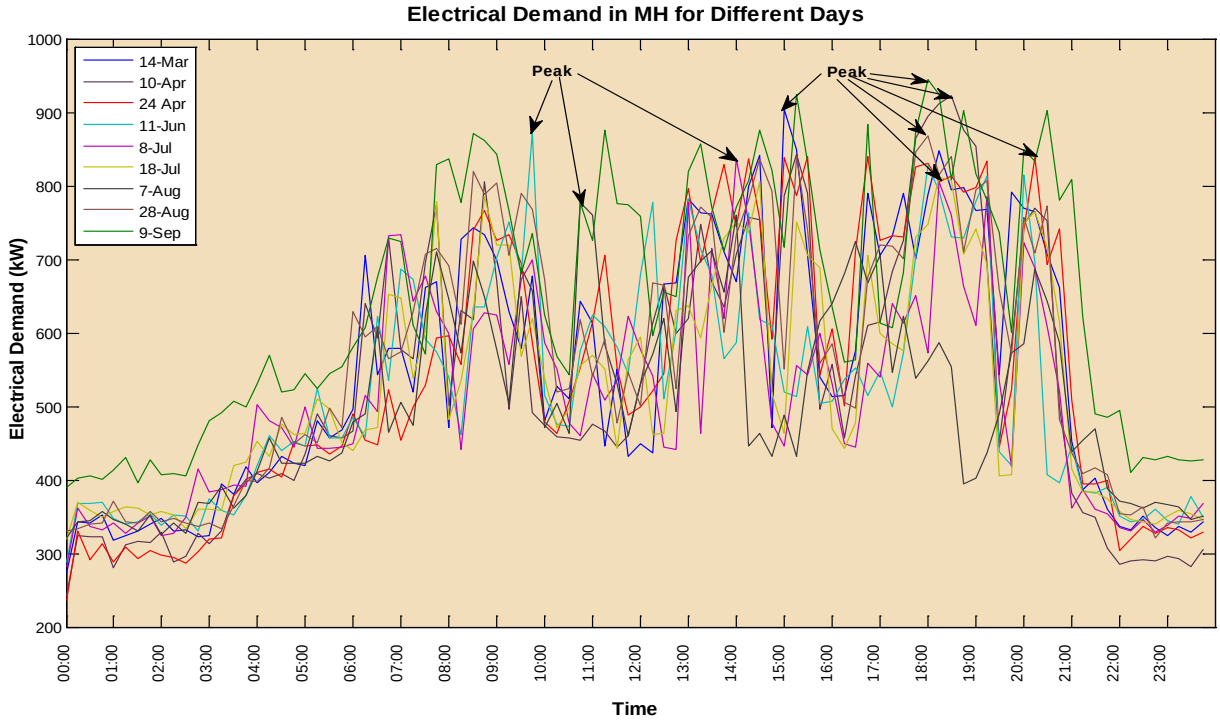


Figure 65: Demand Curves for MH

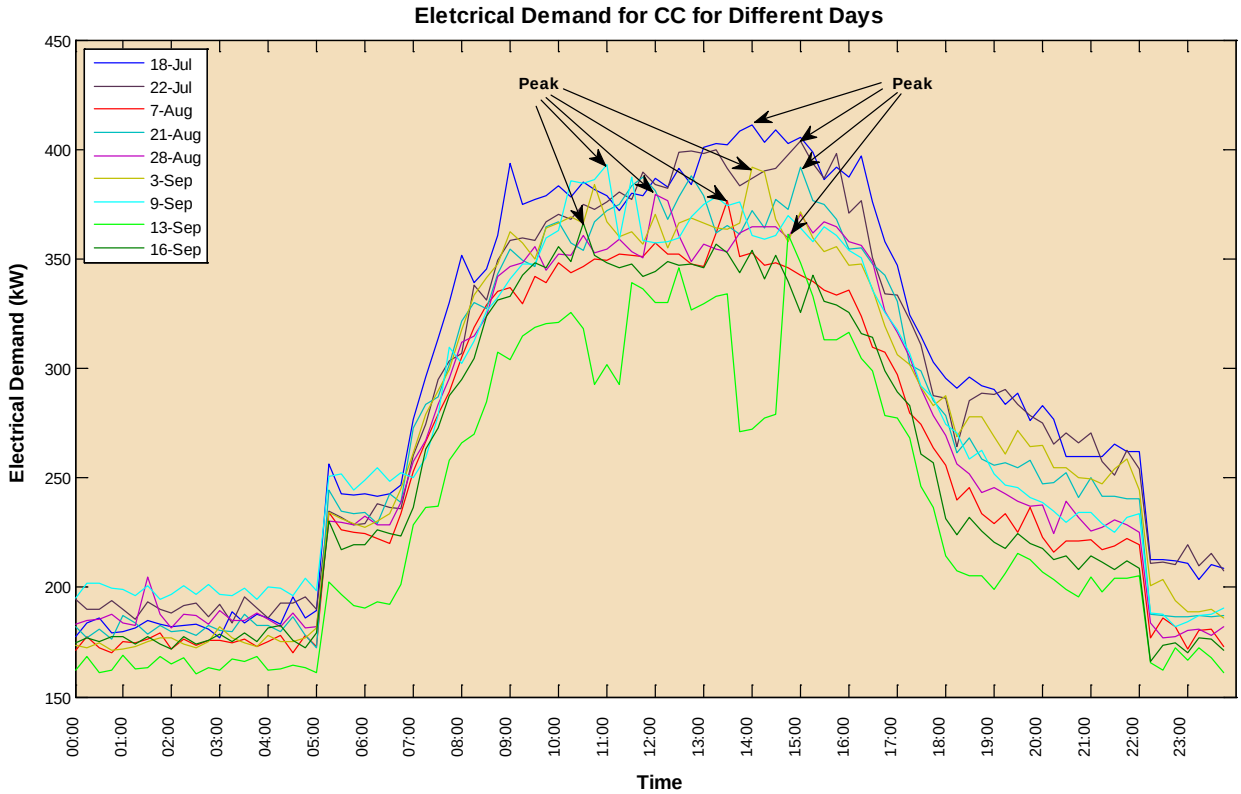


Figure 66: Demand Curves for CC

6.2.1 Baseline Approach

As explained in Section 5.2.3, the EnergyPlus model for AH was used to determine the baseline. For CC and MH, an analytical approach based on weather pattern matching and with additive adjustments was developed and used to establish the baseline.

Figure 67 shows the average weekday load profile for AH. **Figure 68** shows the peak load profile, i.e., the peak values on different days, including weekends between 7/17-9/28. **Figure 69** shows the weekly peak load variation between the same time periods. As it can be seen from this graph, AH weekday peak load varies between 380kW and 580kW. **Figure 70** shows the frequency of the peak occurrence at different time intervals for AH. According to this graph there are 14 instances of peak occurrence between 11-12pm. But in general the electrical load peak can occur, with a very high probability, anywhere from 9:00am to 3:00pm. There are some instances of peak occurring after 6:00 pm and these instances reflect the after hour activities at AH.

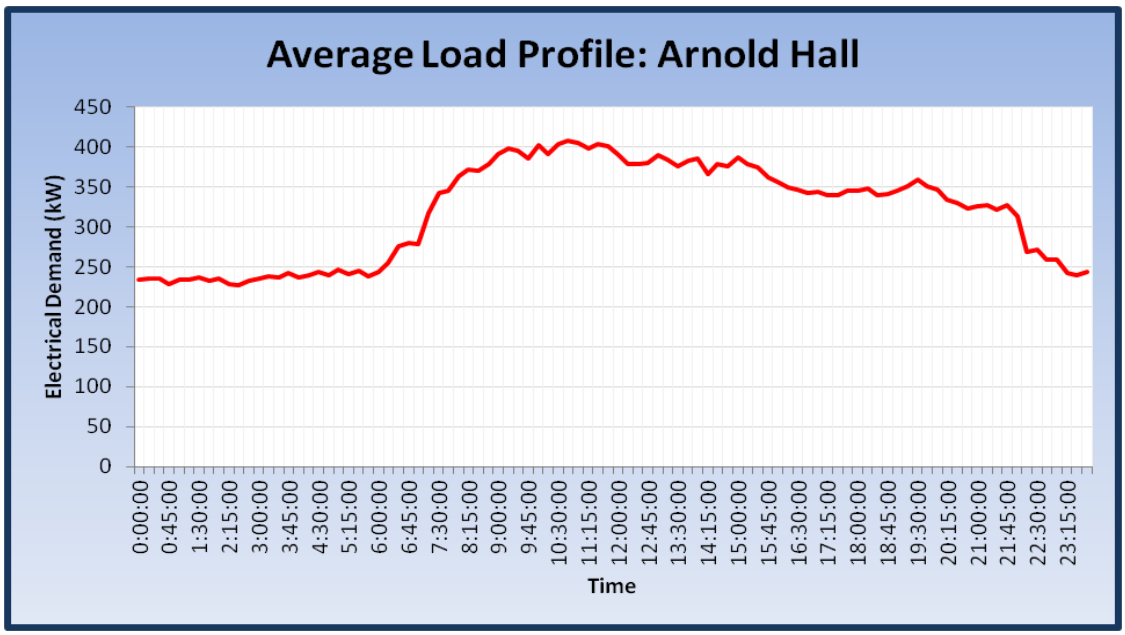


Figure 67: Weekday Load Profile: AH

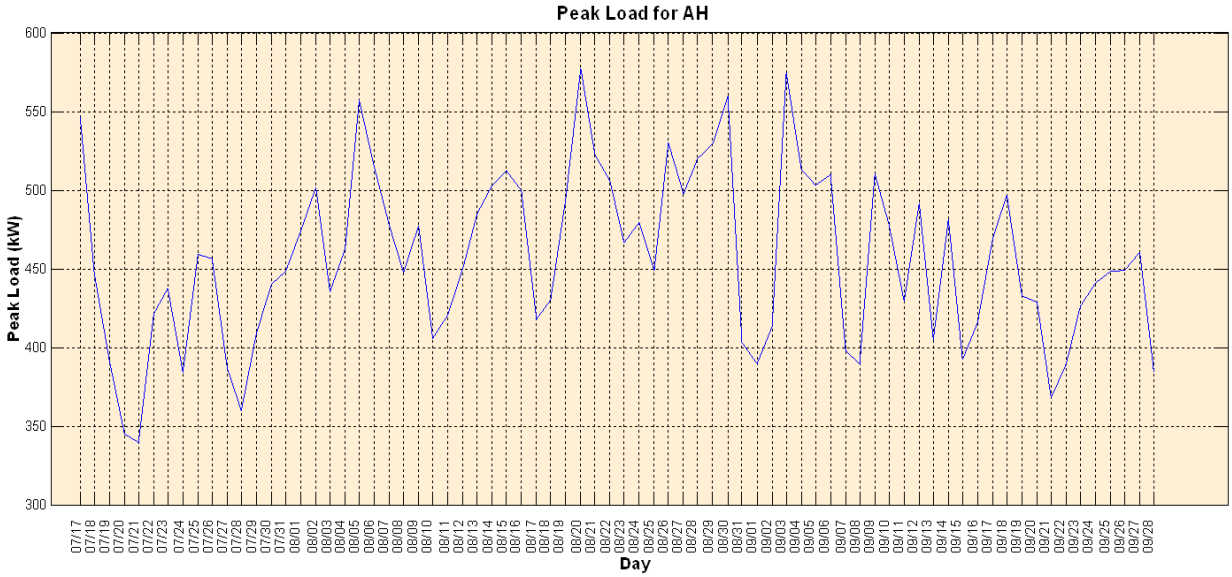


Figure 68: Peak Load Profile for AH

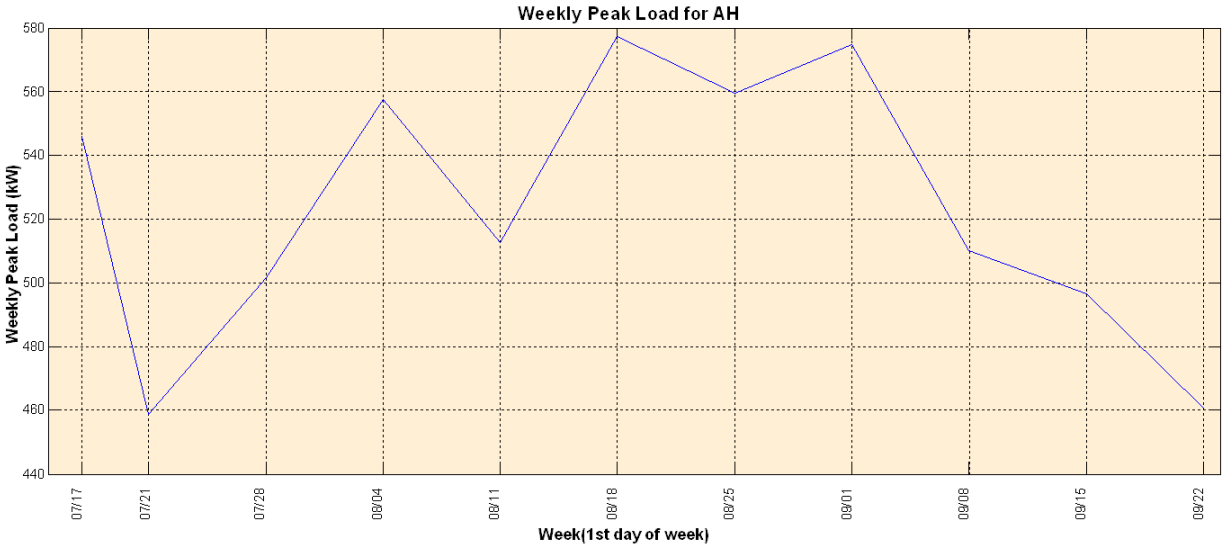


Figure 69: Weekly Peak Load Profile for AH

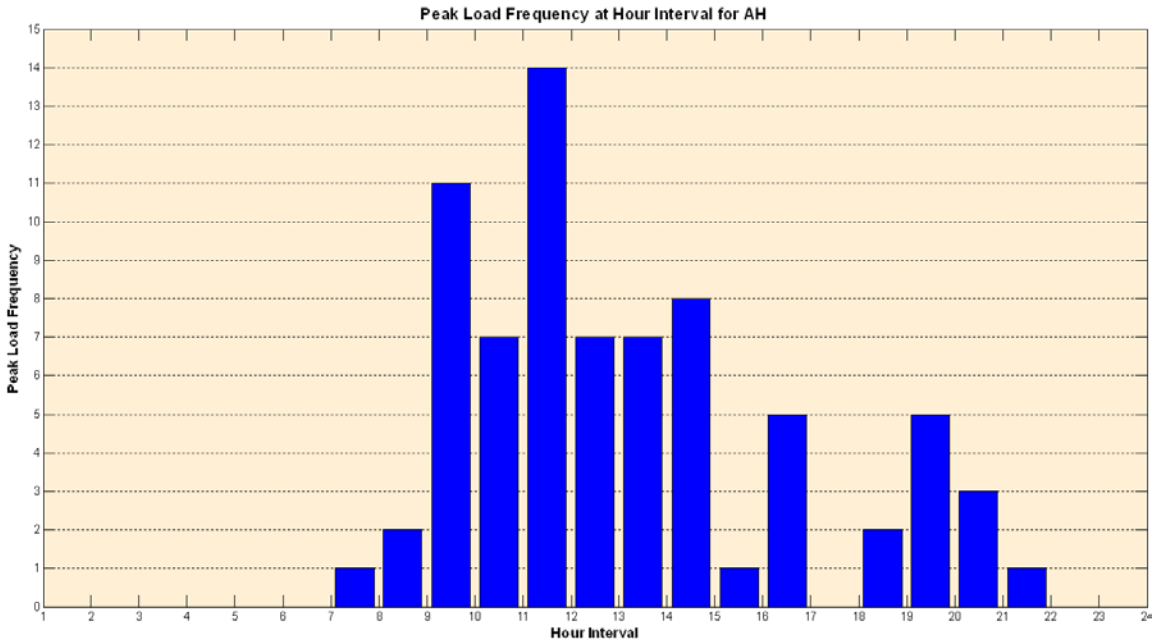


Figure 70: Peak Load Frequency at Hour Interval for AH

Figure 71 shows the average weekday load profile of CC. As observed from this graph, CC has a well-defined load profile with much less variation as compared to AH. **Figure 72** shows the daily peak load between 7/17-9/28. The troughs represent the weekends. **Figure 73** shows the weekly peak load variation for the same time period. As shown in this graph, CC weekday peak load varies between 345kW and 425kW, which is about 23% variations and a lot less than AH. **Figure 74** shows the frequency of the peak occurrence at different time intervals for CC. According to this graph the electrical load peak can occur, with a very high probability, anywhere from 10:00am to

4:00pm while the highest occurrence happened between 2:00-3:00pm. This clearly agrees with CC building type, consisting of shops and office which are generally closed after 5:00pm.

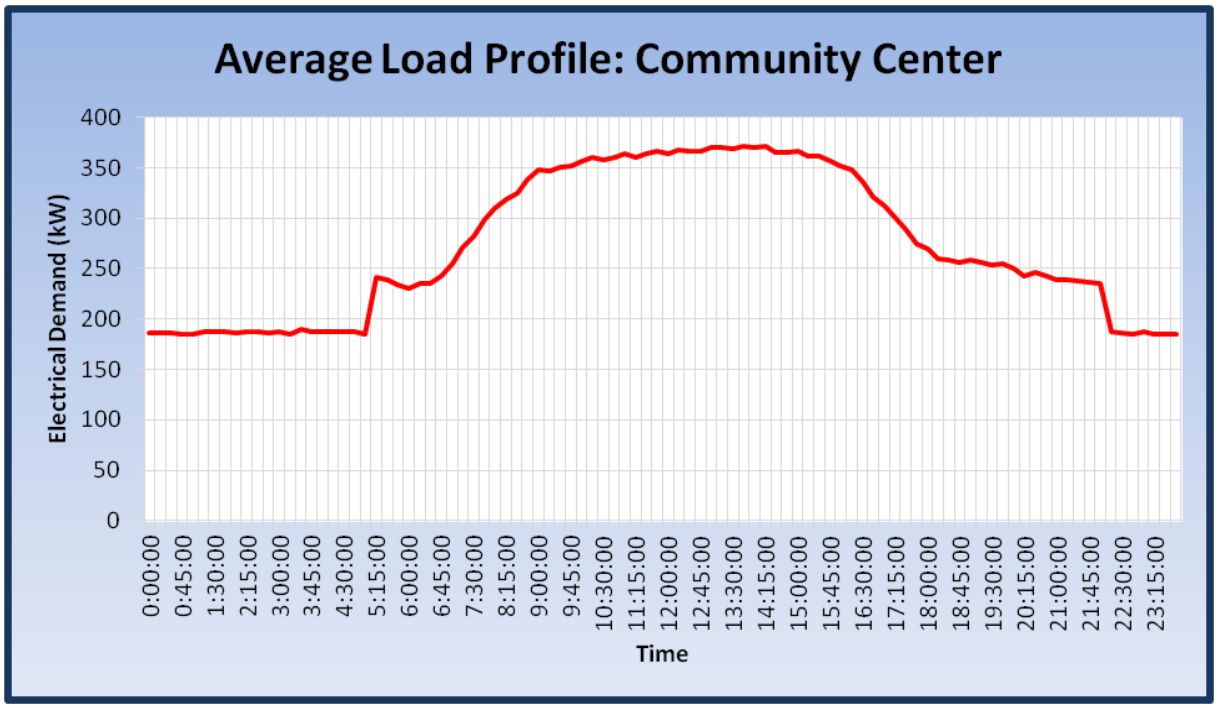


Figure 71: Weekday Load Profile: CC

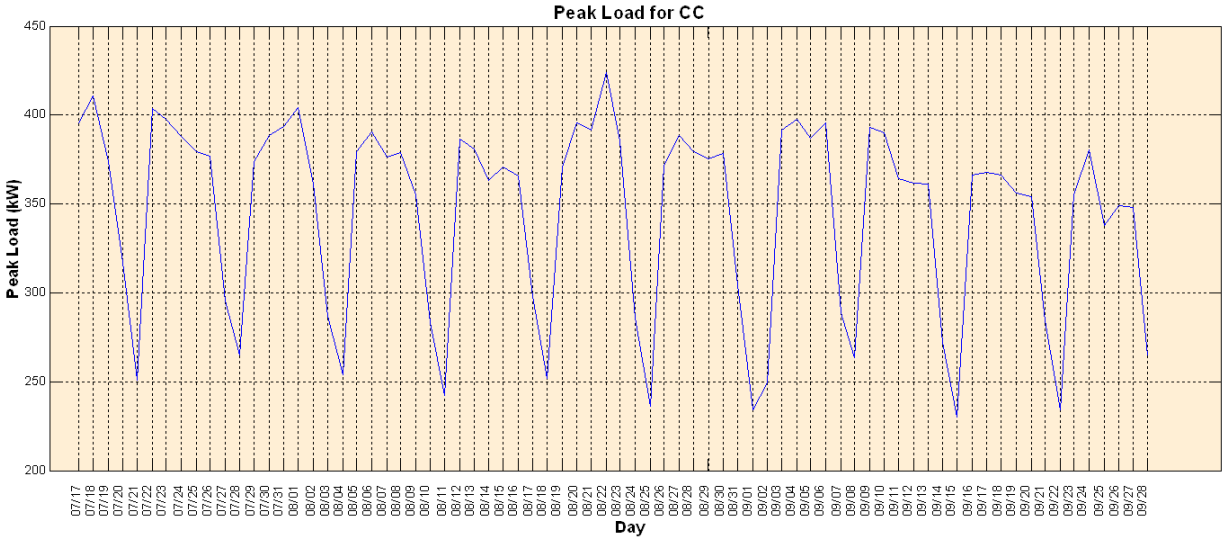


Figure 72: Peak Load Profile for CC

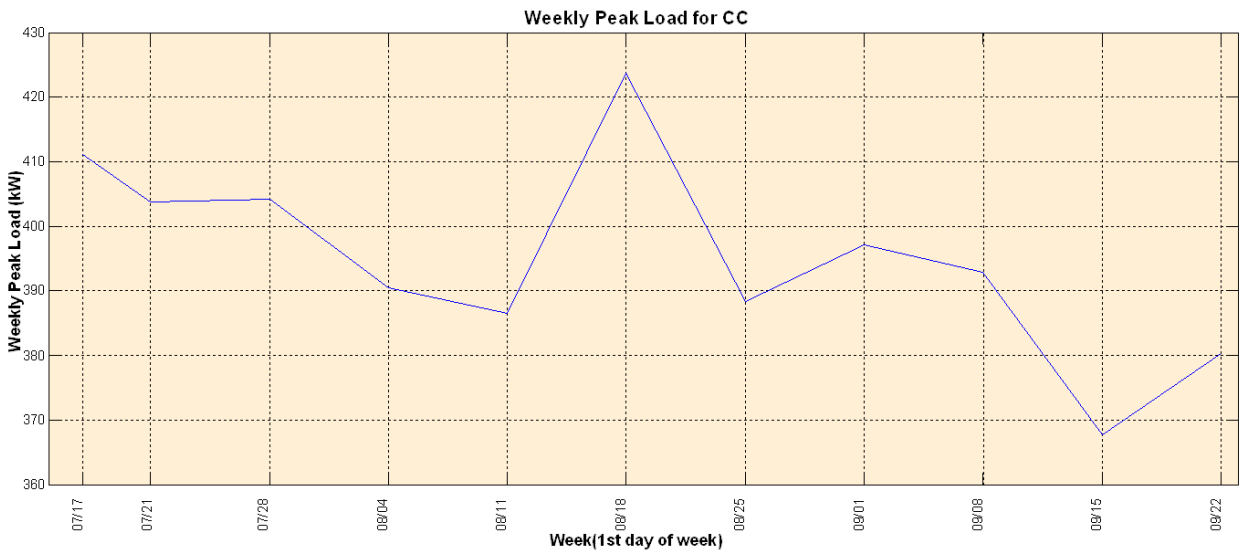


Figure 73: Weekly Peak Load Profile for CC

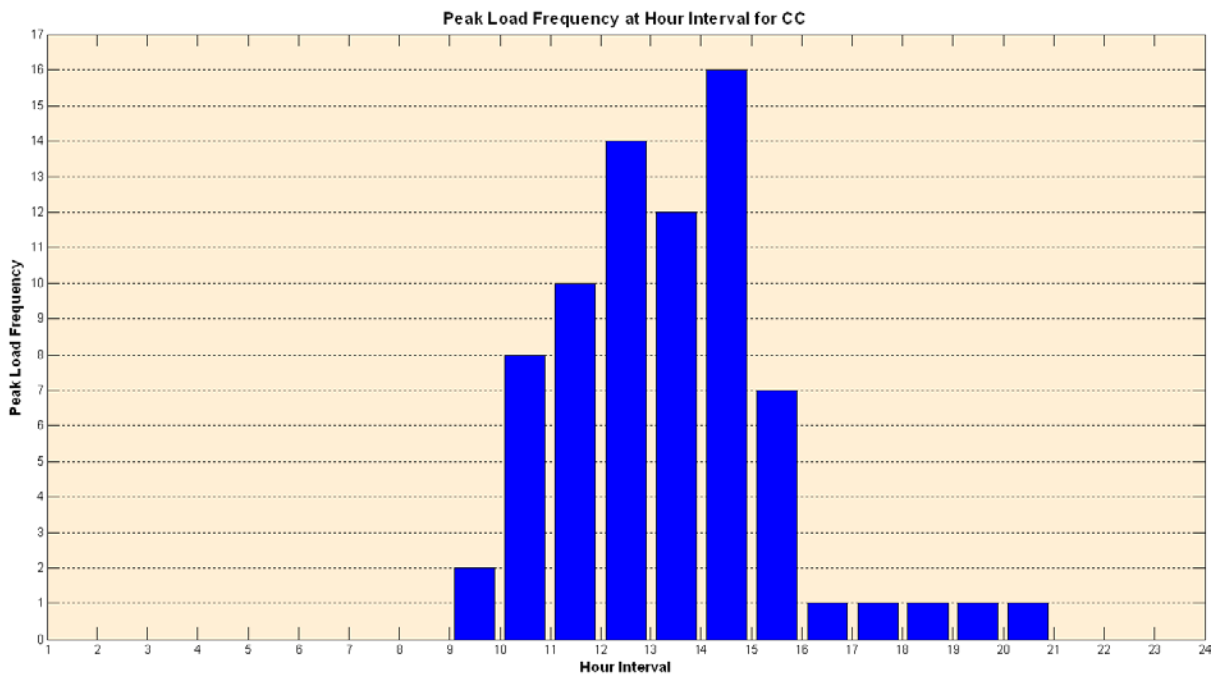


Figure 74: Peak Load Frequency at Hour Interval for CC

Figure 75 shows the average weekday load profile for MH. MH has a highly irregular load profile with lot of variations as compared to CC or even AH. **Figure 76** shows the daily peak load between 7/17-9/28. **Figure 77** shows the weekly peak load variation for the same duration. MH peak load varies between 650kW and 970kW. That is about 50% variation. **Figure 78** shows the frequency of the peak occurrence at different time intervals for MH. Based on this graph there are

19 instances of peak occurrence between 6:00pm-7:00pm, which is reasonable as this is the dinner time and large amount of electricity is used for food preparation. The electrical load peak of MH can occur, with a very high probability, anywhere from 2:00pm to 9:00pm.

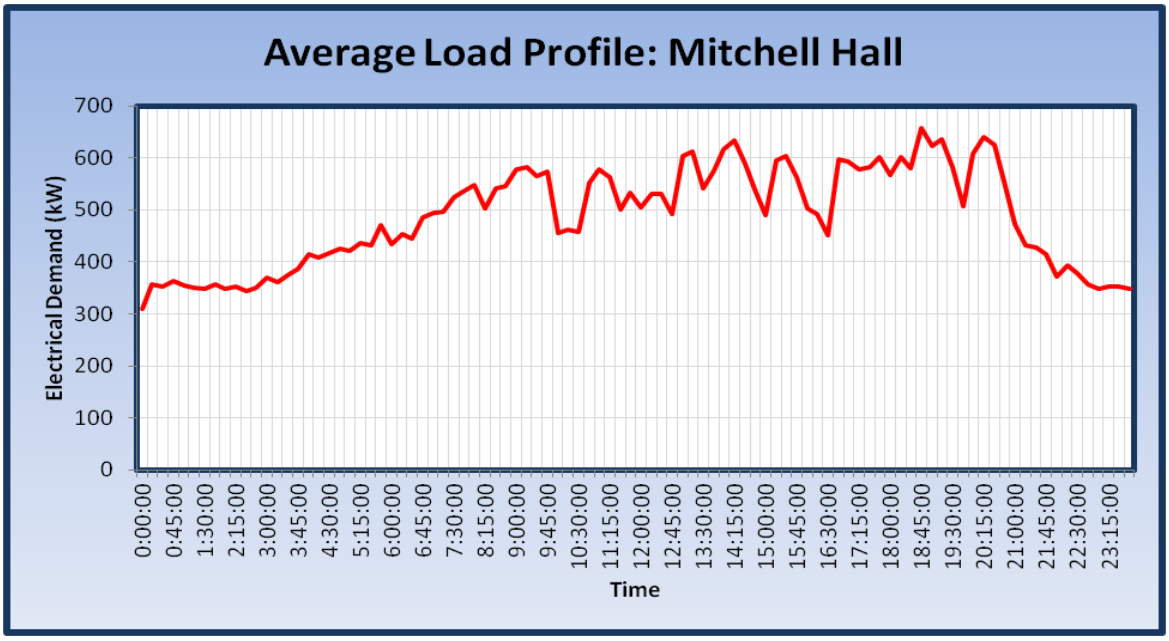


Figure 75: Weekday Load Profile: MH

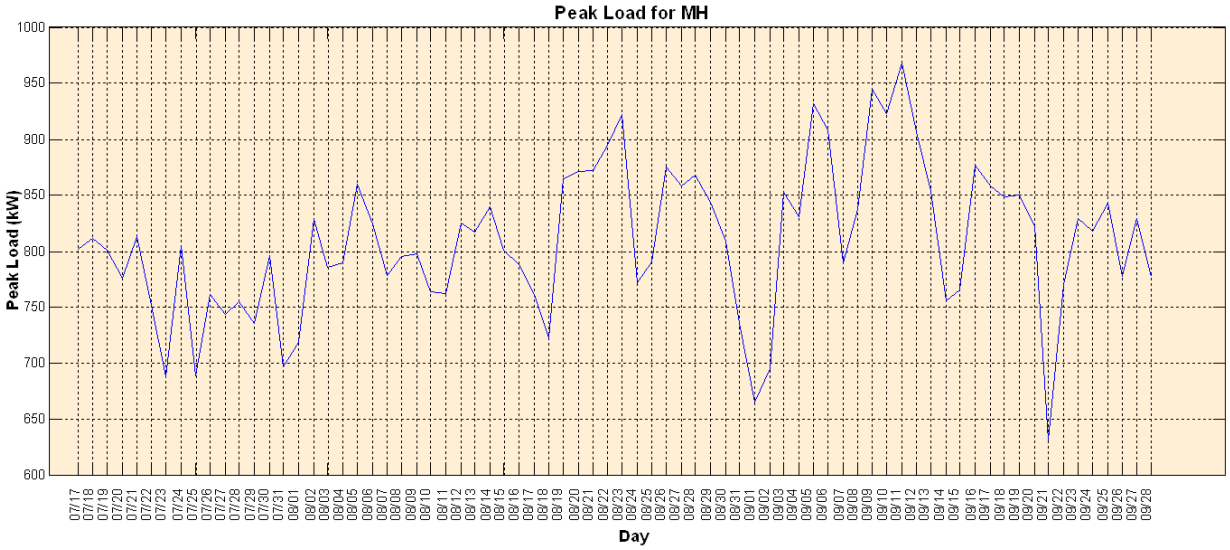


Figure 76: Peak Load Profile for MH

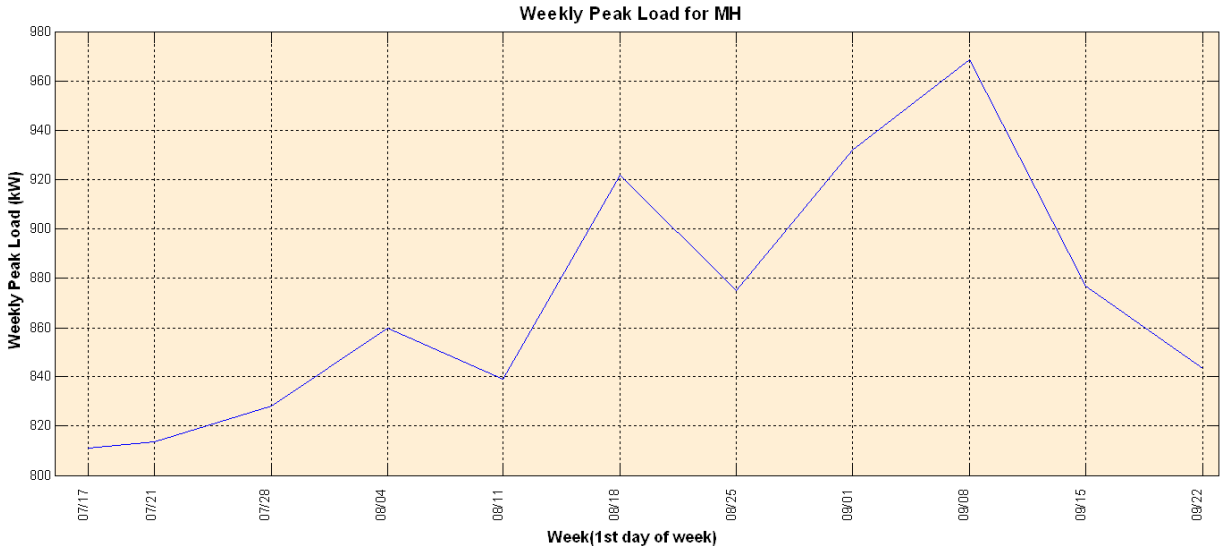


Figure 77: Weekly Peak Load Profile for MH

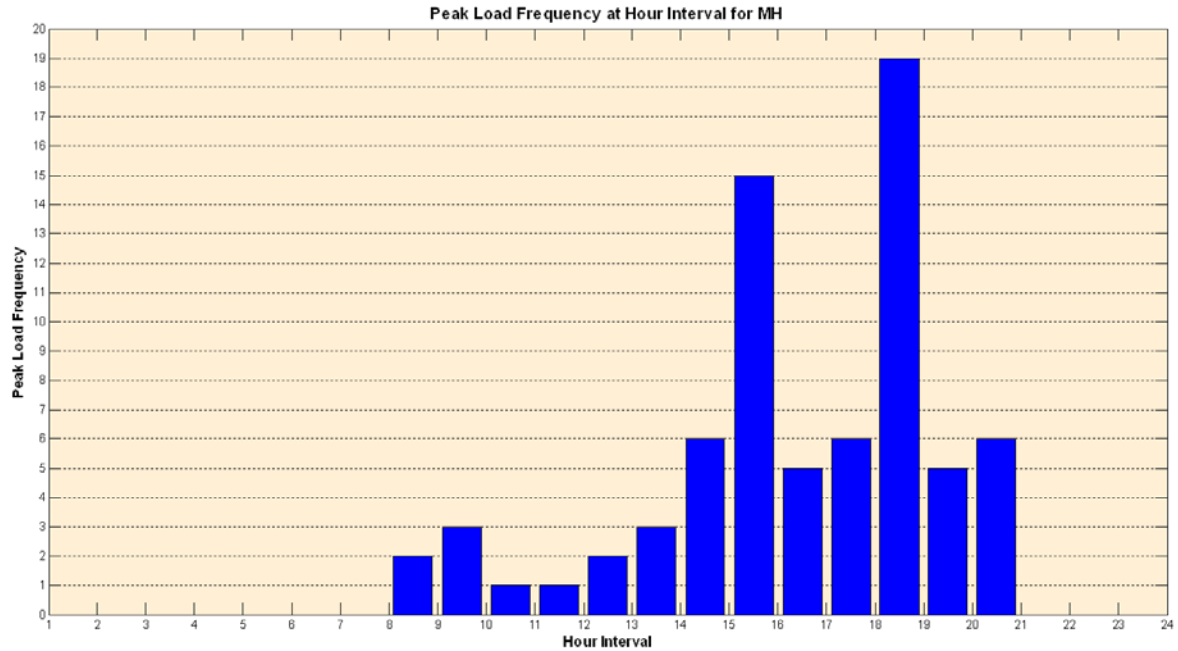


Figure 78: Peak Load Frequency at Hour Interval for MH

Figure 79 shows the average weekday load profile for all the three buildings combined. From the graph, the combined building load has an irregular load profile to some extent. **Figure 80** shows the daily aggregated peak load between 7/17-9/28. **Figure 81** shows the weekly peak load for the same duration. The overall weekday peak load varies between 1375kW and 1740kW. That is about 26% variation. It was also calculated that the average percentages of individual electrical consumptions from AH, CC, and MH are 29%, 22%, and 49%, respectively. **Figure 82** shows the

frequency of the peak occurrence at different time intervals. At the aggregated level, there is a highest probability of peak load between 2:00pm-3:00pm.

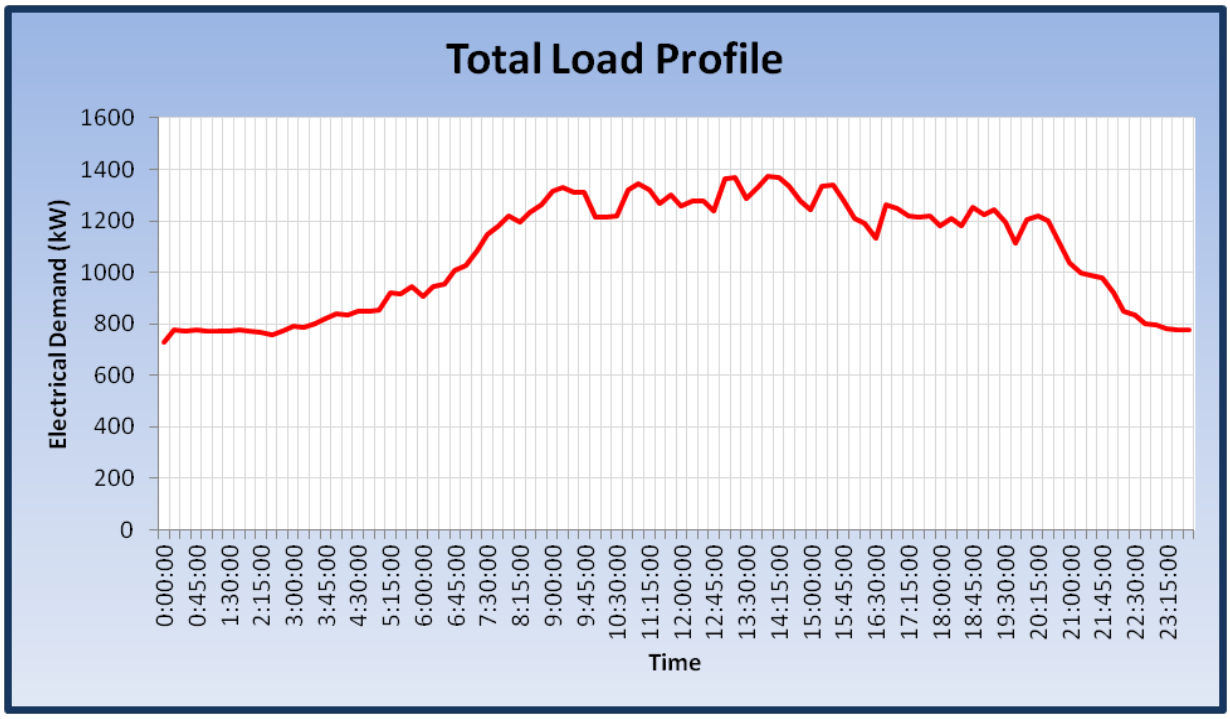


Figure 79: Combined Weekday Load Profile

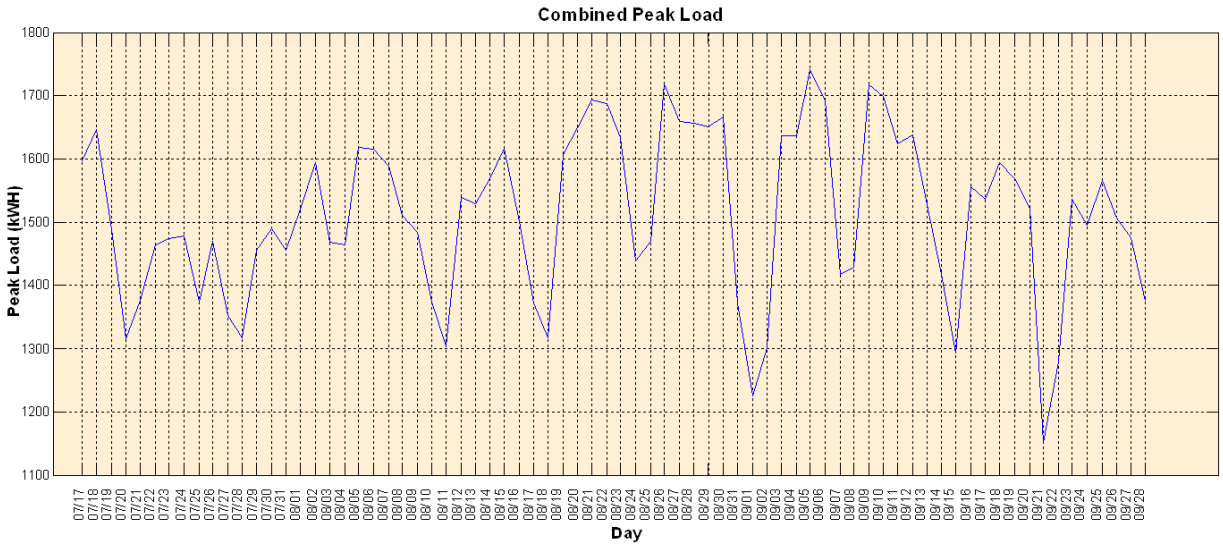


Figure 80: Combined Peak Load Profile

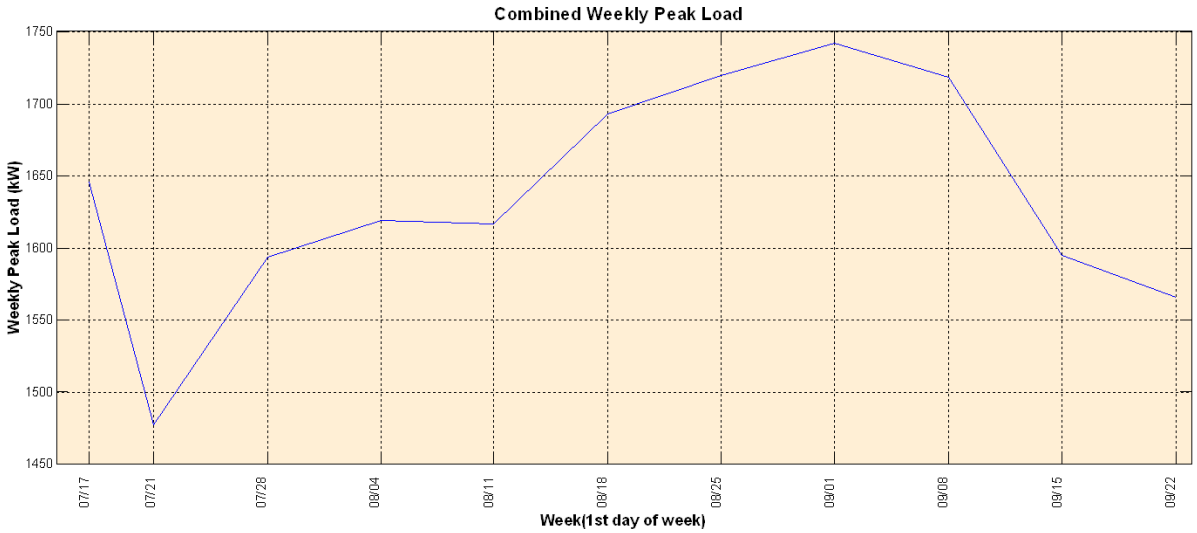


Figure 81: Combined Weekly Peak Load Profile

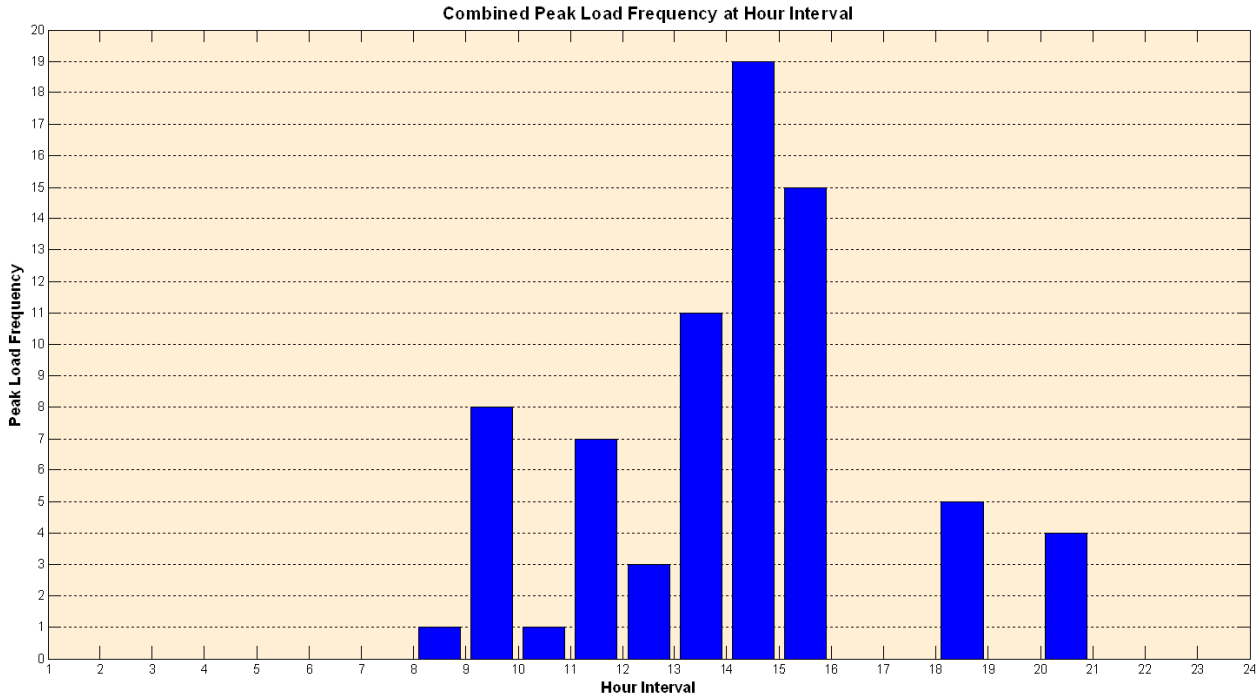


Figure 82: Peak Load Frequency at Hour Interval at the Aggregated level

6.2.2 Methodology

The technical details of the developed adaptive demand management methodology are already presented in Section 2.3. This developed methodology was applied to all the three buildings for various DR events, which were conducted during 23-26 September, 2013. There were total 5 different DR events conducted, as presented in **Table 23** below. In all DR events except DR Test 2, all the three buildings participated.

Table 23: DR Event Schedule

DR Event	Day	Time	Buildings
DR Test 1	23 September	11:12-13:12	AH, MH, CC
DR Test 2	24 September	16:00-18:00	AH, CC
DR Test 3	25 September	11:00-13:00	AH, MH, CC
DR Test 4	25 September	16:02-18:02	AH, MH, CC
DR Test 5	26 September	13:00-15:00	AH, MH, CC

During these DR events, adaptive DR strategies were implemented to achieve the required demand reduction. The DR actions that were considered for dynamic generation during DR events include:

- Increase of SAT to 60°F
- Decrease of SSP by 20% with a floor value of 0.8
- Increase of global temperature setpoint to 78 ^{o}F
- Turning off AHU, if all serving zone are unoccupied
- Power-cycle of AHUs, with a fixed time cycle, if they serve a common area

The results of the DR events are presented in subsequent section.

6.2.3 Results Analysis

A DR-event period is defined as DR-period plus 30 min. Difference between DR-period saving and DR-event saving reflects the energy kickback due to return to pre-DR settings. In the results presented below, actual Min kWh savings refer to total minimum savings that “must” have occurred because of AHU-fan “turn-off” and “fan-speed reduction”. The savings from fan off and speed reduction are determined based on BAS trended data and AHU fan ratings.

In each DR test result section, two figures and one table are used to present the results. The first plot 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 second figure in shows the kW saving due to the DR strategies. The table shows the average kW saving during the period as well as the maximum kW saving that occurred during the DR event. The DR strategies along with individual DR actions at 15 minute interval for the 5 DR events are presented in Appendix E.

DR Test 1: 09/23/2013, 11:12-13:12

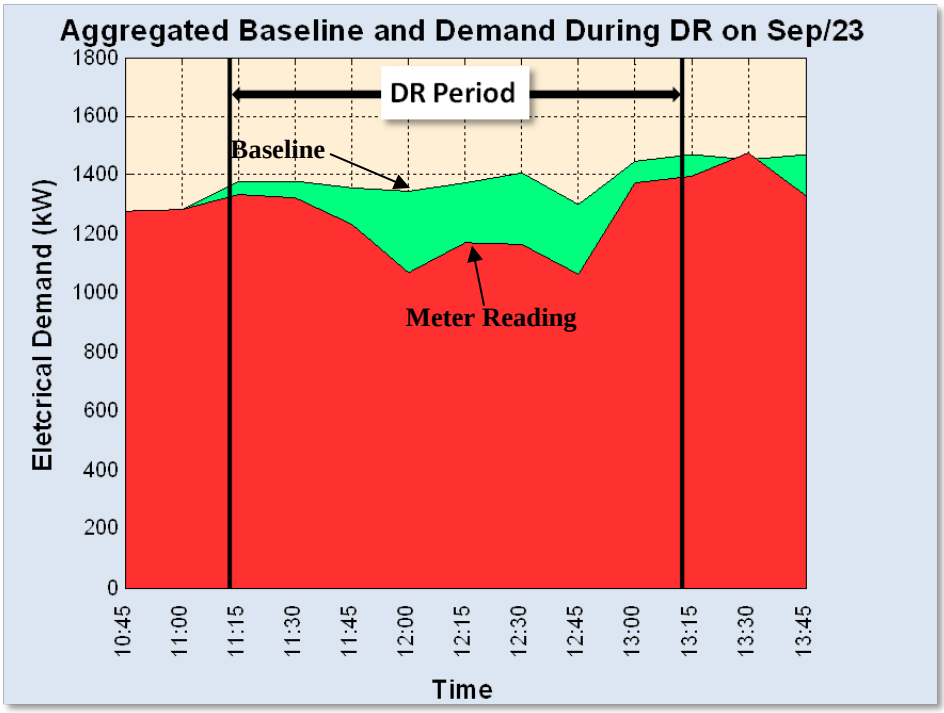


Figure 83: Aggregated Baseline and Actual Demand During DR-1

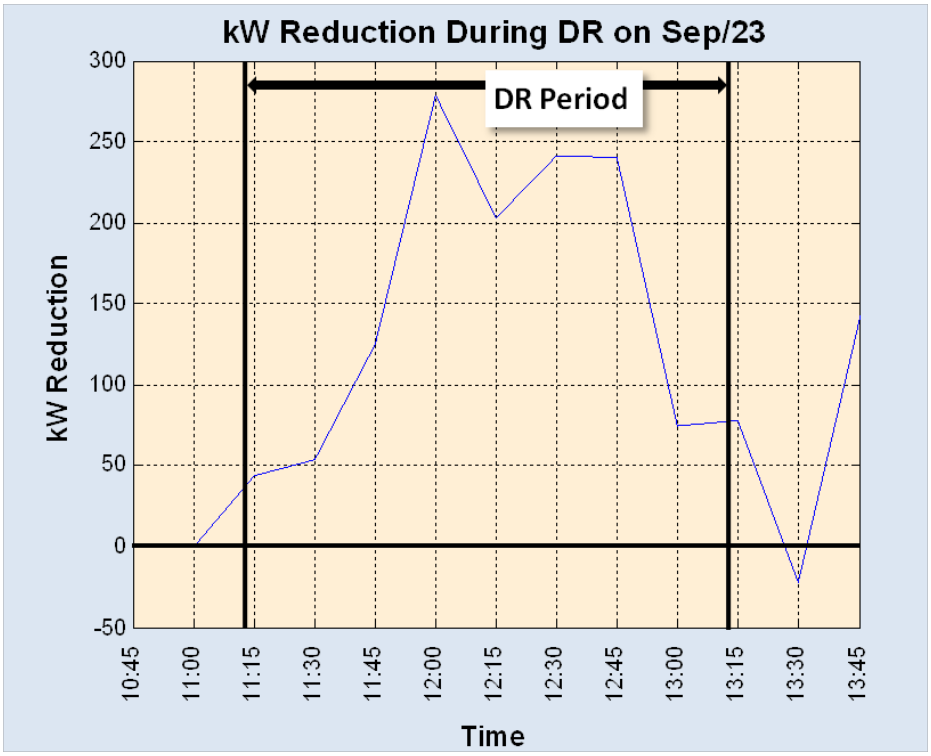


Figure 84: kW Savings During DR-1

Table 24: 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 Peak kW During DR Period	1472.36 kW
Aggregate kWh Savings During DR Period	319.20 kWh (11.56%)
Aggregate kWh Consumption During DR Period	2760.47 kWh
AH: Actual Minimum kWh Savings During DR Period	35.37 kWh
MH: Actual Minimum kWh Savings During DR Period	72.66 kWh
CC: Actual Minimum kWh Savings During DR Period	4.20 kWh
Aggregate Actual Minimum kWh Savings During DR Period	112.23 kWh (4.07%)
Aggregate kWh Savings During DR Event	341.15 kWh (9.77%)
Aggregate kWh Consumption During DR Event	3492.11 kWh

DR Test 2: 09/24/2013, 16:00-18:00

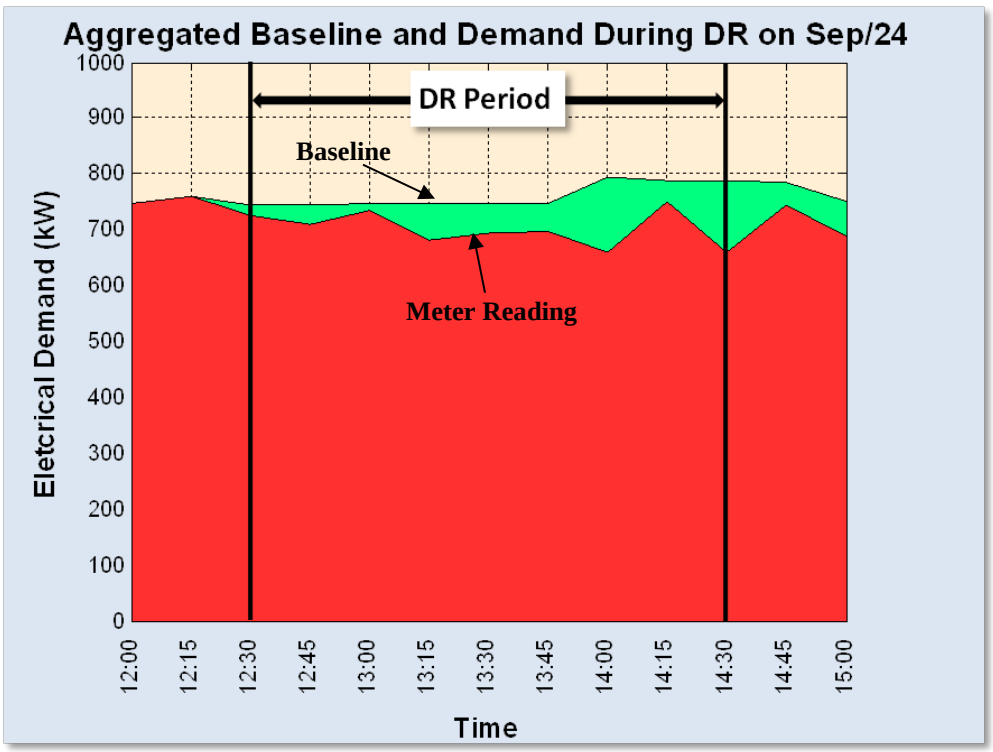


Figure 85: Aggregated Baseline and Actual Demand During DR-2

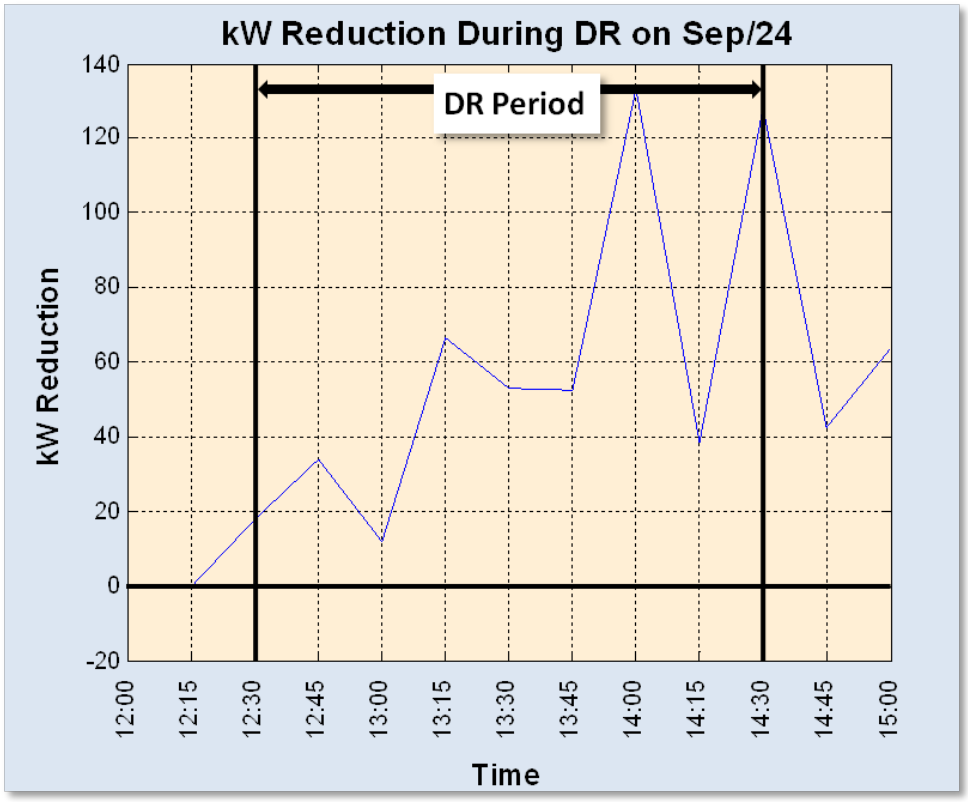


Figure 86: kW Savings During DR-2

Table 25: Results Summary for DR-2

Average Aggregate kW Reduction During DR Period	64.60 kW (8.14%)
Maximum Aggregate kW Reduction During DR Period	133.31 kW (16.81%)
Aggregate Peak kW During DR Period	793.21 kW
Aggregate kWh Savings During DR Period	115.43 kWh (7.59%)
Aggregate kWh Consumption During DR Period	1520.62 kWh
AH: Actual Minimum kWh Savings During DR Period	34.92 kWh
MH: Actual Minimum kWh Savings During DR Period	N.A.
CC: Actual Minimum kWh Savings During DR Period	15.42 kWh
Aggregate Actual Minimum kWh Savings During DR Period	50.34 kWh (3.31%)
Aggregate kWh Savings During DR Event	150.01 kWh (7.86%)
Aggregate kWh Consumption During DR Event	1909.52 kWh

DR Test 3: 09/25/2013, 11:00-13:00

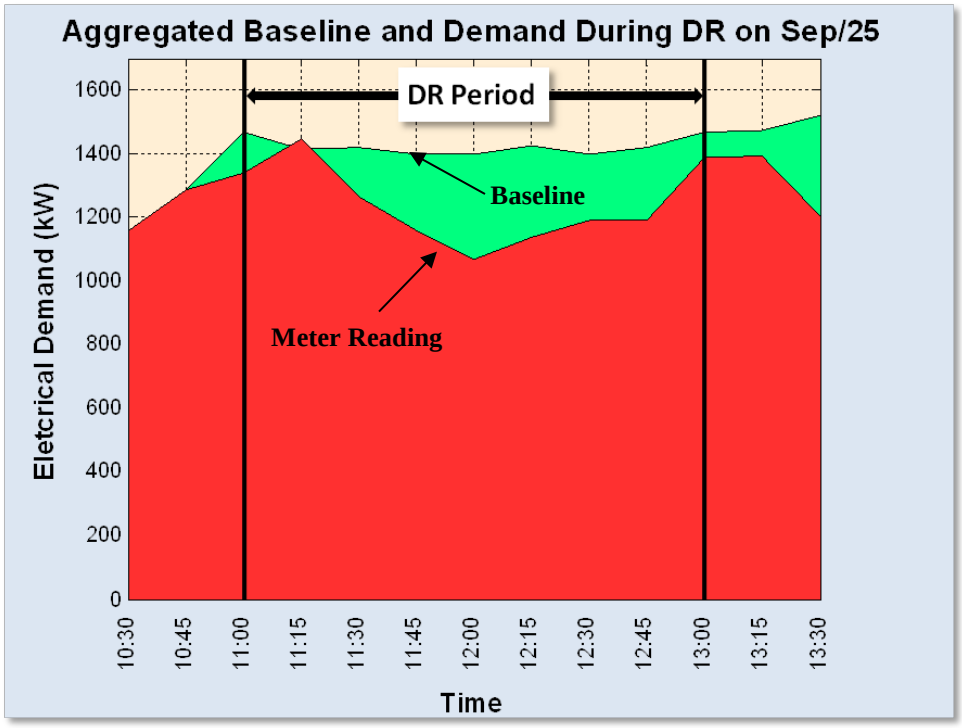


Figure 87: Aggregated Baseline and Actual Demand During DR-3

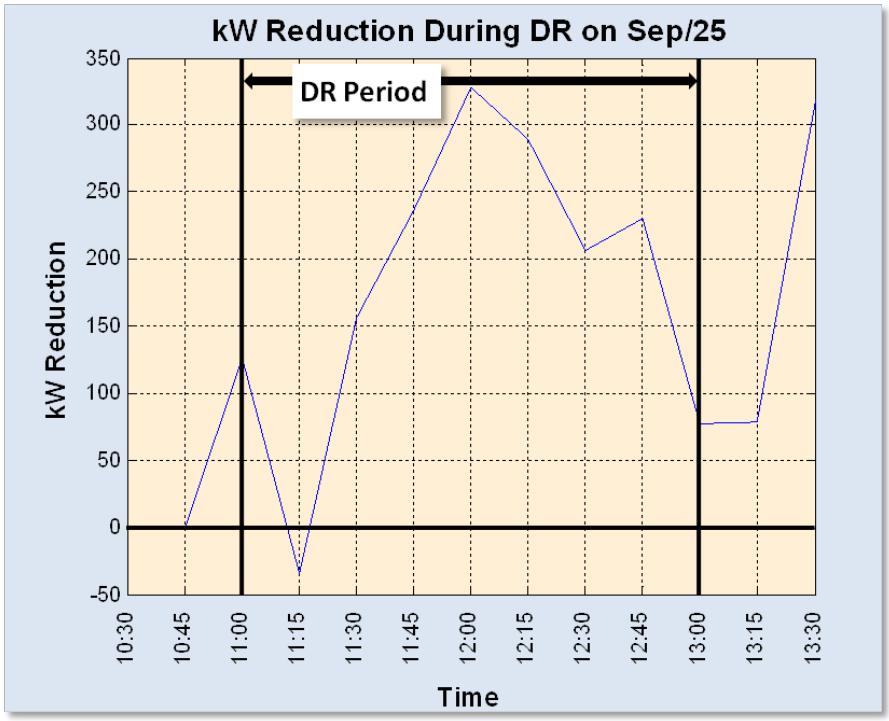


Figure 88: kW Savings During DR-3

Table 26: Results Summary for DR-3

Average Aggregate kW Reduction During DR Period	186.27 kW (12.70%)
Maximum Aggregate kW Reduction During DR Period	328.32 kW (22.38%)
Aggregate Peak kW During DR Period	1467.14 kW
Aggregate kWh Savings During DR Period	378.59 kWh (13.34%)
Aggregate kWh Consumption During DR Period	2837.27 kWh
AH: Actual Minimum kWh Savings During DR Period	32.78 kWh
MH: Actual Minimum kWh Savings During DR Period	96.82 kWh
CC: Actual Minimum kWh Savings During DR Period	14.25 kWh
Aggregate Actual Minimum kWh Savings During DR Period	143.85 kWh (5.07%)
Aggregate kWh Savings During DR Event	447.80 kWh (12.51%)
Aggregate kWh Consumption During DR Event	3579.33 kWh

DR Test 4: 09/25/2013, 16:02-18:02

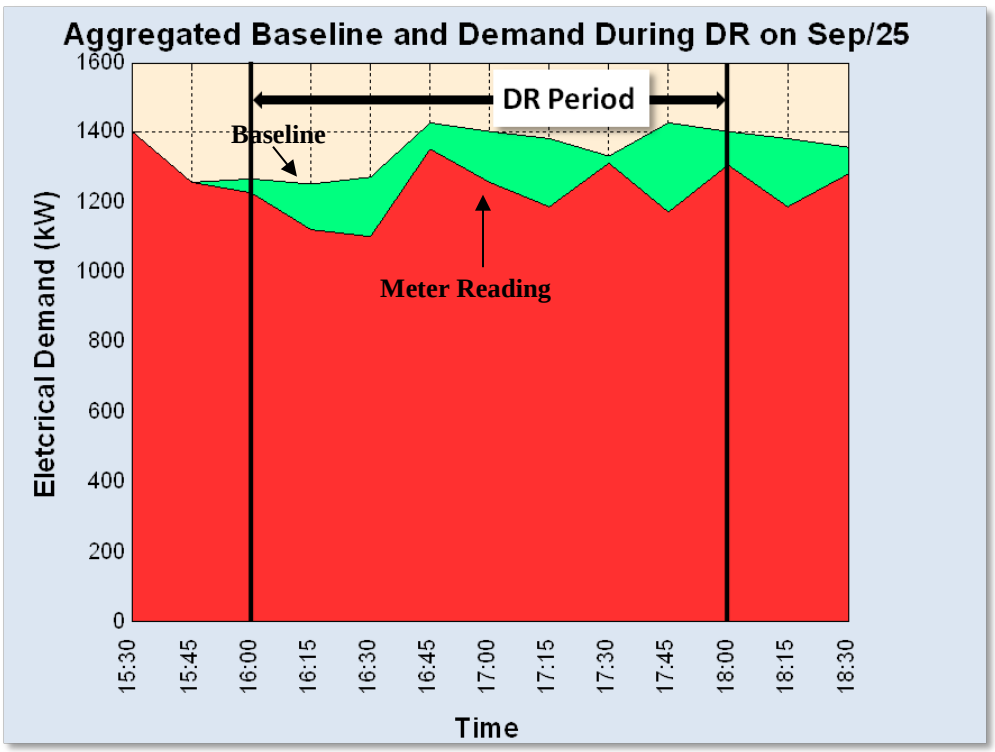


Figure 89: Aggregated Baseline and Actual Demand During DR-4

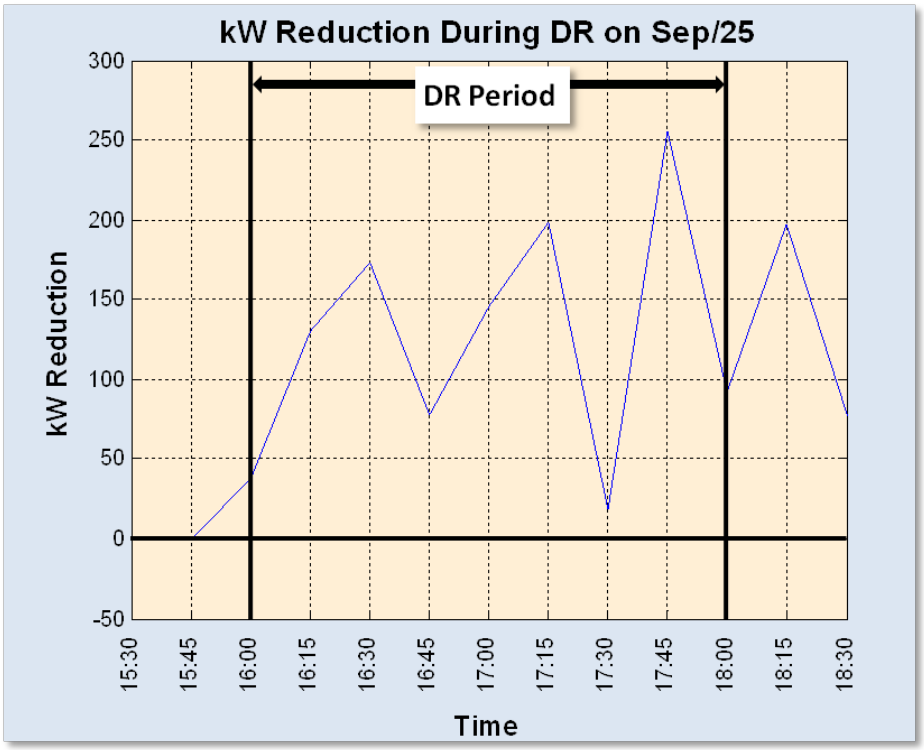


Figure 90: kW Savings During DR-4

Table 27: Results Summary for DR-4

Average Aggregate kW Reduction During DR Period	136.45 kW (9.56%)
Maximum Aggregate kW Reduction During DR Period	255.21 kW (17.87%)
Aggregate Peak kW During DR Period	1427.91 kW
Aggregate kWh Savings During DR Period	266.18 kWh (9.83%)
Aggregate kWh Consumption During DR Period	2707.72 kWh
AH: Actual Minimum kWh Savings During DR Period	65.77 kWh
MH: Actual Minimum kWh Savings During DR Period	85.31 kWh
CC: Actual Minimum kWh Savings During DR Period	35.29 kWh
Aggregate Actual Minimum kWh Savings During DR Period	186.37 kWh (6.88%)
Aggregate kWh Savings During DR Event	336.48 kWh (9.90%)
Aggregate kWh Consumption During DR Event	3398.07 kWh

DR Test 5: 09/24/2013, 13:00-15:00

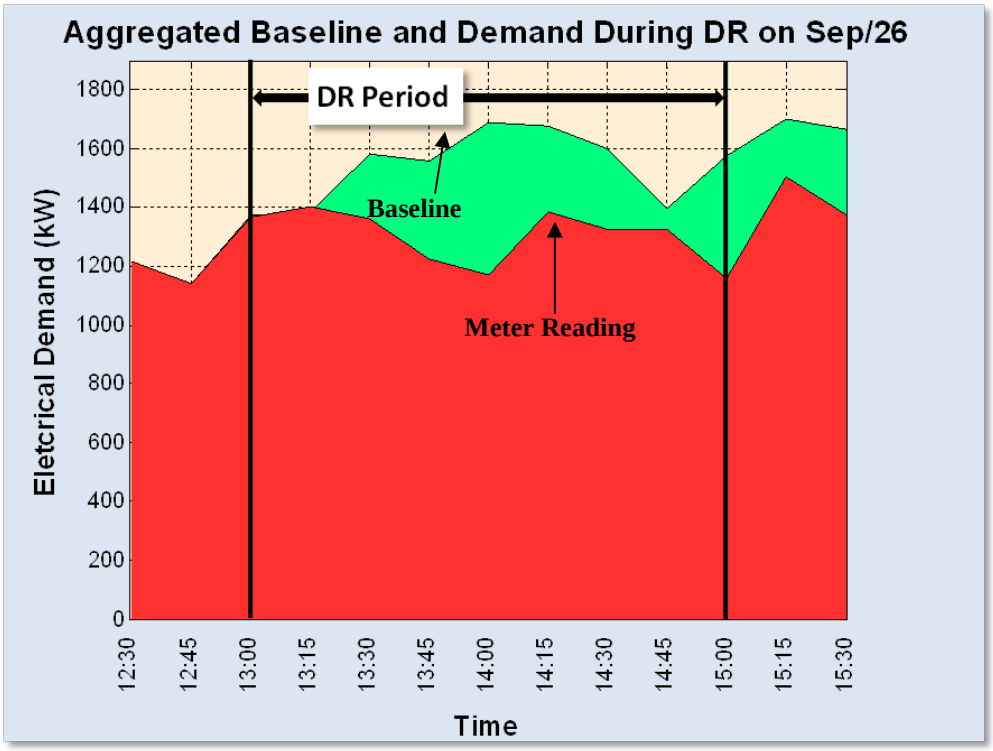


Figure 91: Aggregated Baseline and Actual Demand During DR-5

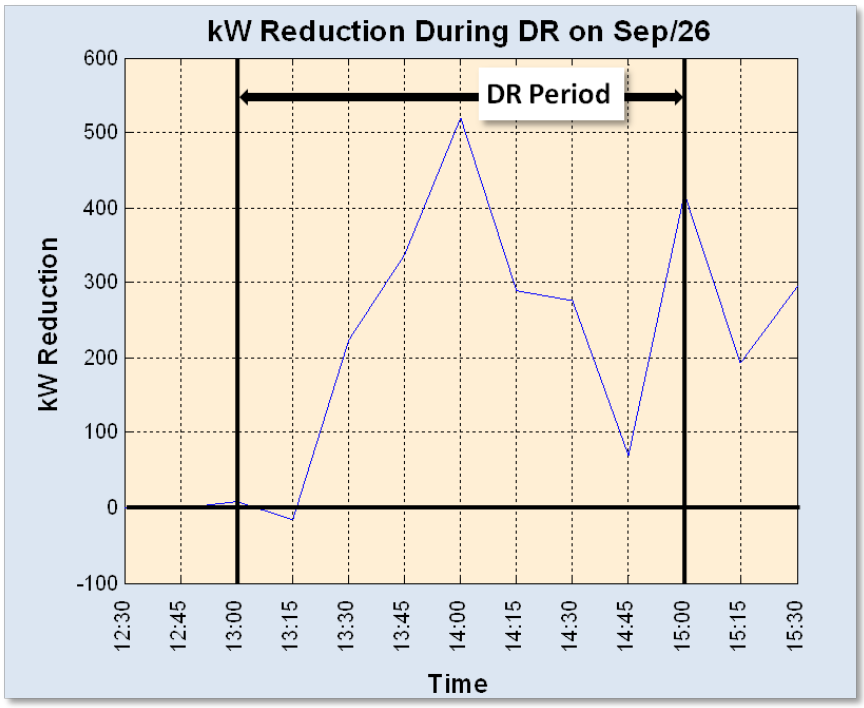


Figure 92: kW Savings During DR-5

Table 28: Results Summary for DR-5

Average Aggregate kW Reduction During DR Period	264.93 kW (15.70%)
Maximum Aggregate kW Reduction During DR Period	519.34 kW (30.77%)
Aggregate Peak kW During DR Period	1687.64 kW
Aggregate kWh Savings During DR Period	478.58 kWh (15.48%)
Aggregate kWh Consumption During DR Period	3091.85 kWh
AH: Actual Minimum kWh Savings During DR Period	28.32 kWh
MH: Actual Minimum kWh Savings During DR Period	81.88 kWh
CC: Actual Minimum kWh Savings During DR Period	42.99 kWh
Aggregate Actual Minimum kWh Savings During DR Period	153.19 kWh (4.95%)
Aggregate kWh Savings During DR Event	615.82 kWh (15.70%)
Aggregate kWh Consumption During DR Event	3921.90 kWh

The overall results of the various DR tests are summarized in **Table 29** below.

Table 29: 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%

As stated earlier, in the three buildings, 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. Moreover, out of all the HVAC equipment only some AHUs were actually controlled for demand reduction. In aggregated form, out of total 8,413 MWh of annual energy consumption of all three buildings, only 3,007 MWh were considered as being consumed from controllable loads, which roughly amounts to 35.7%. The results presented in the above tables (**Table 24-Table 28**) 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 30** below.

Table 30: 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%

The estimated percentage of plug and process loads (interior equipment and refrigeration) for AH, CC, and MH are 36%, 10%, and 62%, respectively, based on the electrical energy usage breakdown information provided in Section 4. Since the breakdown of interior equipment load information, for the three buildings, was not available, it is not possible to differentiate the process

from the plug loads. Hence it is not possible to accurately estimate the amount of possible savings due to the reduction in plug loads only. Instead, energy consumption data from [3] was used as a reference to split the process and plug loads. Based on [3], we can assume that out of total plug and process load consumption, plug loads consume 31% and process load consume 69% of electrical energy. Hence, it can be estimated that plug loads for AH, CC, and MH are 11.2%, 3.1%, and 19.4%, respectively. Assuming a 30% reduction of plug loads during DR period, the additional actual percentage reduction of total building load for AH, CC, and MH are 3.4%, 1%, and 5.8%, respectively. Since the contributions from AH, CC, and MH on total electrical consumption are 29%, 22%, and 49%, respectively, if plug loads were also part of DR demonstration, the combined demand would have been reduced by an extra 4%. Hence in that case **Table 31** shows the modified DR results that we would have been able to achieve if we were allowed to control plug loads for DR events. Hence with plug load control in addition to HVAC controls during DR, we would have been able to achieve an average of 15% demand reduction out of total building load.

Table 31: Modified DR Results with Inclusion of Estimated Reduction Due to Plug Loads

	DR1	**DR2**	**DR3**	**DR4**	**DR5**	**Average**
Avg. % kW Reduction w/o Plug Loads	11%	8.14%	12.7%	9.56%	15.7%	11.42%
Avg. % kW Reduction with Plug Loads	15%	12.14%	16.7%	13.56%	19.7%	15.42%

6.2.4 Conclusions and Recommendations

Based on the DR test results, following conclusions can be drawn.

- 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.
- The conclusion above, however, would not be a fair conclusion as the building lighting, process and plug loads, which are a major chunk of total building electrical consumption at USAFA, were not considered for DR strategies due to USAFA site specific limitations. Only a subset of HVAC loads was allowed being part of demonstrations. 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%, as compared to baseline, during the DR event period.
- During the various DR events, the amount of reduction achieved was primarily dependent on the size of AHU being controlled and the occupancy in the zones served by the AHUs being controlled.
- Since all reported DR events were conducted during the shoulder period, the energy saving or demand reduction potentials from zonal/global temperature setback or AHUs SAT setback were not fully realized. It is expected that during the peak heating/cooling season the demand reduction will be greater due to the reduction in chiller power, cooling tower consumption, and distribution pump power.

Based on the experiences of the various DR events conducted at USAFA, following recommendations can be made:

- In total, for all three buildings combined, the lighting was 24% and plug and process loads constituted 38% of total load. Therefore, it is important to make lighting process, and plug loads a part of DR strategy.
- In buildings with large spaces, since the building thermal inertia is pretty high, 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 section 6.4 in this report, 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.

The use of CO_2e is a standard, internationally recognized unit of GHG emissions, which includes carbon dioxide (CO_2) emissions, and also allows other GHGs to be expressed in terms of CO_2 based on their global warming potential (GWP). The GWP is defined as a relative measure of how much any given GHG is expected to trap heat in the atmosphere, in comparison to the same amount of CO_2. 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* [10] and its accompanying *Technical Support Document*[19], which is the guidance document used by all federal agencies, including the DOD, to annually measure their GHG emissions under Executive Order 13514. This EO requires all federal agencies to annually complete a GHG inventory, and to set goals for future reductions of energy and water consumption, and solid waste reductions, as well as goals for renewable energy generation, among other goals.

Using the Guidance document cited above, GHG emissions can be divided into categories of Scope 1, Scope 2, and Scope 3 emissions. Scope 1 emissions are typically from onsite combustion

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

of fossil fuels, such as natural gas, propane, gasoline, or diesel. These emissions can come from stationary or mobile sources. Scope 2 emissions are from purchased electricity or purchased heating, cooling, or steam from a district system. Scope 3 includes all other emissions, such as emissions of contractors, emissions from solid waste that is sent to an offsite landfill, and numerous other sources. For the purposes of this report, all natural gas emission reductions are categorized as Scope 1 reductions, while all electricity emission reductions are categorized as Scope 2 reductions.

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 * GWP

Where:

Activity data	= Reduction of electricity in kWh or reduction of natural gas (in Therms or MBTU)
Emissions factor	= The appropriate factor for a particular GHG associated with a particular activity data type. An example is: for CO_2 from electricity, an emissions factor of 1,824.51 lbs CO_2/MWh is used.
Standard conversion factors	= Standard factors needed to convert units, such as the conversion from lbs to metric tons, or the conversion from MWh to kWh.
GWP	= Global warming potential for a particular GHG, as described above.

This formula was applied three times for electricity and three times for natural gas, to calculate total emission reductions of CO_2, CH_4, and N_2O. Once the results were calculated for each of the three GHGs, the results were combined using the appropriate GWP for each GHG to find the total GHG emission reduction in CO_2e.

Emission factors for natural gas are fairly standard, and are taken from *Federal Greenhouse Gas Accounting and Reporting Guidance*. As per this document, electricity emission factors were taken from the EPA eGRID 2012 database[20], and the project team used the total output emission factors for the Rocky Mountain Power Area (RMPA) – Western Electricity Coordinating Council (WECC) Rockies Subregion.

The same methodology was used to calculate the GHG emissions from the baseline scenario. From the scalability analysis detailed in section 6.4, the baseline scenario assumes a total annual consumption of 34,514,068 kWh/year and 1,852,083 therms/year.

6.3.3 Results Analysis

The project team established a goal of reducing greenhouse gases by 20% over the established GHG baseline. The GHG goals did not directly parallel the energy reduction goals because the

[20] http://www.epa.gov/cleanenergy/energy-resources/egrid/index.html

two energy sources considered, natural gas and electricity, have different GHG emissions rates. Therefore, energy savings will almost never be proportionate to GHG emissions reductions unless only one fuel source is considered.

Determination of Success versus Project Goals

The GHG baseline was calculated to be 38,549 metric tons CO_2e/year, based on average annual utility bills and additional analysis to normalize the bill data. The energy reductions will lead to a total decrease of 5,917 metric tons CO_2e/year, which is a reduction of 15% below the baseline, not the 20% GHG reductions targeted for the demonstration. A summary of the expected GHG reductions from electricity decreases and natural gas decreases is shown in **Table 32** below.

Table 32: Summary of the Expected 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%

The project did not meet the GHG reduction goal for a variety of reasons. One key factor 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; these strategies could have led to higher reductions of electricity. More explanation of the reasons that some goals were not met is included in section 6.3.4, System Economics.

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. One important factor that could explain why natural gas savings are much larger than electricity savings is the current inefficiency of the system used to generate and distribute hot water for domestic hot water and for heating. The Central Boiler Plant that consumes natural gas is located on campus but is not close to very many of the buildings, and is aging. The equipment in place used to generate and distribute hot water to many of the buildings loses up to 60% of the energy consumed due to inefficiencies and distribution losses. Thus, any savings in heating energy within the buildings is greatly multiplied into actual savings of natural gas therms due to these inefficiencies and losses.

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. A large percentage of the electricity consumed in Colorado is generated from coal-fired plants, and coal is quite a bit more carbon-intensive than natural gas and other common sources of electricity, leading to higher emissions per MBTU of energy consumed. In this analysis, one MBTU of electricity consumed generated 242.72 kg CO_2, which is based on the published emission factor for the region of 1,824.1 lbs CO_2/MWh of electricity. In contrast, one MBTU of natural gas consumed generates only 53.02 kg CO_2, based on the published emission factor for natural gas. Similar differences exist for the emission factors for CH_4 and N_2O. Thus, to achieve higher GHG reductions, future deployments of iBEMS or similar technologies at USAFA should focus on reducing electricity consumption, or increasing the amount of electricity generated by renewable sources, coupled with continued improvements to the heat delivery systems.

6.4 SYSTEM ECONOMICS

The team set goals for energy and economic performance objectives of iBEMS that were not necessarily complementary to each other. For example, EE measure directed by iBEMS were hoped to save 20% - 40% in overall site energy consumption while the team also proposed up to 15% direct cost savings and a simple payback of iBEMS' costs within 5 years. 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.

Assumptions Made for Basis of Cost Analysis

Initial assumptions are described here and including assumptions about natural gas costs and utility data used for the analysis. Some important assumptions about controllable loads are discussed thoroughly in section 4.1. Assumptions about the anticipated scale of implementation of iBEMS, i.e. campus-wide, are described in this section.

Natural Gas Consumption and Savings

As there were no thermal meters installed at the demonstration buildings, the project team had to employ engineering assumptions about hot water consumption at each building and its relationship to natural gas consumed at the Heating Plant.

Gas savings for AH, MH, and the CC were calculated based on a percentage of the total natural gas usage of the Heating Plant. It is important to note that, although other uses of natural gas may have been present within each of the buildings, the Heating Plant was considered the only source of controllable natural gas usage.

Logs of daily distributed heat to the Academic Area, the CC, and the Hospital were collated and analyzed to determine monthly heat distribution ranging from January 2011 through to October of 2013. Further, using data from a 2009 study[21], it was determined that of the total heat energy that is distributed throughout the campus, that 3.1% of this energy goes to AH, 3.3% goes to MH, and 11% goes to the CC. The study calculated that the Heating Plant is 76.0% effective in generating heating energy from natural gas and that 83.1% of this energy is then distributed out to the various usages throughout the campus. Once the heating energy leaves the Heating Plant, 5.2% of the energy is lost en route to AH and MH with 58% lost en route to the CC.

Using these efficiency and loss figures, it was calculated that for fiscal year 2013[22] the Heating Plant effectively delivered 6,115 MBTU to AH, 6,436 MBTU to MH, and 15,835 MBTU to the CC to reach a total delivered energy of 28,386 MBTU of heating. In order to deliver this quantity of heating energy, the Heating Plant had to use 80,321 MBTU of natural gas. The following graph in **Figure 93** shows AH as an example in the disparity between the energy consumed by the Heating Plant (green) and the heating energy delivered to AH (blue).

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. With the calculated heating savings at each building, this value was then divided by the overall plant generation and distribution figures to arrive at a total natural gas consumption savings. To this end, the final overall efficiencies for AH, MH, and the CC are 60%, 60% and 27%, respectively. The percentages represent the portion of each unit of natural gas burned at the Heating Plant that actually contributed heat to the end users.

[21] USAFABuildingEnergyUsage2009.xls[22] Heat Plan Log data for the month of June 2013 was not available and therefore June 2013 was calculated as the average of the values of June 2011 and June 2012.

[22] Heat Plan Log data for the month of June 2013 was not available and therefore June 2013 was calculated as the average of the values of June 2011 and June 2012.

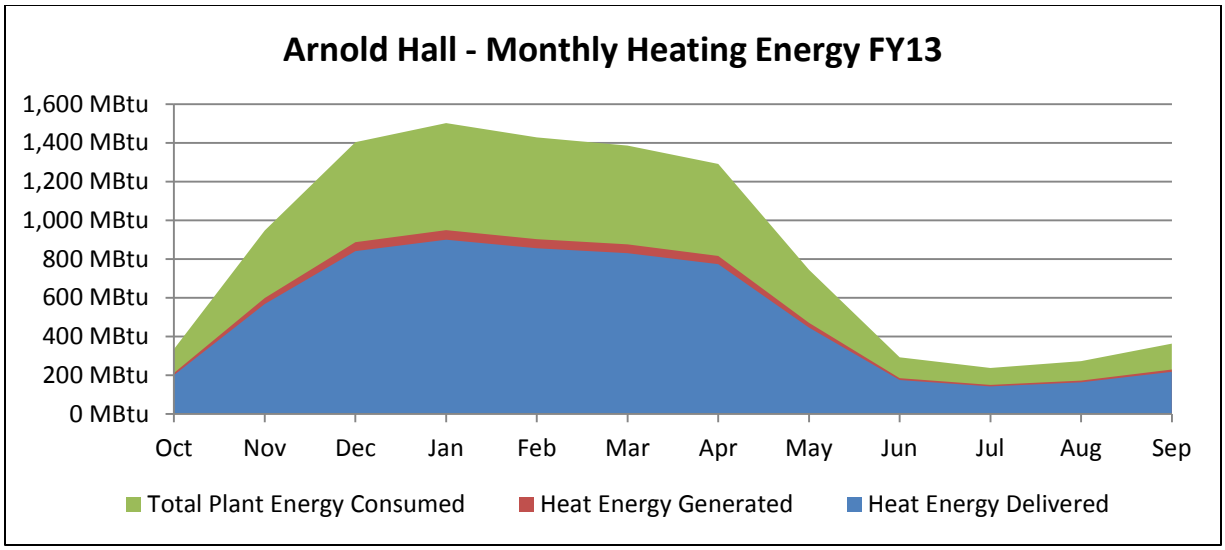


Figure 93: AH - Monthly Heating Energy FY13

Using the calibrated EnergyPlus energy model to calculate the baseline natural gas annual energy use, shown in **Figure 94**, a total value of 75,368 therms of natural gas is calculated to be used as heat energy at AH in a typical calendar year. Similarly, adapting the same calibrated model to include the EE Measures implemented and tested on site, the simulation calculates that 57.6% of this total heat energy can be reduced throughout a calendar year.

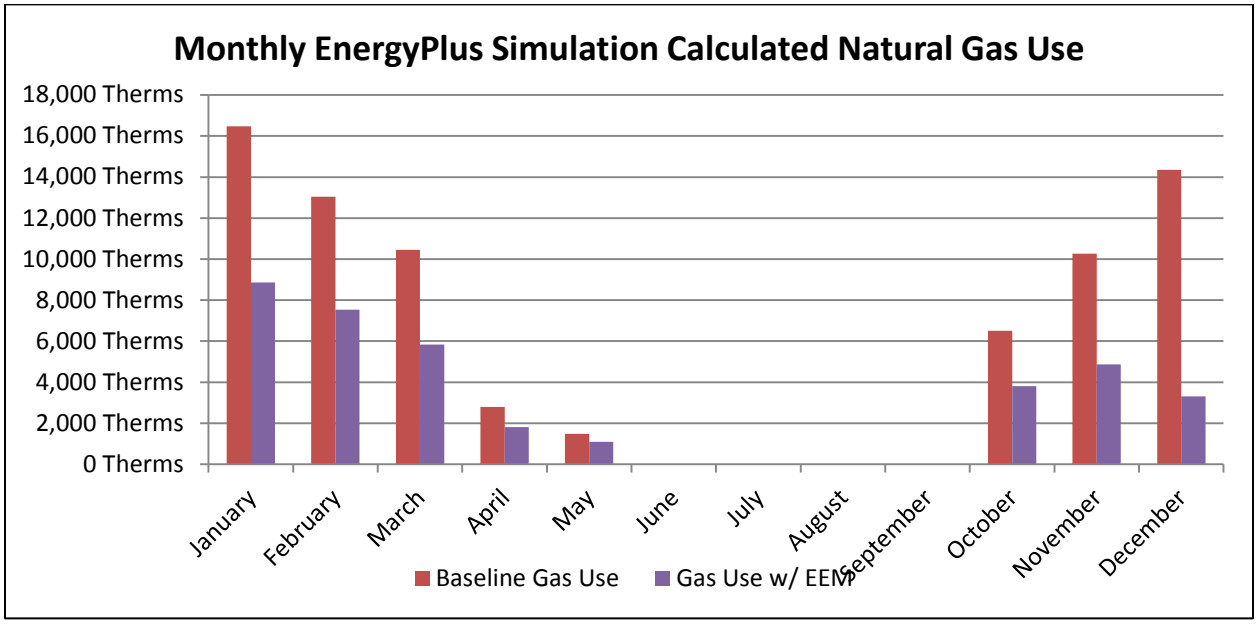


Figure 94: AH: Monthly EnergyPlus Simulation Calculated Natural Gas Use

In comparison, considering the building usage breakdown and losses described in the section above, the average heat energy delivered to AH for fiscal years 2011, 2012, and 2013, tallies to 66,861 therms, a difference of 11.3% from the simulated usage. Applying this difference to the

simulated savings of 38,227 therms, or 57.2% of the baseline natural gas usage, we can estimate that the actual savings in natural gas load at AH would be 33,911 therms, which is 50.7% reduction of average heat energy delivered to AH. Multiplying this value back through the Heating Plant efficiency and loss values (60%), an overall savings of 56,519 therms can be calculated at the level of deferred natural gas usage at the Heating Plant level.

Although calibrated energy models have not been developed for MH or the CC, if it were assumed that implementation of EE Measures utilized at AH yielded similar results, an estimated heating energy savings can be calculated based on this 50.7% reduction. As such, the average heat energy delivered to MH for the past three fiscal years calculates to be 70,830 therms with 35,924 therms of potential savings in terms of reduced heat energy load. Considering the losses and efficiency numbers of the Heating Plant in relation to MH, this savings then calculates to 59,873 therms of deferred natural gas usage at the Heating Plant level. The same methodology also yields 335,849 therms of natural gas usage based on a 27% overall efficiency in the Heating Plant's ability to deliver heat energy to the CC. **Table 33** below summarizes our findings.

Table 33: Summary of Findings Related to Heating Energy Usage

	AH	**MH**	**CC**
Simulated Heating Energy Use	75,368 therms	n/a	n/a
Metered Heating Energy Use[23]	66,861 therms	70,830 therms	178,787 therms
Difference between Metered and Simulated Usage	11.3%	n/a	n/a
Simulated Heating Energy Savings	38,227 therms	n/a	n/a
Simulated Percentage of Heating Energy Savings	50.7%	n/a	n/a
Adjusted Heating Energy Savings	33,911 therms	35,924 therms**	90,679 therms[24]
Efficiency of Heating Energy Deliver from Boiler Plant	60%	60%	27%
Natural Gas Savings at Boiler Plant	56,519 therms	59,874 therms	335,849 therms

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) as described below in **Table 34**. Our review of the Academy's monthly demand, which, at minimum, is 10 MW or greater during the shoulder seasons, indicates that there is virtually no possibility of moving to a lower tiered rate class. Based on the structure of demand charges, however, the Academy could benefit by moving load from "ON peak" periods, typically 6 to 7 hours in the in late morning to afternoon/evening, to "OFF peak" periods. The difference in demand costs is $0.48/kW versus $0.28/kW, respectively.

[23] Value based on average of usage for Fiscal Years 2011, 2012, and 2013
[24] Considering the Simulated Percentage of Heating Energy Savings Calculated for Arnold Hall

Table 34: Colorado Springs Utility Electricity Rates

Large Commercial & Industrial – Time of Day Rate		
	E8S: 4,000 kW min. in last 12 billing periods.	Comments
Access/Facilities charge per day	$27.5860	The per day charge is multiplied by the number of days in the billing period (e.g. 30 or 31)
Electric Supply ON peak[25], per kWh	$0.0512	Charge applies to all ON peak kWh hours during the month.
Electric Supply OFF peak[25], per kWh	$0.0215	Charge applies to all OFF peak kWh hours during the month.
Electric Cost Adjustment per kWh	($0.0010)	The cost adjustment is for the purchase of extra gas or coal during the month to meet demand. The adjustment can be negative or positive.
ON peak[25], demand per kW per day	$0.4814	The peak demand of the month is the maximum 15 minutes average of kW.
OFF peak[25], demand per kW per day	$0.2888	For USAFA, OFF peak demand is any amount over the ON peak demand e.g. if peak during ON peak is 1.2 MW and OFF peak demand is 1.4 MW, then the charge is applied to (1.4 – 1.2 MW) = 0.2 MW
Electric Capacity Charge per kW	$0.0010	Capacity charge is based on the total kWh consumed during the month.

The prime consumer of natural gas is the Academy's Heating Plant, which distributes high temperature and medium temperature hot water throughout the campus. Based on the team's analysis, the Academy operates under the Standard Option rate as seen below in **Table 35**.

Table 35: Colorado Springs Utilities Natural Gas Rates

Natural Gas (12.01 PSIA Pressure Base)	
	Standard Option
Access charge per day	$0.7623
Access charge per CCF	$0.1571
Natural gas cost per CCF	$0.6034
Gas Cost Adjustment (GCA), per CCF	($0.1700)

The utility bills for USAFA site listed individual costs components that included access charges, demand charges (on and off peak), supply charges (on and off peak), capacity charges and energy

[25] On and Off Peak Periods:
On-peak periods Oct. - March: 4 to 10 p.m. Monday through Friday
On-peak periods April - Sept.: 11 a.m. to 6 p.m. Monday through Friday
Off-peak periods: all other hours plus legally-observed holidays

costs adjustments for both electricity and gas fuel types. 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. Billing data was available for 2009 and 2011 fiscal years; however the energy consumptions provided in the 2011 data were inconclusive. Therefore, the costs from the 2009 billing data were increased proportionally to match the 2011 utility rates (escalation was negligible during that period). The calculated rates used in the cost analysis are $0.513/kWh for electricity and $0.44/Therm for gas. This methodology for deriving the blended rate can only be applied on a site by site basis as each location will have different demand and therefore different demand and supply costs that will need to be considered.

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. Since energy consumption varies so dramatically per building depending on square footage, occupancy and function, the team had to make assumptions about the electricity and heating loads that would comprise a campus utilizing the iBEMS. The assumptions are based on available building data for the USAFA site, DOE's reference building models and historical electrical and gas meter data for the site.

Scaling Energy Results

Literature in the specific topic of scaling single building retrofit savings to multiple building is currently limited in number and scope. There is no generally accepted or standardized method that the team could rely upon. However, the parts of the analysis, discussed below, to extrapolate the energy savings from AH to estimate USAFA campus wide energy savings is based on several studies in which similar methods are utilized. Three studies utilize benchmark building models, from varying sources, to base their analyses on. In [11], the authors take averages of several types of common buildings, and in [12] and [13] the authors utilize benchmark building models from a government source. The buildings analyzed in [12] and [13] are compared to benchmark buildings, and the appropriate one is selected as a model. The USAFA scaling analysis computes fan power and energy consumption from the benchmark building power and energy breakdown, as do the authors in [12]. The USAFA scaling analysis took into account the effects of turning off ventilation as an energy conservation measure (ECM). A model of the increase of decrease in temperature in time was developed, similar to the efforts in [13] and [14]. In [14], the authors account for the rise or drop in temperature due to completely shutting off an HVAC unit within a large building, and for the increase in power needed to restore the temperature to the set point, should the indoor air temperature change. In [13] the authors estimate savings in HVAC power and energy due to reduced indoor air temperature increase due to retrofits. Therefore the team based the HVAC savings and penalty off the efforts presented in [13] and [14].

The process of scaling and projecting site energy savings was begun by using normalized annual baseline energy for AH. As mentioned earlier in this report, AH was the only building that had a completely calibrated model and where EE measures were implemented. Normalized, baseline energy was calculated by running the calibrated AH EnergyPlus model using averaged weather (DOE's Typical Meteorological Year weather data) for the site derived for 1991-2005 period of

record. This result (N_{AH}) was then compared to the historical annual energy data for the building (H_{AH}) to generate a percentage difference between the two results. The percentage difference was then used as a multiplying factor for the other buildings (same historical annual metered kWh) to calculate their annual normalized baseline energy (N_X). See **Figure 95** below for a comparison of real-time weather versus normalized weather.

A list of all occupied and unoccupied buildings on USAFA site was then obtained. The buildings' square footages and historical meter data were also collected.

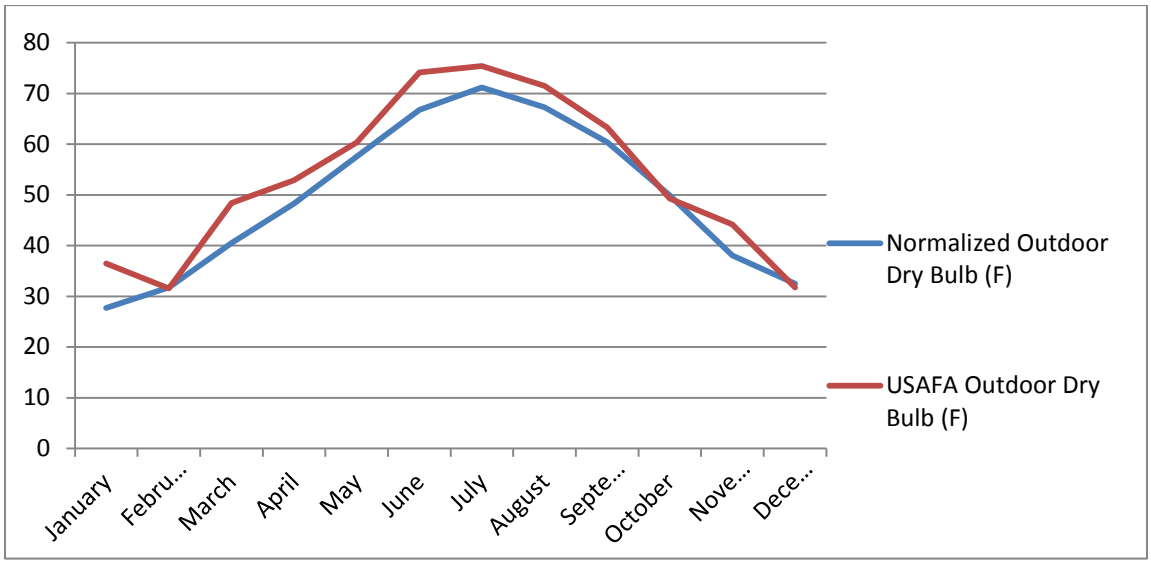


Figure 95: Real-time Weather versus TMY3 Normalized Weather Data

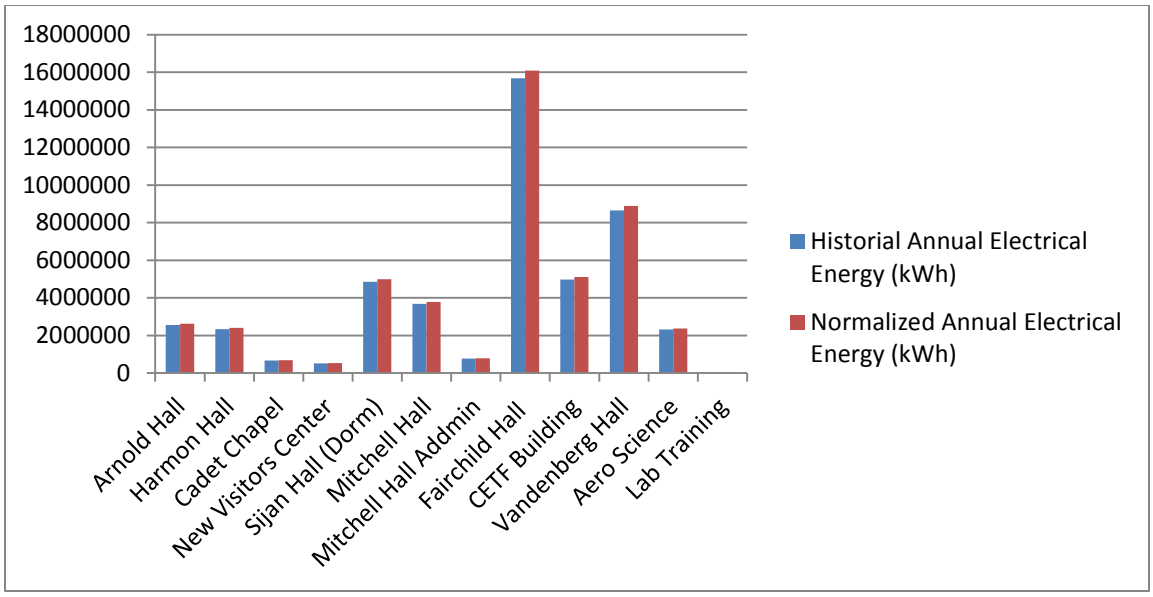


Figure 96: Historical Electrical Data versus Normalized Baseline data for selected buildings on site

Exclusions

When the entire USAFA site was assessed for the scalability analysis, over 50 buildings had to be excluded from the analysis. There were a number of buildings on site that weren't on the Apogee BAS and, therefore, could not be controlled by a SEB. Unoccupied buildings were also excluded from the savings calculations. Furthermore, some of the buildings on site were missing critical information such as square footage and the number of AHU units installed and, as a result, could not be included in the analysis. The team also found that utility data, particularly electricity reported for certain buildings, was remarkably high compared to benchmark values published by ASHRAE for similar building types. These buildings were excluded. Finally, three buildings that presented excessively high heat penalties when EE measures were applied, i.e. the make-up energy required to get building spaces back to temperature setpoints was greater than 59% of the energy saved, were also excluded. This left 14 buildings representing just over 3 million square feet and a total of 54% of occupied building space on the campus.

Benchmark Buildings

To predict the energy use and provide an acceptable degree of accuracy for the entire campus, each occupied building was 'matched' to the appropriate building type in the DOE benchmark building database. Where building types did not align with the DOE reference models, Lawrence Berkeley National Laboratory's Energy-IQ website, which is based on the Commercial Buildings Energy Consumption Survey (CBECS), was used. Both sets of benchmark data provided a breakdown of the end-use energy for each building type on site. This percentage breakdown was used to predict the savings campus wide.

Energy Efficiency and Demand Strategies Implementation

The end-use breakdowns generated for all reference buildings listed the fan, cooling and heating energy as a percentage of total annual energy. The energy consumption for fans, cooling and

heating was then calculated for each of the eligible buildings on site using this percentage and the previously calculated baseline normalized energy. The main EE measure implemented for AH was achieved by reducing fan operation. Therefore, fan energy and demand reduction were the primary focus for the savings projection campus wide. The buildings at USAFA are open 231 days a year according to the academic schedule for 2012/2013. The hours of daily operation for most buildings on site are 7am - 5pm. Therefore, on an annual basis, buildings are operating for 2310 hours. The current fan schedule for most of the buildings on site is 5am - 7pm, which is equivalent to 3234 annual run time hours (t_{op}). The fan demand (F_d^X) was calculated by dividing the total fan energy by the total fan run time hours for each of the buildings. The demand savings was calculated by assuming 20% reduction of the fan demand. This is a conservative estimate considering the actual DR results, for controllable loads, from the 5 DR events conducted during DR demonstration.

EE savings and non-peak demand reductions are quantified by looking at the fan hourly profiles. When the fans are not operating at full capacity (and during non-critical times) savings can be achieved even if it's only for 15 minutes in the day. When these systems are turned off during the non-peak period this subsequently reduces the run times. It was assumed that the fans in each building could be turned off for 15 minute intervals at different periods for a minimum of 4 hours in a 24 hour period. Across the campus, fans could be cycled at different periods because each of the buildings' zones would have different peak loads throughout the day. Subsequently, the annual fan energy savings ($\mathrm{OS_f^X}$) for each building, can be determined by multiplying the total fan demand (previously estimated) by 4 hours a day for 231 days a year.

When a fan system is turned off the mean air space temperature will drop (or increase, depending on exterior temperature). When the system is turned back on again, the space temperature will need to be increased to meet the thermostat requirements for that particular zone. This drop in temperature is seen as a savings “penalty” to the fan savings as it would not occur if the system were on constantly. The savings penalty for each building was calculated based on the hourly room temperature and fan behavior analyzed in AH as this was the only building where EE measures were implemented. The mean air temperatures in various spaces were investigated to identify the behavior when the fans were turned on and off. An average temperature drop ($\Delta°\mathrm{F}/hr$) of 2.14 degrees F/hour was found. The fan kW reduction rate, ($\Delta fan\ kW/°\mathrm{F}$), was calculated to be 0.79 kW/degree F of air temperature. The savings penalty, (X_{sp}), was determined per system on an annual basis. This amount was then subtracted from the fan energy savings calculated previously. The resulting savings were considered the total fan savings (S_f^X). The following flow chart in **Figure 97** outlines this process and the various calculations involved.

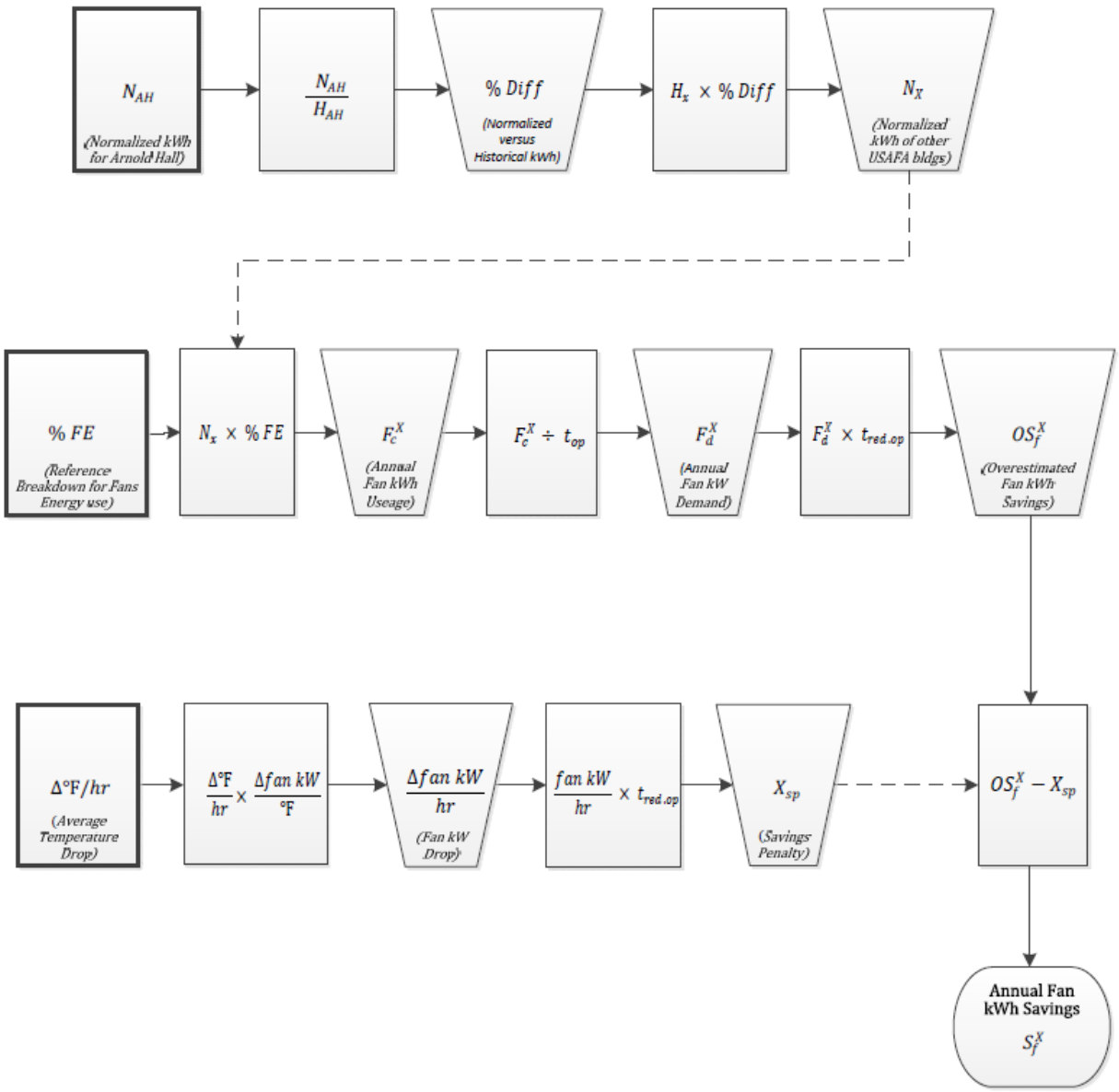
Assumptions

The basic premise of our assumptions when using a methodology to predict energy and demand savings is the ability to influence the operational schedules of building systems to improve energy performance of the facility. The purpose of this demonstration is to show energy and demand savings potential that are directly influenced through schedule modification. When using this methodology to predict energy savings, the project team assumes that USAFA building operators have the ability to operate building systems according to varying occupancy schedules. When this approach is applied campus-wide it is critical that scheduling of building systems is modified so that maximum annual energy savings and peak demand reduction are realized. In particular, we

assume that building operators have the ability to adjust the unitary HVAC systems operation times, ($t_{red.\ op}$).. Limitations in the application of this technology could occur where critical facilities need to maintain more stringent temperature, humidity or zone pressurization. Restrictions on schedule modification can also occur for buildings under high security clearances. Several buildings on the USAFA site were excluded from the campus-wide application of iBEMS for this reason. Assumptions concerning the hourly rates used to determine the savings penalty (X_{sp}) were also made. The following rates were assumed based on the Energy Plus model outputs for AH:

- Average temperature drop ($\Delta°F/hr$)
- Fan kW reduction rate (Δfan $kW/°F$)

Depending on the building type (differing thermal heat loads) and fan system type of different campus buildings, these values can vary greatly and can change the predicted savings significantly. Therefore, temperature drop assumptions and subsequent fan reductions need to be reviewed for each building depending on their heat load characteristics.



$Normalized\ KWH\ for\ Arnold\ Hall = N_{AH}$
$Normalized\ KWH\ for\ all\ other\ USAFA\ buildings = N_X$
$Historical\ KWH\ for\ Arnold\ Hall\ = H_{AH}$
$Historical\ KWH\ for\ all\ other\ USAFA\ buildings\ = H_X$
$Annual\ Fan\ KWH\ Consumption\ =\ F_c^X$
$Annual\ Fan\ Operating\ Hours\ =\ t_{op}$
$Annual\ Fan\ kW\ Demand\ =\ F_d^X$
$Reduced\ Annual\ Fan\ Operating\ Hours\ =\ t_{red.\ op}$

$Overestimated\ Fan\ KWH\ Savings\ =\ OS_f^X$
$Temperature\ Drop\ per\ hour\ of\ fan\ operation = \Delta°F/hr$
$Fan\ kW\ Drop\ per\ Degree\ of\ temperature\ = \frac{\Delta fan\ kW}{°F}$
$Fan\ kW\ Drop\ per\ hour\ of\ fan\ operation = \frac{\Delta fan\ kW}{hr}$
$Savings\ Penalty = X_{sp}$
$Annual\ Fan\ KWH\ Savings\ =\ S_f^X$

Figure 97: Process to Calculate the Fan Energy Savings

Cooling Energy Savings

By turning an AHU off, the AHU's fan motor power is reduced to zero. At the same time, this reduction in fan power demand will reduce the thermal load on the cooling coils, which then reduces the loading on the chiller(s), distribution chilled water pumps, and cooling tower pumps and fans. So while computing the energy savings due to AHU turn off, both fan power reduction and cooling demand reduction should be taken into account. Reduction in cooling demand should include, where available, reduction in chiller power, cooling tower consumption, and distribution pump power. It is also expected that the amount of reduction in cooling demand, when an AHU is turned off, will be proportional to the fan power reduction. In general, without proper metering, it is very difficult to accurately compute cooling demand reduction due to the limited number of AHUs turned off. In such cases, the fan power reduction can be used to approximate the cooling demand reduction. For the USAFA site, we needed an approach for estimating cooling demand reduction due to AHUs turn off, given that fan power reduction and total cooling demand were known. For the USAFA site, we developed such an approach that utilized the detailed information available for AH. The steps for such an approach are given below.

Step 1: For AH, compute the fan ratio of AHU fan's annual kWh saving and fan's annual kWh consumption.

$$R_{Fan,Sav}^{AH} = \frac{Annual\ Fan\ KWH\ Savings\ (S_f^{AH})}{Annual\ Fan\ KWH\ Consumption\ (C_f^{AH})}$$

Step 2: For AH, compute the cooling ratio of annual cooling kWh saving, when AHUs are turned-off, and annual cooling kWh consumption.

$$R_{Chiller,Sav}^{AH} = \frac{Annual\ Cooling\ KWH\ Savings\ (S_c^{AH})}{Annual\ Cooling\ KWH\ Consumption\ (C_c^{AH})}$$

Step 3: For AH, compute the ratio of fan and cooling ratios. This ratio, *k*, is assumed constant for all buildings.

Assume, $\frac{R_{Chiller,Sav}^{AH}}{R_{Fan,Sav}^{AH}} = k = Constant\ for\ any\ building$

Step 4: For a building *X*, for which annual fan saving and annual chiller consumption data is available, the cooling kWh saving can be computed as below.

$$S_c^X = C_c^X * R_{Chiller,Sav}^X$$

$$S_c^X = C_c^X * k * R_{Fan,Sav}^X$$

Computation of k

Table 36 shows the monthly fan power and cooling savings for AH. The last column shows the ratios of these savings. As expected, this value is low during periods when cooling requirements are low (October to March). During this time savings due to fan power reduction will not be affected because the AHU fans are, more or less, still running at same schedule and speed, so

turning them off will also result in similar amount of savings. Whereas, during this time, since the cooling demand is already low, turning AHUs off will not result in too much savings as compared to what achieved during peak cooling periods (May-August). Average value of "*k*" was then obtained is used in computation of cooling saving for other building as explained in the algorithm above.

Table 36: Monthly Fan and Cooling savings for AH

Month	Fan Savings	Cooling Savings	Ratio (*k*)
January	20102.55	4340.76	0.215931
February	18034.03	3334.1	0.184878
March	19865.06	3231.08	0.162651
April	18234.74	8559.83	0.469424
May	18841.7	12707.55	0.674438
June	28039.76	22424.42	0.799737
July	27376.09	24337.1	0.888991
August	24774.95	13776.15	0.556052
September	21669.1	17255.05	0.796297
October	19235.93	1882.27	0.097852
November	20266.53	3628.27	0.179028
December	32640.38	5913.18	0.181161
		Average	0.43387

Heating Energy Savings

A similar approach to predicting the normalized annual electrical kWh for each building on the USAFA site was taken to estimate the normalized gas consumption for each building. Normalized baseline gas energy was found by running the calibrated AH EnergyPlus model using TMY3 weather data for the site. This result was then compared to the historical annual gas usage for the building to generate a percentage difference between the two results. The percentage difference was then applied to the historical gas usage recorded for the other buildings. There was a limit to the available historical gas consumption for the site and therefore heating savings could only be approximated for a handful of buildings. For those buildings, the gas savings were estimated based on the heating savings (57.6%) projected for AH.

Total Annual Energy Savings

The results of the scalability analysis and the projected total energy savings for the fourteen buildings on campus are shown below in **Table 37**. The first table shows potential electricity savings in kWh and cost savings per building.

Table 37: Potential Electricity Savings in kWh and Cost Savings per Building

Building	Square Footage (ft^2)	Building Type	Historical kWh (H_X)	Normalized kWh (N_X)	Annual Fan Energy (F_c^X)	Fan Demand (F_d^X)	Total Fan Savings (S_f^X)	Total Cooling Savings (S_c^X)	**Total Building Electrical Savings (kWh)**	**Total Electrical Cost Savings ($0.0513/kWh)**
Cadet Gym	439,951	Gymnasium	4,424,523	4,424,523	921,544	285	204,858	92,417	**297,274**	**$15,250**
Arnold Hall	178,604	Theater	2,548,618	2,625,077	697,469	216	174,552	78,745	**253,297**	**$12,994**
Sijan Hall	625,272	Dormitory	4,857,964	4,984,271	164,430	51	46,980	21,194	**68,174**	**$3,497**
Mitchell Hall	223,226	Dining Hall	3,675,761	3,778,682	678,127	210	171,273	77,266	**248,539**	**$12,750**
Mitchell Hall (Administration)	74,896	Offices/ Storage	764,366	784,240	177,699	55	41,780	18,848	**60,628**	**$3,110**
CETF Building	310,334	Classrooms	4,973,004	5,122,194	208,875	65	46,192	20,839	**67,031**	**$3,439**
Vandenberg Hall	832,923	Dormitory	8,649,497	8,874,384	292,763	91	83,647	37,735	**121,382**	**$6,227**
BOQ	51,401	Hotel	549,813	550,363	10,731	3	3,066	1,385	**4,449**	**$228**
Golf Course Club House	17,095	Restaurant/ Retail	317,520	318,473	57,153	18	16,330	7,367	**23,696**	**$1,216**
Base Exchange	45,512	Offices	849,607	850,976	249,977	77	66,927	30,192	**97,119**	**$4,982**
Youth Center	19,469	Recreational	289,202	289,202	157,941	49	42,878	19,344	**62,222**	**$3,192**
Community Center	153,657	Retail/ Offices	2,437,718	2,442,593	634,667	196	154,361	69,636	**223,997**	**$11,491**
Family Support Center	10,718	Offices	155,933	156,089	45,852	14	10,853	4,896	**15,749**	**$808**
Civil Engineering	52,810	Offices	921,929	923,773	209,315	65	46,318	20,895	**67,213**	**$3,448**
								TOTAL	**1,110,014**	**$82,633**

Table 38 below shows the potential heating savings for each building and calculates natural gas cost savings. Natural gas would be saved at the Heating Plant, not at individual buildings.

Table 38: Potential Heating and Natural Gas Cost Savings for Each Building

Building	Benchmark therms/ft^2	Normalized therms (N_X)	**Total Building Gas Savings (therms)**	**Total Gas Cost Savings ($044/therm)**
Cadet Gym	0.93	409,154	**207,441**	**$146,039**
Arnold Hall	0.36	64,297	**32,599**	**$22,950**
Sijan Hall	0.30	187,582	**95,104**	**$66,953**
Mitchell Hall	0.20	44,645	**22,635**	**$15,935**
Mitchell Hall (Administration)	0.08	5,992	**3,038**	**$2,139**
CETF Building	0.33	102,410	**51,922**	**$36,553**
Vandenberg Hall	0.30	249,877	**126,688**	**$89,188**
BOQ	0.13	6,682	**3,388**	**$2,385**
Golf Course Club House	0.50	8,548	**4,334**	**$3,051**

Base Exchange	0.08	3,641	**1,846**	**$1,300**
Youth Center	0.30	5,841	**2,961**	**$2,085**
Community Center	0.30	46,097	**23,371**	**$16,453**
Family Support Center	0.50	5,359	**2,717**	**$1,913**
Civil Engineering	0.80	17,427	**8,836**	**$6,220**
		TOTAL	**586,879**	**$413,163**

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 MBTU) and 931,464 therms (93,146 MBTU) for a total of 97,104 MBTU. See **Table 39** below for baseline consumption as well.

Table 39: Campus Wide Energy Consumption and Savings

Implementation of the iBEMS for 14 Academy Buildings			
	Electricity	**Natural Gas[26]**	**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 MBTU's)	117,693 MBTU	185,208 MBTU	302,884 MBTU
iBEMS Reductions (Conversion to MBTU's)	(3,958) 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%

[26] 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 Community Center) as the piping network since associated losses for the entire campus were relatively unknown.

Initially the team had set a goal of 40% annual EE savings which is an aggressive target for all but the most inefficient buildings. Eventually, when demonstration building selection was finalized and the project team realized that only HVAC equipment would be controllable via the iBEMS, the team adjusted energy saving targets to a range of 20% - 40% annually over baseline consumption.

As the results above indicate, the gas savings far outweigh the savings derived by electricity reductions. Of the 14 campus buildings selected for the scaling exercise, all are heated by the Heating Plant for which there is an assumed 60% loss due to combustion losses of the boilers, radiative heat loss of the boilers, and heat loss through the distribution piping. Therefore, any thermal savings at the building level is assumed to have a multiplying effect of 1.67 at the Heating Plant in terms of CCFs of natural gas saved.

Electricity savings were expected to comprise a greater portion of the overall energy savings; reasons for the small proportion of electricity savings are discussed below.

The iBEMS demonstration results are a mixture of successes as well as opportunities for improvement of building selection, data collection methodologies, communications with the Academy, and saving approaches. The potential achievement of an estimated 32% annual energy savings is a significant accomplishment and suggests that the Academy could benefit from updating control sequences and setback temperatures to better match building occupancy. In terms of costs, the savings represent nearly half a million dollars out of an estimated $2,580,000 total cost to heat and cool the 14 demonstration buildings. This represents a 19% cost savings. Therefore, the project results in an estimated greater than 15% direct cost savings, which meets one of the economic performance objectives set by the project team.

When applied to an actual campus of buildings, the project team would target greater electricity savings than 3.4%. Limitations on electricity savings were caused by a handful of problems. As previously mentioned, the iBEMS is designed to control numerous electrical loads, but, at the Academy, there were no opportunities to control lighting loads and virtually no opportunities to control plug loads as part of the ESCTP demonstration project. A few other barriers to electricity savings are listed below:

- Conservative fan savings: As discussed in the scalability methodology of this section, the projected fan savings for the campus were calculated based on reductions in fan run time. This resulted in a savings penalty as the temperature in the space would have increased or decreased based on the system that was shut down and, naturally, the exterior temperature. The team applied a conservative savings penalty to all building air handlers in the scaling estimations. Even though more savings may have been available, we could not verify that all air handlers associated with each of the 14 buildings would have been operating at any given time.
- Conservative demand savings: A 20% reduction in demand was used as a conservative projection for the campus. The demand savings for the three buildings investigated was 31.95% of total controllable loads. As there was not enough data available on controllable

loads for the site to predict accurate demand reduction, 20% was used as a conservative proxy.

- Higher gas savings: The projected gas savings are significantly larger than the electricity savings because heating energy usage is run-hour based and as such, coincides with the implementation of the fan operation. Unlike chiller and pump operation, the hot water coils in the buildings are either "on" or "off' based on the fan operation and do not run at partial load. When the fans are turned off during one of the energy efficiency demonstrations, the chiller and pumps could still be operating but at a reduced load. The heating coils, however, will turn completely off. This results in greater gas savings than electrical savings.
- Electric process loads: The electricity baseline also includes process loads which cannot be controlled by iBEMS. Process loads include large cooking equipment, dishwashers, garbage disposals, beverage coolers, appliances, etc. that can consume far more electricity than the HVAC systems e.g. in MH, and contribute to bigger baseline of electricity consumption. Gas consumption outside of the Heating Plant, on the other hand, is not included in the baseline for natural gas or total therms consumed.

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. Obstacles to achieving 40% savings are described in more detail below.

First, the project encountered considerable hurdles early in the process of securing a suitable site and buildings.

- Site selection proved to be the primary driver in determining project savings due to the following influences:
  - Building energy use and profiles are determined by occupancy and hours of operation.
  - Size of building influenced results in the case of AH where energy efficiency and demand control events were only a small portion of the overall energy consumed; the total amount of energy consumed made it very hard to determine the proportionally smaller impacts of the EE and DR measures.
  - The poor quality of the gas infrastructure provided added savings due to a 60% loss factor through inefficient equipment and unaccounted distribution losses between the Heating Plant and point of use.
  - The site is located in a heating dominated climate resulting in higher gas savings and lower cooling savings, thus resulting in lower cost and GHG savings versus a cooling dominated climate. While GHG savings of 20% were targeted, only 15% were achieved over baseline.

- The central Heating Plant was a vital component in determining the savings. None of the demonstration buildings was metered for heat consumption, nor was historic per building heat consumption available. Additionally, Heating Plant losses were very difficult to determine. In the end, the project team had to make significant assumptions about actual heat energy consumption at the point of use and associated savings at the Heating Plant.

- Secondary factors influencing the results include:
  - Electrical infrastructure determined the ease/difficulty in separating specific loads
  - Utility rate structure for the base provides little opportunity to reduce demand charges to the lower tier as demand control events would need to provide a 1 MW demand reduction.
  - Deferred maintenance on some building equipment resulted in the equipment not operating as designed and therefore the overall energy performance was affected.
  - Lack of automated controls for lighting and no opportunities to use wireless tablets for plug load controls resulted in fewer savings. Lighting controls are one of the most effective energy efficiency strategies that can be implemented in a building. Similarly, regulating a typically unregulated load like receptacle load can result in untapped electricity savings especially during unoccupied periods. The overall energy savings would have been larger if both of these end uses had been controlled during the demonstration.
  - The entire HVAC load in the building was not under the project team's control and therefore the overall savings projections had to be modified. E.g. AHU 4 and AHU 5 in AH were uninstalled halfway through the project, which resulted in the energy model and simulated results being adjusted. Further, the chiller serving AH was turned off in the middle of the baseline period, without notification to the team. Subsequently, the energy efficiency demonstration was performed a second time with different results.

The obvious benefit of completing a demonstration project, particularly with any degree of technological complexity, is that inevitably unforeseen errors emerge, whether related to the technology itself, or where and how it is implemented. For the iBEMS demonstration, we reflect on how our methodologies and results could be improved and offer discrete lessons learned.

From the perspective of the System Economics performance objective, the team feels the following items would have improved outcomes:

- A detailed central Heating Plant analysis should have been included to better characterize actual heating losses, especially because heating savings were far greater than electricity savings. Such an analysis would have been beyond the project budget.

- Better planning for and placement of submeters on equipment instead of electrical panels would have provided more accurate electricity consumption data.
- Both the project team and the energy management staff at the Academy could have communicated more clearly and effectively. Events such as lack of functionality/outages of air handlers and removal of several air handlers at AH (to accommodate construction) should have been reported. Likewise, the project team could have communicated its plans for testing the iBEMS more clearly to building occupants and to energy management staff.
- Due to technological issues, demonstrations were not run during the warmest months. Experiments on cooling occurred during the shoulder seasons.
- Early in the project, understand data needs and plan how to effectively collect the data. The team had to make a lot of assumptions about consumption, some of which could have been avoided with better planning. However, because site and building selection were delayed, the window during which to plan for data collection was also significantly shortened.

6.4.5 Lessons Learned and Recommendations

In terms of System Economics, the team reports the lessons learned from the demonstration and suggests ways to improve outcomes.

- Because it took considerably more time than anticipated to find a suitable site and the appropriate buildings that would accommodate the study, the project would have benefited from a longer time frame by 3 to 6 months.
- Due to the building age (circa late 1950's) and differing missions over a long period, there was limited or outdated information available for many buildings. This led to the only option of making many assumptions, thus increasing the likelihood of errors in resultant calculations. This is a common problem for older buildings and usually cannot be totally avoided. A complete drawing set for buildings of 1950s vintage is nearly impossible to obtain in most cases. Further, plans are rarely updated to incorporate renovations and equipment installations over the years. Therefore, in order to improve the data collection process and limit the amount of assumptions made for future projects, the military personnel should work closely with consultants in a targeted effort to compile the latest and most relevant drawings for the site.
- Determining site wide scale energy savings from only a small sampling proved to be very difficult to reconcile given the large diverse loads and many uncontrolled loads.
- The use of benchmark models developed by NREL and LBNL contributed significantly in determining typical building energy profiles and validating sub metered data.

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. Applying multiple levels of cyber security was a key objective in leveraging the secure OSB in this demonstration. Cyber security was important to this demonstration but a higher priority was the consistency and reliability of the network to support the primary mission of the demonstration, building system level efficiency and management. 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.

The significance of the OSB for this project is to be able to integrate and operate with expanded cyber security capabilities while operating with new and legacy systems. The heightened security features which are used in this project are more advanced than what is probably needed at the USAFA at this time. The USAFA has an isolated network and its mission is important but not as critical as other DOD facilities. The security features of the OSB are leveraged but the integration and testing of these capabilities was important for this project.

As iBEMS type systems are deployed onto facilities with more critical mission requirements, capabilities' the OSB has will be needed and required. Reviews of other DOD facilities highlight the critical aspects of their missions, large ad hoc qualities of their energy infrastructure and the diverse qualities of their infrastructure. Requests for proposals from the DOD, are also identifying this level of security for future deployments. Problems with elements of a facilities energy infrastructure could affect critical mission activities. Leveraging capabilities like the OSB will be required and needed to secure these DOD infrastructures. While there are many security capabilities in the market place today, systems that allow thousands of ad hoc nodes to connect at a high level of security exist primarily in the military domain. These DOD targeted products are usually highly integrated with the specific platform or system. The OSB maintains that high level of security capabilities while leveraging APIs and a service based architecture to be readily applied to different domains, like energy, without having to significantly changing the existing energy system. While there are multiple security products on the market none have all the capabilities available in the OSB. As security requirements on these ICS networks evolve products that have robust protective transport capabilities in an adhoc network environment will be required.

Three primary success criteria, presented earlier in **Table 4**, were selected for further evaluation to make sure consistency and reliability of the network was maintained while still meeting the overall energy management objectives while adding additional levels of security.

6.5.1 Baseline

The determination of baseline data was done through discussions with USAFA 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.

The authorized / unauthorized access of the existing system was collected in discussion with the USAFA ICS operations personnel. IP addresses were used to monitor access to the system and because the network is isolated, topology and geographically, there were no unauthorized access events. More unauthorized access attempts would be expected if the network was not isolated.

Success / unsuccessful communication between the iBEMS elements were baselined in the laboratory with a representative iBEMS (USAFA) system. The baseline data determined for success / unsuccessful communications was close to one hundred percent successful when the system was configured correctly. The only unsuccessful attempts were due to network configuration issues and were not included in the baseline data set.

Transaction latency was also baselined in the laboratory using varying message sizes. During base lining, message sizes ranged from 2048 bytes to 15000 bytes, with the current iBEMS message size being less than 2048 bytes. The latency base lining was also based on round trip timing from one iBEMS node to another and back. Baseline data was from 852 to 1598 messages / sec with latencies ranging from .00062 seconds to .00117 seconds. **Table 41** shows baseline latency data with and without the OSB.

6.5.2 Methodology

The methodology we 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 which 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 we developed a more robust test laboratory environment. The laboratory testing would be much more flexible and allow the project to run many different types of testing, and in some cases, test to failure. The test laboratory environment turned out to be a critical element to get data due to the limited flexibility to leverage the USAFA ICS network. Three types of data focuses would be collected and analyzed against our success criteria. The data focuses included intrusion/access attempts, successful and unsuccessful transactions and transaction latency.

The data accessibility of the USAFA ICS network is very limited due the requirements to keep existing functionality operational thus the iBEMS system could not interfere with existing systems. The network is currently isolated from any external networks and physically limited to on installation connection points. Data transactions on and off the network is control via human-in-the-loop air gap. The iBEMS, with SEBs, was installed and operated in multiple test configurations. Data files and log files were collected and used to gather data of the system operating on the USAFA ICS network. These data log files would be correlated with data gather in the laboratory environment to drive our analysis and results.

The laboratory environment included two actual iBEMS SEBs tied into an isolated 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. This would be

the core elements of the test environment, but part of the goals was to test and collect data in worst case and multiple configuration scenarios. Additional capabilities were added to the environment including a compute server, data monitoring software and a user interface to support testing of the system. The compute server was set up to represent a multiple number of SEBs, data nodes and / or non iBEMS related nodes. Up to 50 virtually represented nodes could be setup to emulate components in iBEMS and / or the USAFA ICS network. During the latency test phase we tested 30 SEBs running, communicating and controlling at the same time. The laboratory environment was able to run all the deployed software including the SEB software, OSB, Host Intrusion Detection software and emulate control /sensor data software. With the hardware and software in place, the lab environment was able to support realistic testing with no impact on the USAFA.

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. Each of these data sets would be analyzed to determine if the success criteria for this objective was met. **Table 40** outlines the data collected and the analysis to be applied to that data.

Table 40: 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 there monitoring data	Successful vs. unsuccessful access
Unauthorized access data (with iBEMS)	USAFA ICS and Lab	Log files on SEB nodes and OSB	Successful vs. unsuccessful access
Data Communication - Successful and unsuccessful (non 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

Collection methods used to gather data for network access and successful communication relied on software and multiple sets of log files to capture actual data. In the laboratory, software to automatically generate access attempts was used to create authorized and unauthorized access attempts. The number of authorized and unauthorized attempts were collected and then compared with the log files the system captured on authorized and blocked access. A specific computer was also configured to do some penetration testing, intercept data packets and manipulate those packets. The results of this data were also examined in files captured on the system. Testing on the USAFA ICS was not as extensive but actual data was collected to understand access and successful transactions realities.

Wireshark[27], an open source packet analysis tool, was used to support packet level intrusion and analysis. Tests included observation of packet level encryption and modification of packets in transit. Tests were conducted with and without the secure OSB functioning and detection data was collected in log files. **Figure 98** shows a packet level representation with and without the secure OSB in place. In this example test data counting from 0 to 255 was passed across the iBEMS test network.

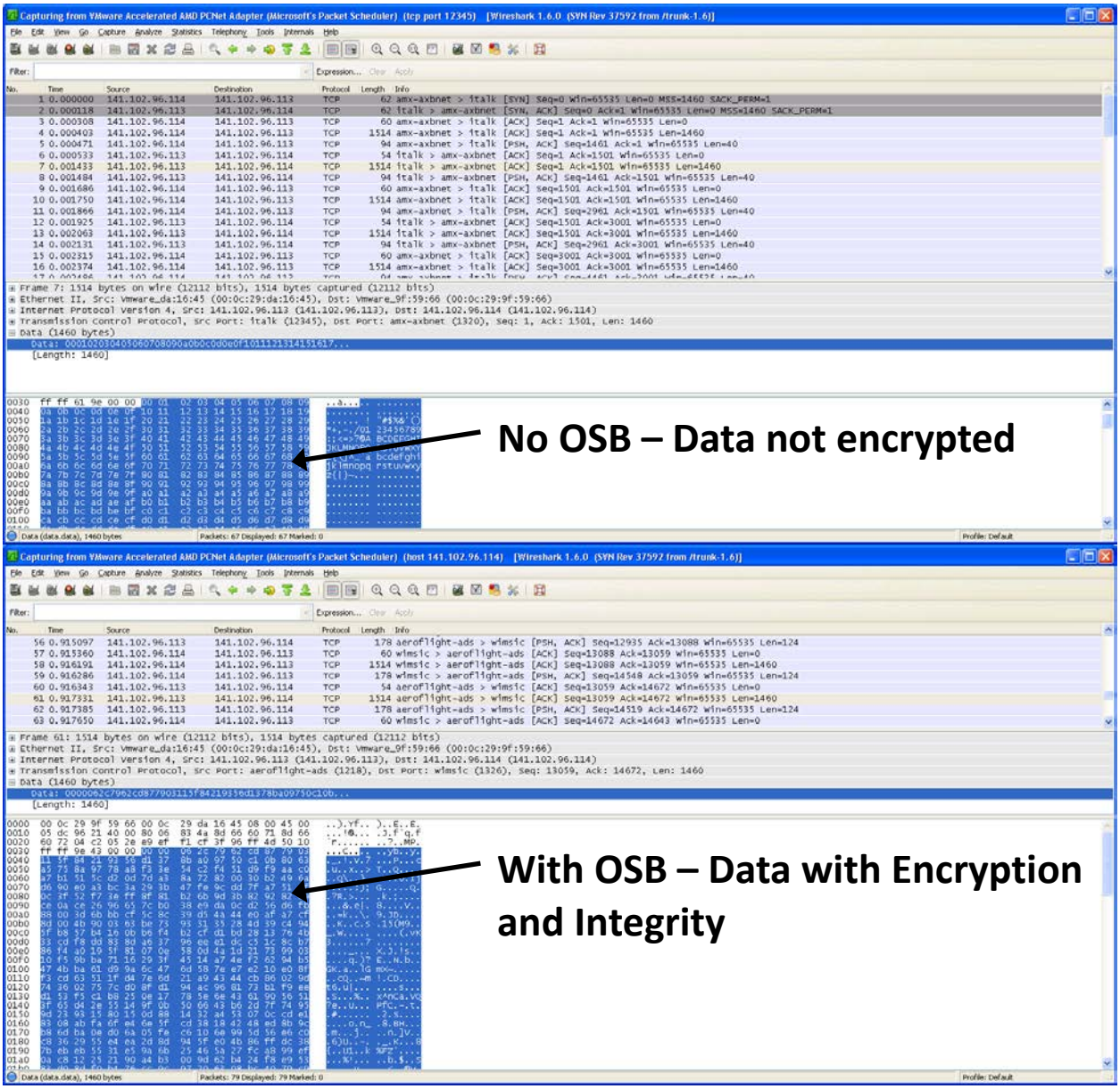


Figure 98: Packet Level Representation with and without the Secure OSB in Place

[27] http://www.wireshark.org/

Specific tests were setup to examine the latency and success rate of the communication data of the system. The tests included a TCP test client and a server using Windows socket APIs. The test client would send and receives 1,000 messages with the server side receiving and echoing back received messages as soon as a message is received. The client side measures average round trip time (send + receive) by first getting starting timestamp before sending the first message then getting ending timestamp after the 1,000 messages are sent/received. The client allows a user to enter message size to be sent and received in bytes.

Tests were run without using the secure OSB to get baseline roundtrip latency using the test client/server, as shown in **Figure 99**. Tests were run with the following message sizes 2048, 5000, 10000, and 15000 byte messages. The time measured is used to calculate average ROUND-TRIP latency for each of the message sizes.

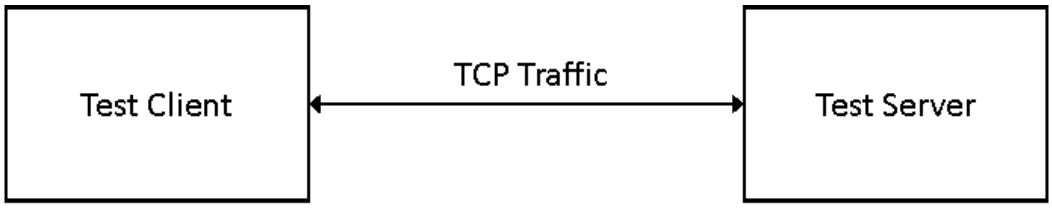


Figure 99: Client/Server Test

The same test client / server code was used to test with secure OSB in place. The test client and server connect to the secure OSB shown below in **Figure 100**.

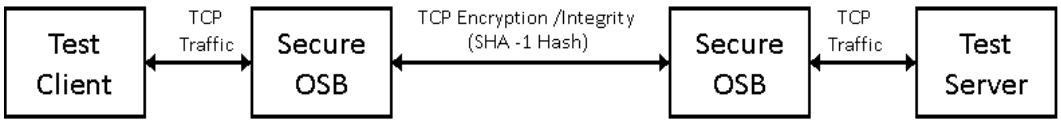


Figure 100: Test Client and Server Connect to the Secure OSB

The secure OSB use FIPS 140-2 libraries (OpenSSL) to perform ephemeral key exchange, encryption, and SHA-1 hash (Integrity). This ephemeral key message exchange adds extra time to establish a connection. Communication on the secure OSB is protected, which includes encryption and Integrity. Integrity includes SHA-1 hash along with NONCE (playback rejection), and timestamp to prevent delayed delivery of messages. There are 4 extra send/receives for round-trip in the secure vs. unsecure communication. This adds latency for each send/receive and adds latency to compute encrypted and integrity checked message.

Due to the embedded nature of some of our tests and the need to adjust elements like packet size, transmission rates and loads on the network, specific tests and support code was incorporated within the OSB and the SEBs. The deployed system consisted of four SEBs, and the data and timing needs that fell well within the USAFA network constraints. To fully understand the effects of incorporating additional security and the OSB, it was important to test and collect data outside of the USAFA deployment envelope. Dynamically adding additional nodes, increasing packet

size, varying message frequency and adjusting network bandwidth via additional loading, were part of the data collection process which expanded the data set for analysis. Capabilities to inject errors in the data, spoof data packets, block nodes and intrude into the network were used to expand the data and test envelope to allow for better understanding of the margins of the system.

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. Three success criteria were targeted at the beginning of the demonstration, secure communication, no significant effects caused by latency and no impact of the iBEMS system on the BAS.

Secure Communications

Secure communications between iBEMS and the existing BAS measured by intrusion and blocking testing. The baseline data without the iBEMS deployed did not show any real intrusion, blocking or external / internal security related issues. This was established through discussions with the USAFA ICS system based on their monitoring software. This was to be expected since this ICS network is isolated to industrial control equipment and physically isolated the USAFA installation. Once iBEMS was deployed we would expect similar results so the introduction of testing that reflected a network that was exposed was what the results were based on.

The iBEMS system was setup to only allow defined IP addresses to access and communicate with one another. Also packet base encryption was associated to each node to secure packet information in transit and authenticate what node was communicating. Intrusion testing was done on both the laboratory and USAFA networks, while the packet level attacks were done the laboratory environment due to the operational nature of the ICS.

During the intrusion testing in all cases the intrusion during the tests were detected, logged and a message could be sent. In certain cases specific nodes were identified as having limited access and those nodes were also detected and granted limited access. In the case a node had limited access and tried to go beyond that access they were also blocked. In total over 1000 tests were made with non legitimate access on both the lab and USAFA environments. Once the system was configured correctly, in all cases that access was designed and logged. **Figure 101** shows an example for a log file and status window during testing.

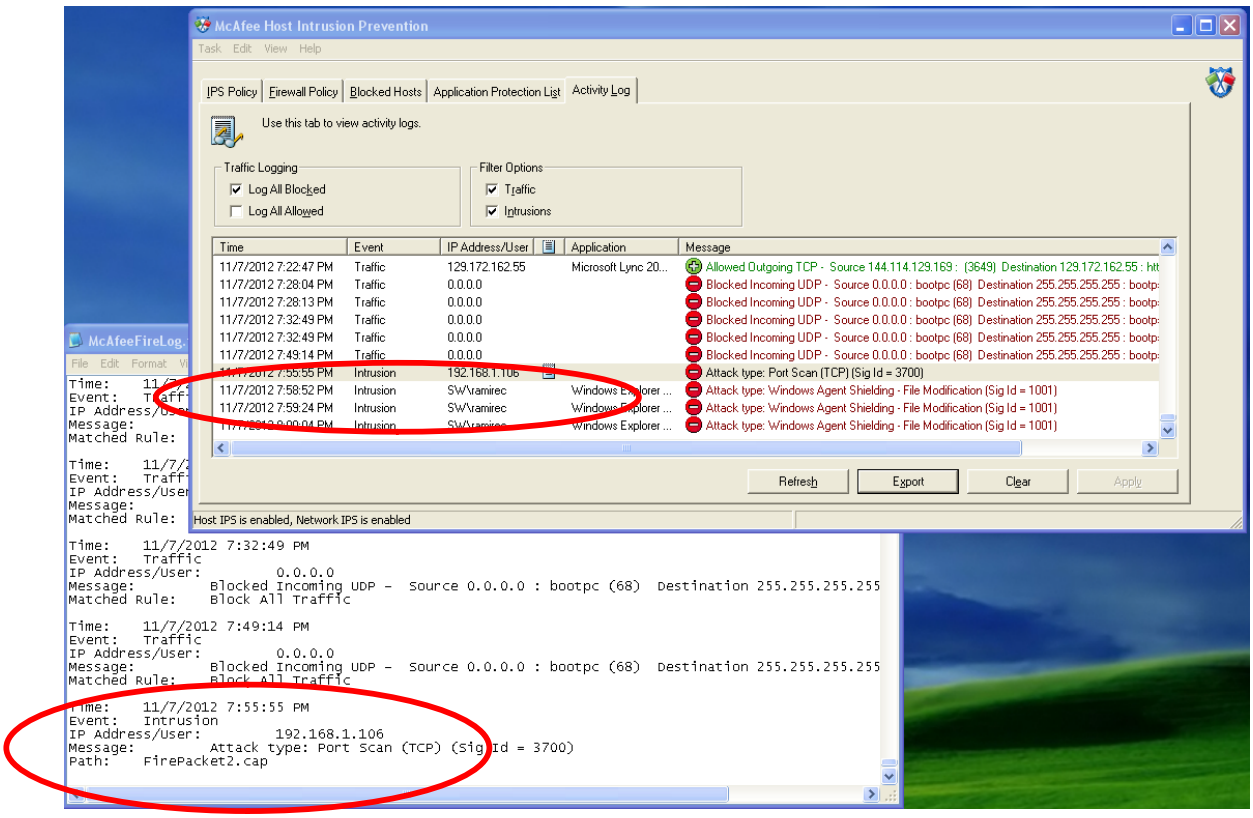


Figure 101: Example for a Log File and Status Window during Testing

The only authorized access issues observed were caused by specific node configuration problems. During initial testing one of the SEB nodes was improperly configured causing all communications between that node and other SEB nodes to be blocked. To continue on site testing, the OSB was disabled until the issues were isolated. As a result of this issue a simple OSB network status was incorporated for the next round of onsite testing. This would allow the operator to receive real time status of all the OSB connections.

Packet level spoofing was also tested in the laboratory environment with the USAFA iBEMS configuration. Packet level injection software attempted to modify and / or spoof packets being passed between iBEMS nodes. One function of the OSB is to examine and authenticate packets to identify any issues. If an abnormality does exist those packets are isolated from the bus and a written message describing the anomaly that has been detected, is sent to syslog. Wireshark was used to spoof and inject packet data into the system with and without the secure OSB. In all cases the modified packets were not detected when the OSB was not running, packets could be manipulated and modified without the system being aware. When the OSB was operational we caught all attempts to modify or spoof the packet data. The secure OSB blocked that packet from being used and alerted the system via syslog.

Our tests were not specifically looking for intrusions into the USAFA ICS network, but intrusions that were targeted at iBEMS' nodes and / or data. The results of the secure communication testing were that all unauthorized access and spoofing was detected and logged. In the cases of intrusion into protected areas of an iBEMS node, those intrusions were blocked and logged. Authorized

access was also success in all cases once the system was configured corrected. Intrusion and spoofing of the data level communication was detected by the OSB and isolated. Details of the data level intrusion were logged within syslog.

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. The laboratory environment was setup similar to the USAFA ICS as far as iBMES nodes, network hardware and network bandwidth.

The existing APOGEE BAS, at the USAFA, sends data at a rate typically of one second or greater. The timing of that data is based on a best attempt strategy and deterministic command and data responses are not critical. Communication latencies are measured in the seconds' time frame with specific critical command requirements being less than one second. The iBEMS system, once integrated with the existing BAS, would be required to perform within the same basic requirements as the existing system.

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 41** below shows the average latency in seconds running test client/server with and without the OSB. All times are in seconds with proxy overhead being around 1.8 milli-seconds to 5.2 milli-seconds, depending on message size. These overhead values are round trip, not one-way.

Table 41: iBEMS Latency Data

iBEMS Latency Data					
	No OSB	No OSB	With OSB	With OSB	OSB Additional
msgSize (Bytes)	msgs/sec	Ave Latency (sec)	msgs/sec	Ave Latency (sec)	Overhead (sec)
2048	1598	0.000625782	409	0.002444988	0.0018192
5000	1278	0.000782473	238	0.004201681	0.0034192
10000	1014	0.000986193	208	0.004807692	0.0038215
15000	852	0.001173709	157	0.006369427	0.0051957

The average message size measured in the actual iBEMS communications is less than 2048 bytes. 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 be no impact to the iBEMS deployed system.

Additional tests were run to understand other factors that could have an effect on latency. These other factors included the one time initial connection time and the run time memory usage. The one time initial connection time would be longer at startup due to two more TCP connections and the ephemeral key exchange. The average connect time was 0.97 seconds. This also is well within the programs goals.

Run time memory was also monitor with the secure OSB operational. On the OSB server node, the OSB uses 16 megabytes of run time memory plus 128 K bytes for stack and 100 K bytes for heap per thread. The OSB Client used 128 K bytes of stack and 100K bytes for heap per thread. When a thread is shutdown memory is recovered so worst case memory utilization is 16 MB + (228K bytes * # of nodes). This is also well within the program requirements and the hardware specified by the iBEMS system which has 1 GB of memory.

6.5.4 Conclusions

The overall conclusions regarding the goals and objectives for the security and reliability elements of the demonstration were very good. Three objectives criteria were targeted, secure communications, no significant effects of latency on the system and no negative impacts concerning iBEMS working with the existing BAS. Based on data collected, testing and observations, these objectives were all met.

Results

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.

Since our data and testing was done on an isolated ICS network, our results are probably better than if we were on an exposed or more complex network topology. Future evolution of the iBEMS system would need to develop results based on more open, complex topologies. Results from that type of network may guide the team on target result improvements.

The most obvious result improvement area, while leveraging a more open / complex network, would be the intrusion detection and control result area. Intrusion threats and attempts happen consistently in the real world, especially DOD hosted networks. These outside intrusion attempts can be complex and change very quickly. Since we tested on an isolated network we were unable to see the full complement of intrusion threats. During testing we did emulate some types of threats, but the scope could be expanded by a more open network. Since the OSB was coupled with a Commercial Off the Shelf (COTS) intrusion protection product we feel the intrusion security was robust and did address potential threats not seem on the USAFA industrial control system (ICS). Leveraging these types of products also helps to protect from evolving threats because these products evolve also with those threats.

Methodology

The main methodology improvement would be to extend or duplicate a representative ICS targeted network into a non isolated environment. This would allow us to test against threats and constraints we envisioned but also threats that we did not foresee. Our results would be different and thus the system going forward might be different.

Since the environment iBEMS will be operating in will be continually evolving, another methodology improvement is expanding the test system and test environments to be more robust and configurable. Currently we developed test and data gathering techniques to focus on our specific objectives. As the iBEMS system matures and the deployment environments are different, we would want a test integration support systems that could easily handle other types of objectives and be readily configurable for new environments.

6.5.5 Lessons Learned

There were a number of lessons learned on this project while focusing on the security and reliability integration, testing and operations. The deployment of the OSB onto the USAFA ICS provided many of those lessons. During this project we had two deployment phases. The initial phase was multiple weeks and was to deploy iBEMS, the OSB security, and intrusion detection, configure iBEMS and configure the iBEMS network. Since this was the first installation we found installing, testing and verifying operations were difficult when doing all of these things concurrently. Phase two we installed the security and configured the network the week prior to iBEMS deployment and were much more successful. Initially since we did integrate the system in the lab, we felt it would be fairly easy to deploy the system at one time. Even with fairly simple systems, a phased deployment approach would be beneficial.

Another lesson learned was the need for improved health and status environments. During development we used a number of tools and methods to do health, checkout and status of the system. During deployment and operations we needed better visibility into what the system is doing, especially during initial setup and updates. These improved tools would apply to the install, test and operation phases of a system.

This project and discussions with other DOD facilities with ICS functionality, reinforces that each facility varies greatly from other facilities. Processes, configuration, operations, conops, hardware, connectivity, security and criticality are typically unique at each facility. The USAF is trying to standardize the facility ICS systems but that standardization is still evolving and will take many years. These systems are operational and typically involve large capital investments so changes will be driven by obsolescence, cost savings and risk (i..e security). Their near term focus is to establish the ability to monitor facility level ICS data at a higher command level via larger DOD networks like NIPRnet. This requires improved security and some standardization. DIACAP is being leveraged, which makes requirements and testing more standardized for the security and verification of these systems but also introduces a complexity that in our case the USAFA was just beginning to address. An example is the use of the Microsoft XP operating system at the USAFA. Many systems on the USAFA ICS are running XP (including iBEMS) but to be compliment with the new DIACAP based Air Force standards Windows 7 (or other operating systems) will be required. During this project the XP systems were grandfathered in, but over time these systems will need to be upgraded. Elements of the iBEMS system, like the OSB, have been hosted on Windows 7 and Lynx but due to the timing of the project the overall project remained on XP. This would need to be updated in future deployments. Understanding the diversity of the DOD facility ICS systems, standard requirements and timing of these standards will help as iBEMS evolves.

6.5.6 Recommendations

Prior to the demonstration, integration of the OSB to the iBEMS system was required. This integration went well but increased benefits could be realized by abstracting the OSB from the iBEMS system with a more standardized interface. Standard interfaces would reduce the cost and effort for future integration and testing as the system is matured. iBEMS runs on Windows and improving the OSB interfaces to look more like the native Windows interfaces would be beneficial. The focus would be to incorporate better interfaces based on the Microsoft Foundation Classes (MFC).

As iBEMS matures and is targeted at other DOD sites, the need to integrate quickly and with varying security requirements will be a factor. Identifying each iBEMS component that would be affected by DIACAP, then working through the DIACAP process with that component prior to the next deployment will be beneficial. By going through some accreditation, the ability to integrate quickly into DOD environments will be improved. Plans to certify the OSB under DIACAP standards have been developed but execution of that certification has not been done. Boeing has gone through the DIACAP process with other network based system on other programs.

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. Specifically, the project team conducted surveys in MH and the CC from September 23-26, prior to or near the beginning of the demonstrations that began on September 25. A few survey respondents were not available before the demonstrations started; these respondents were surveyed during or after the demonstration and were specifically asked if they noticed any thermal comfort issues during the demonstration period. Also, numerous surveys were conducted in AH prior to various iBEMS tests that were completed in August 2013. To avoid excessive duplication of surveys, the survey respondents in AH were asked to record thermal comfort information and, in one case, indoor temperatures from September 17-27, before and during the demonstration period of September 23-26. 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. The most severe thermal comfort issues are in the CC, where some building occupants reported being constantly uncomfortable due to cold temperatures, hot temperatures, or fluctuations between hot and cold temperatures. In AH, all the survey participants noted thermal discomfort issues, and these issues were noted by most building occupants to have existed for

several years. However, based on the building occupants' responses, the warm and cool temperatures did not seem to feel as extreme in AH as in the CC. Survey participants also reported some discomfort in MH due to warm temperatures and temperature fluctuations.

Table 42 below summarizes key information regarding the initial surveys prior to the tests in August and the demonstrations in September.

Table 42: 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
AH	3	3	100%	3	3	0	March 2013
	4	4	100%	1	2	1	August 2013
CC	8	7	78%	3	2	2	September 2013
MH	2	2	100%	1	0	1	September 2013

Complaint Logs

The project team also gathered complaint logs for the period of October 1, 2012 through October 31, 2013 to determine whether any ongoing patterns may exist that relate to thermal comfort, or maintenance issues that may have affected thermal comfort. A summary of results from the maintenance logs is provided in Appendix C, which lists any thermal comfort complaints, as well as any maintenance issue that may have related to the HVAC system, including AHUs, variable frequency drives (VFDs), exhaust fans, and other equipment types. Appendix C does not list any ongoing, regular preventive maintenance completed for the HVAC systems.

All of the buildings had ongoing HVAC maintenance issues or other relevant maintenance issues recorded in the log, but only the CC had a high number of thermal comfort complaints. These findings are consistent with the survey findings, in which ongoing, and, at times severe, thermal comfort issues were noted for the CC. Less severe or persistent issues were reported for MH. While AH building occupants all had persistent thermal comfort issues, the low number of complaints for AH could be due to two reasons: 1) Some building occupants noted that they do not typically log complaints about hot or cold temperatures, and 2) Many of the spaces in AH are not occupied on a regular basis by the ongoing building occupants, but rather, are occupied intermittently by building visitors; thus, thermal comfort issues in these spaces may be under-reported in comparison to MH and the CC. A summary of the information included in Appendix C is shown in **Figure 102** below.

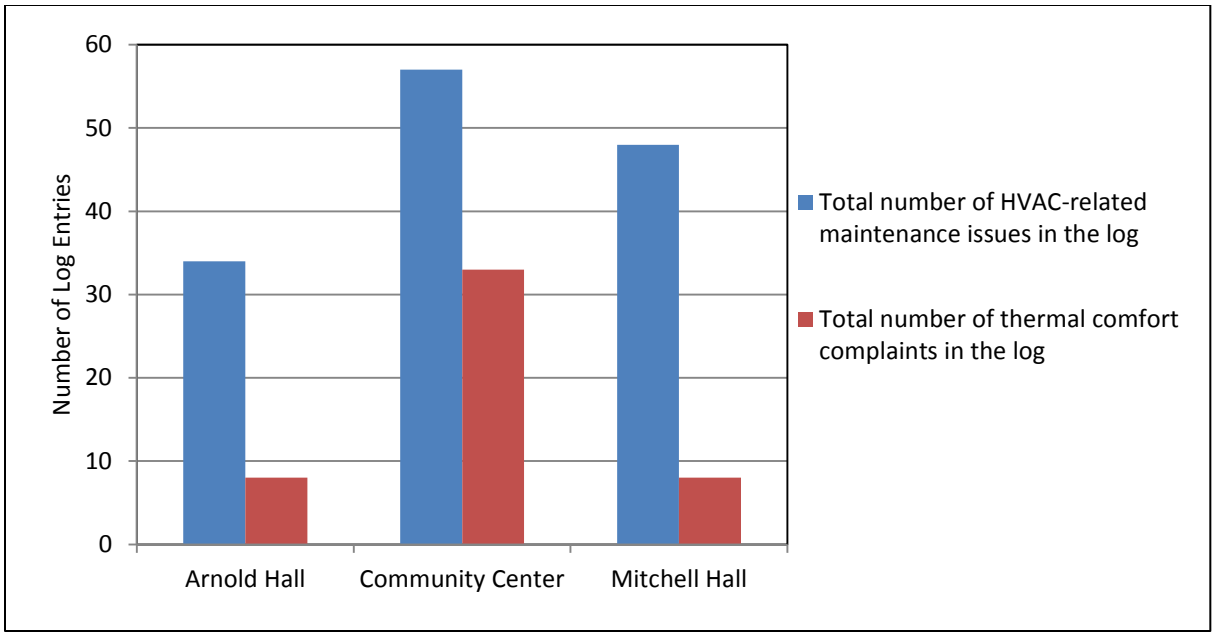


Figure 102: Summary of Maintenance Issues and Thermal Comfort Complaints from the EMCS Logs, October 2012 – October 2013

Furthermore, some maintenance log issues were open during the demonstration periods; these are shown in **Table 43** below. Other maintenance log issues could have affected thermal comfort during the demonstration periods, if the issue appeared and was not yet reported in the maintenance log at the time of the demonstration.

Table 43: Open Maintenance Log Issues or Thermal Comfort Complaints during the iBEMS Demonstration Periods

Demonstration period	Building	Report Date	Date Completed	Maintenance Issue or Thermal Comfort Complaint
March 21-24	AH	12/20/2012	4/17/2013	Troubleshoot water leak on pump 5, Mechanical Room 314
		3/4/2013	4/12/2013	Repair leak on Pump #6 - Mechanical Room 314
		3/21/2013	4/1/2013	Heat pump 340 – check motor
August 19-23	AH	None		
August 20-23	CC	7/16/2013	9/5/2013	Replace demisters on cooling tower
		7/30/2013	9/16/2013	Troubleshoot cooling tower #1 making noise
		8/22/2013	9/9/2013	Replace belts (2) A-40 on exhaust 6
		8/8/2013	8/23/2013	Heat issue in the lower level south side (too hot: 81 degrees)
	MH	6/20/2013	8/21/2013	Install deflector shield on AHU's #1 & #2
September 23-27	AH	9/5/2013	Not yet complete	Replace control panel due to water damage
	CC	9/18/2013	9/27/2013	Troubleshoot: AHU 20 operation

		9/25/2013	10/9/2013	Repair cooling tower motor
		9/19/2013	10/2/2013	Too hot calls from the south side of building (upper & lower)
	MH	8/26/2013	9/30/2013	Install condensate pump for AC unit in MH Annex
		9/27/2013	10/16/2013	South of Exhaust Hood 4, 2nd floor center kitchen, damaged/bent VAV in ceiling - repair/replace

Because of the ongoing thermal comfort and potentially associated maintenance issues, it is difficult to attribute any changes in thermal comfort during the demonstration period to the iBEMS technology testing. However, changes in thermal comfort during the demonstration period, as captured by the surveys and logs, are noted below.

Pre-Test Survey

Prior to the initial March 2013 iBEMS tests in AH, the project team surveyed three facility managers to gather information related to thermal comfort, as well as their overall knowledge of current energy policies at the USAFA, and the typical process used to register thermal comfort complaints.

All three persons surveyed noted ongoing problems with lack of heat, particularly in cold temperatures, and especially in the Theater and the Theater Lobby. At least one survey participant noted that the lack of heat in the Theater had recently been resolved. Survey participants also said that cold temperatures tend to occur in other areas, such as offices, the Banquet Room, and the Ballroom, although the Ballroom was noted to be warm during large dance events. Finally, survey participants also noted problems with warm temperatures during the summer months.

Other key points are provided below:

- All respondents noted the same extreme problems with heating the Theater Lobby and other problems with heating other areas of the building.
- There was no awareness of EE guidelines or automatic building controls, and no consistent awareness of EE strategies in place
- Knowledge of EMCS and various EE and thermal comfort strategies was highly varied amongst the three persons interviewed.

Survey participants were also aware that the EMCS used to control the building HVAC equipment. Two of the three survey participants noted that making thermal comfort complaints to EMCS was not believed to be effective; thus, these two persons mentioned that they no longer send thermal comfort complaints to EMCS due to a perceived lack of response.

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.

Thermal comfort information was gathered in the survey in two ways. First of all, the survey participants were asked to provide their current thermal comfort at the time of the survey, on a numerical scale of 1 – 10, with 1 = very hot and 10 = very cold. Thus an answer of "5" on this scale is considered to be neutral, in which the survey participant was comfortable. Many survey participants did provide a neutral thermal comfort rating on the scale at the time of the survey. However, the survey also asked about general thermal comfort when it is warm outside, and at other times of the year. Many participants noted that they did experience ongoing thermal discomfort; these responses are the basis of the summary shown in **Table 43**.

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 Analysis

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. There were two thermal comfort complaints noted in the logs that were open issues during one of the demonstration periods; however, both of these complaints were reported on a date prior to the start of the demonstration period, and thus, are not easily attributed to the iBEMS demonstration.

Additionally, most of the DR strategies deployed by iBEMS include changes to the HVAC system in 15-minute intervals, which may be continued for up to 2 hours in duration. If not continued for longer durations, the 15-minute intervals would be too short to make a noticeable difference to indoor temperatures, especially in large spaces. In contrast, the EE strategies are typically 2 hours or longer in duration, and also were only deployed in unoccupied areas of AH.

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 at USAFA.

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. From this survey it was determined that USAFA buildings are operated by Siemens BAS system that does not provide any advanced building management capabilities except a schedule–based control enhancer allowing set point manipulation based on the time of day. However this BAS enhancement, supported by Siemens Apogee building automation server mechanism, lacks any advanced energy management capabilities that are based on the building physical properties, building dynamics, occupancy and a real-time weather. Nevertheless the survey also determined that BAS supports BACnet communication protocol and its Apogee server is available for the integration with 3rd party applications. It also has been determined that the latest version of the BACnet client integrated with iBEMS fully supports communication with USAFA Apogee BAS and provides all the runtime functionality required for iBEMS demonstration. Examples of runtime functionality are - connection status, discovery and management of the BAS system set points, real time points monitoring and a remote Apogee server management. 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.

It has been concluded that the optimal location for the iBEMS system deployment is the BAS server room of USAFA. This location allowed iBEMS deployment with a minimal effort. The power supply, the BAS Ethernet cables and hubs were already pre-installed and available for the use. The mounting facilities for the iBEMS hardware were available as well. Finally the adequate temperature conditions in the server room allowed running iBEMS continuously without concerns of a hardware overheating and failure. The authorization for use of the part of the server room was given by the facility management and EMCS personnel who are responsible for the daily building automation operations.

One of the major limitations of running iBEMS at USAFA is the security restriction in accessing a public network. This constraint created some major inconveniences for the iBEMS commissioning in terms of remote access to a system resource, system debugging and real-time communication limitations. This access constraint also created a stumbling point for iBEMS forecast retrieval. Since iBEMS forecasting mechanism relies on the public NOAA web service, it wasn't possible to use it for the real-time weather forecast.

The iBEMS system is designed to support the acquisition of real time and forecasted weather data, and use that data for building energy management. The system leverages a software service to communicate with a public weather data provider, like NOAA. The software service gathers both real time and forecasted data then supplies that data to the iBEMS server in a defined format. Secure communications are used between the software service, which is gathering weather data, and the iBEMS server.

The USAFA ICS network is isolated from other networks so the designed iBEMS weather capabilities cannot be deployed as designed. However, since weather data is needed to optimize the iBEMS performance, we needed to establish both a real time and forecasted data source. The solution for this project included two parts: leveraging existing real time temperature and humidity data that was generated by sensors on the existing ICS network and importing forecasted data files through a human administrator to the network. The forecasted data was gathered by the same software service talking to the public weather service but instead of making the forecasted data available to the iBEMS system over a data network, it would generate a file that could be loaded on the ICS network. The file was manually checked and loaded on the system by an administrator. The forecasted data included data for seven days to reduce the need to load the file every day.

The USAFA is currently connecting their ICS network to the outside unclassified NIPR network. The NIPRnet does have weather data sources available so in the future an iBEMS type system could use its existing weather capabilities and extract data from the NIPRnet source. That change would be technically fairly easy while the most difficult task is to get the proper IT permissions and configurations from the Air Force.

6.7.2 Methodology: iBEMS Commissioning

Before the commissioning took place, the entire iBEMS was replicated and commissioned in the test lab of 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 onsite commissioning. The iBEMS was commissioned in January 2013 in the server room of the Vandenberg Hall. The deployment phase was broken down into five work packages: installation, integration, configuration, training, and execution.

Installation

The installation work package consisted of the following work items:

- Mounting of 4 SEB Controllers - 1 SEB-M and 3 SEB-B. Each SEB was mounted, tested for the power failure and prepared for BAS network configuration.
- Configuration of SEB's on BAS network. A static unique IP address was configured for each network peer (SEB). Each SEB was plugged into iBEMS-dedicated BAS ethernet hub. The hub and the SEBs were tested for the network availability
- Installation of the LEG. The original installation design of the LEG was reconsidered. Because of the cadet's availability constraints and a tremendous BAS network installation effort required for the original demo scope, it was decided to install and demonstrate the plug load management capabilities in the same location where all SEB's are installed. Therefore, the LEG system (a laptop), the LEG router, the plug loads smart strip and demo loads were configured in one of the Vandenberg control rooms. According to the design the LEG must communicate with SEB on the private network. The gateway laptop was configured with a unique static IP address and tested for the network availability. The private network router, a smart strip and a scheduler (tablet) were configured with a unique static IP addresses as well for communication over the private LEG network and all of them were tested for the network availability.
- Installation of the Monitoring Station was conducted at 2 locations: Vandenberg Hall server room and the Civil Engineering building of USAFA. Essentially the pc peripheral's such as monitor, keyboard and a mouse were connected to the SEB-M at a server room for iBEMS management via a WEB HMI, and a remote desktop connection to SEB-M was established at the desk of the Civil Engineering department for the facility management team to be able to manage and monitor the iBEMS demonstration if required. **Figure 103** depicts a deployment diagram of the iBEMS.

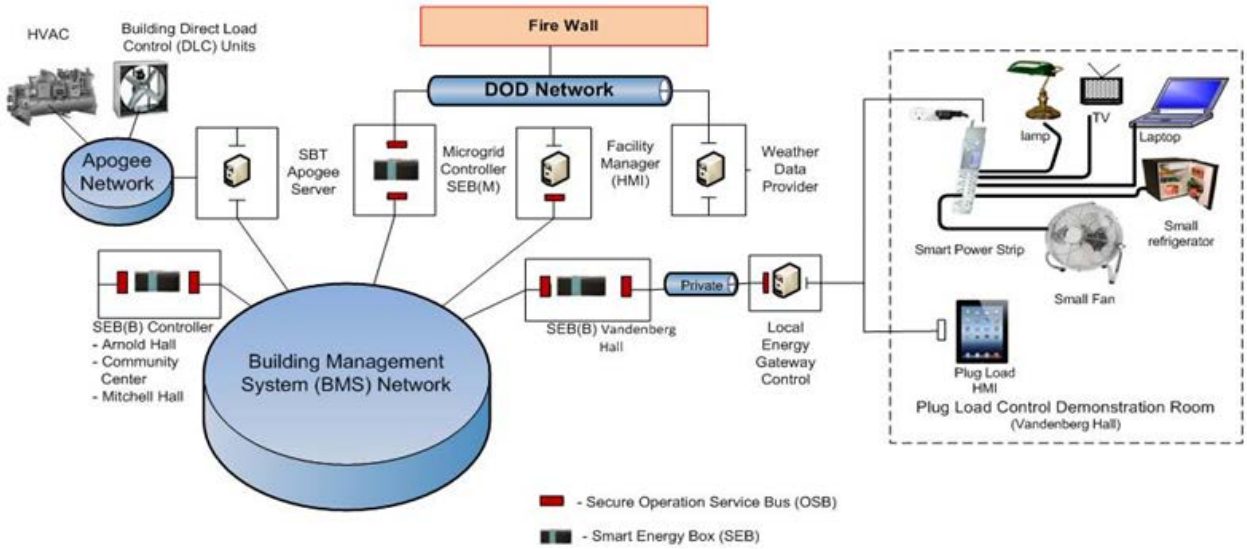


Figure 103: iBEMS Deployment Diagram

Integration

The iBEMS-BAS integration work package consisted of several integration work items: Boeing OSB, SEBs, HMI and plug loads. The integration of OSB is described in section 6.5. The integration workflow has been defined in accordance with a demonstration plan, verified by the USAFA, Siemens BT and EMCS team and rolled out at Vandenberg Hall. Each work item was prioritized and executed as follows:

The installation of the SEB software was conducted in the following steps. First, the configuration of SEB-M controller software was performed using SEB configuration tool. The configuration of SEB-M consisted of the following steps:

- Configuration of Windows XP SP3 OS environment for running SEB runtime.
- Installation and configuration of a BACnet communication client and connection to BAS Apogee server.
- Configuration of the controller runtime services, such as BACnet communication service, trending service, weather service, data service and Microgrid service.
- Analysis and configuration of Apogee automation data points for the weather and humidity monitoring at SEB-M level.
- Configuration of the communication settings with SEB-B controllers.
- Configuration of the negotiation cycle for the Demand Management load shedding goal.
- Configuration of the NOAA weather forecast. As it was previously mentioned, the security constraints prevented configuration of the real-time weather forecast polling from the public NOAA web service, therefore the forecast was generated by the Boeing's team weather service as a file and securely imported into a SEB-M runtime.

- Installation and configuration of the WEB server. A freeware version of a Wamp web server for Windows was used to host iBEMS WEB HMI pages.
- Configuration of the WEB HMI with SEB's network addresses. **Figure 104** depicts a Building Dashboard of the WEB HMI of the HMI station deployed at USAFA.

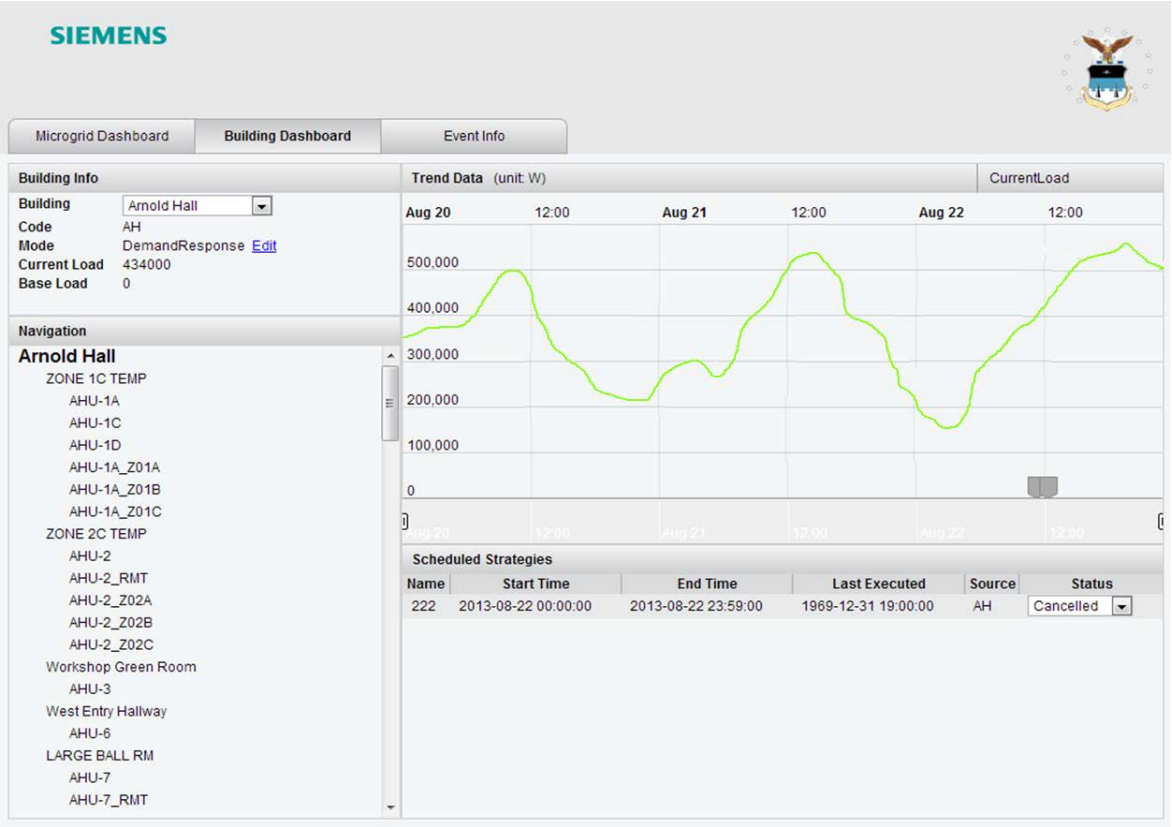


Figure 104: WEB-based iBEMS HMI

After the SEB-M and a WEB HMI installation and configuration was completed, the SEB-B controller software was installed and configured. The configuration of SEB-B consisted of the following steps:

- Configuration of the controller runtime services such as BACnet communication, trending, data service for communication with the SEB-M.
- Installation and configuration of a BACnet communication client in each SEB-B and connection to the BAS Apogee server.
- Configuration of the building zones to be controlled by the iBEMS for each building.
- Apogee data points configuration for each building. The information about existing data points was previously exported from the Apogee server, formatted with SEB data exchange format and imported to the corresponding SEB-B.

- Configuration of the building schedule and a historic baseline was performed for each SEB-B
- Configuration of the rule-based strategies for EE demonstration. **Figure 105** depicts a screen shot of a rule-based strategy setting using SEB configuration tool.

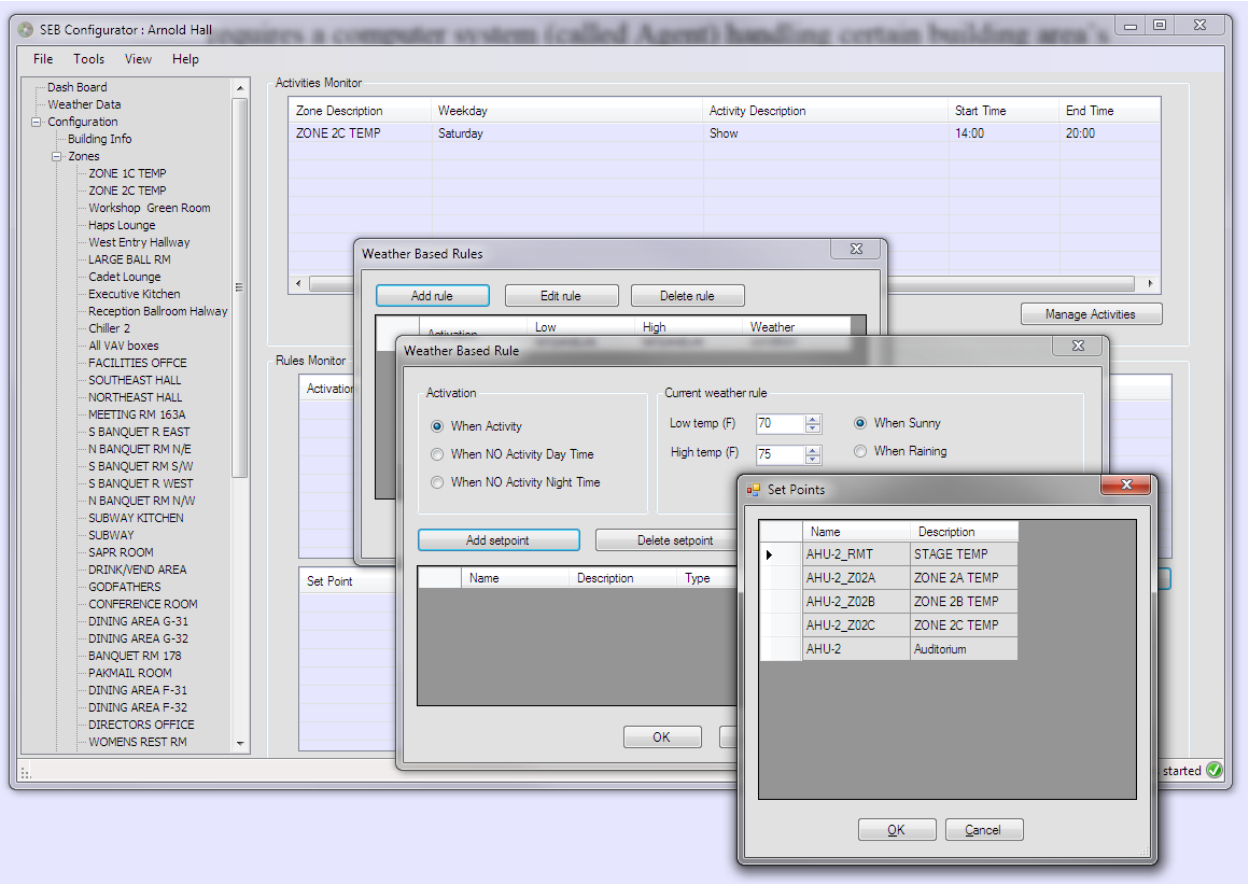


Figure 105: Rule-based Strategy Setting

Finally, the configuration of the SEB-B and the plug load demonstration components was done at Vandenberg Hall. The installation and configuration of SEB-B and the plug load control included the following steps:

- Configuration of SEB communication with SEB-M services.
- Configuration of LEG communication with SEB-B (Vandenberg Hall).
- Configuration of the LEG WEB HMI.
- Installation and configuration of the physical and virtual plug loads for the demonstration.

After the installation, the system readiness check was performed, documented and reported to the team.

6.7.3 Methodology: iBEMS Integration Test

After the installation completion, the iBEMS system runtime test and a 24 hour "dry run" test were performed. During the system runtime test the iBEMS was checked for integrity of the runtime components, system performance, secure internal communication with BAS Apogee system, execution of algorithms and read/write tests of the control points for the supply air temperature, static air pressure and a VAV control of the specific zones in all three buildings: AH, MH and CC.

Also, before the "Dry Run" test the configuration and the runtime of the iBEMS engineering tools were checked. The SEB configuration tool was checked for the SEB connection, data exchange, data integrity and configuration capabilities. The WEB HMI was checked for the stability of a runtime, data integrity, and monitoring and EE/DM Event management capabilities. A "Dry Run" included the following tests:

1. EE mode test (EE)
2. Instantaneous DR test
3. Day-ahead DR test

The EE mode test was performed in AH. During the EE mode test, the building operation mode of the SEB was switched to EE. The switch triggered an invocation of the rule-based strategies that in turn commanded a collection of the data point values for the HVAC system to adopt a given strategy. The point value change was observed in the WEB HMI as well as the runtime console of the SEB designated for AH and the Insight Application – the Apogee HMI.

The instantaneous DR test was performed to all four buildings: AH, MH, Vandenberg Hall and CC. During the DR test the building operation mode for each SEB was switched to DR. The time and the period of the DR event were configured, and the event was issued by the SEB-M via WEB HMI. The event triggered an instantaneous generation of the dynamic DR strategies for each negotiation cycle for each building. Each strategy was executed in the time span defined by the SEB-M negotiation cycle period, and commanded a collection of the data point values for the HVAC system to adapt to a given strategy. The point value changes were also observed in the WEB HMI, the runtime console and the Apogee HMI.

The day-ahead DR strategy was performed on AH and the CC facilities thereafter. In essence the day-ahead DR differentiates from instant DR in its preparation phase. As soon as the building operation mode was switched to DR, and the day-ahead DR event is issued by the SEB-M, each SEB-B (AH and CC) invoked a strategy simulation mechanism based on the EnergyPlus model of the building. The goal of the strategy simulation is to select the most appropriate load shedding strategy for the next day's pre-cooling start/stop time, based on the weather forecast. After the completion of strategy simulation, the day-ahead DR strategy was selected for each participant (building). As mentioned in section 6.2, combined peak load can occur anytime in between 11:00am-4:00pm. For our test, the DR duration for the peak load shedding was selected as 2:00 pm – 4:00 pm for the day ahead DR test.

Finally, the EMCS staff was trained and qualified to operate the iBEMS. The training also allowed a Princeton team to delegate some of the tests to a local EMCS personnel. **Figure 106** shows the deployed iBEMS during the "Dry Run" test in the server room of Vandenberg Hall.

Figure 106: iBEMS during the "Dry Run" Test at Vandenberg Hall

6.7.4 Result Analysis

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:

System performance

- 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 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.

Logic performance

- One of the main capabilities that can drastically contribute in the success of the energy management logic of the iBEMS is to control facility lighting. In this demonstration, the control of the lighting was not possible, implying a dramatic constraint on meeting the demonstration objectives.
- A lot of building equipment was out of iBEMS control as well, such as chillers, and some AHUs and thermostat controllers for certain building automation zones.
- Some of the buildings had ongoing renovation projects that frequently required equipment shutdowns which impacted the results of the demonstration.

The usability survey, presented in Appendix F, was conducted after the iBEMS commissioning, during the demonstration and right after the demonstration. During the demonstration, the facility operators (EMCS team) had permission for the full operation of the iBEMS. 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 a room for improvement in terms of usability:

- The system should provide more validation capabilities during the configuration. For example, the control points validation.
- 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.

The EE and Demand Management interfaces are intuitive and easy to use. However, the strategy implementation information could be more explicit and beneficial. Currently this information is hidden behind a few mouse clicks in a popup dialog of the HMI. The day-ahead DR events were not tested completely. The instant DR events showed that the iBEMS is fully capable to provide instant load shedding and can shape loads.

6.7.5 Conclusions

Overall, the iBEMS system performed as expected, without runtime crashes, performance glitches or logic failures and therefore 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 therefore requires a tight 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 allow controlling as many building equipment as possible in order to maximize EE logic and overall energy savings.

6.8 PROJECT IMPACT ON UTILITY PLANS FOR DEMAND RESPONSE PROGRAMS

6.8.1 Baseline Electric Utility Operations

Colorado Springs Utilities was contacted for this research study to learn more about the seasonal and time-of-day peaks on their electrical distribution system and whether the utility is contemplating more robust DR programs or incentives for ancillary services[28]. The municipal utility currently has a program called the Business Peak Demand Rebate program that incentivizes retrofit and equipment upgrades resulting in permanent and verifiable demand reduction. The program offers $400/kW-reduction subject to reimbursement caps of 50% of project costs or a maximum of 50% of their $500,000 annual program budget. However, according to the program manager, the Business Peak Demand Rebate program will soon be cancelled. Recent analysis suggests that the rebates for kW reductions have been overvalued at $400. Because Colorado Springs Utilities has adequate capacity reserves, the kW reduction values are actually about $100/kW-reduction.

Nevertheless, Colorado Springs Utilities does not currently offer dynamic DR programs for its business customers. The motivation to offer DR program is apparently tied to the fate of the utility's 254 MW coal-fired Drake Power Plant, located within Colorado Springs itself. A third party assessment was presented to the City Council and Utility Board showing financial scenarios for plant closure (e.g. immediate) ranging to closure in 30 years. In terms of load management, the utility would have to develop alternatives to the Drake Plant to supplant its generation whether closure is immediate (unlikely) or 10-15 years off (more likely). At that time, the utility could implement a tiered DR program for summer and potentially winter peaking that rewards participants based on the total number of kW that can be shed and the total number of events that the customer will participate in. The greater the kW and commitment to DR events, the more money per kW the customer will receive.

Colorado Springs Utilities is contemplating how to manage its grid as more and larger solar PV arrays are installed at client sites. (The Air Force Academy currently hosts a grid-tied 6 MW array on its land.) Depending on the timing of the closure of the Drake Plant, the utility will have to consider how to address grid ancillary services and to determine whether customers can offer ancillary services, like DR, when called upon. Currently, not enough solar PV is on the utility's grid to cause power quality concerns, but that may change as larger systems continue to be built at customer sites. Nor is natural gas a go-to solution for Colorado Springs. Although the utility has some natural gas peaking units, local natural gas delivery is limited due to the Front Range, i.e. installation of natural gas pipes in or over mountains is cost prohibitive. Finally, the city does have some mountain reservoirs that power turbines from 2 – 3 MW up to 28 MW, but the reservoirs serve the dual purpose of providing energy and drinking water. The reservoirs can only be dispatched when water is plentiful and no drought conditions exist.

[28] DNV KEMA contacted the program manager for the Business Peak Demand Rebate program at Colorado Springs Utilities on April 28, 2014.

7.0 COST ASSESSMENT

7.1 COST MODEL

The DOD's Environmental Security and Technology Certification Program determines the methodology that will be used for calculating life cycle costs. The ESTCP requires that project teams apply NIST standards and methodologies. Discount and escalation rates have been provided to NIST by the DOE for 2013. The length of the life cycle was selected based on the experience of the project team. By selecting 15 years, the relatively short time period means that technologies and equipment investments must result in net present value > 1 to be of value; selecting a time period too far in the future decreases the accuracy of the net present value due to inherent inaccuracies in long term energy and economic forecasts.

The LCCA presented here is based on standards published by NIST in *Handbook 135*[29] and the *Annual Supplement to Handbook 135*[30]. NIST software, BLCC5[31], 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.

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 44** below shows the summary of the AH LCCA inputs and savings, and **Table 45** shows the LCCA inputs for the extrapolation of the iBEMS to 14 campus (or campus wide) buildings.

Table 44: 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	$ 3,508
Software Capital Costs (One-time cost)	Estimates of Siemens' Smart Energy Box software costs and Boeing's Operational Service Bus software	$ 481,900
Installation Costs (One-time cost)	Labor to install hardware and software and to commission iBEMS system	$ 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 (NPV)	$ 9,760
Hardware Lifetime	Estimate based on components degradation during demonstration	15 years
Operator Training (One-time cost)	Estimate of training costs.	$ 24,800

[29] http://fire.nist.gov/bfrlpubs/build96/PDF/b96121.pdf
[30] http://www1.eere.energy.gov/femp/pdfs/ashb13.pdf
[31] http://www1.eere.energy.gov/femp/information/download_blcc.html

Table 45: Cost Model for Campus Wide Intelligent Building Energy Management System 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' Smart Energy Box software costs and Boeing's Operational Service Bus 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 (NPV)	$ 21,280
Hardware Lifetime	Estimate based on components degradation during demonstration	15 years
Operator Training (One-time cost)	Estimate of training costs.	$ 24,800

7.1.1 Cost Elements

Cost data to deploy the iBEMS at 14 buildings (representing just over 3 million square feet of interior space) from SCT and Boeing are for the following categories:

Data Collection and Energy Modeling

These represent the costs of developing EnergyPlus models for use by Siemens' SEBs. The SEB's use the building energy simulations to optimize building operations when EE and DR events are called. In the single building case, for AH, the data collection and energy modeling effort was assumed to be a total of 5 weeks effort. Assuming a 40 hour week with $120/hour work rate, the total cost for a single building modeling, as given in **Table 44**, is $24,000. For the campus wide case, it was assumed that for each building a 3 week effort would be required for data collection and energy modeling. The reduction of data collection and energy modeling effort from 5 week to 3 week for a single building is due to the fact that in case of multiple buildings, in most cases, various models developed for a building can later be used for remaining buildings. Therefore, in the case of campus wide effort the total cost would be $201,600, as shown in **Table 45**.

Hardware Costs

Additional CPU's, laptops, network hubs, and ethernet cable are needed to run the iBEMS software and communicate with the BAS system. For the single building case this cost consists of 1 Siemens industrial box-PC, 1 industrial level hub, 1 network cable and 1 monitoring station in the form of dedicated laptop computer. The total cost amounted to $3,508. For the campus wide

case, 7 Siemens industrial box-PC, 3 industrial level hub, 12 network cables, and 3 monitoring stations would be required. The total hardware cost in that case would be $22,214.

Software costs

They are any costs related to initial iBEMS and OSB software installations that include integration of software with existing BAS software, system testing, and software documentation. For the single building case, this includes iBEMS software cost of $29,400 and onetime non-recurring engineering costs for OSB integration with iBEMS of $452,500. Together it amounts to $481,900. For the campus wide case, the total of cost of iBEMS software for 14 buildings comes out to be $135,000. The cost of OSB software remained same as $452,500. Hence, the total software cost incurred for campus wide case was $587,500.

Installation costs

These costs include system commissioning (regression testing, dry runs), and hours of installation time (Boeing labor rate: $200/hr, Siemens labor rate: $120/hr). For the single building case, the installation cost of iBEMS was computed as 1 week of labor totaling to $4,800. The cost of OSB installation was $64,000. So, the total installation cost for a building was $68,800. For campus wide, the iBEMS installation cost was computed as a 5 week effort totaling into $24,000. For OSB installation a further $64,000 cost was required for rest of the building (after 1st installation). So total software cost for the campus was computed to be $152,000.

Facility Operation and Maintenance (O&M) Costs

Operation and maintenance costs are for software, hardware, troubleshooting and iBEMS configuration. For a single building case, the O&M cost for iBEMS were estimated based on the feedback from the Siemens' engineer responsible for Apogee system at USAFA. Based on those discussions, 6 day effort was estimated for annual O&M cost. This amounts to $5,760 annually. For OSB, a yearly flat rate of $4,000 was assumed. The total O&M cost then comes out to $9,760. For the campus wide case, a total of 18 day effort was estimated for annual O&M cost for iBEMS and for OSB the O&M value remained unchanged. Hence, in this case the total annual O&M cost comes out to be $21,280.

Hardware Lifetime

Lifetime costs were provided in ranges and the middle of the range was selected for the LCCA. For example, equipment expected to last 5 to 10 years was entered as 7.5 years for its life cycle.

Operator training

Training is necessary for building system operators to optimize use of iBEMS to its full capabilities. The training cost is independent of single or multi-building. The training cost for iBEMS was estimated as 1 week effort, amounting to $4,800. For Boeing's OSB the one time training cost was estimated as $10,000. So, the total operator training cost for both single building and campus wide case is $14,800.

The two primary types of costs associated with the iBEMS system are specific to actual integration and deployment costs (initial costs), and the overall products lifecycle costs (operations and

maintenance). Integration and deployment address specific costs associated with the actual USAFA integration, deployment, hypothetical deployment to 14 additional buildings and the cost to operate and maintain this system. Product lifecycle costs associated with iBEMS are defined as the costs to refine, update and maintain the larger iBEMS products over fifteen years. In terms of the iBEMS, it is our hope and assumption that the product would be sold to multiple clients. Therefore, we assume that these lifecycle costs would not be applied to a specific facility, but would be shared over multiple sites over the 15 year lifecycle. In other words, the USAFA would be charged a percentage cost for software development and improvements across all deployments and on an as yet undetermined business model for internal investment.

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. The following table highlights the specific security costs that were removed from the single building analysis.

Table 46: Security Cost Model for AH Intelligent Building Energy Management System at USAFA

Cost Element	Data Tracked During the Demonstration	Estimates
Security Capital Costs	Equipment and Installation Costs	$ 526,500
Recurring Security Costs	Development/Support/Test Server Hardware Costs	$ 20,000
Security Maintenance Costs	Software upgrades every 3 years	$ 4,000

The following alternative presents the results when equipment, installation and recurring costs related to security are removed from the single building life cycle cost calculation. The initial investment cost ($63,000) is the total sum of the data collection and modeling costs ($24,000), iBEMS software capital costs ($14,400, $15,000), installation costs ($4,800) and training costs ($4,800). The initial investment cost is a one –time cost for the system. The energy consumption costs listed for the Baseline and Alternative are annual costs. The routine recurring operation, maintenance and replacement costs are $2,910, $598 and $5760 occurring every 7, 4 and 1 year respectively.

The Savings-to-Investment Ratio (SIR) is the ratio of Present Value (PV) operational savings to PV additional investment costs.

$$SIR = \frac{PV\ operational\ savings}{PV\ of\ additional\ investment\ costs}$$

AIRR (Alternate Internal Rate of Return) is the measure of performance of investment as a percentage yield, assuming reinvestment of cash flows at a given rate (r).

$$AIRR = (1 + r)SIR^{1/N} - 1$$

Table 47: Energy Efficiency Alternative for AH

Comparison of Present-Value Costs			
PV Life Cycle Cost for AH			
	Base Case	Alternative	Savings from Alternative
Initial Investment	$ -	$ 63,000	-$63,000
Future Costs:			
Energy Consumption Costs	$ 2,008,456	$ 1,663,481	$ 344,974
Energy Demand Charges	$ -	$ -	$ -
Energy Utility Rebates	$ -	$ -	$ -
Water Costs	$ -	$ -	$ -
Routine Recurring & Non-Recurring OM&R Costs	$ -	$ 131,976	-$131,976
Major Repair & Replacements	$ -	$ -	$ -
Residual Value at End of Study Period	$ -	$ -	$ -
Subtotal (for Future Cost Items)	$ 2,008,456	$ 1,795,457	$ 212,999
Total PV Life-Cycle Cost	$ 2,008,456	$ 1,858,457	**$ 149,999**
Savings-to-Investment Ratio			
SIR - 3.38			
Adjusted Internal Rate of Return			
AIRR - 11.17%			
Payback Period			
Estimated Years to Payback (from beginning of Beneficial Occupancy Period)			
Simple Payback occurs in year: 4			
Discounted Payback occurs in year: 4			

In 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.

Results of the life cycle cost analysis for the campus wide application, including security costs, are even more rewarding and are presented in the table below. The initial investment cost ($955,900) is the total sum of the data collection and modeling costs ($201,600), iBEMS software capital costs ($587,500), installation costs ($152,000) and training costs ($14,800). The initial investment cost is a one –time cost for the system. The energy consumption costs listed for the Baseline and Alternative are annual costs. The routine recurring operation, maintenance and replacement costs

are $20,420, $1,994 and $21,280 occurring every 7, 4 and 1 year respectively. The calculations of SIR and AIRR were identical to the single building analysis.

Table 48: Results of the Life Cycle Cost Analysis for 14 Campus Buildings

Comparison of Present-Value Costs **PV Life Cycle Cost for 14 Campus Buildings**	Base Case	Alternative	Savings from Alternative
Initial Investment	$ -	$ 955,900	-$955,900
Future Costs:			
Energy Consumption Costs	$ 32,859,507	$ 26,744,497	$ 6,115,010
Energy Demand Charges	$ -	$ -	$ -
Energy Utility Rebates	$ -	$ -	$ -
Water Costs	$ -	$ -	$ -
Routine Recurring & Non-Recurring OM&R Costs	$ -	$ 609,057	-$609,057
Major Repair & Replacements	$ -	$ -	$ -
Residual Value at End of Study Period	$ -	$ -	$ -
Subtotal (for Future Cost Items)	$ 32,859,507	$ 27,353,554	$ 5,505,953
Total PV Life-Cycle Cost	$ 32,859,507	$ 28,309,454	**$ 4,550,053**
Savings-to-Investment Ratio SIR - 5.76			
Adjusted Internal Rate of Return AIRR - 15.19%			
Payback Period			
Estimated Years to Payback (from beginning of Beneficial Occupancy Period)			
Simple Payback occurs in year: 3			
Discounted Payback occurs in year: 3			

The net present value of the iBEMS system, for campus 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.

7.2 COST DRIVERS

Initially, the project team had approached Port Hueneme in southern California as a demonstration site for the iBEMS. After investigating BASes, controllable loads, and the existence of BAS

networks at the base, the team realized that the iBEMS was wholly unsuited to the site. Why? Port Hueneme is in a temperate climate with virtually no air conditioning or heating loads. The BAS was connected to a handful of buildings via dial-up modem. A substitute wireless system, which could have networked some of the BAS's, was prohibited at the base (and all military bases for that matter).

As can be inferred from the example above, 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. We researched average commercial electricity costs for 2012 for different states and selected states where the average $/kWh was $0.10 or greater. Bases that are located in Hawaii are excellent candidates in terms of electricity rates, which are more than double the next lower electricity rate (found in Alaska). Other areas with high electricity rates include New England, northeast states such as New York, New Jersey, Delaware, Maryland, and Washington, D.C. The southern states of Alabama and Tennessee have rates above $0.10/kWh as do Wisconsin and California.

Additionally, bases located in utility territories that have high rates per kWh and active DR programs are also good candidates for the iBEMS. Furthermore, iBEMS will add value to bases that rely on coal-fired electricity or heating oil (or both) due to the greater GHG emissions associated with each fossil fuel.

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, testing and documenting to meet the requirements. In some cases where system elements and the system installation has not gone through a previous DIACAP process, large costs and schedule impacts could be associated with the DIACAP accreditation and approval.

To offset some of the nonrecurring costs and risks associated with installing an iBEMS system under the DIACAP process, accreditation of the reuse components of the iBEMS system should be done, independent of any specific facility deployment. Once components are accredited specific deployment costs and schedule impacts would be greatly reduced. The costs to do this type of reuse accreditation would not be tied a specific deployment but associated to iBEMS product life cycle costs.

The iBEMS USAFA deployment did not have to meet DIACAP requirements due to the configuration of the ICS network and the status of USAFA IT security at the time. Specific security requirements were addressed but these were minimal and costs were low. Currently the USAFA is upgrading its security posture and as they address the larger USAF IT and cyber security requirements the costs to deploy systems like IBEMS will increase. Cost to upgrade the existing deployed iBEMS system maybe relatively low because the primary focus to meet the new security requirements would look at securing existing systems not going back and doing accreditation on these systems. The primary cost elements would be focused on network configuration of the system, possible upgrades at the Operating System level and the labor to do

this. Costs to install a new system would likely be much higher once the USAFA transitions to the USAF DIACAP based solution.

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. Some DOD sites lack a unified BAS network among their buildings and therefore run BAS's independently. These sites would require an update of networking infrastructure to be suitable for the iBEMS deployment. The iBEMS could be deployed for each building individually, but this type of deployment wouldn't be sufficient for generating the best energy strategies in the context of the entire site, because building loads wouldn't be balanced by the microgrid-level energy management system.

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. The lack of remote access to the system required a physical presence of the iBEMS administrator throughout all phases of the demonstration. Also, the security limitations disallowed commissioning of the wireless control panel (tablet) for the plug load scheduling and management by the USAFA staff. The hard-wired deployment of the control panel would have required unnecessary and costly extension of the BAS network to a certain building zones where plug load management would be beneficial, e.g. cadet dorms.

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

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 iBEMS user experience.

8.1 PERTINENT REGULATIONS

As of November 28, 2007, the United States Department of Defense mandates that all the IT equipment on DOD sites must pass the DIACAP certification. Even though the iBEMS deployment did not have to meet DIACAP requirements due to status quo of the USAFA ICS network and IT security at the time, any future iBEMS installations on DOD sites must meet DIACAP security requirements. Therefore it is recommended to identify each iBEMS subsystem that would be affected by the DIACAP, and then work through the DIACAP certification process for that subsystem before the iBEMS commissioning.

8.2 END-USER CONCERNS

8.2.1 Single SEB controller on a single SIMATIC Micro-Box PC

One of the concerns expressed by the USAFA facility management team was the iBEMS availability. The unexpected shutdown of iBEMS could result a failure to relinquish control points, and the shutdown could lead to equipment operational or even physical failure. In order to address this concern, along with extensive system test of the software, it was decided that acquisition of the robust, industrial-quality hardware for execution of SEB runtime would be necessary. The availability requirement drove the decision to dedicate one CPU for each SEB, which is responsible to control one individual building. Given architecture allowed running each SEB-B independently from each other, thus in case of a subsystem failure on the building level, the iBEMS would continue to execute energy management tasks for the rest of the buildings without interruption. 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. Although, the SEB runtime can be executed in a standard PC, the iBEMS system was deployed on four SIMATIC Micro-Box PC's (one for each SEB instance) to satisfy the overall availability requirements.

8.2.2 Comfort-tuned EE and DR strategies

Another facility management concern was maintenance of the occupancy comfort during the iBEMS demonstration. The iBEMS energy saving strategies were tuned in the way that wouldn't compromise occupancy comfort. E.g. the ranking of the equipment by its mission and prioritizing by criticality, the occupancy-based strategies, the partial equipment shutdown - all these strategies were defined according to occupancy comfort standards and a site regulations. In addition, the pre- and post-demonstration occupancy surveys indicated that the comfort wasn't compromised.

8.3 PROCUREMENT ISSUES

8.3.1 Facility Audit Issues

A comprehensive facility equipment and energy audit is a first "must do" step that iBEMS relies on. The results of the auditing are used as an input for building modeling and simulation to identify the most efficient energy savings strategies for iBEMS. The auditing happened to be one of the great challenges of this demonstration. In order to accurately develop calibrated building model, identify the building control sequences and zones that can be controlled by the iBEMS, the building drawings and logical charts had to be obtained. 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. At this point there is no standard data exchange mechanism or repository that can be accessed programmatically by the authorized system to retrieve building information or quickly identify the physical properties of the building or building's dynamics. In most cases, the control sequence data is buried in the PPCL code and it requires a special expertise in order to understand it. This makes the building modeling and calibration one of the most tedious and time-demanding tasks of the iBEMS pre-commissioning phase.

8.3.2 Monitoring Equipment Issues

It was concluded that existing building automation equipment at USAFA did not provide comprehensive and accurate information about the energy consumption by an individual load. It also lacked a middleware that would provide this information virtually. Although the iBEMS is capable of data trending and logging, at present point it's not capable of identifying and isolating specific loads that are controlled by the iBEMS system. Therefore it was necessary to acquire and install the electrical energy sub-meters and data loggers, in order to create an environment that allowed us to monitor and log energy loads that were under the control of iBEMS during EE and DR events.

Another constraint of the current BAS at USAFA is a lack of standard mechanism for the energy consumption data collection. At this point it is not possible to connect to an industry-standard database and programmatically retrieve trended data that is necessary for the energy consumption analysis. A lot of manual effort went into the logging and acquisition of building trend data for iBEMS.

8.4 INTEGRATION WITH ICS

8.4.1 iBEMS- ICS integration troubleshooting

Because the iBEMS used a loose-coupling approach with the BAS via 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 BACstac client library is a commercial-of-the-shelf product of Cimentrix[32] that was integrated into iBEMS as part of SEB functionality. iBEMS also provided another adapter that is configurable to communicate with BAS via MODBUS.

[32] http://www.cimetrics.com/index.php/cimetrics-announces-bacstac-v62.html

The advantage of using a loosely coupled BACnet client vs. tight coupling with BAS is that the client only applies COV commands to BAS via self-descriptive control points, without affecting overall BAS communication by loading the BACnet with heavy packets of system-proprietary data. The success or failure of COV's was subscribed in the callback function of the client. Since this approach does not require any specific configuration from on BAS side, it simplified the commissioning of the iBEMS as well. The mapping of the BAS control points to iBEMS control point objects was also necessary before the iBEMS startup. Each building controlled by the iBEMS has a subset of control points defined and published through the BACnet communication. The subset of control points is responsible for controlling equipment components e.g. chilled water supply, SAT, SSP of AHU or the thermostat value for certain building's zone. Mapping the current weather and overall building meter data (current load) via read-only control point's subscription was also required, as part of the input condition for the iBEMS runtime control strategies. It was determined that the iBEMS system could not automatically import the control point information from BAS. 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. The automatic data point exchange mechanism should be in the agenda for the next generation of iBEMS.

8.5 RUNTIME COMMUNICATION

8.5.1 Runtime Diagnostics and Troubleshooting Issues

The iBEMS communication was implemented using standard TCP/IP model of BAS. Because the iBEMS consisted of four individual CPU nodes – one for each controlled building, it was necessary to create a private subnet for all five systems including the Microgrid SEB. The Boeing's OSB provided a secured TCP/IP communication tunnel via peer proxy libraries that were configured for each individual CPU node. The tunnel was dynamically created and managed by the OSB server during the node startup. The SEB-M node hosted the OSB server and supervised the health of the OSB communication infrastructure. 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 onsite. Finally the real-time monitoring of EE demonstration was troublesome, because it required a person be located on site. When system ran in EE mode continuously for one-two weeks, it was not possible to monitor the system on site all the time during this period. The restriction from a public network access of the iBEMS also created difficulty in obtaining a weather forecast from NOAA public weather service. The forecast had to be handled via file transfer, which required an off-site system generating this file specifically for the iBEMS demonstration. The file then was manually imported by the system administrator using the portable thumb drive.

8.6 USER EXPERIENCE

The EMCS team at USAFA was the main user of the iBEMS during the demonstration. The EMCS team was generally satisfied with the features and functionality for both: engineering and runtime UI. The system UI was intuitive, simple and easy to use. However some of the obvious issues were pointed out as follows:

8.6.1 iBEMS Configuration Tool

- The configuration of control points is rather difficult, due to the fact that it requires manual mapping of the point attributes from Apogee to iBEMS. There is no tool to validate the attributes after the configuration, so it is difficult to correct mistakes.
- The configuration of the rule-based strategies requires a lot of browsing through dialogs, less pop-up windows would be beneficial.
- The rules creation is not intuitive for the user; a simpler interface is required.
- There is no explicit information for the configured strategies in the configuration tool. The information is hidden in the sub-dialog
- There is no history of the executed strategies in the tool. This information is logged and stored in the database, but it is not possible to retrieve this information by the user at runtime.

8.6.2 Web HMI

- There is no secure login to the WEB UI. Any system user can invoke the web HMI application via web browser
- 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.
- The selected strategy list is not intuitive for the user.
- The current user interface for the configuration tool had already gone through several updates and the latest version of the same had been presented and tested at USAFA. In the next generation of the iBEMS the issues found in web HMI shall be addressed.

9.0 REFERENCES

[1] "Energy Independence and Security Act of 2007, Title III and Title IV".

[2] "Department of Defense Annual Energy Management Report Fiscal Year 2011," Office of the Deputy Undersecretary of Defense, 2012.

[3] D&R International Ltd., "2011 Buildings Energy Data Book," Building Technologies Program, Energy Efficiency and Renewable Energy, U.S. Department of Energy, March 2012.

[4] "Energy Policy Act of 2005," Washington D.C., 2005.

[5] D. Auslander, D. Culler, P. K. Wright, Y. Lu and M. A. Piette, "A Distributed Intelligent Automated Demand Response Building Management System," Final Report for DOE Award# DE-EE0003847, March 2013.

[6] B. Griffith, N. Long, P. Torcellini, R. Judkoff, D. Crawley and J. Ryan, "Methodology for Modeling Building Energy Performance across the Commercial Sector," 2008.

[7] "Revit," AutoDesk, 2013. [Online]. Available: http://www.autodesk.com/products/autodesk-revit-family/overview.

[8] ASHRAE, Guideline 14-2002, Measurement of Energy and Demand Savings, Atlanta, Georgia: American Society of Heating, Ventilating, and Air Conditioning Engineers, 2002.

[9] R. D. Brager and G. Schiller, Developing an Adaptive Model of Thermal Comfort and Preference, 1998.

[10] "The Federal Greenhouse Gas Accounting and Reporting Guidance Technical Support Document, Revision 1: June 4," 2012.

[11] H. Hua, L. Tian-yu, Z. Zhi-yong and Z. Juan, "Energy Saving Potential of Public Building in Jiangbei District of Chongqing," in *IEEE International Conference on Management and Service Science*, Wuhan, China, 2009.

[12] N. Fernandez, S. Katipamula, W. Wang, Y. Huang and a. G. Liu, "Energy Savings Modeling of Standard Commercial Building Returning Measures: Large Office Buildings," 2012.

[13] H. Akbari, S. Konopacki and M. Pomerantz, "Cooling Energy Savings Potential of Reflective Roofs for Residential and Commercial Buildings in the United States," *Energy*, vol. 24, no. 5, pp. 391-407, May 1999.

[14] G. Escrivá, A. Marrec, M. Ortega, I. Salazar and C. Álvarez-Bel, "Evaluation of Control Strategies in HVAC Split Systems," in *IEEE/IAS Conference on Sustainable Alternative Energy*, Valencia, Spain, 2009.

[15] C. Labato, M. Sheppy, L. Brackney, S. Pless and a. P. Torcellini, "Selecting a Control Strategy for Plug and Process Loads," 2012.

[16] N. Motegi, M. A. Piette, D. S. Watson, S. Kiliccote and P. Xu, "Introduction to Commercial Building Control Strategies and Techniques for Demand Response," 2007.

APPENDICES

Appendix A: Points of Contact

Point of Contact	Organization	Phone & E-mail	Role in Project
Dr. Yan Lu	Siemens Corporation, Corporate Technology	yanlu@siemens.com 609-734-3549	PI
Sue DeMeo	Siemens Corporation, Corporate Technology	susan.demeo@siemens.com 609-734-4469	Business Contact
Dmitriy Okunev	Siemens Corporation, Corporate Technology	dmitriy.okunev@siemens.com 609-734-3546	PM
Thomas Hykes	US Air Force Academy	thomas.hykes.1.ctr@us.af.mil	Site Support

Appendix B: Operating Schedules and Lists of Controllable Equipment

This appendix contains detailed operating schedules and lists of controllable equipment for AH, MH, and the CC.

Arnold Hall

Table 49: Detailed Schedule of Occupancy for AH

Operational Timeframe	Activity Type	Zone Name
0900 - 1600 (Mon-Sun)	Circulation	Corridor (Level 1)
		North Theater Arcade (Ground Level)
		Southwest Theater Arcade (Ground Level)
		West Entry Hallway
	Entrance	Front Vestibule/Entrance
	Lounge Area	Cadet Lounge (Ground Level)
		The Alley (Ground Level)
	Restroom	Restrooms (Ground Level)
1000 - 1500 (Mon- Sat)	Dining	Food Court
	Food Prep	Main Kitchen (Ground Level)
0800 - 1700 (Mon-Fri)	Food Prep	Executive Kitchen (Ground Level)
	Office	Offices (Ground Level)
		Tax Center (Ground Level)
	Workshop	Workshop (Ground Level)
1600 - 2400 (Mon-Thurs), 0700 - 2400 (Fri), 1500 - 2200 (Sat-Sun) (Only Mar thru May)	General Assembly/Leisure	Ballroom
		Reception Ballroom Hallway
All:	Performance	Auditorium

23 events a year 1800 - 2300 *Spring,Fall,Winter:* 0930 - 1800 (Mon-Sat) (50%-100% full) *Summer:* 0930 - 1800 (Mon-Sat) (25%-50% full)	General Assembly/Leisure	Auditorium Lobby
	Office	Projection Booth
	Conditioned Storage	Backstage (Level 1)
		Backstage (Level 2)
	Lounge Area	Green Room (Ground Level)
	Storage/Lounge Area	Rehearsal & Dressing Room (Basement Level)
Unoccupied	Mechanical/Elec	Electrical Room
Winter: 1800 - 2200 (Mon-Thur), 1800 - 2400 (Fri), Off (Sat-Sun) *Spring:* 1900 - 2300 (Mon-Fri), Off (Sat-Sun) *Summer:* Off (Mon-Sun) *Fall:* 1900 - 2300 (Fri-Sun)	Lounge Area	HAPS Lounge (Ground Level)
Winter: 1900 - 2100 (Mon-Thur), 1600 - 2400 (Fri), 1100 - 2200 (Sat-Sun) *Spring:* 1600 - 2300 (Mon-Thur), 1900 - 2300 (Fri), 1100 - 2200 (Sat-Sun) *Summer:* 1600 - 2000 (Mon-Thurs), 2000 - 2400 (Fri), 1200 - 1900 (Sat-Sun) *Fall:* 1600 - 1900 (Mon-Thurs), 1600 - 2300 (Fri), 1200 - 2200 (Sat-Sun)	Lounge Area	Richter Lounge (Ground Level)

Regarding the installed controllable equipment, the following table[33] provides a listing of equipment and its rated power based on a preliminary site audit.

Table 50: Arnold Hall Controllable Equipment

Location	Qty	Tag	Type of Equipment	Motor HP / Eff	Capacity / Size	Power (kW) at max Capacity	Daily Scheduled Running time (min)	Controllable? (Yes/No)	Max % of Allowed Power Reduction	Flexible Load (kW)
Kitchen	1	-	Kitchen Hood	7.5	estimate	5.625	960	Yes	15%	0.84375
	1	-	Kitchen	7.5	estimate	5.625	960	Yes	15%	0.84375

[33] Provided by Emmanuel Bisse as Excel file "EnergyProfileEstimation 8-17-12.xlsx"

			Hood							
Mech Room A	1	SF-1 (AHU-1)	Supply Fan	75	38,340 CFM	56.25	1080	Yes	15%	8.4375
	1	R-1 (AHU-1)	Return Fan (x2)	5	-	3.75	1080	Yes	15%	0.5625
	1	SF-6 (AHU-6)	Supply Fan	20	20,000 CFM	15	1080	Yes	15%	2.25
	1	R-6 (AHU-6)	Return Fan	3	-	2.25	1080	Yes	15%	0.3375
	1	SF-7 (AHU-7)	Supply Fan	20	31,700 CFM	15	1080	Yes	15%	2.25
	1	R-7 (AHU-7)	Return Fan	5	-	3.75	1080	Yes	15%	0.5625
	1	SF-8 (AHU-8)	Supply Fan	10	20,000 CFM	7.5	1080	Yes	15%	1.125
	1	R-8 (AHU-8)	Return Fan	3		2.25	1080	Yes	15%	0.3375
	1	SF-9 (AHU-9)	Supply Fan	2	3,975 CFM	1.5	1080	Yes	15%	0.225
	1	R-9 (AHU-9)	Return Fan	1	-	0.75	1080	Yes	15%	0.1125
	1	SF-10 (AHU-10)	Supply Fan	5	14,400 CFM	3.75	1080	Yes	15%	0.5625
	1	R-10 (AHU-10)	Return Fan	2	-	1.5	1080	Yes	15%	0.225
Mech Room B	1	CH-1	Chiller CH1	-	300 tons/ 600gpm @ 56 Deg F EWT	165	480	Yes	20%	33
	1	CH-2	Chiller CH2	-	300 tons/ 600gpm @ 56 Deg F EWT	60	480	Yes	20%	12
	1	P-16	Primary Chilled Water Pump	15 / 91%	600 gpm @ 40'	11.25	480	Yes	20%	2.25
	1	P-17	Primary Chilled Water Pump	15 / 91%	600 gpm @ 40'	11.25	480	Yes	20%	2.25
	2	P-12 & 13	Secondary Chilled Water Pump	40 / 93%	480 gpm @ 150'	30	480	Yes	20%	6
	1	E-45A	Exhaust Fan	-	-	7.5	1440	Yes	30%	2.25

	1	P-15	ECS Pump	2 / 85%	-	2	480	Yes	10%	0.2
	1	P-14	MTHWS Pump	1 / 88%	-	1	480	Yes	10%	0.1
	P-15	ECS Pump	1 / 85%		0.75	1440	Yes	15%	0.1125	1
	1	P-9	Pump	2 / 86%	170 gpm @ 30'	1.5	1440	Yes	15%	0.225
	1	P-8	Pump	5 / 84%	200 gpm @ 70'	3.75	1440	Yes	15%	0.5625
	1	S-4	AHU	7.5	-	5.625	1440	Yes	15%	0.84375
	2	S-5	AHU	5 / 90%	-	7.5	1440	Yes	15%	1.125
	1	S-12	Utility Set Fan	-	-	2	1440	Yes	15%	0.3
	1	E-5	Utility Set Fan	1 / *	21	0.75	1440	Yes	15%	0.1125
	1	E-4	Utility Set Fan	1 / *	21	0.75	1440	Yes	15%	0.1125
	1	E-15B	Return Exhaust Fan	-	-	7.5	1440	Yes	20%	1.5
	1	-	Plate and Frame Heat Exchanger	-	-	4	480	Yes	30%	1.2
	1	-	Wtr to Wtr Heat Exchanger	-	-	0	-	-	-	0
	1	CV-7	Wtr to Wtr Heat Exchanger	-	-	0	-	-	-	0
	3	**UH-1**	**Hot Water Unit Heater**	**0.03**	**3.5gpm / 34,800Btuh**	**0**		**NO**		**0**
Mech Room C	1	SF-1C	Supply Fan	20	5,092 CFM	15	1080	Yes	15%	2.25
	1	RF-1C	Return Fan	2	-	1.5	1080	Yes	15%	0.225
	1	SF-2C	Supply Fan	20	7,340 CFM	15	1080	Yes	15%	2.25
	1	RF-2C	Return Fan	2	-	1.5	1080	Yes	15%	0.225
	1	SF-3C	Supply Fan	5	1,312 CFM	3.75	1080	Yes	15%	0.5625
	1	RF-3C	Return Fan	1	-	0.75	1080	Yes	15%	0.1125
Roof	1	-	Cooling Tower Fan	15	estimate	11.25	1080	Yes	15%	1.6875
	1	-	Cooling Tower Fan	15	estimate	11.25	1080	Yes	15%	1.6875

-	1	EF-3	Exhaust Fan (Interlocked w/SF-1)	-	-	0	1080	Yes	15%	0
-	-	EF-15A	Exhaust Fan	0.50	1,200 CFM	0.375	1440	Yes	30%	0.1125
-	-	EF-15B	Exhaust Fan	2.00	6,500 CM	1.5	1440	Yes	30%	0.45
-	2	P-5 & 6	Condenser Water Pump	50 / 93%	600 gpm @ 175'	75	1440	Yes	15%	11.25
-	1	SF-1D	Supply Fan	5	8,200 CFM	3.75	1080	Yes	15%	0.5625
-	1	RF-1D	Return Fan	2		1.5	1080	Yes	15%	0.225

Mitchell Hall

Below is the table of controllable equipment and its rated power collected by site audit.

Table 51: Mitchell Hall Controllable Equipment

Location	Qty	Tag	Type of Equipment	Motor HP / Eff	Capacity / Size	Power (kW) at max Capaciy	Daily Scheduled Running time (min)	Controllable? (Yes/No)	Max % of Allowed Power reduction	Flexible Load (kW)
AHU-1 & 2	2	-	MTPG Coil Pump	0.75	98 gpm	0.5625	480	Yes	20%	0.225
AHU-3	1	-	MTPG Coil Pump	1	131 gpm	0.75	480	Yes	20%	0.15
AHU-6 & 7	2	-	MTPG Coil Pump	0.75	87gpm	0.5625	480	Yes	20%	0.225
AHU-8	1	-	MTPG Coil Pump	0.75	12 gpm	0.5625	480	Yes	20%	0.1125
Chiller	1	-	-	3 / 89.5%	162 gpm	2.25	480	Yes	20%	0.45
	1	-	CHW pump	10 / 91.7%	205 gpm	7.5	480	Yes	20%	1.5
Comm Rm	1	EF-6	Exhaust Fans	0.5	1,000 ACFM	0.375	1440	Yes	30%	0.1125
Compressor RM	1	EF-51	Exhaust Fans	2	4,000 ACFM	1.5	1440	Yes	30%	0.45
Conveyor Fryer	1	EF-45	Exhaust Fans	0.25	350 ACFM	0.1875	1440	Yes	30%	0.05625
Dishwashers 164 amps each 480v	3	-	-	-	-	78.72	1440	Yes	30%	70.848
East Dining	2	EF-3 & 4	Exhaust Fans	7.5	44,410 ACFM	5.625	1440	Yes	30%	3.375
	2	EF-21 & 23	Exhaust Fans	0.5	675 ACFM	0.375	1440	Yes	30%	0.225
East Fish Oven	1	EF-41	Exhaust Fans	0.5	975 ACFM	0.375	1440	Yes	30%	0.1125
East Kitchen	1	EF-9	Exhaust Fans	5	7,450 ACFM	3.75	1440	Yes	30%	1.125
	1	EF-19	Exhaust Fans	0.5	1,000 ACFM	0.375	1440	Yes	30%	0.1125

East Mezzanine	3	EF-100, 101 & 102	Exhaust Fans	0.75	900 ACFM	0.5625	1440	Yes	30%	0.50625
	2	EF-111& 112	Exhaust Fans	7.5	9,712 ACFM	5.625	1440	Yes	30%	3.375
	1	EF-113	Exhaust Fans	1.5	1,950 ACFM	1.125	1440	Yes	30%	0.3375
	1	EF-114	Exhaust Fans	0.75	1,025 ACFM	0.5625	1440	Yes	30%	0.16875
East Mezzanine Kitchen	2	EF-110	Exhaust Fans	10	11,025 ACFM	7.5	1440	Yes	30%	4.5
East Oven Rack	1	EF-42	Exhaust Fans	0.5	975 ACFM	0.375	1440	Yes	30%	0.1125
East Staff Tower	1	EF-27	Exhaust Fans	0.75	2,000 ACFM	0.5625	1440	Yes	30%	0.16875
Elev. Equip Rm	1	EF-5	Exhaust Fans	0.5	1,000 ACFM	0.375	1440	Yes	30%	0.1125
Fluid Cooler	1	-	Indirect evap Pump	2 / 86.5%	75 gpm	1.5	480	Yes	20%	0.3
Hot carts 15amps each 120v	26	-	-	-	-	1.65	1440	Yes	30%	12.87
Hot storage containers 20amps each	6	-	-	-	-	2.2	1440	Yes	30%	3.96
Mech Rm Conveyor Fryer	1	EF-46	Exhaust Fans	3	5,100 ACFM	2.25	1440	Yes	30%	0.675
Mech Room 200	1	AHU-8	AHU - 8	20	16,000 ACFM / RF = 10hp	15	1440	Yes	15%	2.25
	1	AHU-9	AHU - 9	15	17,100 ACFM	11.25	1440	Yes	15%	1.6875
	1	AHU-10	AHU - 10	15	17,100 ACFM	11.25	1440	Yes	15%	1.6875
Mech Room 404	1	AHU-2	AHU - 2	25	3 fans / 90,000 ACFM	18.75	1440	Yes	15%	2.8125
	1	AHU-5	AHU - 5	7.5	12,500 ACFM / RF = 5hp	5.625	1440	Yes	15%	0.84375
	1	AHU-7	AHU - 7	10	3 fans / 30,000 ACFM	7.5	1440	Yes	15%	1.125
Mech Room 409	1	AHU-1	AHU - 1	25	3 fans / 90,000 ACFM	18.75	1440	Yes	15%	2.8125
	1	AHU-3	AHU - 3	20	2 fans / 45,000 ACFM	15	1440	Yes	15%	2.25
	1	AHU-4	AHU - 4	7.5	6,000 ACFM / RF = 3hp	5.625	1440	Yes	15%	0.84375

	1	AHU-6	AHU - 6	10	3 fans / 30k ACFM	7.5	1440	Yes	15%	1.125
Mezzanine	1	EF-24	Exhaust Fans	0.5	460 ACFM	0.375	1440	Yes	30%	0.1125
	1	EF-25	Exhaust Fans	0.5	550 ACFM	0.375	1440	Yes	30%	0.1125
	2	EF-38	Exhaust Fans	0.33	1,120 ACFM	0.2475	1440	Yes	30%	0.1485
North Dock	1	EF-49	Exhaust Fans	0.5	750 ACFM	0.375	1440	Yes	30%	0.1125
	1	EF-50	Exhaust Fans	0.5	2,000 ACFM	0.375	1440	Yes	30%	0.1125
North Lobby	1	-	Fan Coil Unit	0.1	400 ACFM / 20 MBH	0.075	1440	Yes	15%	0.01125
Pulper RM	2	EF-48	Exhaust Fans	0.5	1,000 ACFM	0.375	1440	Yes	30%	0.225
Roof exh. Well	1	EF-46	Exhaust Fans	3	5,100 ACFM	2.25	1440	Yes	30%	0.675
Service Level	1	EF-33	Exhaust Fans	1.5	3,100 ACFM	1.125	1440	Yes	30%	0.3375
	1	EF-34	Exhaust Fans	3	6,650 ACFM	2.25	1440	Yes	30%	0.675
	1	EF-35	Exhaust Fans	1	3,000 ACFM	0.75	1440	Yes	30%	0.225
	1	EF-38A	Exhaust Fans	0.33	1,120 ACFM	0.2475	1440	Yes	30%	0.07425
Service Level Mech Rm	1	EF-28	Exhaust Fans	0.75	4,000 ACFM	0.5625	1440	Yes	30%	0.16875
Service level Potwash	1	EF-32	Exhaust Fans	1.5	2,100 ACFM	1.125	1440	Yes	30%	0.3375
Service Level Toilet & Lockers	1	EF-30	Exhaust Fans	1	3,940 ACFM	0.75	1440	Yes	30%	0.225
South Dock	1	EF-52	Exhaust Fans	0.5	750 ACFM	0.375	1440	Yes	30%	0.1125
	1	EF-53	Exhaust Fans	0.33	2,630 ACFM	0.25	1440	Yes	30%	0.075
	1	EF-53	Exhaust Fans	0.5	2,640 ACFM	0.375	1440	Yes	30%	0.1125
South Mech	2	-	Primary MTPG Pumps	30 / 93.6%	1050 gpm	22.5	480	Yes	20%	9
	1	-	DHW pump	0.5	16 gpm	0.375	481	Yes	20%	0.075
	1	-	DHW pump	0.5	8 gpm	0.375	480	Yes	20%	0.075
West & East Lobby	2	-	Unit Heater pump	0.5	15 gpm	0.375	480	Yes	20%	0.15
	4	-	Fan Coil Unit	5	6000 ACFM	3.75	1440	Yes	15%	2.25

	4	-	Fan Coil Unit	3	3000 ACFM / 75 MBH	2.25	1440	Yes	15%	1.35
West Dining	2	EF-1 & 2	Exhaust Fans	7.5	40,580 ACFM	5.625	1440	Yes	30%	3.375
	1	EF-22	Exhaust Fans	0.5	660 ACFM	0.375	1440	Yes	30%	0.1125
	1	EF-36	Exhaust Fans	0.5	1,000 ACFM	0.375	1440	Yes	30%	0.1125
West Fish Oven	1	EF-40	Exhaust Fans	0.5	810 ACFM	0.375	1440	Yes	30%	0.1125
West Kitchen	1	EF-8	Exhaust Fans	3	5,000 ACFM	2.25	1440	Yes	30%	0.675
	1	EF-12	Exhaust Fans	5	4,800 ACFM	3.75	1440	Yes	30%	1.125
	1	EF-17	Exhaust Fans	1.5	2,000 ACFM	1.125	1440	Yes	30%	0.3375
	1	EF-18	Exhaust Fans	0.5	1,000 ACFM	0.375	1440	Yes	30%	0.1125
	1	EF-20	Exhaust Fans	0.5	1,000 ACFM	0.375	1440	Yes	30%	0.1125
West Kitchen Fryer	1	EF-31	Exhaust Fans	5	8,450 ACFM	3.75	1440	Yes	30%	1.125
West Mezzanine	1	EF-103	Exhaust Fans	2	2,500 ACFM	1.5	1440	Yes	30%	0.45
	1	EF-104	Exhaust Fans	3	6,300ACFM	2.25	1440	Yes	30%	0.675
	3	EF-105, 106 & 107	Exhaust Fans	1	1,200 ACFM	0.75	1440	Yes	30%	0.675
	1	EF-108	Exhaust Fans	2	3,600 ACFM	1.5	1440	Yes	30%	0.45
	1	EF-109	Exhaust Fans	3	5,400 ACFM	2.25	1440	Yes	30%	0.675
	1	EF-116	Exhaust Fans	1.5	1,500 ACFM	1.125	1440	Yes	30%	0.3375
	1	EF-117	Exhaust Fans	1.5	2,300 ACFM	1.125	1440	Yes	30%	0.3375
	1	EF-118	Exhaust Fans	1.5	1,900 ACFM	1.125	1440	Yes	30%	0.3375
	1	EF-119	Exhaust Fans	7.5	8,552 ACFM	5.625	1440	Yes	30%	1.6875
West Staff Tower	1	EF-26	Exhaust Fans	0.75	2,000 ACFM	0.5625	1440	Yes	30%	0.16875
Wests Oven Rack	1	EF-39	Exhaust Fans	0.5	1,070 ACFM	0.375	1440	Yes	30%	0.1125
-	1	-	Chiller	-	-	84.9	480	Yes	20%	16.98
-	8	-	Unit Cooler	1/4 hp	2 Fans	5.35	480	Yes	15%	6.42
-	13	-	Unit Cooler	1/4 hp	1 Fan	2.73	480	Yes	15%	5.3235
-	1	-	Unit Cooler	1/4 hp	3 Fans	7.75	480	Yes	15%	1.1625

-	13	-	Unit Cooler	1/4 hp	-	-	480	Yes	15%	0
-	2	-	Compressor Rach Schl	-	11.6 tons	3.03	1440	Yes	20%	1.212
-	1	-	Compressor Rach Schl	-	22.5 tons	3.03	-	-	20%	0.606
-	1	-	Compressor Rach Schl	-	25.3 tons	3.036	1440	Yes	20%	0.6072
-	1	-	Compressor Rach Schdl	-	27.5 tons	4.12	1440	Yes	20%	0.824
-	1	-	Fluid Cooler	15	368 MBH / 75gpm	11.25	480	Yes	20%	2.25
-	2	-	Water source Heat Pump	-	40 MBH	0	480	Yes	20%	0
-	1	-	Split System AC Schdl	-		0	1440	Yes	15%	0
-	1	-	Electric Unit Heater Schdl	0.5	700 ACFM / 17.1 MBH	0.375	1440	Yes	15%	0.05625

Community Center

Table 52: Community Center Schedule of Operations

Operational Timeframe	Location
0730 – 1630 (Mon – Fri)	Military Post Office/FOIU
	Mental Health/Family Advocacy/Union
	ROTC
	IT Accountability
0700 – 1700 (Mon - Fri)	10 Force Support Sq. Sections (to include Command Section, Personnel Sections, Marketing, etc.)
0800 – 1600 (Mon – Fri)	JPPSO
0800 – 1700 (Mon – Fri), 0800 – 1300 (Sat)	Civilian Post Office
0800 – 1700 (Mon – Fri), 0800 – 1600 (Sat)	Barber Shop
0800 – 1730 (Mon – Fri), 0800 – 1630 (Sat), 1000 – 1700 (Sun)	GNC
0830 – 1730 (Mon – Fri)	Pharmacy
0830 – 1730 (Mon – Fri), 0800 – 1630 (Sat)	Beauty Shop
0830 – 2000 (Mon – Thu), 0900 – 1700 (Fri & Sat)	Library
0900 -1700 (Mon, Tue, Thu & Fri), 1000 – 1700 (Wed)	Bank
0900 – 1730 (Mon – Fri), 0930 – 1600 (Sat)	Dry Cleaners
0900 – 1800 (Mon – Fri), 0700 – 1600 (Sat)	Outdoor Rec
0930 – 1400 (Tue, Wed & Fri)	Thrift Shop
0930 – 1700 (Mon – Fri), 0930 – 1400 (Sat)	Florist

	Optical Shop
1000 – 1700 (Mon – Fri), 1000 – 1500 (Sat)	Military Clothing Sales
Varies depending on training schedule	Honor Guard

The following table provides a listing of the equipment and its rated power based on preliminary site audit.

Table 53: Community Center Controllable Equipment

Location	Qty	Tag	Type of Equipment	Motor HP / Eff	Capacity / Size	Power (kW) at max Capaciy	Daily Scheduled Running time (min)	Controllable? (Yes/No)	Max % of Allowed Power reduction	Flexible Load (kW)
Mech Room B	1	CH-1	Chiller		Estimate	150	720	Yes	20%	30
	1	CH-2	Chiller		Estimate	150	720	Yes	20%	30
	1	P-16	Primary Chilled Water Pump	15 / 91%	600 gpm@ 40'	11.25	480	Yes	20%	2.25
	1	P-17	Primary Chilled Water Pump	15 / 91%	600 gpm@ 40'	11.25	480	Yes	20%	2.25
	1	P-12	Secondary Chilled Water Pump	40 / 93%	480 gpm@ 150'	30	480	Yes	20%	6
	1	P-15	ECS Pump	2 / 85%		2	480	Yes	10%	0.2
	1	P-14	MTHWS Pump	1 / 88%		1	480	Yes	10%	0.1
	1	P-15	ECS Pump	1 / 85%		0.75	1440	Yes	15%	0.1125
	1	P-9	Pump	2 / 86%	170 gpm@ 30'	1.5	1440	Yes	15%	0.225
	1	P-8	Pump	5 / 84%	200 gpm@ 70'	3.75	1440	Yes	15%	0.5625
	1	S-4	AHU			0	1440	Yes	15%	0
	2	S-5	AHU	5 / 90%		7.5	1440	Yes	15%	1.125
	1	S-12	Utility Set Fan			2	1440	Yes	15%	0.3
	1	E-5	Utility Set Fan	1 / *	21	0.75	1440	Yes	15%	0.1125
	1	E-4	Utility Set Fan	1 / *	21	0.75	1440	Yes	15%	0.1125
	1	E-45A	Exhaust Fan			7.5	1440	Yes	30%	2.25
	1	E-15B	Return Exhaust Fan			7.5	1440	Yes	20%	1.5
	1		Plate and Frame Heat Exchanger			4	480	Yes	30%	1.2
	1		Wtr to Wtr			0				0

			Heat Exchanger							
	1	CV-7	Wtr to Wtr Heat Exchanger			0				0
	3	UH-1	Hot Water Unit Heater			0		NO		0

Appendix C: Maintenance and Thermal Comfort Complaint Log

Table 54: Summary of Relevant Maintenance Log and Thermal Comfort Complaint Log Data for Demonstration Buildings

Report Date	Date Completed	Maintenance Issue or Thermal Comfort Complaint
Arnold Hall: Maintenance Issues		
10/16/2012	11/16/2012	Replace VFD - Mechanical Room B Chiller, Pump 13 alarm
10/19/2012	11/9/2012	Replace bolts on AH # 10
10/29/2012	10/30/2012	Troubleshoot AHU #3 Return VFD
10/29/2012	11/6/2012	Replace motor on pump # 12
10/29/2012	11/9/2012	Investigate chilled water leak in tunnel, Mechanical Room B-3
10/30/2012	10/30/2012	Replace Contactor in VFD
11/9/2012	12/14/2012	Replace motor on pump # 13
11/13/2012	11/13/2012	HVAC pipe leaking – in between Theater office and tool room
11/14/2012	12/18/2012	Replace VFD AH #8
11/16/2012	12/24/2012	Troubleshoot VFD pump 12
11/16/2012	1/13/2013	Troubleshoot VFD pump 16
11/19/2012	12/13/2012	Replace pump #1 in Mechanical Room 314
11/26/2012	12/12/2012	Check heating systems in building
12/20/2012	4/17/2013	Troubleshoot water leak on pump 5, Mechanical Room 314
12/20/2012	12/21/2012	Air supply vent loose in Ballroom, at east stairs
1/2/2013	1/4/2013	Troubleshoot AH for HAPS - Mechanical Room B
1/17/2013	1/22/2013	Troubleshoot heat pump on west dock
1/25/2013	1/29/2013	Check operation of pumps 8 & 9 in Mechanical Room B
1/30/2013	1/31/2013	Per EMCS - AHU's not working - Trouble Shoot for no heat in entire building
2/6/2013	2/6/2013	Cooling tower pump #5 in alarm
2/19/2013	2/28/2013	Suite 3800: Troubleshoot heat pump
2/26/2013	2/26/2013	Check operation of VFD Pump # 1 - Mechanical Room 314
3/4/2013	4/12/2013	Repair leak on Pump #6 - Mechanical Room 314
3/6/2013	3/15/2013	Green Room - check HVAC Operation
3/21/2013	4/1/2013	Heat pump 340 – check motor
3/7/2013	3/8/2013	Air Handler 9 - check VFD
4/10/2013	4/18/2013	Ventilation hood for Godfather's Pizza not working
4/26/2013	5/6/2013	Replace motor on roof exhaust fan
5/2/2013	5/16/2013	Replace motor on AH 7
5/13/2013	5/13/2013	Troubleshoot Chiller Control
5/24/2013	6/28/2013	AHU #1 – repair evaporative cooler
6/25/2013	6/25/2013	AHU #7 and #8: Ballroom very stuffy – change of command starting soon
6//28/2013	7/2/2013	Troubleshoot all AH's for control voltage
9/5/2013	Not yet complete	Replace control panel due to water damage
Arnold Hall: Thermal Comfort Complaints		
10/9/2012	10/25/2012	Theater area is too cold – per EMCS – pumps are in alarm
10/18/2012	11/9/2012	Four rooms seem to have no heat
12/13/2012	12/14/2012	Ladies restroom is cold
4/16/2013	4/25/2013	HVAC units in theater and stage area blowing cold air.
4/23/2013	5/2/2013	HVAC units in theater and stage area blowing cold air.
5/13/2013	5/20/2013	Office Room #137 too hot (85 degrees)
5/14/2013	5/15/2013	Conference room 181 & Director's Office Room 137 – too hot (87F, 83F, respectively).

Report Date	Date Completed	Maintenance Issue or Thermal Comfort Complaint
6/3/2013	6/10/2013	HAPS room on northeast corner too cold (62 degrees)
Community Center: Maintenance Issues		
10/4/2012	1/10/2013	Replace the A/C at the Computer Resources Office
10/9/2012	10/22/2012	Troubleshoot MTHW pump for AHU 5
10/10/2012	10/10/2012	Pump motor hanging by wires and leaking oil
11/1/2012	11/14/2012	Calibrate refrigerant monitor
11/8/2012	12/5/2012	Clean outside of cooling towers and yard
11/8/2012	11/13/2012	Service AHU 4
11/15/2012	11/27/2012	Replace condenser water loop pressure switch
11/15/2012	12/5/2012	De-scale cell #2 on Cooling Tower
11/19/2012	1/16/2013	Fix leaks on backwash pump for cooling towers
11/21/2012	11/21/2012	Change filters on AHU
11/27/2012	12/7/2012	Inspect/repair fan in men's bathroom – Education and Training section
11/29/2012	12/10/2012	SW area – Upper Level – AHU is very loud and getting worse
12/5/2012	12/27/2012	Replace motor on fan coil unit
12/18/2012	2/8/2013	Replace blades on unit heater
12/18/2012	12/20/2012	Adjust air flow in ROTC offices
12/19/2012	12/20/2012	Replace belts on return fan 21
12/26/2012	1/9/2013	Install duct dampers in Computer Resources
1/17/2013	2/19/2013	Troubleshoot: pump 8 noise
1/22/2013	5/6/2013	Troubleshoot status on heat pump
1/23/2013	2/15/2013	Repair exhaust fan motor 1
1/24/2013	2/1/2013	HVAC check: Command Center Communications closet
1/24/2013	2/11/2013	Insulate MTHW pipes
1/29/2013	1/30/2013	Barber Shop – upper southwest side of building – supply fan is off/ Re-set.
1/30/2013	2/12/2013	Replace motor on AHU above the GNC Store
2/27/2013	2/28/2013	Per EMCS - T/S AHU # 23 -Unit has very loud noise and high temps
3/15/2013	3/18/2013	Repair MTHW leak on coil #20
3/18/2013	3/18/2013	Troubleshoot communications to AHU #18
3/21/2013	6/11/2013	Service chiller #1 and chiller #2
3/26/2013	4/11/2013	Chiller room: chilled water loop needs new gauges
3/27/2013	4/29/2013	Troubleshoot chiller #1 – it's down
4/1/2013	4/4/2013	Secure line for mini-split AC at Computer Resources
4/9/2013	5/8/2013	Troubleshoot: flow switch on chiller #2
4/29/2013	5/1/2013	Replace drain ball valve on cooling tower
4/29/2013	5/20/2013	Replace unit heater in chiller room
5/2/2013	5/2/2013	Reset AHU # 20 - Not Running
5/6/2013	5/21/2013	Replace belts on return fan 18
5/9/2013	7/3/2013	Install temporary filter on chilled water loop
5/28/2013	5/28/2013	Troubleshoot controls on AH that services outdoor recreation
5/28/2013	6/17/2013	Water running down ceiling in the GNC Store
5/31/2013	7/10/2013	Inspect HVAC system – Base Library
6/6/2013	6/7/2013	Loud noise coming from ceiling in pharmacy waiting room. (Sounds like an AHU) Rm 210
6/14/2013	6/14/2013	AHU 22 tripped on VFDs, no CFM.
6/28/2013	7/18/2013	Credit Union – troubleshoot air conditioning
7/3/2013	7/10/2013	Repair thermostat – Base Library
7/11/2013	7/15/2013	Troubleshoot HVAC issues
7/15/2013	7/31/2013	Trace VFD line voltage conduit on AHUs
7/16/2013	7/17/2013	AHU #3: repair chilled water pump
7/16/2013	9/5/2013	Replace demisters on cooling tower

Report Date	Date Completed	Maintenance Issue or Thermal Comfort Complaint
7/30/2013	7/31/2013	Rattling noise coming from duct vent in doctor's office room 204 (in Family Advocacy)
7/30/2013	9/16/2013	Troubleshoot cooling tower #1 making noise
8/2/2013	8/16/2013	Replace hot water pump – AH 4
8/22/2013	9/9/2013	Replace belts (2) A-40 on exhaust 6
9/13/2013	9/13/2013	AH 18 in alarm
9/16/2013	9/18/2013	Troubleshoot: Supply fan VFD on AH #20
9/18/2013	9/27/2013	Troubleshoot: AHU 20 operation
9/25/2013	10/9/2013	Repair cooling tower motor
10/3/2013	10/4/2013	Program terminal equipment controller for VAV B-13 (near AHU-21)
Community Center: Thermal Comfort Complaints		
10/10/2012	10/12/2012	Check controls for Pharmacy: Building too hot
10/10/2012	10/23/2012	ROTC Office – upper level – too hot, 92 degrees
11/20/2012	12/5/2012	Troubleshoot: no air flow in FSS resource office
12/3/2012	12/18/2012	Troubleshoot: heating at Computer Resources
12/10/2012	12/10/2012	No heat – Barber Shop – Southwest upper level
12/18/2012	12/18/2012	Mental Health – TS – Room 209, 215, 216: Too cold
12/28/2012	12/28/2012	Library NE corner is 80+ degrees (Rooms 202, 205, 206, 207). EMCS said to check valves.
1/14/2013	1/17/2013	Barber Shop – very cold temperatures – Multiple calls
1/29/2013	1/30/2012	Too Hot - 206, 207A, 205: 80's/ EMCS send HVAC. AH22 is putting out 94.
2/11/2013	2/11/2013	AHU # 1 tripped: Barber shop - upper level southwest side has no heat at all
2/22/2013	2/27/2013	Education office has no heat - Upper Southwest area
2/28/2013	3/4/2013	Beauty salon is very hot West Upper Side: 3:30 PM - Per EMCS - 83 Degrees
3/1/2013	3/1/2013	Too cold in Mental Health Clinic
3/16/2013	3/19/2013	Flower Shop is too hot and plants are dying
4/2/2013	4/2/2013	Too hot in Dry Cleaning Room - upper level, middle area, east side
4/16/2013	4/17/2013	Rooms too cold - Lover level, SE side (Civ Personnel) & Upper level, Base Library
4/23/2013	5/20/2013	Resource Management Section - Located Upper North - No Heat - very cold
4/24/2013	5/8/2013	Upper level south side – Major Graham's office – cold air kicked on
4/20/2013	5/6/2013	Cold temperatures in Alterations and Dry Cleaners area
4/30/2013	5/20/2013	Resource Management section – located upper north – no heat; very cold.
5/21/2013	5/21/2013	Very hot - upper level southwest side - military personnel area - Per EMCS - send HVAC
6/4/2013	6/13/2013	Upper level south side of building – Education Office – 80+ too hot
7/1/2013	7/1/2013	Too hot – 10 FSS area, and floor below, SW corner of building
7/9/2013	7/11/2013	Too hot 81 degrees - upper level SE side NAF HR Offices (63 - 73 degrees per EMCS 12:43)
7/11/13	7/12/2013	Temps too hot in Pharmacy Room 200
7/15/2013	7/15/2013	Pharmacy area too hot
7/22/2013	7/24/2013	Library (Rooms 202-206): Too Hot (77F), Fans Not Running
7/29/2013	7/31/2013	T/S too hot - lower level south side - too hot and thrift shop upper level NW side.
7/31/2013	8/1/2013	No air flow in Library
8/8/2013	8/23/2013	Heat issue in the lower level south side (too hot: 81 degrees)

Report Date	Date Completed	Maintenance Issue or Thermal Comfort Complaint
8/27/2013	8/28/2013	Too Hot - Upper Level SW Side - Major Graham's Office: 84 degrees
8/30/2013	9/3/2013	Too hot – upper level east side NAF Office (81 degrees at 08:00.)
9/19/2013	10/2/2013	Too hot calls from the south side of building (upper & lower)
Mitchell Hall: Maintenance Issues		
10/30/2012	11/29/2012	2nd floor kitchen at south end of hood 4, replace broken/bent ceiling vent/VAV
10/30/2012	11/21/2012	332 - Repair exhaust fans 6,7,8 and 9 per semi annual fire suppression testing
11/9/2012	12/4/2012	Replace temperature gauges - Annex Mechanical Room
11/23/2012	11/23/2012	Mechanical Room 404 - Replace belts exhaust fan #103
12/7/2012	12/10/2012	Low water alarm on cooling tower
12/26/2012	12/31/2012	Replace belts on exhaust fan 36, Mechanical Room 409
1/9/2013	1/17/2013	Replace belts on exhaust fan #5 in Annex Mechanical Room
1/17/2013	5/6/2013	Cadet Issue Main Warehouse: repair motor on heater
1/28/2013	2/4/2013	High temperature alarm on condensate
2/12/2013	6/7/2013	Install heat pump in the Cadet Issue Main Warehouse
2/13/2013	2/27/2013	Formal Dining Room - Check Ceiling Vents/Filters - massive amount of dead flies and bugs on 2 tables
2/15/2013	2/15/2013	Replace belts on exhaust fans 21 & 23 - Mechanical Room 404
2/19/2013	2/19/2013	Mechanical Room 200 – Start converter #2
2/19/2013	3/15/2013	Cadet Issue M/R - Replace belts on air handler #2.
2/19/2013	4/5/2013	Cadet Issue M/R - Replace belts on air handler #1.
2/19/2013	3/15/2013	Cadet Issue M/R - Replace belts on air handler #3.
2/20/2013	2/20/2013	Mechanical Room 409 - replace belts on exhaust fans # 18, 20 & 22
2/21/2013	2/28/2013	Annex Mechanical Room - Repair control valve on AH #1
3/6/2013	5/1/2013	Repair space heater - Electrical Room# 213.1, Service Level
3/7/2013	3/6/2013	Replace belts on Exhaust Fan # 116
3/7/2013	3/20/2013	Mechanical Room 200: Replace solenoid valve on steam generator #1
3/7/2013	3/15/2013	No power to fans under exhaust hood #7, service level, VP area, Room 243
3/15/2013	3/18/2013	High temperature alarm on converter 1&2, went off at 79.8
3/27/2013	4/3/2013	Exhaust fan # 113 - replace belts
4/1/2013	4/3/2013	Check MTHW system
4/4/2013	5/14/2013	Troubleshoot heat pump, Mechanical Room 204
4/9/2013	4/9/2013	Mechanical Room 409 - Replace belt on Exhaust Fan 118
4/9/2013	4/16/2013	Troubleshoot air curtain temperature, C Mechanical Room
4/10/2013	4/10/2013	Troubleshoot hoods 2 and 8 in kitchen
4/16/2013	4/24/2013	Troubleshoot #103 (hood 6) missing belt
4/16/2013	4/24/2013	#117 (hood 8) off line – over loads tripped, reset exhaust fan
4/16/2013	4/26/2013	#109 (Hood 7), off line – over loads tripped, reset exhaust fan. Started working at 10:00.
4/22/2013	4/26/2013	#118 (Hood 9), off line – over loads tripped, reset exhaust fan. Started working at 10 AM
4/30/2013	4/30/2013	Converter 1 high temperature alarm
5/28/2013	5/30/2013	Help contractor isolate condensate receiver tank.
6/11/2013	6/26/2013	Replace belts on exhaust fan # 33, Mechanical Room 409
6/17/2013	6/27/2013	AH1 leaking lots of water into entrance
6/20/2013	8/21/2013	Install deflector shield on AHU's #1 & #2
6/24/2013	7/31/2013	Order and install an exhaust fan in the Cadet Issue Main Warehouse
7/9/2013	7/23/2013	Mechanical Room 404 - replace filters on AHU # 5
7/9/2013	7/23/2013	Mechanical Room 404 - Replace belts on Exhaust Fan # 113

Report Date	Date Completed	Maintenance Issue or Thermal Comfort Complaint
7/11/2013	7/17/2013	Replace one ceiling airflow vent @ south end of Hood 4, center kitchen, 2nd floor
7/17/2013	7/24/2013	Exhaust fans not sucking up air; fire alarms about to go off
8/6/2013	8/15/2013	Mechanical Room 404 – Replace motor on Exhaust Fan #21
8/26/2013	9/30/2013	Install condensate pump for AC unit in Mitchell Hall Annex
8/26/2013	9/3/2013	Please check east & west buffet rooms, north side of dining room - need more exhaust
9/16/2013	9/20/2013	Investigate feasibility of increasing the exhaust fan draw/suction under hoods 4 and 5: 2nd floor
9/27/2013	10/16/2013	South of Exhaust Hood 4, 2nd floor center kitchen, damaged/bent VAV in ceiling - repair/replace
Mitchell Hall: Thermal Comfort Complaints		
11/1/2012	11/13/2012	Please check temperature, air flow, etc. on the dining room floor - reported 63 degrees only
12/11/2012	12/18/2012	Check heat in VP area (243) service level and west staff tower offices (415) – COLD in these areas
1/14/2013	1/14/2013	Dining Room is 58 degrees
1/14/2013	2/5/2013	Building is cold, about 40 degrees
1/16/2013	1/24/2013	No heat coming from vents in center entrance from the terrazzo (at spiral stairs)
8/27/2013	9/3/2013	Please check airflow into Clipper Room, east side of 2nd floor kitchen - TOO HOT
8/27/2013	9/3/2013	Please check air flow in the dishwasher room, east side, 2nd floor kitchen - TOO HOT
8/29/2013	9/3/2013	Clipper Room too hot – no exhaust fans

Appendix D: Thermal Comfort Survey

Thermal Comfort Pre- Demonstration Survey

Intelligent Building Energy Management System Demonstration
Environmental Security and Testing Certification Program
Project: EW-201255
PRE-DEMONSTRATION IN-DEPTH INTERVIEW GUIDE FOR BUILDING OCCUPANTS
AT THE U.S. AIR FORCE ACADEMY
COLORADO SPRINGS, CO

Interviewer		Survey Length (min.)	
Completion Date			

Respondent Information

Contact Name	
Company Name/ Contractor	
Location	
Phone	
Email	

Call Tracking

Date/Time	Notes/result/actions: (Who spoke to, new contact info, when to call back, etc.)
Date/Time	
Date/Time	

[NOTES TO INTERVIEWER]

Introduction

PRIMARY PROJECT GOAL:

The primary project goal is to determine whether advanced building controls, housed in Siemens' building level Smart Energy Box and system level microgrid controller, are an effective means by which to achieve significant energy efficiency and demand response savings for three demonstration buildings at the U.S. Air Force Academy in Colorado Springs, CO.

PRIMARY INTERVIEW OBJECTIVES:

1. **Determine if the Demand Response (or Energy Efficiency) demonstrations will affect building occupant thermal comfort by asking a series of questions regarding temperatures and comfort in the building before the Demand Response (or Energy Efficiency) Demonstration Period. The responses will establish a baseline of building occupant thermal comfort.**

LEAD-IN:

Hello, my name is [NAME]. I work for DNV KEMA, an energy consulting firm. We are continuing to work on a project in a team led by Siemens Corporate Research to demonstrate advanced building control technologies that will save energy and electricity demand. We are working with the U.S. Air Force Academy this summer on a series of demonstrations to test our advanced control systems on Arnold Hall, Mitchell Hall, and the Community Center to help save electricity and heat.

[For Arnold Hall only: A few months ago, we spoke with you regarding a number of topics including typical activities in Arnold Hall; complaints that you receive relating to thermal comfort; and building upgrades and operations.] We would like to ask you some questions today focusing on thermal comfort, and we would like to follow up after the demonstration period to ask a few more questions and to see if the demonstration caused any changes.

BI. Background Information – Pre Demonstration

[QUESTIONS IN THIS SECTION ARE INTENDED FOR THE INTERVIEWER TO ANSWER PRIOR TO CONDUCTING INTERVIEWS.]

BI1. Select the building below which is the subject of this interview:

[Arnold Hall, Mitchell Hall, or the Community Center building? (Circle One.)]

BI2. When is the Demonstration Period scheduled to begin?
Date /Time
XXXX - XX - XX / XX:XX

_____
YEAR-MONTH-DAY / HOUR : MIN (Military time)

BI3. When is the Demonstration Period scheduled to end?
Date /Time
XXXX - XX - XX / XX:XX

_____
YEAR-MONTH-DAY / HOUR : MIN (Military time)

TC. Thermal Comfort

The questions in this section have been developed to determine a baseline of occupant thermal comfort prior to the controls demonstrations that will be conducted at the occupant's building

TC1. What is the approximate outdoor temperature today?

TC2. Which area of the building are you currently occupying?

TC3. How many occupants are in this room or area of the building?

.

TC4. To which direction do the windows nearest you face?

a. ☐ North
b. ☐East
c. ☐West
d. ☐South
e. ☐Not Applicable
f. ☐Don't Know

TC5. Which of the following best describes your personal workspace or the area you occupied today?

a. ☐Enclosed office, private
b. ☐Enclosed office, shared with other people
c. ☐Cubicles with high partitions (about five or more feet high)
d. ☐Cubicles with low partitions (lower than five feet high)
e. ☐Workspace in open office with no partitions (just desks)
f. ☐Kitchen
g. ☐ Dining Hall
h. ☐ Other, please describe: _____

TC6. The next question asks about what attire you are wearing. We are asking this question to help us understand how your indoor thermal comfort may be related to your clothing. This question does not concern basic undergarments but does include some layers of clothing that may not be visible, such as t-shirts, long underwear, and slips under the garments that are visible. The questions also concern the visible layers of clothing, such as shorts, pants, skirts, long-sleeved shirts etc. I will

provide examples of layers of clothing; please respond with an answer that best fits your current attire.

Current attire:
_____
_____

[Interviewer. If needed, prompt the interviewee with examples of layers based on the list below. Write down the response above, then choose which of the following best describes the person's current attire (choose one only):]

I. Trousers

a. ☐ Trousers, short-sleeve shirt

b. ☐ Trousers, long-sleeve shirt

c. ☐ #b plus suit jacket

d. ☐ #b plus suit jacket, vest, and a T-shirt underneath

e. ☐ #b plus long-sleeve sweater, and a T-shirt underneath

f. ☐ #b plus suit jacket, and long underwear bottoms underneath

II. Skirts/Dresses

g. ☐ Knee-length skirt, short-sleeve shirt

h. ☐ Knee-length skirt, long-sleeve shirt, and a full slip underneath

i. ☐ Knee-length skirt, long-sleeve shirt, a half slip underneath, long-sleeve sweater

j. ☐ Knee-length skirt, long-sleeve shirt, a half slip underneath, suit jacket

k. ☐ Ankle-length skirt, long-sleeve shirt, suit jacket

III. Shorts

l. ☐ Walking shorts, short-sleeve shirt

IV. Overalls/Coveralls

m. ☐ Long-sleeve coveralls, and a T-shirt underneath

n. ☐ Overalls, long-sleeve shirt, and a T-shirt underneath

o. ☐ Insulated coveralls, and long-sleeve thermal underwear tops and bottoms underneath

V. Athletic

p. ☐ Sweat pants, long-sleeve sweatshirt

TC7. Please describe your general activity level today? Were you mostly sitting down all day? If you have been standing, have you performed much activity?

_____

[Interviewer: Write down the response above, and then choose the one from the list below that is most appropriate]

a. ☐ Reclining
b. ☐ Seated
c. ☐ Standing Relaxed
d. ☐ Light Activity Standing
e. ☐ Medium Activity, Standing
f. ☐ High Activity

TC8. What electrical equipment is located nearby? [Interviewer: Please read all choices and check all that apply.]

a. ☐ Computers
b. ☐ Copiers
c. ☐ Overhead Lighting
d. ☐ Desk lighting or lamps
e. ☐ Fans
f. ☐ Cooking equipment (stove, oven, etc.)
g. ☐ Other, Please describe: _____

TC9. In warm/hot weather, the temperature in my workspace or the area I occupied is: [Interviewer: Please read all choices and check only one that is most appropriate or fill in the "Other" section below.]

a. ☐ Often too hot
b. ☐ Often a little hot
c. ☐ Just right
d. ☐ Often a little cool
e. ☐ Often too cold

Other: _____

_____

_____

TC10. If you checked anything except "Just Right," when is this most often a problem? (check all that apply): [Interviewer read time periods if needed.]

a. ☐ Morning (before 11am)
b. ☐ Mid-day (11am - 2pm)
c. ☐ Afternoon (2pm - 5pm)
d. ☐ Evening (after 5pm)
e. ☐ Weekends/holidays
f. ☐ Monday mornings
g. ☐ No particular time
h. ☐ Other: _____

TC11. What is your current thermal comfort level? [Interviewer: please read entire list to interviewee and circle one number that is most appropriate.]

1	2	3	4	5	6	7	8	9	10
Hot		Warm	Slightly Warm		Neutral	Slightly Cool		Cool	Cold

TC12. If you experienced discomfort, how would you best describe the source of your current discomfort? [Interviewer: Please read all choices and check all that apply.]

a. ☐ Humidity too high (damp) or too low (dry)
b. ☐ Air movement too high or too low
c. ☐ Incoming sun
d. ☐ Hot/cold surrounding surfaces (floor, ceiling, walls or windows) or heat from office equipment
e. ☐ Drafts from windows and/or drafts from vents
f. ☐ Thermostat is inaccessible or is adjusted by other people
g. ☐ Heating/cooling system does not respond quickly enough to the thermostat
h. ☐ Clothing policy is not flexible
i. ☐ Other: _____

TC12. Are you currently adjusting or controlling one of the following items in the area you occupy? [Interviewer: Please read all choices and check all that apply.]

a. ☐ Window blinds or shades

b. ☐ Operable window

c. ☐ Thermostat

d. ☐ Portable heater

e. ☐ Permanent heater

f. ☐ Room air-conditioning unit

g. ☐ Portable fan

h. ☐ Ceiling fan

i. ☐ Adjustable air vent in wall or ceiling

j. ☐ Adjustable floor air vent (diffuser)

k. ☐ Door to interior space

l. ☐ Door to exterior space

m. ☐ None of the above

CC. Closing Comments

CC1. Do you have any other input regarding the questions discussed here today?

Those are all the questions I wanted to ask. Thank you for your time and participation.

Thermal Comfort Post- Demonstration Survey

Intelligent Building Energy Management System Demonstration
Environmental Security and Testing Certification Program
Project: EW-201255
POST DEMONSTRATION IN-DEPTH INTERVIEW GUIDE FOR BUILDING OCCUPANTS
AT THE U.S. AIR FORCE ACADEMY
COLORADO SPRINGS, CO

Interviewer		Survey Length (min.)	
Completion Date			

Respondent Information

Contact Name	
Company Name/ Contractor	
Location	
Phone	
Email	

Call Tracking

Date/Time	Notes/result/actions: (Who spoke to, new contact info, when to call back, etc.)

[NOTES TO INTERVIEWER]

Introduction

PRIMARY PROJECT GOAL:

The primary project goal is to determine whether advanced building controls, housed in Siemens' building level Smart Energy Box and system level microgrid controller, are an effective means by which to achieve significant energy efficiency and demand response savings for three demonstration buildings at the U.S. Air Force Academy in Colorado Springs, CO.

PRIMARY INTERVIEW OBJECTIVES:

1. **Determine if the Demand Response (or Energy Efficiency) demonstrations affected building occupant thermal comfort by asking a series of questions regarding temperatures and comfort in the building after the Demand Response (or Energy Efficiency) Demonstration Period.**

LEAD-IN:

Hello, my name is [NAME]. I work for DNV KEMA, an energy consulting firm. We are continuing to work on a project in a team led by Siemens Corporate Research to demonstrate advanced building control technologies that will save energy and electricity demand. We are working with the U.S. Air Force Academy this summer on a series of demonstrations to test our advanced control systems on Arnold Hall, Mitchell Hall, and the Community Center to help save electricity and heat.

We would like to ask you a few more questions today focusing on thermal comfort during the demonstration period of [list period here].

BI. Background Information – Post Demonstration

[QUESTIONS IN THIS SECTION ARE INTENDED FOR THE INTERVIEWER TO ANSWER PRIOR TO CONDUCTING INTERVIEWS.]

BI1. Select the building below which is the subject of this interview:

[Arnold Hall, Mitchell Hall, or the Community Center building? (Circle One.)]

BI2. What was the beginning of Demonstration Period?
Date /Time
XXXX - XX - XX / XX:XX

_____
YEAR-MONTH-DAY / HOUR : MIN (Military time)

BI3. What was the end of Demonstration Period?
Date /Time
XXXX - XX - XX / XX:XX

_____
YEAR-MONTH-DAY / HOUR : MIN (Military time)

BI4. [TO INTERVIEWER] [Describe the energy saving measures that were demonstrated at the building listed in BI1. Be sure to include what measure was implemented as well as when the measure was implemented and terminated.]

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

TC. Thermal Comfort

The questions in this section have been developed to determine whether occupants experienced any thermal discomfort as a result of the controls demonstrations conducted at the occupant's building.

TC1. What is the approximate outdoor temperature during the demonstration period of [list period here.]

TC2. Which area of the building did you occupy during [list period here]?

TC3. How many occupants were in this room or area of the building?

TC4. Earlier today we asked you about your attire. Are you currently wearing the same attire as before? If not, please describe any changes.

[Check appropriate boxes on the next page.]

[Interviewer may need to prompt with some options. Write down the response, then choose which of the following best describes the person's current attire (choose one only):]

I. Trousers

a. ☐ Trousers, short-sleeve shirt

b. ☐ Trousers, long-sleeve shirt

c. ☐ #b plus suit jacket

d. ☐ #b plus suit jacket, vest, and a T-shirt underneath

e. ☐ #b plus long-sleeve sweater, and a T-shirt underneath

f. ☐ #b plus suit jacket, and long underwear bottoms underneath

II. Skirts/Dresses

g. ☐ Knee-length skirt, short-sleeve shirt

h. ☐ Knee-length skirt, long-sleeve shirt, and a full slip underneath

i. ☐ Knee-length skirt, long-sleeve shirt, a half slip underneath, long-sleeve sweater

j. ☐ Knee-length skirt, long-sleeve shirt, a half slip underneath, suit jacket

k. ☐ Ankle-length skirt, long-sleeve shirt, suit jacket

III. Shorts

l. ☐ Walking shorts, short-sleeve shirt

IV. Overalls/Coveralls

m. ☐ Long-sleeve coveralls, and a T-shirt underneath

n. ☐ Overalls, long-sleeve shirt, and a T-shirt underneath

o. ☐ Insulated coveralls, and long-sleeve thermal underwear tops and bottoms underneath

V. Athletic

p. ☐ Sweat pants, long-sleeve sweatshirt

TC5. Please describe your general activity during the [list period here]. Were you mostly sitting down all day? If you have been standing, have you performed much activity?

_____

_____

[Interviewer: Write down the response above, and then choose the one from the list below that is most appropriate]

a. ☐ Reclining
b. ☐ Seated
c. ☐ Standing Relaxed
d. ☐ Light Activity Standing
e. ☐ Medium Activity, Standing
f. ☐ High Activity

TC6. Did you notice any change in the indoor temperature and/or your comfort level during [list the demonstration period here]?

a. Yes

b. No

c. I don't know

d. I don't remember

e. Other: _____

TC7. If you did notice a change, did you feel warmer or cooler? [Interviewer: If there was no change, please circle "No change" and continue to question TC8. If the answer was "warmer," please follow up question (a) below. If the answer was "cooler," please follow up with question (b) below. Please circle the appropriate answer on the scale below.]

(a) If you felt warmer, did you feel very hot, much warmer, or just slightly warmer?

(b) If you felt cooler, did you feel very cold, much cooler, or just slightly cooler?

[Interviewer to circle the appropriate answer below.]

Very hot	Much warmer	Slightly Warmer	No change	Slightly cooler	Much cooler	Very cold

TC8. What is your thermal comfort level right now? [Interviewer: Read all levels of comfort and associated numbers. Please circle one number that is most appropriate]:

1	2	3	4	5	6	7	8	9	10
Hot		Warm	Slightly Warm		Neutral	Slightly Cool		Cool	Cold

TC9. Could you rate your comfort level during the demonstration period? [Interviewer: Please read all numbers and levels of comfort, and circle one number that is most appropriate]:

1	2	3	4	5	6	7	8	9	10
Extremely uncomfortable		Very uncomfortable		Somewhat uncomfortable		Almost right but felt some discomfort		Extremely comfortable and felt just right	

TC10. If you experienced discomfort, how would you best describe the source of your discomfort during this period? [Interviewer: Please read all choices and check all that apply.]

a. ☐ Humidity too high (damp) or too low (dry)

b. ☐ Air movement too high or too low

c. ☐ Incoming sun

d. ☐ Hot/cold surrounding surfaces (floor, ceiling, walls or windows) or heat from office equipment

e. ☐ Drafts from windows and/or drafts from vents

f. ☐ Thermostat is inaccessible or is adjusted by other people

g. ☐ Heating/cooling system does not respond quickly enough to the thermostat

h. ☐ Clothing policy is not flexible

i. ☐ Other: _____

CC. Closing Comments

CC1. Do you have any other input regarding the questions discussed here today?

Those are all the questions I wanted to ask. Thank you for your time and participation.

Appendix E: Implemented DR Strategies during Various DR Events

Table 55: Implemented Strategies During DR-1

DR1: 9/23/2013		11:12		11:22		11:32		11:42		11:52		12:02		12:12		12:22		12:32		12:42		12:52		13:02	
		Strategy	Reading	Strategy	Reading	Strategy	Reading	Strategy	Reading	Strategy	Reading	Strategy	Reading	Strategy	Reading	Strategy	Reading	Strategy	Reading	Strategy	Reading	Strategy	Reading	Strategy	Reading
AH	AHU2:ON/OFF							OFF		OFF		OFF		OFF		OFF		OFF		OFF		OFF		OFF	
	AHU6:ON/OFF							ON		ON		ON		ON		ON		ON		OFF		OFF		OFF	
	AHU7:ON/OFF							OFF		OFF		OFF		OFF		OFF		OFF		OFF		OFF		OFF	
	AHU8:SSP							0.875		0.875		0.875		0.875		0.875		0.875		0.875		0.875		0.875	
	AHU10:SSP							0.875		0.875		0.875		0.875		0.875		0.875		0.875		0.875		0.875	
	Global Temp							78		78		78		78		78		78		78		78		78	
MH	AHU1:ON/OFF	ON		ON		ON		ON		ON		ON		ON		ON		ON		ON		ON		ON	
	AHU2:ON/OFF	OFF		OFF		OFF		OFF		OFF		OFF		OFF		OFF		OFF		OFF		OFF		OFF	
	AHU4:SSP	0.8		0.8		0.8		0.8		0.8		0.8		0.8		0.8		0.8		0.8		0.8		0.8	
	AHU5:ON/OFF	ON		ON		ON		ON		ON		OFF		OFF		OFF		OFF		OFF		OFF		OFF	
	AHU9:ON/OFF	ON		ON		ON		ON		ON		ON		ON		ON		ON		ON		ON		ON	
	AHU10:ON/OFF	OFF		OFF		OFF		OFF		OFF		OFF		OFF		OFF		OFF		OFF		OFF		OFF	
	Global Temp	78		78		78		78		78		78		78		78		78		78		78		78	
CC	AHU18:ON/OFF	ON		ON		ON		ON		ON		ON		ON		ON		OFF		OFF		OFF		OFF	
	AHU21:ON/OFF	ON		ON		ON		ON		ON		ON		ON		ON		OFF		OFF		OFF		OFF	
	AHU23:ON/OFF	ON		ON		ON		ON		ON		ON		ON		ON		OFF		OFF		OFF		OFF	
	AHU23:SSP	65		65		65		65		65		65		65		65		-		-		-		-	
	AHU23:SAT	0.8		0.8		0.8		0.8		0.8		0.8		0.8		0.8		-		-		-		-	
	AHU24:ON/OFF	ON		ON		ON		ON		ON		ON		ON		ON		OFF		OFF		OFF		OFF	
	AHU24:SSP	65		65		65		65		65		65		65		65		-		-		-		-	
	AHU24:SAT	0.8		0.8		0.8		0.8		0.8		0.8		0.8		0.8		-		-		-		-	
	Global Temp	78		78		78		78		78		78		78		78		78		78		78		78	

Table 56: Implemented Strategies During DR-2

DR2: 9/24/2013		12:30		12:45		13:00		13:15		13:30		13:45		14:00		14:15	
		Strategy	Reading	Strategy	Reading	Strategy	Reading	Strategy	Reading	Strategy	Reading	Strategy	Reading	Strategy	Reading	Strategy	Reading
AH	AHU2:ON/OFF	OFF		OFF		OFF		OFF		OFF		OFF		OFF		OFF	
	AHU3:ON/OFF	OFF		OFF		OFF		OFF		OFF		OFF		OFF		OFF	
	AHU6:ON/OFF	OFF		OFF		OFF		OFF		OFF		OFF		OFF		OFF	
	AHU7:ON/OFF	ON		ON		ON		ON		ON		OFF		OFF		OFF	
	AHU7:SSP	0.8		0.8		0.8		0.8		0.8		-		-		-	
	AHU8:SSP	OFF		OFF		OFF		OFF		OFF		OFF		OFF		OFF	
	AHU10:SSP	OFF		OFF		OFF		OFF		OFF		OFF		OFF		OFF	
	Global Temp	78		78		78		78		78		78		78		78	
CC	AHU18:ON/OFF	ON		ON		ON		ON		ON		OFF		OFF		OFF	
	AHU18:SSP	0.8		0.8		0.8		0.8		0.8		-		-		-	
	AHU18:SAT	65		65		65		65		65		-		-		-	
	AHU21:ON/OFF	ON		ON		ON		ON		ON		OFF		OFF		OFF	
	AHU21:SSP	0.8		0.8		0.8		0.8		0.8		-		-		-	
	AHU21:SAT	65		65		65		65		65		-		-		-	
	AHU23:ON/OFF	ON		ON		ON		ON		ON		OFF		OFF		OFF	
	AHU23:SSP	0.8		0.8		0.8		0.8		0.8		-		-		-	
	AHU23:SAT	65		65		65		65		65		-		-		-	
	AHU24:ON/OFF	ON		ON		ON		ON		ON		OFF		OFF		OFF	
	AHU24:SSP	0.8		0.8		0.8		0.8		0.8		-		-		-	
	AHU24:SAT	65		65		65		65		65		-		-		-	
	Global Temp	78		78		78		78		78		78		78		78	

Table 57: Implemented Strategies During DR-3

DR3: 9/25/2013 - Demo		11:00		11:15		11:30		11:45		12:00		12:15		12:30		12:45	
		Strategy	Reading	Strategy	Reading	Strategy	Reading	Strategy	Reading	Strategy	Reading	Strategy	Reading	Strategy	Reading	Strategy	Reading
AH	AHU2:ON/OFF	OFF		OFF		OFF		OFF		OFF		OFF		OFF		ON	
	AHU3:ON/OFF	OFF		OFF		OFF		OFF		OFF		OFF		OFF		ON	
	AHU6:ON/OFF	OFF		OFF		OFF		OFF		OFF		OFF		OFF		OFF	
	AHU7:ON/OFF	ON		ON		OFF		OFF		OFF		ON		ON		ON	
	AHU8:SSP	OFF		OFF		OFF		OFF		OFF		OFF		OFF		OFF	
	AHU10:SSP	OFF		OFF		OFF		OFF		OFF		OFF		OFF		OFF	
	Global Temp	78		78		78		78		78		78		78		78	
MH	AHU1:ON/OFF	ON		ON		ON		ON		ON		ON		ON		ON	
	AHU2:ON/OFF	OFF		OFF		OFF		OFF		OFF		OFF		OFF		OFF	
	AHU4:SSP	0.8		0.8		0.8		0.8		0.8		0.8		0.8		0.8	
	AHU5:ON/OFF	ON		ON		ON		OFF		OFF		OFF		ON		ON	
	AHU8:SSP	0.8		0.8		0.8		0.8		0.8		0.8		0.8		0.8	
	AHU9:ON/OFF	ON		ON		ON		ON		ON		ON		ON		ON	
	AHU10:ON/OFF	OFF		OFF		OFF		OFF		OFF		OFF		OFF		OFF	
	Global Temp	78		78		78		78		78		78		78		78	
CC	AHU18:ON/OFF	ON		ON		ON		ON		OFF		OFF		OFF		ON	
	AHU18:SSP	0.8		0.8		0.8		0.8		-		-		-		0.8	
	AHU18:SAT	65		65		65		65		-		-		-		65	
	AHU21:ON/OFF	ON		ON		ON		ON		OFF		OFF		OFF		ON	
	AHU23:ON/OFF	ON		ON		ON		ON		OFF		OFF		OFF		ON	
	AHU23:SSP	0.8		0.8		0.8		0.8		-		-		-		0.8	
	AHU23:SAT	65		65		65		65		-		-		-		65	
	AHU24:ON/OFF	ON		ON		ON		ON		OFF		OFF		OFF		ON	
	AHU24:SSP	0.8		0.8		0.8		0.8		-		-		-		0.8	
	AHU24:SAT	65		65		65		65		-		-		-		65	

Table 58: Implemented Strategies During DR-4

DR4: 9/25/2013		16:02		16:12		16:22		16:32		16:42		16:52		17:02		17:12		17:22		17:32		17:42		17:52	
		Strategy	Reading	Strategy	Reading	Strategy	Reading	Strategy	Reading	Strategy	Reading	Strategy	Reading	Strategy	Reading	Strategy	Reading	Strategy	Reading	Strategy	Reading	Strategy	Reading	Strategy	Reading
AH	AHU1A:ON/OFF	ON		ON		ON		ON		ON		ON		OFF		OFF		OFF		OFF		OFF		ON	
	AHU1C:ON/OFF	ON		ON		ON		ON		ON		ON		OFF		OFF		OFF		OFF		OFF		OFF	
	AHU1D:ON/OFF	ON		ON		ON		ON		ON		ON		OFF		OFF		OFF		OFF		OFF		OFF	
	AHU2:ON/OFF	ON		ON		ON		ON		ON		ON		OFF		OFF		OFF		OFF		OFF		OFF	
	AHU3:ON/OFF	ON		ON		ON		ON		ON		ON		OFF		OFF		OFF		OFF		OFF		OFF	
	AHU6:ON/OFF	OFF		OFF		OFF		OFF		OFF		OFF		OFF		OFF		OFF		OFF		OFF		OFF	
	AHU7:ON/OFF	ON		ON		ON		ON		ON		ON		OFF		OFF		OFF		OFF		OFF		OFF	
	AHU7:SSP	0.8		0.8		0.8		0.8		0.8		0.8		-		-		-		-		-		-	
	AHU8:SSP	OFF		OFF		OFF		OFF		OFF		OFF		OFF		OFF		OFF		OFF		OFF		OFF	
	AHU10:SSP	OFF		OFF		OFF		OFF		OFF		OFF		OFF		OFF		OFF		OFF		OFF		OFF	
	Global Temp	78		78		78		78		78		78		78		78		78		78		78		78	
MH	AHU1:ON/OFF	ON		ON		ON		ON		ON		ON		ON		ON		ON		ON		ON		ON	
	AHU2:ON/OFF	OFF		OFF		OFF		OFF		OFF		OFF		OFF		OFF		OFF		OFF		OFF		OFF	
	AHU4:ON/OFF	ON		ON		ON		ON		ON		ON		OFF		OFF		OFF		OFF		OFF		OFF	
	AHU5:ON/OFF	ON		ON		OFF		OFF		OFF		OFF		OFF		OFF		OFF		OFF		OFF		OFF	
	AHU8:ON/OFF	ON		ON		ON		ON		ON		ON		OFF		OFF		OFF		OFF		OFF		OFF	
	AHU9:ON/OFF	ON		ON		ON		ON		ON		ON		ON		ON		ON		ON		ON		ON	
	AHU10:ON/OFF	OFF		OFF		OFF		OFF		OFF		OFF		OFF		OFF		OFF		OFF		OFF		OFF	
	Global Temp	78		78		78		78		78		78		78		78		78		78		78		78	
CC	AHU1:ON/OFF	ON		ON		ON		ON		ON		ON		OFF		OFF		OFF		OFF		OFF		OFF	
	AHU3:ON/OFF	ON		ON		ON		ON		ON		ON		OFF		OFF		OFF		OFF		OFF		OFF	
	AHU3:SSP	0.875		0.875		0.875		0.875		0.875		0.875		-		-		-		-		-		-	
	AHU18:ON/OFF	ON		ON		ON		ON		ON		ON		OFF		OFF		OFF		OFF		OFF		OFF	
	AHU20:ON/OFF	ON		ON		ON		ON		ON		ON		OFF		OFF		OFF		OFF		OFF		OFF	
	AHU20:SSP	0.875		0.875		0.875		0.875		0.875		0.875		-		-		-		-		-		-	
	AHU20:SAT	65		65		65		65		65		65		-		-		-		-		-		-	
	AHU21:ON/OFF	ON		ON		ON		ON		ON		ON		OFF		OFF		OFF		OFF		OFF		OFF	
	AHU22:ON/OFF	ON		ON		ON		ON		ON		ON		OFF		OFF		OFF		OFF		OFF		OFF	
	AHU22:SSP	0.875		0.875		0.875		0.875		0.875		0.875		-		-		-		-		-		-	
	AHU22:SAT	65		65		65		65		65		65		-		-		-		-		-		-	
	AHU23:ON/OFF	ON		ON		ON		ON		ON		ON		OFF		OFF		OFF		OFF		OFF		OFF	
	AHU24:ON/OFF	ON		ON		ON		ON		ON		ON		OFF		OFF		OFF		OFF		OFF		OFF	
	Global Temp	78		78		78		78		78		78		78		78		78		78		78		78	

Table 59: Implemented Strategies During DR-5

DR5: 9/26/2013		13:00		13:09		13:18		13:27		13:36		13:45		13:54		14:03		14:12		14:21		14:30		14:39		14:48		14:57	
		Strategy	Reading	Strategy	Reading	Strategy	Reading	Strategy	Reading	Strategy	Reading	Strategy	Reading	Strategy	Reading	Strategy	Reading	Strategy	Reading	Strategy	Reading	Strategy	Reading	Strategy	Reading	Strategy	Reading	Strategy	Reading
	AHU2:ON/OFF	ON		ON		ON		ON		ON		ON		OFF		OFF		OFF		OFF		OFF		OFF		OFF		OFF	
	AHU3:ON/OFF	ON		ON		ON		ON		ON		ON		OFF		OFF		OFF		OFF		OFF		OFF		OFF		OFF	
	AHU6:ON/OFF	OFF		OFF		OFF		OFF		OFF		OFF		OFF		OFF		OFF		OFF		OFF		OFF		OFF		OFF	
	AHU7:ON/OFF	ON		ON		ON		ON		OFF		OFF		OFF		OFF		OFF		OFF		OFF		OFF		OFF		OFF	
	AHU8:ON/OFF	OFF		OFF		OFF		OFF		OFF		OFF		OFF		OFF		OFF		OFF		OFF		OFF		OFF		OFF	
	AHU10:ON/OFF	OFF		OFF		OFF		OFF		OFF		OFF		OFF		OFF		OFF		OFF		OFF		OFF		OFF		OFF	
	Global Temp	78		78		78		78		78		78		78		78		78		78		78		78		78		78	
MH	AHU1:ON/OFF	ON		ON		ON		ON		ON		ON		ON		ON		ON		ON		ON		ON		ON		ON	
	AHU2:ON/OFF	OFF		OFF		OFF		OFF		OFF		OFF		OFF		OFF		OFF		OFF		OFF		OFF		OFF		OFF	
	AHU4:ON/OFF	ON		ON		ON		ON		ON		ON		ON		OFF		OFF		OFF		OFF		OFF		OFF		OFF	
	AHU5:ON/OFF									OFF		OFF		OFF		OFF		OFF		OFF		OFF		OFF		OFF		OFF	
	AHU8:ON/OFF	ON		ON		ON		ON		ON		ON		ON		OFF		OFF		OFF		OFF		OFF		OFF		OFF	
	AHU9:ON/OFF	ON		ON		ON		ON		ON		ON		ON		ON		ON		ON		ON		ON		ON		ON	
	AHU10:ON/OFF	OFF		OFF		OFF		OFF		OFF		OFF		OFF		OFF		OFF		OFF		OFF		OFF		OFF		OFF	
	Global Temp	78		78		78		78		78		78		78		78		78		78		78		78		78		78	
CC	AHU1:ON/OFF	ON		ON		ON		ON		ON		ON		ON		OFF		OFF		OFF		OFF		OFF		OFF		OFF	
	AHU2:ON/OFF	ON		ON		ON		ON		ON		ON		ON		OFF		OFF		OFF		OFF		OFF		OFF		OFF	
	AHU3:ON/OFF	ON		ON		ON		ON		ON		ON		ON		OFF		OFF		OFF		OFF		OFF		OFF		OFF	
	AHU18:ON/OFF	ON		ON		ON		ON		ON		ON		ON		OFF		OFF		OFF		OFF		OFF		OFF		OFF	
	AHU20:ON/OFF	ON		ON		ON		ON		ON		ON		ON		OFF		OFF		OFF		OFF		OFF		OFF		OFF	
	AHU21:ON/OFF	ON		ON		ON		ON		ON		ON		ON		OFF		OFF		OFF		OFF		OFF		OFF		OFF	
	AHU22:ON/OFF	ON		ON		ON		ON		ON		ON		ON		OFF		OFF		OFF		OFF		OFF		OFF		OFF	
	AHU23:ON/OFF	ON		ON		ON		ON		ON		ON		ON		OFF		OFF		OFF		OFF		OFF		OFF		OFF	
	AHU24:ON/OFF	ON		ON		ON		ON		ON		ON		ON		OFF		OFF		OFF		OFF		OFF		OFF		OFF	
	Global Temp	78		78		78		78		78		78		78		78		78		78		78		78		78		78	

Appendix F: iBEMS Usability Survey

iBEMS usability survey										
Questions	**Unlikely**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**Likely**	**N/A**
Perceived Usefulness Questionnaire										
Using the system would make it easier to do my job							■			
I would find the system useful in my job								■		
Perceived Ease of Use										
Learning to operate the system would be easy for me						■				
I would find it easy to get the system to do what I want it to do					■					
My interaction with the system would be clear and understandable						■				
I would find the system to be flexible to interact with							■			
It would be easy for me to become skillful at using the system							■			
I would find the system easy to use					■					

Most Negative Aspects
No easy way to access and monitor energy strategies at runtime
Sometimes, commending points times-out showing failure even if command was successful
Very easy to make a mistake while configuring set points, no additional validation or cross-check
Energy Efficiency provides no history for the implemented strategies at runtime
Sometimes, the set point don't get relinquished and require manual input on the Apogee side
The Energy Efficiency rules are hidden behind dialogs, should be accessed more easily
Manual scheduling, no automatic access to a building activities schedule
Most Positive Aspects
The system deployment and configuration is easy and straight forward
No additional drivers or third party configuration required.
The configuration data import vs. manual configuration (rules and activities) save a lot of time

Best,