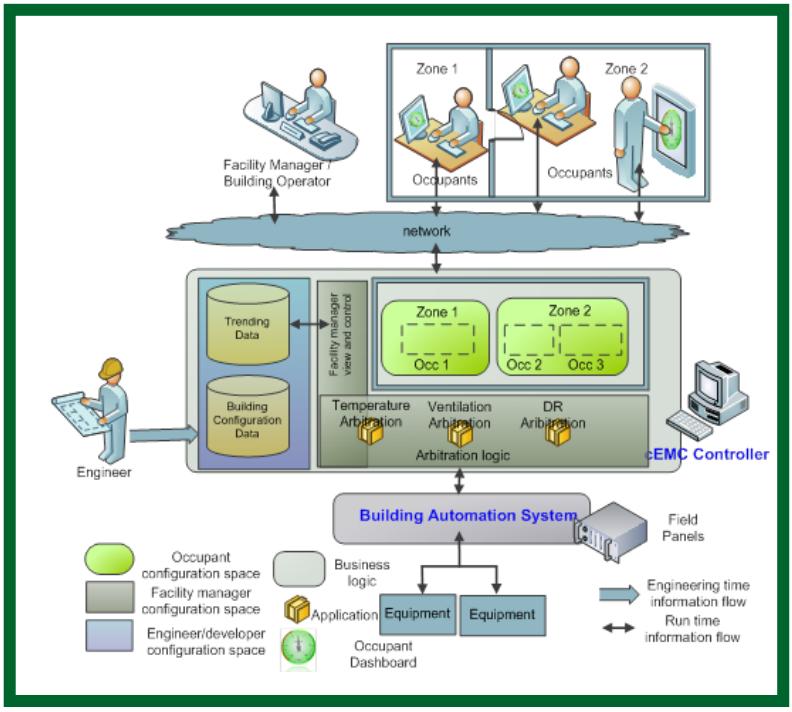
ESTCP
Cost and Performance Report

(EW-201336)



Concentrating Photo-Voltaic System for DoD Collaborative Building Energy Management and Control at 171st Air Refueling Wing, USAF Pennsylvania Air National Guard (PaANG)

December 2014

This document has been cleared for public release; Distribution Statement A

ESTCP

ENVIRONMENTAL SECURITY
TECHNOLOGY CERTIFICATION PROGRAM

U.S. Department of Defense

COST & PERFORMANCE REPORT
Project: EW-201336

TABLE OF CONTENTS

Page

EXECUTIVE SUMMARY ES-1

1.0 INTRODUCTION 1
- 1.1 BACKGROUND 1
- 1.2 OBJECTIVE OF THE DEMONSTRATION 2
- 1.3 REGULATORY DRIVERS 2

2.0 TECHNOLOGY DESCRIPTION 5
- 2.1 TECHNOLOGY OVERVIEW 5
  - 2.1.1 cBEMC Architecture 5
  - 2.1.2 cBEMC Controller 6
- 2.2 TECHNOLOGY DEVELOPMENT 7
  - 2.2.1 Demand Response Logic 7
  - 2.2.2 Social Network Integration 7
  - 2.2.3 Collaborative HMI 7
- 2.3 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY 8
  - 2.3.1 Performance Advantages 8
  - 2.3.2 Cost Advantages 8
  - 2.3.3 Performance Limitations 8
  - 2.3.4 Cost Limitations 8

3.0 PERFORMANCE OBJECTIVES 11
- 3.1 SUMMARY OF PERFORMANCE OBJECTIVES 11

4.0 FACILITY/SITE DESCRIPTION 13
- 4.1 FACILITY/SITE LOCATION AND OPERATIONS 13
  - 4.1.1 Demonstration Site Description 13
  - 4.1.2 Key Operations 14
  - 4.1.3 Demonstration Site Floor Plan 14
- 4.2 SITE-RELATED PERMITS AND REGULATIONS 15
  - 4.2.1 Regulations & Environmental Permits 15
  - 4.2.2 Agreements & Arrangements 15

5.0 TEST DESIGN 17
- 5.1 CONCEPTUAL TEST DESIGN 17
- 5.2 BASELINE CHARACTERIZATION 19
- 5.3 DESIGN AND LAYOUT OF SYSTEM COMPONENTS 20
  - 5.3.1 Facility Conditions 20
  - 5.3.2 Building Energy Audits and Occupant Survey 20
  - 5.3.3 System Design and Integration 20

TABLE OF CONTENTS (continued)

Page

5.3.4 System Integration 21
5.3.5 System Controls 22
5.4 OPERATIONAL TESTING 22
5.5 SAMPLING PROTOCOL 23
5.6 SAMPLING RESULTS 23

6.0 PERFORMANCE ASSESSMENT 25
6.1 PO-I: BUILDING ENERGY USE REDUCTION 25
6.1.1 Baseline 25
6.1.2 Method 25
6.1.3 Results and Conclusions 25
6.2 PO-II: FACILITY ELECTRICAL LOAD SHEDDING 26
6.2.1 Baseline 26
6.2.2 Method 26
6.2.3 Results and Conclusions 27
6.3 PO-III: SCOPE 2 GREENHOUSE GAS (GHG) EMISSIONS 28
6.4 PO-IV: SYSTEM ECONOMICS 28
6.5 PO-V: OCCUPANT CONTROL AND DSM ENGAGEMENT 29
6.5.1 Baseline 29
6.5.2 Method 29
6.5.3 Results and Conclusions 30
6.6 PO-VI: OCCUPANT COMFORT AND SATISFACTION 30
6.6.1 Baseline Environmental Satisfaction and Measurements 30
6.6.2 Method 30
6.6.3 Results and Conclusions 31
6.7 PO-VII: FACILITY MANAGER/OPERATORS FEEDBACK 32

7.0 COST ASSESSMENT 33
7.1 COST MODEL 33
7.2 COST DRIVERS 33
7.3 COST ANALYSIS AND COMPARISON 34

8.0 IMPLEMENTATION ISSUES 35
8.1 END-USER CONCERNS 35
8.2 PROCUREMENT ISSUES 35
8.3 INTEGRATION WITH BAS 35
8.4 USER EXPERIENCE 36

9.0 REFERENCES 37

APPENDIX A POINTS OF CONTACT A-1

LIST OF FIGURES

Page

Figure 1. cBEMC architecture..... 5
Figure 2. Temperature arbitration logic in cBEMC controller..... 6
Figure 3. Building PaANG-300..... 13
Figure 4. 2nd floor plan for PaANG-300. 14
Figure 5. cBEMC system installation architecture at PaANG-300..... 17
Figure 6. Baseline estimation for energy saving determination..... 19
Figure 7. cBEMC network integration at PaANG. 21
Figure 8. Extrapolated yearly energy savings with cBEMC deployment. 26
Figure 9. Average monthly weekday demand curves for PaANG-300..... 26
Figure 10. Baseline and actual demand during DR Test 3 (Mode 4)..... 27
Figure 11. User satisfaction: temperature in your work area. 31

LIST OF TABLES

Page

Table 1. Demonstration results summary. 2
Table 2. Performance objectives. 11
Table 3. Test design summary. 18
Table 4. DR modes 19
Table 5. Sampling protocol table. 23
Table 6. Results summary for DR-3 (Mode 4). 27
Table 7. DR results summary. 27
Table 8. Comparison of baseline emission to the post cBEMC intervention. 28
Table 9. cBEMC savings. 29
Table 10. Cost model for the cBEMC at PaANG-300. 33

ACRONYMS AND ABBREVIATIONS

AHU	air handling unit
ARW	Air Refueling Wing
ASHRAE	American Society for Heating, Refrigerating and Air Conditioning Engineers
BACnet	Building Automation and Control Network Communication Protocol
BAS	building automation system
BLCC	building life cycle cost
BMS	building management system
cBEMC	Collaborative Building Energy Management and Control
cEMC	Collaborative Energy Management and Control
CMU	Carnegie Mellon University
COPE	Cost-effective Open-Plan Environment
DCV	demand controlled ventilation
DLC	Direct Load Control
DoD	U.S. Department of Defense
DOE	U.S. Department of Energy
DR	demand response
DSM	demand side management
EE	energy efficiency
EISA	Energy Independence and Security Act
ESTCP	Environmental Security Technology Certification Program
EUI	energy usage intensity
FM	Facility Manager
FY	fiscal year
GHG	greenhouse gas
GForge	web-based project management portal for software projects
HMI	human-machine interface
HVAC	heating, ventilation, and air conditioning
iBEMS	Intelligent Building Energy Management
IEQ	indoor environmental quality
IRB	Independent Review Board
IT	information technology
LCCA	life cycle cost analysis
LTC	Lieutenant Commander
MOU	Memorandum of Understanding

NATO	North Atlantic Treaty Organization
NEAT	National Environmental Assessment Toolkit
NIST	National Institute of Standards and Technology
NIST RMF	NIST Risk Management Framework
PaANG	Pennsylvania Air National Guard
PC	personal computer
PNNL	Pacific Northwest National Laboratory
PPCL	Powers Process Control Language
PO	performance objective
POC	point of contact
PVN	private virtual network
QC	quality control
ROI	return on investment
RTU	roof top unit
SBT	Siemens Building Technologies
SCT	Siemens Corporation, Corporate Technology
SEB	Siemens Smart Energy Box
SVN	version control/source control software for Windows
TCP/IP	transmission control protocol/internet protocol
TRNSYS	Transient System Simulation platform
TVOC	total volatile organic compound
UI	user interface
VAV	variable air volume
VLAN	virtual local area network

ACKNOWLEDGEMENTS

This work is supported by the U.S. Department of Defense (DoD) Environmental Security Technology Certification Program (ESTCP) program under Project EW-201336. The team would like to thank Dr. James Galvin for his leadership during the project execution. We are also very thankful to the technical support provided by Glen DeWillie and Scott Clark of HydroGeoLogic, Inc. The team gratefully acknowledges the support from the staff of Building 300 of the 171st Air Refueling Wing of the Pennsylvania Air National Guard who not only provided information and coordination assistance for the project, but also actively participated in the project, by evaluating our software.

Technical material contained in this report has been approved for public release.
Mention of trade names or commercial products in this report is for informational purposes only;
no endorsement or recommendation is implied.

This page left blank intentionally.

EXECUTIVE SUMMARY

To move the U.S. toward greater energy independence and security, the U.S. Department of Defense (DoD) seeks 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). One approach toward meeting this mandate is enhancing building controls to a) minimize energy usage in response to occupancy schedules, b) utilize weather forecasts to shift loads in advance of heat and cold waves, and c) decrease expenses and increase revenue stream from the utility's demand response (DR) programs. While building automation system (BAS) operators can readily achieve energy and cost savings for a few buildings through changes to the building controls, the task becomes much more difficult to implement across a campus of buildings. Campus-wide savings are particularly complicated because even state-of-the-art BASs are incapable of coordinating electricity demand among buildings.

To address the above mentioned issues, Siemens, in collaboration with the Carnegie Mellon University (CMU), deployed and demonstrated an innovative building energy management technology called Collaborative Building Energy Management and Control (cBEMC) at Building 300 of the 171st Air Refueling Wing of the Pennsylvania Air National Guard (PaANG) located at the Pittsburgh International Airport in Coraopolis, Pennsylvania. The objective of this demonstration was to achieve energy savings using cBEMC 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 Intelligent Building Energy Management (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.

cBEMC is a vendor-independent software platform that enhances the capabilities of an existing BAS by actively engaging occupants in energy management and comfort control for their environment. These capabilities are designed to improve building EE and the ability to rapidly respond to fluctuations in the grid. In particular, the following innovations were introduced by cBEMC:

- "cBEMC Controller" – a runtime software component that is integrated with BAS network and communicates with BAS server via Building Automation and Control Network Communication Protocol (BACnet protocol). It is also connected to a virtual private network exposing parts of its controlling functions to building occupants and facility management via Web Human-Machine Interface (HMI). cBEMC controller provides real-time methods for both occupancy-based energy management, and comfort-based building environmental control to optimize building energy efficiency and to manage DR events.

- Social network-type participation of building occupants in EE and DR events.
- HMI for social interaction among building occupants.
- Visualization of energy centric results to promote healthy competition among building occupants for energy reduction.
- Dynamic DR capability to achieve rapid target load shedding capacity in response to grid or microgrid needs.

Several quantitative and qualitative performance objectives (PO) were identified and corresponding metrics were defined, as described in Table 1, to assess the performance of cBEMC. To investigate the ability of cBEMC technology to achieve the success criteria for the defined POs, a series of system tests were conducted at PaANG to measure the performance of cBEMC with reference to a baseline conditions. The tests were grouped into two test scenarios – EE scenario and DR scenario. Two weeks of real data coupled with one year Transient System Simulation platform (TRNSYS) simulation were used for the performance analysis of cBEMC technology. The table below provides the summary of the overall achievements, for each PO, during various EE and DR tests that were conducted at PaANG.

Table 1. Demonstration results summary.

Objective	Success Criteria	Performance Assessment
Quantitative Performance Objectives		
PO 1: Building Energy Use Reduction	30% annual reduction in HVAC energy usage and 10% annual reduction for overall building energy consumption.	Partially achieved. Average reduction achieved was 14% and the best case scenario of 22% HVAC reduction. Corresponding overall energy reduction (including electricity) were 10.4% and 15.8%, respectively.
PO 2: Facility Electric Load Shedding	Load shedding by 20% within 15 minutes lasting for 60 minutes	Partially achieved. Over three DR test average kW/kWh reduction achieved was 28%
PO 3: Scope 2 GHG Emissions	20% reduction	Target was achieved. Reduction achieved was 20%
PO 4: System Economics	Simple payback in 5 years	Not achieved.
Qualitative Performance Objectives		
PO 5: Occupant Control and DSM	softThermostat used weekly by occupants; and real time use for setback and DR	Partially achieved.
PO 6: Occupant Comfort and Satisfaction	Improvements in occupant satisfaction; IEQ measurement meets ASHRAE standards	Achieved.
PO 7: FM / Operator Feedback	Averaged rating greater than 5 (out of 7); and desire of FM to continue using the system	Achieved.

ASHRAE = American Society for Heating, Refrigerating and Air Conditioning Engineers
DSM = demand side management
FM = facility manager
GHG = greenhouse gas
HVAC = heating, ventilation, and air conditioning
IEQ = indoor environmental quality

As is common when designing and implementing control technologies that have a wide range of capabilities, field conditions are not always optimal to fully “test drive” a technology’s controls and algorithms. The team was not able to achieve some of the objectives due to several onsite constraints, whereas some objectives were only partially achieved, as shown in Table 1. Details of possible reasons for not fully realizing some of the objectives are explained in Section 6. It can be safely stated that in spite of several constraints, the cBEMC performed as expected most of the time. Although it was not able to achieve some of its POs, it was able to increase energy awareness among building occupants.

This page left blank intentionally.

1.0 INTRODUCTION

Siemens Corporation, Corporate Technology (SCT), in collaboration with Carnegie Mellon University (CMU), deployed and demonstrated an innovative building energy management technology called Collaborative Building Energy Management and Control (cBEMC) at Building 300 of the 171st Air Refueling Wing of the Pennsylvania Air National Guard (PaANG) located at the Pittsburgh International Airport in Coraopolis, Pennsylvania through funding provided by the U.S. Department of Defense (DoD) Environmental Security Technology Certification Program (ESTCP). The objectives of the demonstration were to validate the building energy efficiency (EE) improvement and demand response (DR) capability of cBEMC, as well as the beneficial impacts of cBEMC on increased awareness of energy conservation opportunities and active engagement in workplace EE enhancement by the DoD personnel who are building occupants.

This report describes the results of the demonstration of cBEMC at the PaANG site. In addition to validating the effectiveness of the technology, the demonstration allowed the team to determine the system installation costs, assess the system's regulatory acceptance, and provide a viable transfer plan to other DoD sites.

1.1 BACKGROUND

According to a study by Pacific Northwest National Laboratory (PNNL) [2], approximately 53% of the 318,090 total DoD buildings are used for housing, offices, and schools. Buildings of these types are usually in active use for several hours per day with dynamic occupancy. However, a typical state-of-the-art building automation system (BAS) used by DoD supports only static heating, ventilation, and air conditioning (HVAC) and lighting schedules; and existing DoD energy policies often limit control of the climate within these spaces to building operators and facility managers (FM). In most cases, buildings are managed to provide regulated environmental conditions designed to support high comfort levels for maximum occupancy during periods of time that are longer than necessary, e.g., 6am-11pm daily, in order to avoid occupant complaints. This management policy leads to substantial energy waste without necessarily assuring occupant satisfaction. In fact, based on surveys conducted at DoD sites and studies in civilian settings, occupant complaints are frequent at those buildings that adopt such policies; and, ironically, typical complaints are about buildings being over-cooled in summer and over-heated in winter.

About 60% of the employees at PaANG-300, who are assigned to occupy approximately 50% of the building area, use the facilities on a limited basis, with many of such "part time" employees coming to the office only one day per week. Because the schedules of these part-timers are subject to change, the BAS is set to air condition the space as if they were "full time" employees. *Due to such persistent, excessive over-scheduling and over-ventilation, the energy waste is significant.*

The project team hypothesized that allowing occupant participation in selection of climate setpoints can significantly reduce both energy waste and comfort complaints. To facilitate this, SCT developed a low-cost software solution—the cBEMC system—that allows interactive communications and actions among occupants, FMs, and building control systems. Savings in

direct building energy use (and associated energy cost) of between 20% and 40% was demonstrated from the adoption of Siemens cBEMC technology for housing, office, and school types of DoD buildings [3] [4] [5]. Furthermore, the cBEMC collaborative intelligent load management function can be used to help DoD meet its energy security targets for DR agility. Moreover, use of cBEMC can enhance the productivity of both occupants and the building operator as the result of better comfort experience leading to a more productive workplace and fewer complaints.

1.2 OBJECTIVE OF THE DEMONSTRATION

The objective of this project is to demonstrate at a DoD site the ability of a cBEMC system to empower deep occupant-engagement that can achieve ongoing building energy savings and, on command, to obtain a targeted fast load-shedding relative to baseline building total load.

Specifically, the team sought 30% HVAC energy savings and 20% of electric load reduction at PaANG-300 building through the cBEMC deployment. Also tested were greenhouse gas (GHG) emissions reduction; greater occupant control and engagement; and increased occupant comfort and satisfaction through cBEMC implementation.

As an extension of a traditional BAS, cBEMC allows collaborative building control among building occupants and FMs to determine *optimal* set points for the BAS in order to save energy and reduce peak load. Although cBEMC technology had previously been tested and proven effective within living labs as a new, groundbreaking technology, neither its performance nor its cost had been quantified prior to this demonstration; and the new feature of load management had not been tested. Demonstration of this technology will help DoD assess the potential for the adoption of collaborative building energy management and control technology to increase energy security at its installations. In particular, the demonstration addressed application of the social media aspects of the technology within the security limitations of military environments; and it assessed the adequacy and acceptance of the human-machine interface (HMI) developed by Siemens for the technology implementation.

A cBEMC system was engineered and deployed at Building 300 of the PaANG installation at the Pittsburgh International Airport following a Level 3 energy audit of the building. The system was rolled out first for a small group of occupants and tuned for optimal performance before full-scale deployment. Before and during the testing period, comparable meter data, building control data, and feedback from occupancy interaction logs were collected; and project costs were tracked during the engineering and testing phases. Deep data analysis was conducted by SCT and CMU in accordance with American Society for Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) and U.S. Department of Energy (DOE) guidelines to validate the performance, costs, and benefits of the technology.

1.3 REGULATORY DRIVERS

The energy saving activities of this demonstration are aligned with legislative mandates, Executive Orders, and DoD policy.

1) **Legislative Mandates: Energy Policy Act of 2005 [6], Energy Independence and Security Act (EISA) of 2007:**

   These laws serve to move the United States toward greater energy independence and security, increased efficiency of products and buildings, and improved energy performance by the Federal Government. The technology used in this demonstration specifically addresses both *Title III: Energy Savings Though Improved Standards for Appliance and Lighting* and *Title IV: Energy Savings in Buildings and Industry* of this mandate. The core objective of this project is demonstration of cBEMC abilities to achieve energy savings by following the guidelines and regulations stipulated in the mandates and in the industry standards, such as Federal Leadership in High Performance and Sustainable Buildings, etc.

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:

   - Subsections (a) "improve energy efficiency and reduce GHG emissions of the agency, through reduction of energy intensity by (i) 3% annually through the end of fiscal year 2015, or (ii) 30% by the end of fiscal year 2015," and
   - Subsection (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 Memorandum of Understanding (MOU) with 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 that current and emerging mission needs are addressed along with anticipation of future challenges. The technology used in this demonstration specifically addresses Goal 7 of this plan, "Sustainability Practices Become the Norm Sub-Goal 7.2 15% of Existing Buildings Conform to the Guiding Principles on High Performance and Sustainable Buildings By Fiscal Year (FY) 2015, and Thereafter Through FY 2020."

This page left blank intentionally.

2.0 TECHNOLOGY DESCRIPTION

2.1 TECHNOLOGY OVERVIEW

2.1.1 cBEMC Architecture

cBEMC is a vendor independent software platform which extends the functionality of an existing BAS by means of active occupant engagement in energy management and comfort control. Figure 1 shows the system's architecture, where communication between cBEMC and the BAS is provided by an industry standard open communication protocol, Building Automation and Control Network Communication Protocol (BACnet).

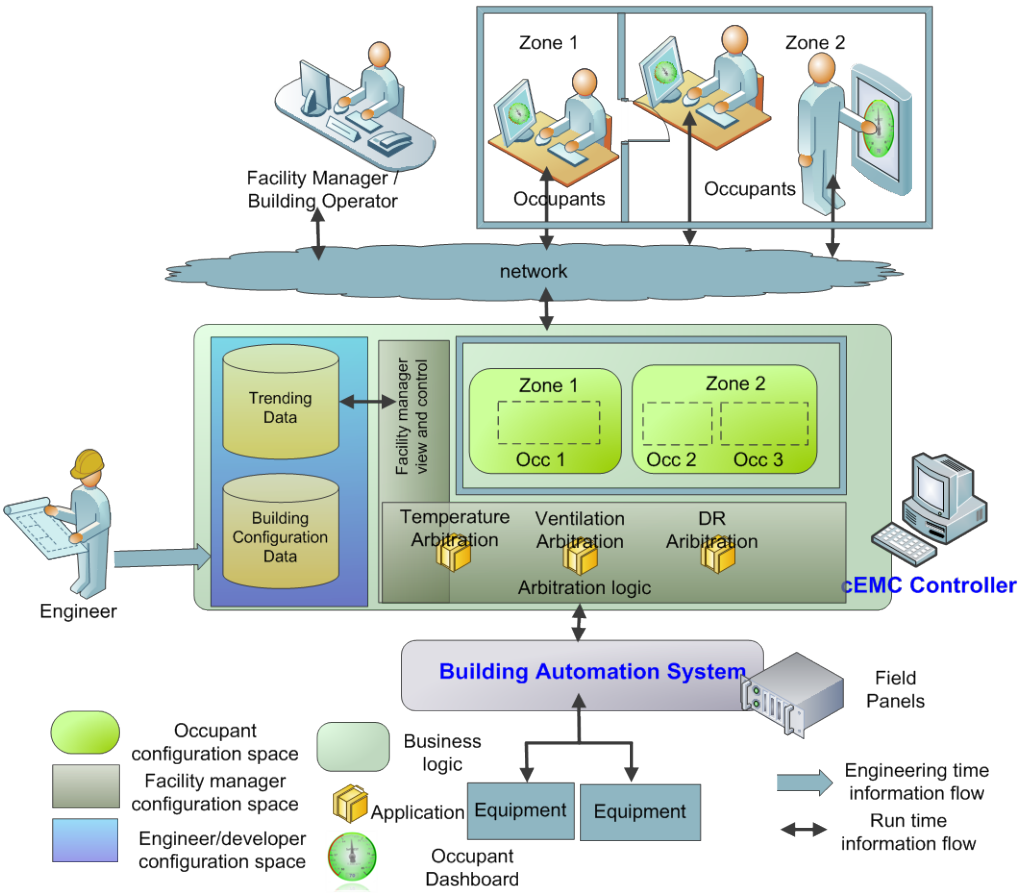


Figure 1. cBEMC architecture.

The cBEMC system was designed and developed as a hybrid software platform that combines engineering (cBEMC controller configuration) and runtime (cBEMC User HMI) components with a cBEMC controller as a core runtime engine. The design of the cBEMC controller is based on the Siemens Smart Energy Box (SEB). SEB is a vendor-independent middleware for enhancing existing BAS with advanced energy management functions and to facilitate communication among different information sources, including building management system (BMS), power grid, weather forecast web services, etc. Within the scope of cBEMC project, Siemens has extended SEB's capabilities with weather-based and occupancy-based energy

efficiency implementation; dynamic demand management; and implementation of an advanced HMI for building operators as well as building occupants.

2.1.2 cBEMC Controller

At the center of the cBEMC system is a device called the "cBEMC Controller," which sits on the network to interconnect building occupants, the FMs, and the BAS. The cBEMC Controller (the "Controller") integrates Occupant Dashboards, FM Dashboards, and the BAS. The Controller applies both occupancy-based energy management and comfort-based building environmental control to maximize building EE and DR capacities. Algorithms of the Controller integrate modules that address three key logic issues: temperature arbitration, demand controlled ventilation (DCV), and DR logic.

Automatic Temperature Set Point Arbitration: Energy efficient temperature arbitration rules are building-specific and time-varying. One simplified example of the temperature arbitration method is shown in Figure 2, where the desired temperature settings of multiple occupants within the same zone are averaged first, and the averaged zone temperature settings are then sent to a multi-zone arbitartion component to ensure that achieving those temperature setpoints are both feasible by the HVAC system and energy efficient. If the settings of adjacent zones in an open space are too far apart from each other, then they cannot be physically achieved simultaneously. Excessive air flow between zones, in attempts to achieve impossible environmental conditions, can cause both discomfort and energy waste. To prevent this potential energy waste, FM or the control engineer shall specify the "maximal temperature difference" using cBEMC FM portal.

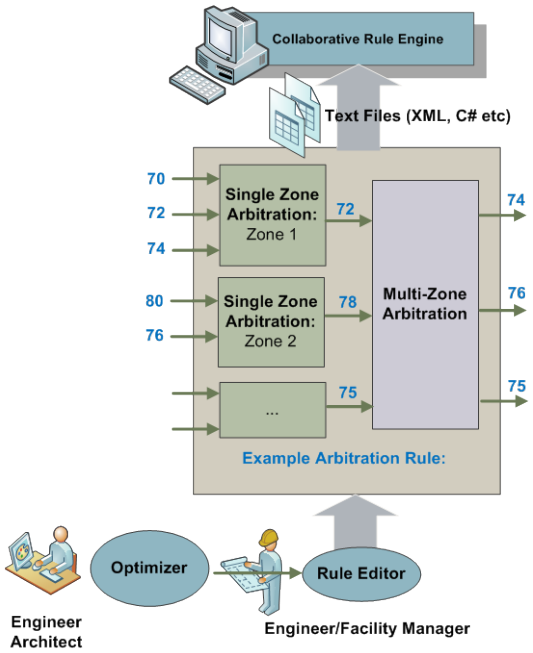


Figure 2. Temperature arbitration logic in cBEMC controller.

Demand Controlled Ventilation: DCV provides other opportunities for energy savings. The occupant-engaged DCV logic is split into two parts and implemented in both cBEMC and

Apogee, using C# and Powers Process Control Language (PPCL) respectively. The rationale for splitting the logic in this manner is to achieve reliability and speed. Based on calendar aggregation, cBEMC estimates the total number of occupants as well as the number of occupants in each zone for controlling the ventilation. Based on this information, cBEMC calculates the minimal requirements for outdoor air intake based on the ASHRAE 62.1 standard.

Demand Response Logic: The cBEMC logic for occupant-engagement in DR events includes two parts: 1) automatic DR actions on central systems (HVAC, lighting, and local energy generation/storage where available) and 2) occupant-engaged DR actions on plug loads and process loads. Given a specified demand limit target, the cBEMC DR logic will first evaluate the feasible load reduction up to the boundary of the occupants' comfort range and automatically generate control actions on HVAC systems and lighting systems, as well as on local energy resources (if available). If the demand reduction goal cannot be met by simply reducing central loads, the controller will generate actions for occupants to shed process/plug loads. The occupant-side load shedding strategy is customized for each individual. Upon receiving notifications, occupants can commit to take certain load reducing actions and to monitor their demand during the DR period. These commitments from occupants help the FM to achieve the DR target. Feedback from the occupants prior to the DR event provides the FM with opportunities to identify and plan for nuanced actions when the FM finds that additional measures are needed to meet the DR target.

2.2 TECHNOLOGY DEVELOPMENT

During the course of the project, SEB functionality was extended by the addition of several modules with new functions and an enhanced HMI to implement cBEMC technology. The following sections describe the new components of SEB for cBEMC in details.

2.2.1 Demand Response Logic

This component has already been explained earlier in section 2.1.2.

2.2.2 Social Network Integration

Social networking capability is an important feature in cBEMC for facilitating communication and collaboration among and between occupants and building operators/FMs. It also enables applications such as occupants' comfort voting, and it facilitates implementation of demand management by the FM. A private social network for both EE and DR scenarios was designed and implemented. Occupants and FMs can exchange their opinions on building performance and control issues via an internal social networking engine.

2.2.3 Collaborative HMI

The project team designed and developed the Advanced HMIs for building collaborative control that allows interactive communications and collaborations among and between occupants and FMs to refine energy policies in ways that optimize energy saving and improve occupants' comfort. The resulting Occupant Dashboard includes a "softThermostat" and a DR portal. The softThermostat allows occupants to set up their comfort preference as a range, input their out-of-office schedules, command their desired zone temperature settings, and monitor their

environmental conditions and individual energy performances. The DR portal displays DR information from FMs including detailed DR instructions customized for different groups of occupants. The FM Dashboard supports FMs by allowing them to monitor building energy performance, occupant comfort, and zone level energy use, and to initiate DR events.

2.3 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

2.3.1 Performance Advantages

Unique performance advantages are derived from the ongoing engagement of building occupants, in collaboration with their FM and through interaction with their building's BAS, to control and improve their working environment and to actively participate in EE efforts and DR events. cBEMC bases its control of the BAS on occupant preferences and feedback, including accommodation of dynamic occupancy schedules, as well as on outside weather conditions and the parameters of building systems. In addition, cBEMC is capable of networking and managing an unlimited number of facilities, executing energy management strategies for each individual building based on that building's energy demand. cBEMC is also capable of managing EE for multiple buildings and simultaneously managing instantaneous DR for a subset of those buildings. Also, the mobile scheduler (a tablet personal computer [PC]) allows unprecedented flexibility and simplicity for occupant management of personal comfort settings and work schedule.

2.3.2 Cost Advantages

Because cBEMC is software based, its acquisition, installation, and maintenance costs are much lower than the costs of hardware-based solutions. The major cost of cBEMC is associated with engineering effort during the commissioning phase. After commissioning, very little maintenance is required in contrast with hardware based systems. The integration of SEB-based cBEMC with BAS is quick, easy, and cost effective. Furthermore, the scalability of the system allows it to coordinate DR and EE for multiple facilities to achieve greater load reduction and participation in utility incentive offerings.

2.3.3 Performance Limitations

For purposes of EE improvement, the primary cBEMC performance limitation is the availability of up-to-date occupancy information. Also, cBEMC EE control depends on the availability and condition of the assets that are actually controllable in the field. These limitations can pose constraints to EE and DR strategy design. In addition, lack of access due to site-specific security limitations and unsecured web architecture of cBEMC system can significantly constrain user access, and thus can drastically impact the overall energy savings results. Moreover, cBEMC support for notification and diagnosis of BAS failures is limited. cBEMC does not handle real-time alarms.

2.3.4 Cost Limitations

Engineering efforts during the commissioning phase account for the primary cost of cBEMC. cBEMC also requires an initial effort to develop building energy models, which can be time-consuming. Development of control point listing and mapping is a manual process that requires a

great deal of communication effort between the FM and the BAS service team. This is currently a cost-limitation.

This page left blank intentionally.

3.0 PERFORMANCE OBJECTIVES

The technology and economic Performance Objectives (PO) to evaluate cBEMC technology were defined based on following DoD goals on military installations:

- ***Cost Avoidance:*** The POs measure installation energy use reduction resulting from collaborative building control, and the ability to achieve savings from peak load reduction by having the ability to quickly reduce electrical loads.
- ***Greenhouse Gas Reduction:*** The POs measure the reduction of GHG emissions for installations.
- ***Sustainability Practices Become the Norm:*** The POs measure the active engagement from occupants in energy conservation activities.
- ***User Comfort:*** The POs address system inadequacies and identify opportunities to achieve energy savings while increasing user comfort and satisfaction.

3.1 SUMMARY OF PERFORMANCE OBJECTIVES

Investigators collected data before, during, and after cBEMC system operation to evaluate the technical and economic objectives of the project. These POs are summarized below in Table 2.

Table 2. Performance objectives.

PO	Metric	Data Requirements	Success Criteria	Results
Quantitative POs				
Building Energy Use Reduction	Energy Intensity (site and source kWh/ft^2)	Trended BAS data and incremental meter readings. Load profiles developed through TRNSYS models or energy audits of the buildings.	30% reduction of annual HVAC Energy Use[1]; 10 % of overall building energy usage reduction	Partially achieved. Average reduction was 14% and the best case scenario of 22% HVAC energy reduction. Corresponding overall energy reduction were 10.4% and 15.8%, respectively.
Facility Electric Load Shedding	Electricity Demand (kW) and response time (measured in 15 minutes)	Interval meter readings every 15-minutes. Load profiles developed through TRNSYS models or energy audits of the buildings. DR feedback survey.	Load shedding by 20% achieved within 15 minutes and maintained for 60 minutes without adverse impact to mission.	Partially achieved. Over three DR test average kW/kWh reduction achieved was 28%

TRNSYS = Transient System Simulation platform

[1] Energy savings calculations will be driven by the granularity of existing utility and energy use information for this building separate from the military installation as a whole. Operational set points for the BAS system and trended data will be used to estimate building specific electric and gas uses across all systems (heating, cooling, ventilation, lighting, plug).

Table 2. Performance objectives (continued).

PO	Metric	Data Requirements	Success Criteria	Results
Scope 2 GHG Emissions	Purchased Energy GHG emissions (metric tons CO_2 and other GHG)	Estimated release of GHG based on energy baseline, meter readings, historical energy data, or simulations; information about energy sources.	20% GHG emission reduction.	Target was achieved. Reduction achieved was 20%
System Economics[2]	ROI (# of years to payback and ROI %)	Energy costs based on metered data and rate structure from utility; cBEMC installation costs and ongoing costs.	Payback in 3-5 years based on the metered energy savings and cost of implementing cBEMC; 20% ROI.	Not achieved.
Qualitative Performance Objectives				
Occupant Control and DSM Engagement	Tracked engagement of occupants in cBEMC supported user participation in energy conservation and demand management	On-line occupant control of HVAC set points, calendar control, cBEMC prompted actions for lighting, cBEMC arbitration traces and plug load management, and on-line discussion and survey response.	Goal of softThermostat used weekly by occupants for schedule inputs; and real time use for setback and DR.	Partially achieved.
Occupant Comfort and Satisfaction	1) Occupant Comfort Surveys 2) Measured IEQ conditions	Occupant survey data on comfort and satisfaction as well as control satisfaction and energy awareness before and after cBEMC intervention. Building IEQ measurements compared to national standards for in thermal, air quality, lighting and acoustic quality.	Measured improvements in occupant satisfaction after cBEMC installation, compared to baseline based on occupant surveys. IEQ measurement meeting ASHRAE standards (1000ppm).	Achieved.
FM/ Operator Feedback	FM interviews and surveys regarding experiences using the cBEMC system	Voting on features of cBEMC (See Appendix C of the Final Report)	Average rating > 5 (out of 7). Desire of FM to continue using the system.	Achieved.

DSM = demand side management
IEQ = indoor environmental quality
ROI = return on investment

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

4.0 FACILITY/SITE DESCRIPTION

PaANG, a reserve component of the U.S. Air Force, plays an important role in the nation's defense and for support of the Commonwealth of Pennsylvania in times of need. The 171st Air Refueling Wing (ARW) is based at the Pittsburgh International Airport in Coraopolis, Pennsylvania. The primary mission of the 171st ARW is to refuel U.S. and North Atlantic Treaty Organization (NATO) aircraft. Building PaANG-300 houses the Headquarters of the 171st ARW. This building is an approximately 52,000 square feet, two-story office building with a dining hall wing, built on a concrete slab foundation. PaANG-300 is used dynamically. During the week, operations are ongoing in most of the second floor offices and in a few scattered locations on the first floor; the dining hall and kitchen are generally not used. Because the technology demonstration required the participation of building occupants who have been trained in cBEMC and are present consistently throughout the test period, the focus of the demonstration was on second floor spaces and their full-time occupants.

4.1 FACILITY/SITE LOCATION AND OPERATIONS

4.1.1 Demonstration Site Description

PaANG-300, as shown in Figure 3, is located on a hillside in a campus setting. Consequently, it is surrounded by parking areas and lawns traversed by sidewalks; part of the building is in a berm on the hillside. From the perspective of the building's enclosure in relationship with its immediate environment, the structure is a stand-alone property. Internally, however, the first and second floor environments and their mechanical systems are interrelated, as also is, to a lesser extent, the dining wing. Nevertheless, for purposes of the major focus of the project on collaboration related to efficient control of energy use, the second floor can be effectively isolated from the rest of the building.

Figure 3. Building PaANG-300.

4.1.2 Key Operations

Weekday operations on the second floor of PaANG-300 include the commander's suite, operations planning, legal, finance, recruiting, and public affairs. The spaces for these activities include a mix of private offices, office suites with secretarial space, open areas with work stations, and a conference room. As a result, the second floor provides a mix of HVAC control zones serving single occupants (such as for the commanding officer), shared suites (such as for the attorneys), and interacting open areas of desks (such as for the recruiting personnel). Some occupants use their assigned desks on a regular schedule (such as for the finance department), while others have schedules that often require their presence elsewhere within (such as for operations planning) and/or outside (such as for recruiting) the building. Such a dynamic mix of building occupant usage profiles provided a robust test bed for the project. The second floor of PaANG-300 was the primary test bed for this project. Although the HVAC systems for PaANG-300 serve the entire building and thermal/physical dynamics affects are interactive throughout the structure, measurable delivery of energy through ventilation systems, as well as electrical service, can be effectively isolated for the second floor.

4.1.3 Demonstration Site Floor Plan

The second floor of PaANG-300 presents a common layout, as shown in Figure 4, of peripheral (fenestrated) and internal (windowless) offices with entrances from connecting corridors. Two stairways descend to the first floor, and two exits access ground level at the north side of the building. The shaded area indicates air space above the dining hall/kitchen wing of the building.

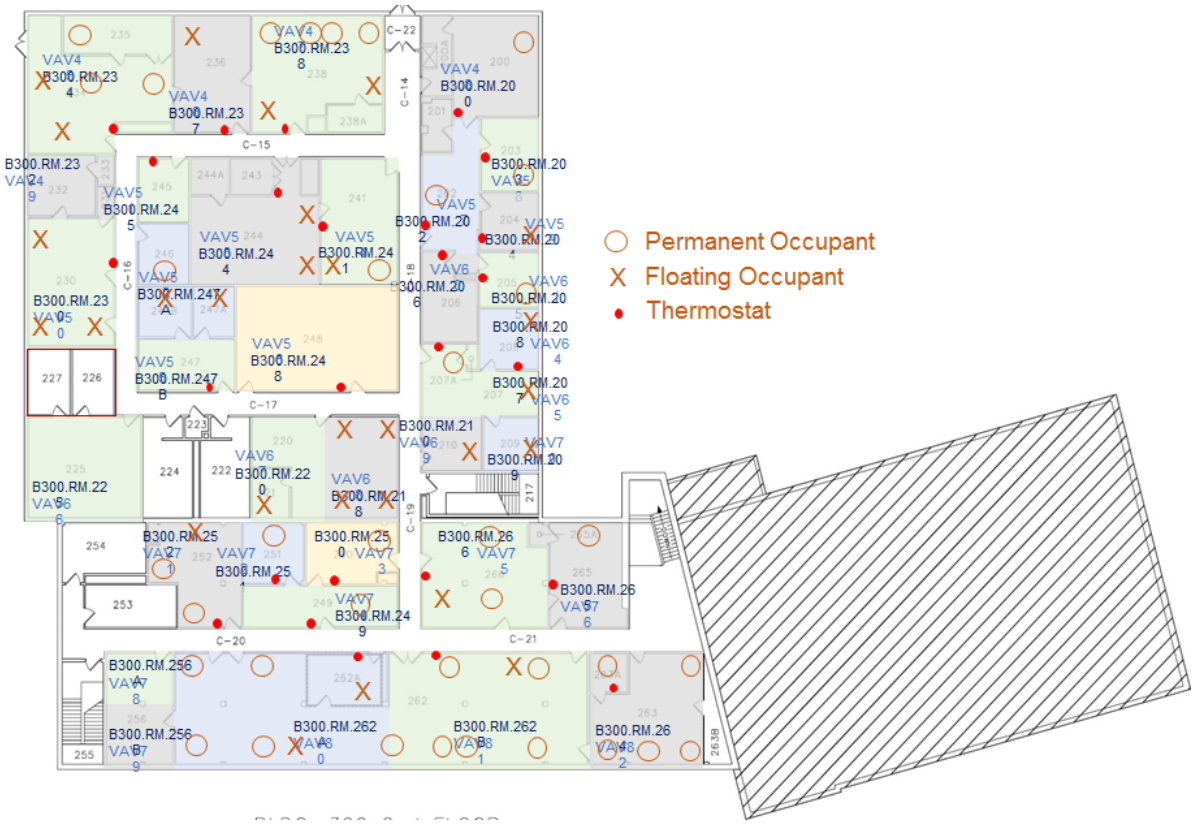


Figure 4. 2nd floor plan for PaANG-300.

Weekday activities related to medical and personnel support are conducted at a few disbursed locations on the first floor. These areas were excluded from the test bed. Approximately one weekend per month, the reserve personnel are on duty and the building is then fully occupied with first-floor offices and examining rooms being used for medical and dental examinations. These spaces within the building that are excluded from the second floor test bed are also used on other occasions, when appropriate.

4.2 SITE-RELATED PERMITS AND REGULATIONS

4.2.1 Regulations & Environmental Permits

No special permits were required for the technology demonstration. No specific regulations at the federal, state, or local levels of government are applicable to the demonstration. All permissions from the perspective of military operations and security were obtained by the PaANG military partner for the project; there was a concern raised by PaANG primary point of contact (POC), Lieutenant Commander (LTC) Joseph Sullivan regarding the use of SCT proprietary equipment/hardware on site. It was decided to use PaANG equipment (laptop computers) for installation and execution of the cBEMC demonstration. The technology demonstration does not produce any emissions or have any other environmental effects. In fact, one aspect of the project is the measurement of IEQ to correlate physical working conditions with occupant satisfaction. No environmental permits or other approvals related to environmental impact were required for this demonstration.

4.2.2 Agreements & Arrangements

Since the demonstration specifically studies occupant behavior and perception, approval of the study protocols by an Independent Review Board (IRB) was required for CMU to proceed. A letter of support for this process was provided by ESTCP, and PaANG collaborated with CMU to expedite IRB approval. Coordination of the IRB process was conducted by CMU POC Dr. Vivian Loftness and PaANG POC LTC Joseph Sullivan.

Three additional electrical meters were installed prior the demonstration to measure energy consumption by the assets on the second floor with appropriate precision. No special permits were required for this metering. The additional metering process was coordinated between PaANG POC LTC Joseph Sullivan and Siemens Building Technologies (SBT) POC Stephen Campbell. LTC Sullivan and the Pittsburgh Branch also coordinated the cBEMC information technology (IT) infrastructure installation (cBEMC server, cBEMC kiosks, communication hub, etc.).

This page left blank intentionally.

5.0 TEST DESIGN

The demonstration was designed to show how cBEMC can help DoD reduce its energy cost. The project examined the economic and technical feasibility of implementing cBEMC at PaANG-300. Figure 5 depicts the deployment of cBEMC at PaANG-300. Specifically, the demonstration targeted up to 30% in energy savings on a continuous basis and provided several scenarios of coordinated demand management designed to achieve up to 20% peak load reduction.

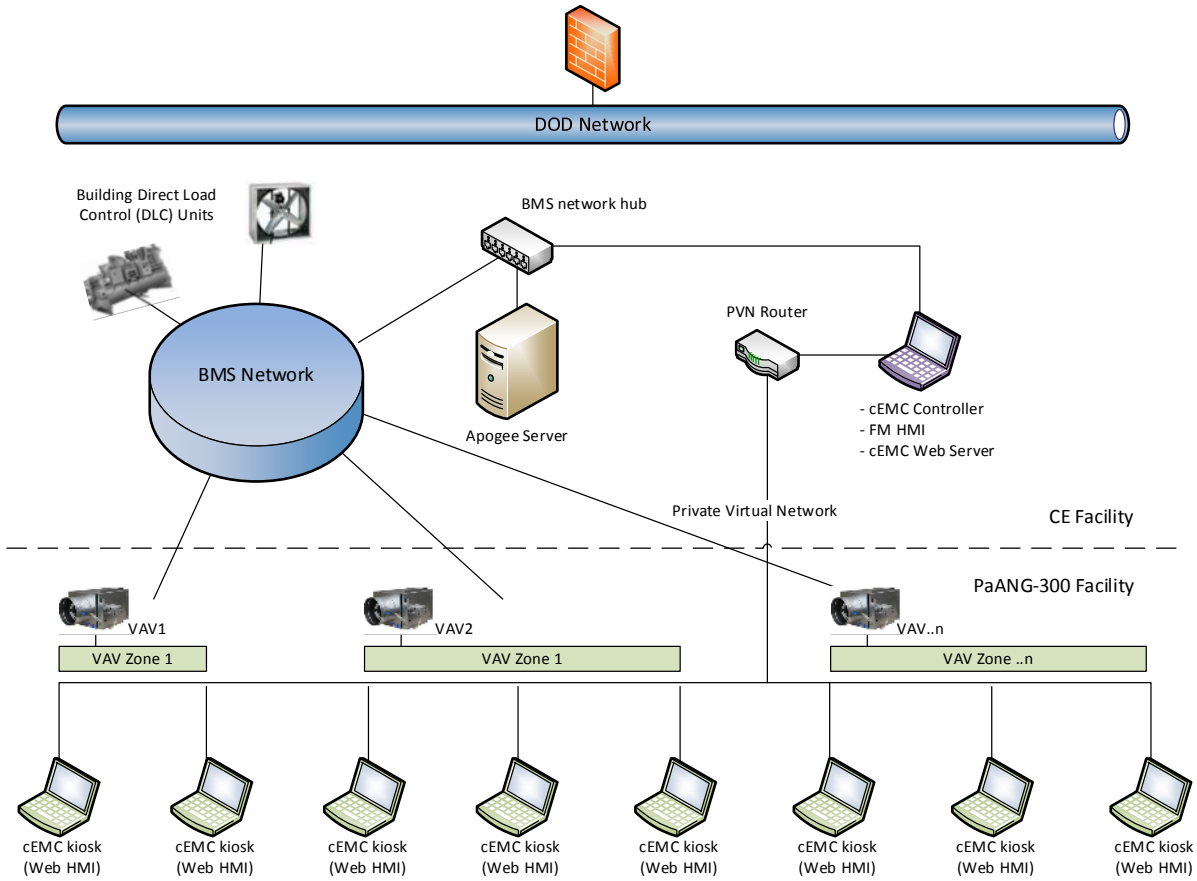


Figure 5. cBEMC system installation architecture at PaANG-300.

5.1 CONCEPTUAL TEST DESIGN

The hypothesis of the demonstration is:

> Employing the cBEMC system leads to major improvements in EE, agile peak load shaving, active occupant participation in energy saving actions, and greater information sharing with occupants; and it enables occupant energy saving awareness and behavior to be a sustainable operation as a "norm," compared to the baseline case where cBEMC is not installed.

To validate the hypothesis, a series of system tests were designed to measure iBEMS performances. The variables for the design of the tests are shown below in Table 3.

Table 3. Test design summary.

Controlled Variables	Independent Variables	Dependent Variables
• Building characteristics (size, set points, etc) • Weather pattern • Occupancy pattern • Duration of baseline • Demonstration periods	• Use of cBEMC software versus no use of cBEMC software	• Energy usage for whole building • Peak demand • GHG emissions • Total electricity costs • Occupant comfort voting

To validate the hypothesis, a series of tests were conducted in which the dependent variables were monitored and the correctness and sufficiency of cBEMC algorithms were tracked. The performance and integrity of the cBEMC design was also tested. During the testing the project team applied:

- cBEMC EE Method to the second floor of the building PaANG -300
- 4 types of cBEMC DR methods to the second floor of the building PaANG -300

The results of these tests were analyzed in the context of changes of dependent variables such as energy usage of PaANG-300 in comparison to its energy consumption baseline, energy demand of PaANG-300 in comparison to its demand baseline, and the number of occupancy comfort complaints as a result of the cBEMC 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, and cBEMC system controller. The engineering costs were collected in the application development phase of cBEMC, and the facility operational cost was calculated using kWh utility rates and kW demand charges from Moon Township, Pennsylvania Utilities.

Energy Efficiency Test: The EE subsystem of cBEMC provided a cost effective approach to manage energy consumption of the existing building equipment. In essence, this approach relies on the occupancy based EE strategies for VAV boxes, air handling units (AHU), chillers, boiler and thermostats operations. The main inputs of EE strategies are building occupancy, occupants' comfort settings, and the weather. One of the key logics for improving EE for PaANG-300 was comfort based temperature control and DCV that was implemented on VAV boxes via ventilation arbitration algorithm, as explained in Section 2. This dynamic strategy at PaANG-300 was based on the number of occupants and their comfort preference in a zone. The EE strategies were configured and managed in the cBEMC controller located in the Facility Management Room of PaANG-CE building. The EE experiments were conducted from June 15th through September 15th.

Demand Response Test: The main objective of DR subsystem of cBEMC is to provide demand reduction, within a short notification time, by a specific amount for a short duration. The DR tests included strategies involving turn-off of lighting, plug and process loads by occupants. One of the unique aspects of cBEMC system is active involvement of occupants in DR events. Four different DR modes have been defined, as presented in Table 4.

Table 4. DR modes.

DR Mode	Type	HVAC Central Controlled[3]	HVAC Load Occupant Preference[4]	Plug Load Occupant Choice	Plug Load Occupant Mandatory	Information About Impact To User Comfort
1	Email based, traditional. No cBEMC system is installed for this DR scenario		X (manual temperature setting with hard thermostat)	X		X
2		X (AHU optimized to follow occupant settings)	X (automatic temperature setting by considering the occupant comfort temperature band)	X		X
3	Unified Setback	X		X		X
4	Unified Setback	X			X	X

5.2 BASELINE CHARACTERIZATION

Figure 6 shows the baseline estimation methodology for energy saving determination.

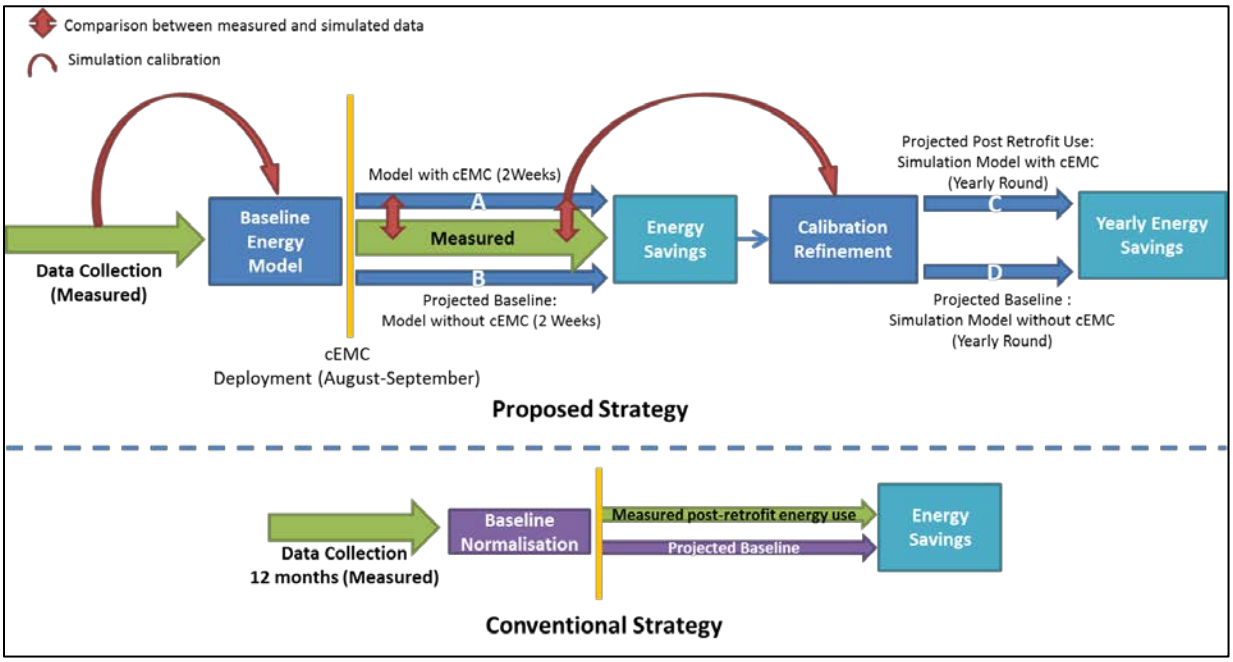


Figure 6. Baseline estimation for energy saving determination.

[3] AHU turn off; SAT/SSP settings, chiller settings, boiler settings, exhaust fan turn-off, chiller pump (when AHU is turned off), room temperature settings
[4] Room temperature preference settings

A baseline model representing the existing building operation was created using the TRNSYS. The simulation model integrates and computes building attributes, HVAC system operation sequences and attributes, lighting and plug load consumption, occupancy, weather at a defined simulation time step (5 to 15 minutes interval). The building and system description was obtained using "as built" drawings and design documents provided by the FM. When the information was incomplete or outdated, on-site measurements were performed. HVAC information was obtained from the existing Siemens Apogee BAS, with the collaboration of field engineers. 37 thermal zones were created in the TRNSYS model to match the VAV system of 2nd floor of PaANG-300. The lighting and plug load consumption were measured by sub-metering the building with 3 current transducers. Due to a fixed and predictable occupancy profile a deterministic approach was used to model occupancy. The building simulation results were calibrated with measured data (2.5 weeks baseline + 2 weeks of cBEMC deployment) by tuning the model input data. This simulation model was used as a baseline and allowed the quantification of the energy savings induce by the cBEMC implementation.

5.3 DESIGN AND LAYOUT OF SYSTEM COMPONENTS

5.3.1 Facility Conditions

The overall conditions of PaANG-300 are well suited for its daily operations. No major renovations or retrofits were planned during the technology demonstration, as far as the facility itself was concerned. However, its BAS panels still used an old serial communication technology that had limited data throughput and, therefore, required an upgrade to an automation panel that supports BACnet protocol over TCP/IP.

5.3.2 Building Energy Audits and Occupant Survey

Before the deployment of the cBEMC system at PaANG-300, a Level 3 building energy audit was conducted. Data pertaining to the HVAC systems, lighting systems, plug loads, and other energy-consuming building components were collected to establish an energy and demand baseline. To fully validate the POs of cBEMC, occupant satisfaction surveys and IEQ assessments were conducted at the building. CMU used the National Environmental Assessment Toolkit ("NEAT")[5], to collect data on occupant comfort. During the time when the IEQ measurements and building technical attributes were recorded, each occupant was asked to complete a user satisfaction questionnaire related to today's specific environmental conditions, as compared to a year-round satisfaction questionnaire. A few questions related to building control were integrated into the questionnaire to capture occupants' satisfaction with, and engagement to, cBEMC.

5.3.3 System Design and Integration

The main component of the cBEMC is a runtime "soft" controller which interconnects occupants and facility management with BAS via a user friendly web interface. The internal cBEMC communication is based on the non-deterministic RESTful web services. The cBEMC control logic uses a lightweight data model that is scalable and easily extensible to accommodate additional controlling logic, if necessary. Figure 7 shows the architecture of the cBEMC system,

[5] http://research.cbei.psu.edu/research-digest-reports/indoor-environmental-quality-and-productivity

where the communication between cBEMC system and the BAS is based on industry standard BACnet protocol.

5.3.4 System Integration

To demonstrate cBEMC functionality, the system was deployed at the PaANG-300 facility. The occupants of the second floor were active participants in the cBEMC experiment. Figure 7 shows cBEMC network integration at PaANG.

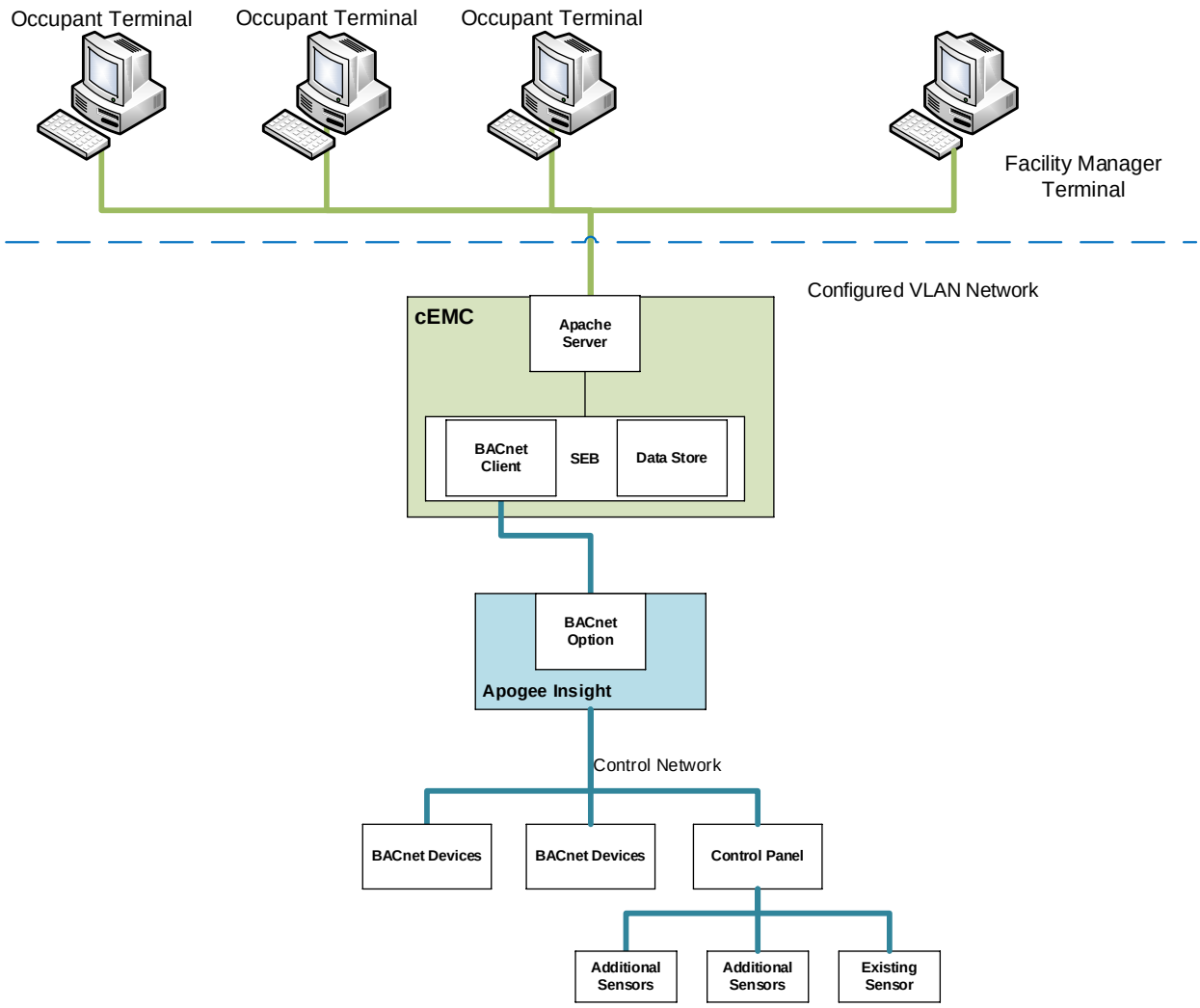


Figure 7. cBEMC network integration at PaANG.

The HVAC equipment of PaANG-300 was controlled by an existing Siemens Apogee BAS legacy system without a BACnet support. The FM terminal, occupant terminals and cBEMC controller all reside in the same network with the Apogee BAS, which was isolated from other IT network devices using VLAN. Network information can neither come in to this network nor go out of it to ensure the control devices are not accessible from other devices in the office network. To further enhance security, the cBEMC controller had a “boundary checker” component to reject any set points that may potentially damage HVAC devices. This strategy ensures system

safety even if the network is hacked by internal users. While the network isolation protects the cBEMC and HVAC system from cyber-attacks in an overly conservative manner, it also restrains the cBEMC system from accessing information for enhanced building intelligence, for example, controls responsive to weather forecast and energy price signals. The FM's terminal was located in the control room where the Apogee Insight server is located. PaANG also provided 12 occupant terminals at several locations close to the occupants' offices on the second floor of PaANG-300, e.g., hallways and office rooms. Both the occupant terminals and the FM terminal ran Windows 7 64-bit operating system.

5.3.5 System Controls

During cBEMC demonstration, the FM and the occupants had a limited control of each room's temperature using a virtual thermostat feature, provided by cBEMC via Web HMI. While the occupants could change their zone temperature settings indirectly, the FM has a final decision on building energy policy. The FM had the authority to monitor and control the BASes using both the existing BAS HMI and cBEMC FM Dashboard.

5.4 OPERATIONAL TESTING

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

- cBEMC EE Test Scenario (cooling season) – EE tests for a PaANG-300 building during the cooling season were conducted over a period of 3 months from July 15 - September 15, 2014 with two breaks for the baseline development (June 13 – June 25; August 26 – September 11).
- cBEMC DR Test Scenario (cooling season) – two DR site tests for the PaANG-300 building were conducted during the cooling season in the month of July. These tests included application of all four DR modes that are described in section 6.2.

The project team employed TRNSYS modeling software to assess EE and DR strategies before the onsite demonstration. Based on this analysis optimal EE and DR strategies were formed to respond to varying conditions such as outside air temperature, relative humidity, occupancy, etc. During the cBEMC deployment, the simulation was used to predict the baseline and was also updated to integrate control strategies implemented by the cBEMC. The model calibration was refined with new data from measurements during the cBEMC deployment. These two models were then compared to quantify the energy savings induced by the cBEMC implementation. To project and estimate annual energy savings induced by cBEMC, projected yearly baselines were then compared with results from a projected yearly simulation model that accounted for cBEMC control strategies (simulation C in Figure 6).

The onsite deployment of this demonstration was anticipated to start in early January 2014 and run for about three months to include the heating season. Due to technical issues, the demonstration was extended into the cooling season and continued through September.

SBT has an established relationship with PaANG which includes servicing Building 300 and conducted the transfer of cBEMC technology to the Base. As for decommissioning, the control sequence discussed earlier addresses the restoration of the BAS set points when cBEMC stops;

and the cBEMC software can be easily removed from the facility team's PC through un-installation function the software provides.

5.5 SAMPLING PROTOCOL

Different segments of the demonstration used different data types and sampling periods. Table 5 summarizes the types as well as the sampling rates used.

Table 5. Sampling protocol table.

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

GForge = web-based project management portal for software projects
SVN = version control/source control software for Windows

5.6 SAMPLING RESULTS

Quality Assurance Sampling: The CMU and SCT team performed an internal quality control (QC) process of its TRANSYS models to ensure that data collected was properly represented. 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, are described in Chapter 6.

This page left blank intentionally.

6.0 PERFORMANCE ASSESSMENT

The criteria for each of the POs were measured (and, where appropriate, validated as follows):

6.1 PO-I: BUILDING ENERGY USE REDUCTION

Performance was measured as the difference between projected annual energy use under baseline and cBEMC conditions as extrapolated by applying the TRANSYS model to the heating-season test period measurements of gas and electric consumption.

6.1.1 Baseline

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

6.1.2 Method

Details of EE approach is discussed in Section 5.1. The project team collected pre-baseline, baseline, and cBEMC EE experimental data using Apogee and the database (Mongo DB) in cBEMC. In addition, these three scenarios were simulated using TRNSYS. Due to the limited project time, one year of energy performance could not be measured. Instead, one year TRNSYS simulation with two weeks of real data was used for the performance analysis. The energy usage intensity (EUI) for the PaANG-300 second floor was calculated in order to compare with national office building average.

6.1.3 Results and Conclusions

From September 8 to September 21, cBEMC was fully deployed at the second floor of the PaANG-300 building and successfully reduced the working hours from 12 hours per day per zone to 4 to 12 hours per zone, and averaged about 8 hours per weekday per zone. Calibrated data from PaANG-300 indicates that cBEMC will save 14% HVAC energy savings as comparing to this baseline on the PaANG-300 building second floor, as shown in Figure 8. This performance was compromised due to some hardware issues, including the (1) outdoor air flow meter, (2) outdoor air damper and (3) leaking VAV dampers. If these hardware issues are fixed, TRNSYS simulation predicts 22% HVAC energy saving as compared to the baseline. The corresponding overall energy reduction (including electricity), for these two cases, shall be 10.4% and 15.8%, respectively.

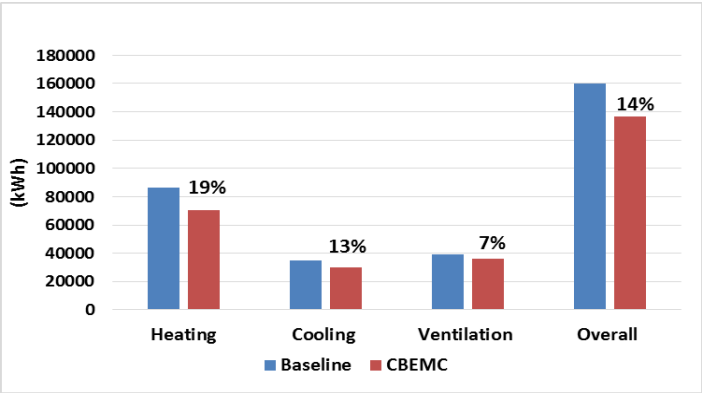


Figure 8. Extrapolated yearly energy savings with cBEMC deployment.

6.2 PO-II: FACILITY ELECTRICAL LOAD SHEDDING

The graph below in Figure 9 show some average monthly demand curves for PaANG-300. Through examination of such curves it was clear that there is no prominent peak load time. The demand, in general, varies a lot and these variations do not occur at any specific times. Therefore, 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%.

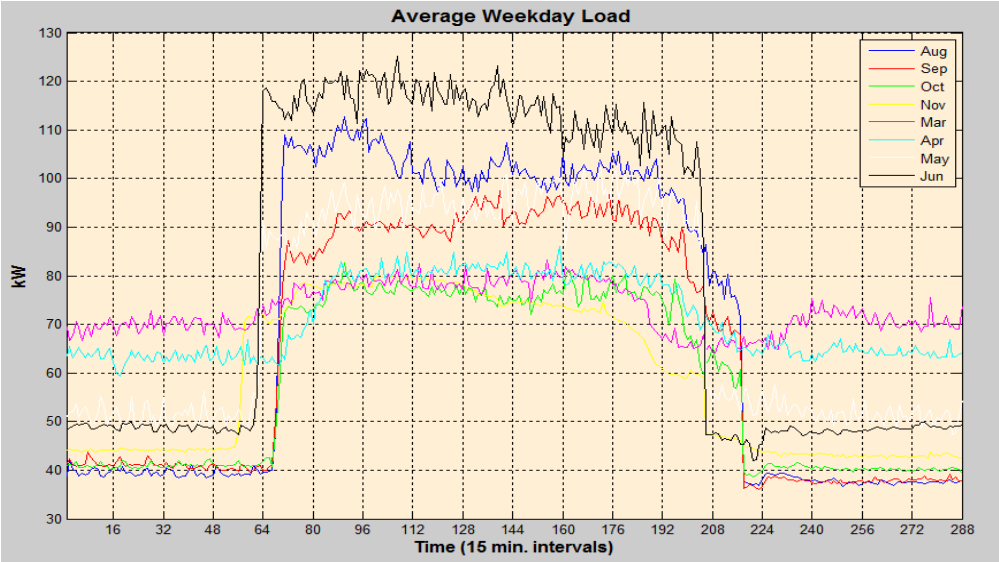


Figure 9. Average monthly weekday demand curves for PaANG-300.

6.2.1 Baseline

A weather pattern matching based approach, developed in a previous ESTCP sponsored project [7], was utilized to estimate the baseline. 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.

6.2.2 Method

The technical details of the developed adaptive demand management methodology are already presented in Section 2.2.1 and 5.1. This developed methodology was applied to conduct various DR events. Although DR events were tried on several days, only the DR events on July 24, 2014 were successfully implemented. On this day three different DR events (DR-1, DR-2, DR-3 for DR Modes 2, 3, and 4, respectively) were conducted. The DR actions that were considered for dynamic generation during DR events include:

- Increase of thermostat set point based on occupant choice: DR Mode 2

- Maintain the set point of a virtual thermostat in 75-78 EF range: DR Mode 3
- Plug load turn off by occupants: DR Mode 2, DR Mode 3
- Lighting turn off by occupants: DR Mode 2, DR Mode 3
- Mandatory lighting turn off by occupants: DR Mode 4
- Mandatory non mission-critical plug load turn off by occupants: DR Mode 4
- Turning off AHU: DR Mode 4

6.2.3 Results and Conclusions

As stated in previous section three DR events were successfully conducted. Figure 10 shows the actual meter reading and the baseline during the DR-3 test, where the red area represents the actual electricity consumption and the green area reflects the electrical energy saving from the DR strategies. Table 6 shows the average kW reduction and kWh savings during the DR period.

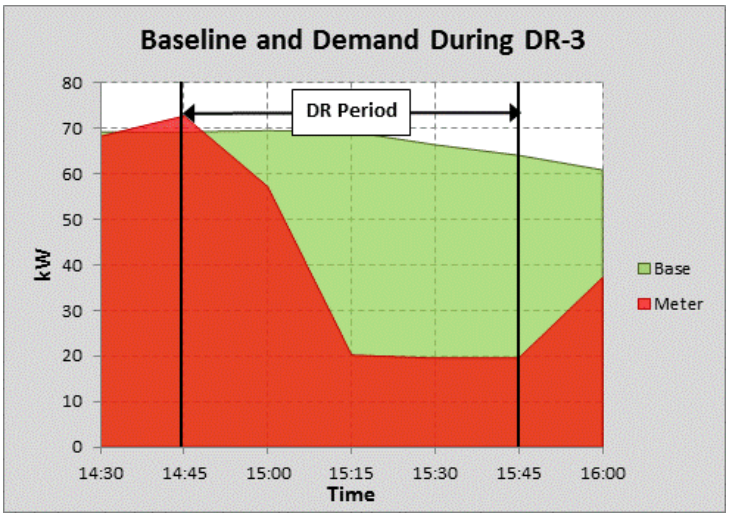


Figure 10. Baseline and actual demand during DR Test 3 (Mode 4).

Table 6. Results summary for DR-3 (Mode 4).

Aggregate kWh Consumption During DR Period	29.13 kWh
Aggregate kWh for Baseline During DR Period	67.33 kWh
kWh Savings During DR Period	38.20 kWh (56.7%)
Average kW Reduction During DR Period	38.20 kW (56.7%)

The results of savings from different DR tests are summarized in Table 7 below.

Table 7. DR results summary.

DR Modes	kWh/kW Savings %
DR Mode 2	11.2
DR Mode 3	15.1
DR Mode 4	56.7
Average	**27.7**

It can be clearly seen that the amount of savings increases substantially as we move from mode 2 to mode 4. This is as expected because DR mode 4 is a case in which drastic DR strategies like - AHU turn off and mandatory plug load switch off, were implemented. The goal of 20% load reduction was not achieved for DR mode 2 & 3 but it was achieved DR mode 4. On average the amount of reduction achieved over all the three DR events was 27.7%. From the various DR tests it was concluded that in buildings with large spaces, since the building thermal inertia is pretty high, electrical load can be quickly reduced by turning the AHUs off, if multiple AHUs are present, for short durations without affecting the building occupants' comfort.

6.3 PO-III: SCOPE 2 GHG EMISSIONS

The annualized HVAC electrical energy (cooling and ventilation) consumption from the baseline model of PaANG-300 second floor is 148,561 kWh. Post the cBEMC intervention, annualized HVAC consumption was found to be 133,308 kWh, amounting to a 22% reduction in total energy consumption. The environmental benefits that are directly linked to electric energy savings relate to the reduction in scope 2 emissions particularly CO_2, CH_4, N_2O emissions and pollutants like SO_X, NO_X. The emission factor-based methodology, which estimates GHG emissions by multiplying a level of activity data by an emission factor, has been used to calculate the GHG reduction [8]. Activity data is a quantified measure of an activity, in this case the electricity consumption. The emission factors convert activity data into emission values and are source-specific. The emissions factors for electricity produced by coal are higher than for electricity produced by natural gas.

$$\text{Activity Data x Emission Factor} = CO_2 \text{ Emissions}$$

The fuel mix of electricity delivered to the PaANG is dominated by coal fired power plants by 69% [9]. While the reduction in the metric tons of CO_2 was the primary focus from the suite of Scope 2 GHG emission, the research team also considered the other major GHGs and pollutants and calculated significant reduction in the GHG and pollutant emissions. The optimization of building EE and facility peak energy demand results in the reduction of 20% in the CO_2 emissions (see Table 8 below). Hence for this PO, the target was achieved.

Table 8. Comparison of baseline emission to the post cBEMC intervention.

	Baseline Emissions (lbs)	Post cBEMC intervention (lbs)
CO_2	223,357.7	179,094.8
CH_4	2.7	2.2
N_2O	3.7	2.9
SO_2	739.8	593.2
NO_x	206.5	165.6

6.4 PO-IV: SYSTEM ECONOMICS

In order to compute the annual savings resulting from cBEMC implementation calibrated TRNSYS model of second floor of PaANG-300 was used. The electricity price ($0.08 per kWh) used in the cost benefit calculation is the average price billed to the base for the year 2013. The gas price (sales + transportation) was also defined using the same method and is equal to $0.7 per

therm. The annual cost of heating, cooling, and ventilation, when cBEMC was not implemented was $15,267. When cBEMC was implemented the annual cost was $11,594. Thus the total monetary annual savings, resulting from reduction in heating, cooling, and ventilation due to cBEMC implementation was $3342, as shown in Table 9 below. Based on the simulation generalized data, cBEMC achieved 22% savings on HVAC energy. It is below the 30% saving target.

Table 9. cBEMC savings.

	Cooling (Electrical)	Ventilation (Electrical)	Heating (Gas)	Total
Utility Cost	$0.08 per kWh	$0.08 per kWh	$0.70 per therms	
Baseline Consumption	91011 kWh	57550 kWh	3382 therms 128832 kWh	277393
Baseline Cost ($)	$7280.90	$4604.02	$3382.30	**$15,267.21**
cBEMC Consumption (kWh)	69076	50045	2395 therms 91261 kWh	210383
cBEMC Cost	$5526.107	$4003.617	$2395.93	**$11,925.65**
cBEMC Savings				**$3341.56**

6.5 PO-V: OCCUPANT CONTROL AND DSM ENGAGEMENT

In order to measure occupant's engagement and their impact on cBEMC results the interactions with cBEMC system via WEB HMI was recorded by the cBEMC system logger mechanism. The overall occupant's involvement in cBEMC control was evaluated based on the number of interactions of each registered cBEMC account with the softThermostat, and how often the arbitration logic was engaged for each automation zone. Also, occupancy schedules comfort complaints/suggestions were recorded for each registered cBEMC account.

6.5.1 Baseline

The on-site training before the cBEMC rollout was conducted. With respect to occupant control, the training determined the ease-of-use criteria of the cBEMC web-based HMI portal. This determined the probability of the user engagement throughout cBEMC demonstration. In addition the facility management was also trained to use HMI to inform occupants about the upcoming system maintenance, malfunction or DR events.

6.5.2 Method

The cBEMC web HMI allowed occupants of PaANG-300 register their accounts based on the automation zone logical location and provide dynamic input on thermal comfort, availability and verbal complaints or suggestions. The data was continuously collected by cBEMC in real-time and archived to a cBEMC repository that was deployed together with cBEMC system. The repository also was capable to retrieve the account historical data and display to the user of the account on demand. The data collection was a continuous weekly process that started in August 2013 and completed at the end of the demonstration period (September 2014). The data then was analyzed by the team. At the end of the cBEMC demonstration, occupants were interviewed as to determine their opinion about the system and whether participation impacted their behavior and

energy awareness. Figure 1 depicts the excerpt from the weekly user engagement report. At the end of the cBEMC demonstration, the cBEMC team had conducted an on-site satisfaction questionnaire. Seven full-time occupants of PaANFG-300 participated in the survey and filled out the questionnaire form.

6.5.3 Results and Conclusions

The overall data analysis and results of the questionnaire had shown that occupant's engagement in controlling the comfort and energy-awareness had been sufficient. At least 65% of the registered cBEMC accounts have been updated/modified at least once. About 30% of the accounts have been modified on a weekly basis. The web-based HMI was available for the occupants for 5 months in the period from cBEMC commissioning to the end of the demonstration. Many occupants used cBEMC as primary tool for sending complaints and recommendation to facility management. Also, the reporting through cBEMC web portal allowed the cBEMC team to identify and address the issues with the building's automation hardware and some of the control logic. However the usability and overall control could be significantly improved if the security restrictions for the portal accessibility were eased. Overall it can be said that this PO was partially achieved, as only 30% of accounts were modified on weekly basis.

6.6 PO-VI: OCCUPANT COMFORT AND SATISFACTION

To measure the impact of the cBEMC on indoor environmental quality and user satisfaction at PaANG-300, field measurements and surveys were performed. One measure of performance collected was the percentage change in satisfaction for thermal, air, visual and acoustic quality, assessed through user satisfaction questionnaires. A second measure of performance collected during the study was objective field measurements of thermal, visual, acoustic, and air quality conditions using the

6.6.1 Baseline Environmental Satisfaction and Measurements

Three user satisfaction surveys and two IEQ measurement studies were conducted to assess occupant comfort and satisfaction. The first study, incorporating user surveys coincident with workstation instrumented measurements was conducted on January 15, 2014 to capture Pre-cBEMC IEQ conditions. The second study incorporating user surveys and workstation measurements was conducted during the heating season on April 30, 2014 to capture conditions during cBEMC deployment. The third study combined user satisfaction surveys and in-situ IEQ equipment from Grey Wolf to capture conditions during the cooling season. The resulting quantitative environmental measurements of thermal, visual, acoustic, and air quality, as well as surveys to determine environmental satisfaction of occupants were analyzed comparatively.

6.6.2 Method

Field Measurement Protocols: The NEAT[6] toolkit is comprised of an instrument cart for spot IEQ measurements, an Aircuity Optima and a GreyWolf unit for continuous IAQ measurements,

[6] Project descriptions: http://research.cbei.psu.edu/research-digest-reports/indoor-environmental-quality-and-productivity

a checklist on the technical attributes of the building systems that define each measurement location, and a user satisfaction questionnaire. The instrument cart for thermal, air, lighting and acoustic measurement is placed in the position of the occupant for approximately 15 minutes at each occupant location sampled and the environmental measurements are then taken. At the same time, hand held readings of light levels, acoustic levels, and radiant temperatures are logged into the data logger.

While spot measurements capture the diversity of conditions across a space, 24-hour continuous measures capture the diversity of conditions across time. An Aircuity Optima system and GreyWolf IAQ monitoring systems are utilized to measure temperature, relative humidity, CO_2 and CO, large and small particulates, total volatile organic compound (TVOC), radon and ozone.

During the time when the physical measurements are recorded, the occupant is asked to complete a 'User Satisfaction Questionnaire' related to that day's specific environmental conditions. The Cost-effective Open-Plan Environment (COPE) Questionnaire was developed by the National Research Council Canada to support the COPE Project, and has been modified slightly to address U.S. work environmental conditions.

6.6.3 Results and Conclusions

Thermal and Air Quality Field Measurement Findings: The user satisfaction surveys were issued before and during the cBEMC deployment, with the assessments completed in both the heating and cooling season. During the cBEMC 'heating season' deployment period, temperature satisfaction rose from 18% to 30% satisfied, as shown in Figure 11. Dissatisfaction dropped correspondingly from 72% to 60%, with the remaining employees giving neutral responses. Satisfaction with air movement went from 26% to 50%, and all other thermal/IAQ indices remained approximately the same. During the cBEMC 'cooling season' deployment period, temperature satisfaction rose further to 75% (6 of the eight occupants surveyed) with only two occupants dissatisfied on August 5.

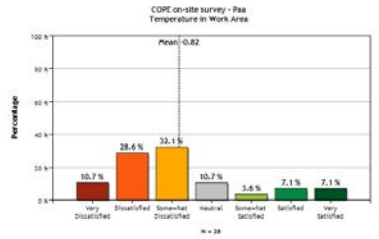
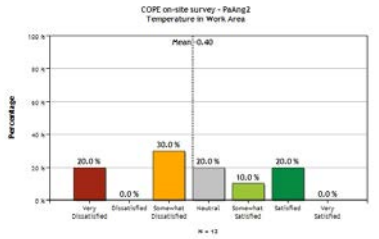
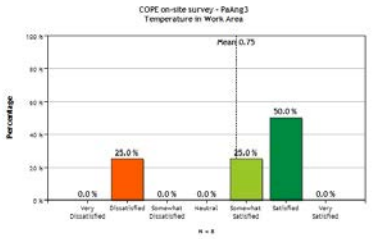
PaANG before cBEMC, Jan. 15 2014	PaANG during cBEMC, Apr. 30 2014	PaANG during cBEMC, Aug. 5 2014
		
User Satisfaction Survey (n=28)	User Satisfaction Survey (n=12)	User Satisfaction Survey (n=8)

Figure 11. User satisfaction: temperature in your work area.

In addition to air temperature, the field measurements also included several air quality indices. During the heating season deployment of the cBEMC, CO_2 levels dropped to a mean of 600 ppm, which corresponds with the rise in user satisfaction with both air quality and air movement. For two weeks in August from the 5th - 20th 2014, a GrayWolf Sensor Suite was placed in one

interior group workstation to measure cooling season room air temperature, relative humidity, CO_2, CO and TVOC levels. During unoccupied periods, night and weekend temperatures were allowed to rise, and on many mornings overcooling was used to reset indoor temperatures, resulting in user dissatisfaction with comfort. CO_2 was well managed, reflected in user satisfaction with air quality. However, several spikes in TVOC late at night or early morning are a cause for concern, and may correspond with cleaning chemicals that are in use.

Lighting/Visual Quality: User satisfaction with lighting was relatively high to begin with and improved over the seasons, despite the fact that lighting was not modified in any way. Daylight may play a role in increased satisfaction, since over half of the occupants are in windowed offices.

Acoustic Quality: The HVAC provides an even but relatively loud low frequency sound in most of the offices. However, those under the rooftop AHU hear and feel noise at 48 – 55 dBA even on a mild day, which we are told gets even worse when it is really hot or really cold. When the air handler turns off at the end of the day, they find themselves shouting. The combination of these factors leads to the 35% dissatisfaction scores. For some locations and time periods, the low density and low occupancy helps to minimize dissatisfaction.

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

6.7 PO-VII: FACILITY MANAGER/OPERATORS FEEDBACK

In order to improve the controlling methods, functionality and the overall usability of the cBEMC system, the technical interview of the FM was conducted at the end of the cBEMC demonstration. The interview was constructed by putting the emphasis on the overall usefulness and ease of use of the demonstrated system. The overall feedback was positive, and the usability expectations were met, however the recommendations of the interviewee suggested that the system has room for improvement. One of the main limitations of the demonstrated version of cBEMC is a lack of configuration validation and inability to send error/warning notifications. The accessibility limitations, as a result of security restrictions, were also highlighted. Finally, it was stressed out that the cBEMC operations will require a process change, which could lead to some deviations in review of standard operating procedures, e.g. using cBEMC as a main portal for complaints handling or facility notifications. Overall it can be concluded that this objective was achieved as average rating was 5 or greater.

7.0 COST ASSESSMENT

The life cycle cost analysis (LCCA) presented here is based on standards published by NIST in *Handbook 135*[7] and the *Annual Supplement to Handbook 135*[8]. To the extent possible, the team utilized NIST's *Building Life Cycle Cost* (BLCC5[9]) to compute the LCCA over a 15 year period. The data inputs include duration of life cycle, capital and labor costs, equipment and software replacement costs, recurring maintenance and site specific utility charges for electricity and natural gas.

7.1 COST MODEL

Table 10 shows the data, relevant to the cBEMC technology, tracked by project team during the demonstration. These data were used to estimate life cycle costs at full scale operation. Please note: some costs for PaANG-300 are for experimental and energy audit purposes. They are not required for typically installations.

Table 10. Cost model for the cBEMC at PaANG-300.

Cost Element	Estimated Values
Data Collection	$9600
Hardware Capital Costs	$3510
Software Costs	$9600
Commissioning and Installation	$4800
Facility Operational Cost	$5760
Hardware Lifetime	15 years
Operator Training	$4800
Total	**$29,070**

7.2 COST DRIVERS

As demonstration had shown, the most significant cost drivers for cBEMC are the loads for heating and cooling, the automation and control of facilities and the costs associated with utilities. One cost driver not associated specifically with energy is the need to meet/address security and NIST Risk Management Framework (NIST RMF) requirements. Costs typically associated with meeting NIST RMF requirements include understanding NIST RMF and unique facility requirements, deployment, configuring the system, testing and documenting to meet the requirements. The cBEMC and PaANG deployment did not have to meet NIST RMF requirements due to the configuration of the cBEMC on the private isolated network and the requirements of PaANG IT security at the time. Another cost driver is the site's BAS network infrastructure. At PaANG, the BAS was networked throughout the entire site; however, the fact that security constraints disallowed the cBEMC to be configured and operated remotely drove the cost of system commissioning, servicing and operation.

[7] http://fire.nist.gov/bfrlpubs/build96/PDF/b96121.pdf
[8] http://www1.eere.energy.gov/femp/pdfs/ashb13.pdf
[9] http://www1.eere.energy.gov/femp/information/download_blcc.html

7.3 COST ANALYSIS AND COMPARISON

The demonstration of the cBEMC on the 2nd floor of PaANG-300 reveals annual energy savings of $3342 from reduced electricity and gas use. The simple payback analysis depends on the baseline energy consumption for a given building and the energy savings achieved from new technology implementation, which in the case of PaANG-300 is about 20%. The economic impact from occupant productivity due to lower thermal comfort is not quantified here, but when included can shorten the payback period.

In this section, we address the cost analysis on four scenarios to covers both new buildings, existing buildings, short term and long term cases. For the short term solution, we need to deploy dedicated laptops as kiosks. For long term solution, we can pass cBEMC software through the NIST RMF certification, which allows the cBEMC system to be connected to the IT network. The benefit of RMF is not only to save laptop costs for each building, but also may strengthen the occupant engagements, therefore improve system energy performances. For each of these scenarios revised cost structures were computed based on industry standards and references.

Scenario 1: New DoD building No NIST RMF: New buildings do not have hardware defects and should have a dedicated PC to host the BAS software. Typically, the building IT networks are not connected with the control network. For a mid-size building, 10~20 laptops may be required as kiosks. For this scenario, the cBEMC software does not need to pass NIST RMF certification.

Scenario 2: Existing DoD building No NIST RMF: Existing buildings are referring to those office buildings with potential HVAC hardware defects. In these cases, engineers need to test the function of AHU/RTU, boiler, chiller and each VAV box.

Scenario 3: DoD new building with NIST RMF: If we want to deploy cBEMC to large number of buildings, it is more cost effective to certify the software with NIST RMF. The process is required once for multiple buildings. In the following estimation, we assume there are N new buildings and M existing buildings.

Scenario 4: DoD existing building with NIST RMF: If cBEMC system had NIST RMF license, we don’t need to deploy laptops as kiosks. Users can use their desktop PCs instead.

For both scenarios 3 and 4, after one time investment to pass the NIST RMF certification, there is no costs to deploy laptops as kiosks.

The ROI of new building with NIST RMF is 3.68 years (Scenario 3), while that ROI of No NIST RMF solution stays at 5.6 years (Scenario 1). For the existing building scenario, the ROI for No NIST RMF solution (Scenario 2) is about 4.8 years, while the ROI for the existing building with NIST RMF (Scenario 4) case is about 3.3 years.

8.0 IMPLEMENTATION ISSUES

The commissioning and demonstration of the cBEMC system at PaANG helped the development team to understand the advantages as well as shortcomings of the cBEMC implementation in the areas of equipment, integration, communication, facility assets management, and user experience of the system.

8.1 END-USER CONCERNS

cBEMC Controller Availability: One of the major concerns raised by the PaANG facility management was the cBEMC availability. The unexpected shutdown of cBEMC could result in a failure to relinquish control points back to the BAS, and in extreme cases this can lead to physical failure of certain equipment. In order to address this concern, along with extensive system testing of the software, the cBEMC integration team developed a heartbeat solution. Also, if the cBEMC becomes unavailable for a certain (configurable) period of time, all BAS control points would be automatically relinquished, giving the full control over the set points back to the Apogee server.

Comfort-tuned EE strategies: The maintenance of occupant comfort during the cBEMC demonstration wasn't considered less important than achievement of energy savings. The cBEMC energy saving strategies were tuned in ways such that occupant comfort wouldn't be compromised. In addition, pre- and post-demonstration occupancy surveys were conducted to identify the relevant occupancy comfort concerns and to gather occupant's suggestions for improving the cBEMC comfort strategies.

8.2 PROCUREMENT ISSUES

Facility Audit: The lack of facility equipment data, trending data, and standardized process for the facility energy auditing made the auditing process a challenge. The fact that there is no standard data exchange mechanism or data repository to retrieve building information, or to quickly identify the physical properties of the building, or the building's daily schedule, etc., makes energy auditing expensive and time-consuming.

Data Collection: Three sub-meters were installed at PaANG-300 in order to provide monitoring and logging of specific energy loads. In addition, the security constraints did not allow the cBEMC development team to set up a mechanism to collect trending data automatically.

8.3 INTEGRATION WITH BAS

cBEMC-BAS Runtime Communication: After conducting series of communication tests, the team came to the conclusion that quite a few calls failed as a result of slow-speed serial connections of older field panels. A new field panel was installed and the control points were migrated to the new panel. The mapping of the BAS control points to cBEMC logic was also necessary before the cBEMC startup. It was determined that the cBEMC system could not automatically import control point information from the BAS and so this task was performed manually. Moreover, the network security constraints made the processes of cBEMC runtime troubleshooting very inefficient. It was not possible to access the site remotely; and, therefore, at

least one team member was required to be present on site for upgrades, data collection, and troubleshooting.

Issues with Automation Equipment: The installed CO_2 sensor was not properly calibrated and malfunctioned during out testing phase. Also, even though the cBEMC supported an occupant-engaged Demand Control Ventilation algorithm, the existing outdoor air flowmeter had a hardware defect. Due to a limited timeframe, insufficient budget and resources to replace the hardware, the team decided to use temperature sensors to estimate the outdoor air flow intake. Regrettably, such estimation wasn't always reliable. It was also determined that cBEMC nigh control strategy during the cooling season sporadically fails to shut close air dampers on some of VAV controllers. Development of additional strategy for the heat valve control helped cBEMC team to solve this problem.

8.4 USER EXPERIENCE

Both the facility management team and occupants were satisfied with the features and functionality of their cBEMC WEB user interface (UI); however, some critical points were also identified.

cBEMC Access: Due to the fact that site security procedures required the cBEMC to be commissioned on a separate private network, the stand-alone user HMI kiosks had 2-level password access. This created a great inconvenience for the users and contributed to lowering user participation.

cBEMC Facility Management UI: It was identified that—the configuration of control points is rather difficult; the energy consumption graphs display for only 24 hours of history; the zone information in the UI does not provide information about the corresponding rooms and their designations; sometimes, the energy savings summary view did not work; there is no information in the UI about communication errors or failures; and when the cBEMC is started, the EE control has to be activated manually by pressing a button, which is not a step that is obvious to a FM.

cBEMC Occupant UI: It was identified that - the account access via web browser requires an additional login; when cBEMC control is not enabled, the occupant UI does not reflect that condition; when the cBEMC system is down, it simply cannot be accessed via web browser; and there is no help or training assistance available in the UI to guide new users who are trying to understand the cBEMC functionality.

Social Acceptance: Although initially concerned that cBEMC would impose additional time and work requirements for training, analysis, maintenance and management, the FM was positively disposed toward cBEMC due to its automation capabilities and provision of feedback information. The facility management functions are fully exposed in the HMI for the FM and provide easy access to cBEMC administration of EE and DR events. In addition, using cBEMC HMI a FM can opt out of the system's DR operation, if necessary. The FM was particularly pleased with the ability of cBEMC to help manage and measure DR events. Overall, the FM was satisfied with cBEMC and believes that it would be accepted by other FMs in similar situations.

9.0 REFERENCES

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

[2] S.A. Loper, and W.F. Sandusky, "Attributes of the Federal Energy Management Program's Federal Site Building Characteristics Database," PNNL, 2010.

[3] Z. Song, L. Wang, and Y. Lu, "Social Learning SoftThermostat for Commercial Buildings," in Proceedings of the Fourth ACM Workshop on Embedded Sensing Systems for Energy-Efficiency in Buildings, Toronto, 2012.

[4] Z. Song, S. Zhen, and Y. Lu, "Collaborative Building Control to Optimize Energy Saving and Improve Occupants' Experience," ASHRAE Transactions, vol. 119, no. 1, 2013.

[5] Y. Lu, "Advanced, Integrated Control for Building Operations to Achieve 40% Energy Saving," 2012.

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

[7] Y. Lu, "Integrated Control for Building Energy Management," 2014.

[8] S.P. Pino, and P. Bhatia, "Working 9 to 5 on Climate Change: An Office Guide." Published by the World Resource Institute, 2002.

[9] "EPA Power Profiler (2014) Clean Energy Power Profiler," 2014. [Online]. Available: http://oaspub.epa.gov/powpro/ept_pack.charts.

This page left blank intentionally.

APPENDIX A

POINTS OF CONTACT

Point of Contact	Organization	Phone E-Mail	Role In Project
Dmitriy Okunev	Siemens Corporation, Corporate Technology	Phone: 609-734-3540 E-Mail: dmitriy.okunev@siemens.com	PI
Sue DeMeo	Siemens Corporation, Corporate Technology	Phone: 609-734-4469 E-Mail: susan.demeo@siemens.com	Business Contact
Thomas Gruenewald	Siemens Corporation, Corporate Technology	Phone: 609-734-3546 E-Mail: thomas.gruenewald@siemens.com	PM
Vivian Loftness	CMU	Phone: 412-268-2350 E-Mail: loftness@cmu.edu	Key Contributor
Joseph Sulivan	Airforce PaANG	E-Mail: joseph.sullivan.1@ang.af.mil	Site Support
Andrea Leeson	ESTCP Office	Phone: 571-372-6398 Email: Andrea.Leeson.civ@mail.mil	Environmental Restoration Program Manager

ESTCP Office
4800 Mark Center Drive
Suite 17D08
Alexandria, VA 22350-3605

(571) 372-6565 (Phone)

E-mail: estcp@estcp.org
www.serdp-estcp.org