FINAL REPORT

Climate Management System for Corrosion Control Facilities

ESTCP Project EW-201345

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Raphael Siebenmann
Geosyntec

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14. ABSTRACT
Many Department of Defense (DoD) facilities include climate-controlled buildings. Industrial buildings may require energy intensive heating and cooling, and these requirements may vary depending on operations. Furthermore, Corrosion Control Facilities (CCFs) pose multiple climate control challenges. Minimizing energy use in CCFs can be especially challenging because of the intensity and breadth of environmental control requirements including (i) lighting control; (ii) generating hot water and steam; (iii) providing breathing air; (iv) removing hazardous air pollutants; (v) heating; (vi) cooling and (vii) meeting air flow standards, all changing with work flow. It is important to manage this energy use carefully. A Climate Management System (CMS) was designed to increase the ability to identify, prioritize, and communicate needed maintenance, system upgrades, and other energy savings opportunities. The CMS was installed at Building 59 (B59) of Warner Robins Air Force base and evaluated for a period of one year. Analysis of the data indicate that the CMS did not change the behaviors of B59 staff and thus energy consumption did not achieve the performance targets. However, the potential energy savings at B59 are still significant, and estimated to be on the order of 17% of fan energy and 10% of chiller-energy.

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FINAL REPORT
Project: EW-201345

TABLE OF CONTENTS

Page

TABLE OF CONTENTS (Continued)

Page

LIST OF FIGURES

LIST OF FIGURES

Page

LIST OF TABLES

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ACRONYMS AND ABBREVIATIONS

ADS	Application and Data Server
AFB	Air Force Base
ASHRAE	American Society of Heating, Refrigeration, and Air Conditioning Engineers
B59	Building 59
B59D	Building 59 Depainting
B59P	Building 59 Painting
CCF	Corrosion Control Facility
CEEM	U.S. Council for Energy Efficient Manufacturing
CFM	cubic feet per minute
CMS	Climate Management System
Dem/Val	demonstrate/validate
DIACAP	Department of Defense Information Assurance Certification and Accreditation Process
DoC	Department of Commerce
DoD	Department of Defense
DoDI	Department of Defense Instruction
DoE	Department of Energy
EO	Executive Order
EPA	U.S. Environmental Protection Agency
ESTCP	Environmental Security Technology Certification Program
°F	degrees Fahrenheit
FDD	fault detection and diagnosis
GUI	Graphical User Interface
IA	information assurance
ICS	Industrial Control System
JCI	Johnson Controls, Inc.
kW	kilowatt
MW	megawatt
NAE	Network Automation Engine
NIST	National Institute of Standards & Technology
O&M	operation and maintenance

PI	Principal Investigator
PM	particulate matter
PO	Process Order
POC	Point of Contact
RCRA	Resource Conservation and Recovery Act
SAME	Society of American Military Engineers
SQL	Structured Query Language
TCP/IP	Transmission Control Protocol/Internet Protocol
TO	Technical Order
UFC	Unified Facilities Criteria
UNCC	University of North Carolina Charlotte
VOC	Volatile Organic Compound

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This research was supported by Environmental Security Technology Certification Program (ESTCP). We thank our colleagues from Robins Air Force Base, who provided insight and expertise that greatly assisted the research, although they may not agree with all of the interpretations/conclusions of this paper.

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ABSTRACT

Introduction and Objectives

Geosyntec Consultants and the University of North Carolina Charlotte (UNCC) worked with Robins Air Force Base (AFB) in Warner Robins, Georgia, to pilot a behavior-based Climate Management System (CMS) to provide real-time energy use information and feedback to personnel at the Building 59 (B59) Corrosion Control Facility (CCF). As with many large industrial facilities, different tasks at B59 require different moisture content, air flow, temperature and other parameters to optimize the conditions for the given task.

Technology Description

The CMS was designed to identify and realize energy savings by alerting operators to place the building in the most appropriate mode for the task being performed. Currently, it appears that operators often use excessively energy-intensive modes because of a general lack of awareness. The CMS thus provided an opportunity to extract energy savings from improved energy management rather than from issues arising from inherent system inefficiencies.

Performance and Cost Assessment

Analysis of the data indicate that the CMS did not change the behaviors of B59 staff and thus energy consumption did not achieve the performance targets. However, the potential energy savings at B59 are still significant, and estimated to be on the order of 17% of fan energy and 10% of chiller-energy.

Implementation Issues

The primary implementation issue during the demonstration period was the general lack of usage of the CMS. Despite frequent visits by the project team and solicitation of feedback on the performance of the system, it appears that the CMS did not in and of itself result in a change in organizational behavioral modification. It is believed that quickly after installation of the digital signs, fatigue set in and the dashboards and reports developed became something that did not trigger attention.

Publications

None.

EXECUTIVE SUMMARY

INTRODUCTION

Many Department of Defense (DoD) facilities include climate-controlled buildings. Industrial buildings in particular may require energy intensive heating and cooling, and these requirements may vary depending on operations. Furthermore, Corrosion Control Facilities (CCFs) pose multiple climate control challenges. For example, depainting and painting aircraft in a hangar requires careful monitoring and control of lighting, air flow, temperature, relative humidity, and concentrations of particulate matter (PM) and volatile organic compounds (VOCs), not only to optimize conditions for depainting and painting but also to ensure the health, safety, and comfort of personnel.

OBJECTIVES

Minimizing energy use in CCFs can be especially challenging because of the intensity and breadth of environmental control requirements including (i) lighting control; (ii) generating hot water and steam; (iii) providing breathing air; (iv) removing hazardous air pollutants; (v) heating; (vi) cooling and (vii) meeting air flow standards, all changing with work flow. It is important to manage this energy use carefully.

The 225,000 ft2 B59 CCF at Robins AFB includes two 65,000 ft^2 hangar bays used to depaint and paint aircraft; a small-parts paint bay; common central facility systems; and a process equipment plant. B59 is designed to optimize paint removal and application for C-5, C-17, and other similar-sized aircraft, and increase the level of health and safety for Base employees. B59 uses approximately $1.7M of electricity and $250K of gas per year, or about 8% and 7%, respectively, of the Robins AFB totals ($20.3M and $3.6M, respectively, FY2011).

Generally, the hardware, sensors, and building controls in B59 are designed, sized, and installed properly and, when functioning, operate well to condition B59 as designed. However, observations indicate that lighting is maintained, steam and hot water boilers run, and conditioned air is moved at full flow through hangars even in the absence of aircraft. Therefore, there are energy savings opportunities in B59 related to energy management.

Tools that improve the sensing, tracking, processing and communication of information among B59 personnel would allow for continuous "retro-commissioning" of the facility for better operation of existing hardware to ultimately decrease energy use while maintaining or improving workflow, product quality, and worker health and safety.

TECHNOLOGY DESCRIPTION

A Climate Management System (CMS) was designed to increase the ability to identify, prioritize, and communicate needed maintenance, system upgrades, and other energy savings opportunities. CMS desktop software was installed on paint shift supervisor desktops and dashboards were displayed on monitors installed in a highly visible location, the hallway outside the office of the painting supervisor that is immediately next to the entrance to the hangar. The supervisor was asked, when beginning a new shift, to input the specific activity to be performed, and was guided to set the building to the appropriate mode based on the task being performed.

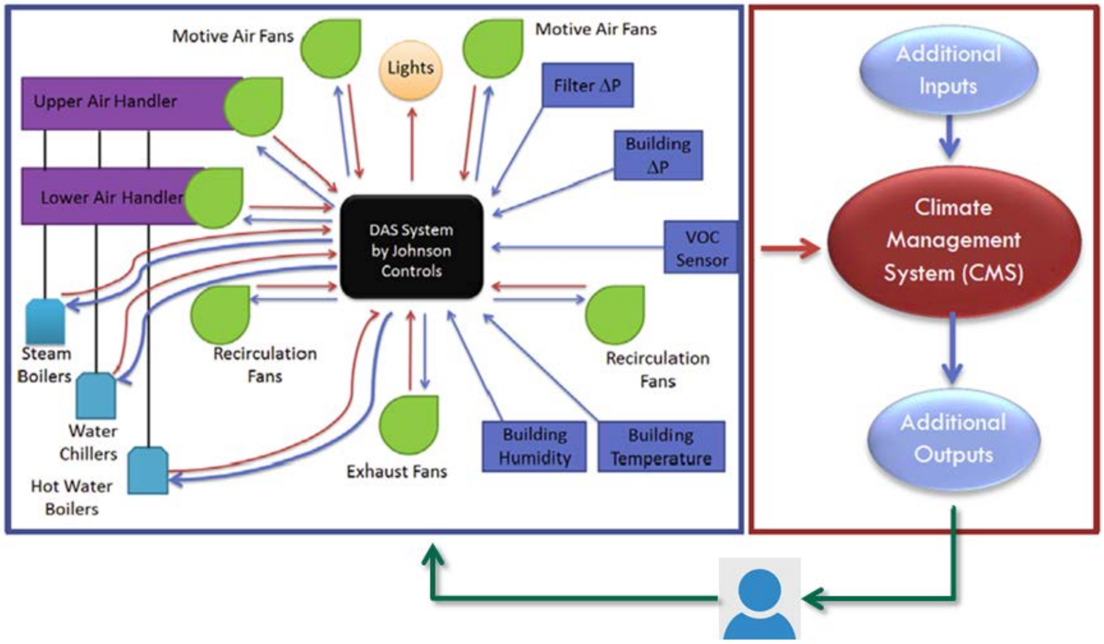

Figure E-1. Schematic of Interactions Between Existing System (blue box) and the CMS (red box)

In addition to a real-time dashboard, the team worked with B59's management to develop a summary report, for use by supervisors and other management providing analysis related to overall performance and energy usage. 15-minute interval data from the building automation system (BAS) was periodically downloaded, typically on a one-week frequency, but occasionally more or less frequently, to extract fan speed, mode usage, and other information. Data were reduced, summarized, and reported to appropriate staff at B59. The report provides a color-coded representation of mode usage for the current week of reporting, along with data from the previous three weeks, therefore allowing management to quickly compare mode usage to the tasks that were performed during a given week.

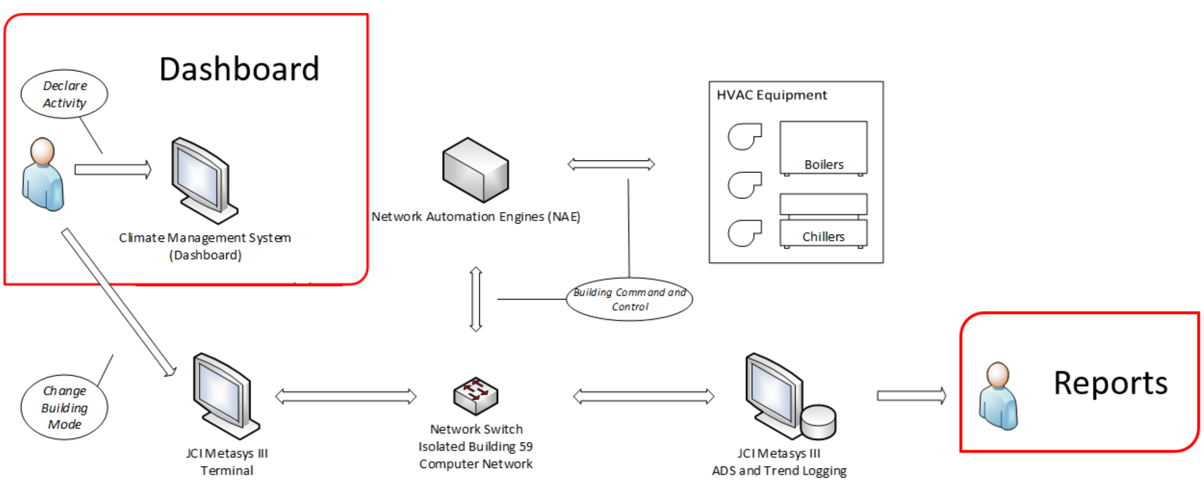

Figure E-2. Diagram of Existing ICS and CMS Components

The primary advantage of the CMS is that augmentation of existing Industrial Control System (ICSs), rather than replacement, allows the CMS to be readily translated to other DoD facilities. The majority of ICSs operate on "refresh" rate of 20 years, meaning that the physical components including boilers, chillers, fans, and associated sensor networks are replaced on a 20-year cycle. Since the primary purpose of the CMS is to gather building use information and make base personnel more aware of how their use of the existing ICS affects energy consumption rather than direct control of the existing CMS, the system can be installed side-by-side without disrupting the existing ICS.

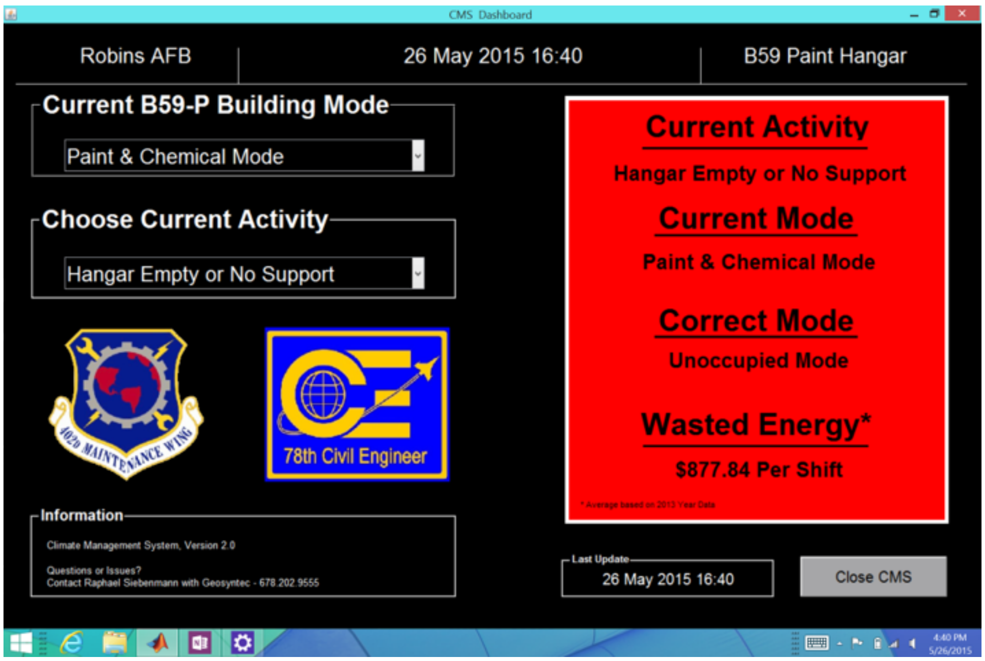

Figure E-3. Screenshot of the Dashboard to Be Displayed on the CMS Terminal in Building 59.

The red box indicates that the wrong mode has been selected for the current activity.

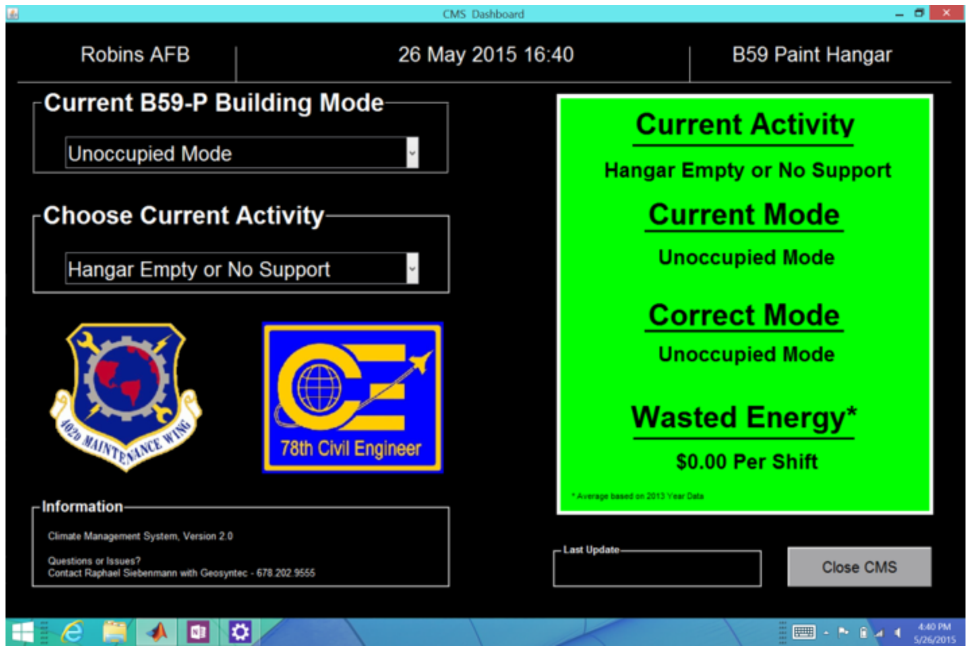

Figure E-4. Screenshot of the Initial Dashboard to be Displayed on the CMS Terminal in Building 59.

The green box indicates that the correct mode has been selected for the current activity.

The primary limitation of the technology is reliance on organizational acceptance and organizational behavioral change in a challenging environment. The team observed an overall a lack of positive participation from B59 personnel and fatigue with the system set in quickly. Communication and close coordination with all levels of stakeholders, including upper management, shift supervisors and operators, is required to ensure the CMS is successfully integrated into facility operations.

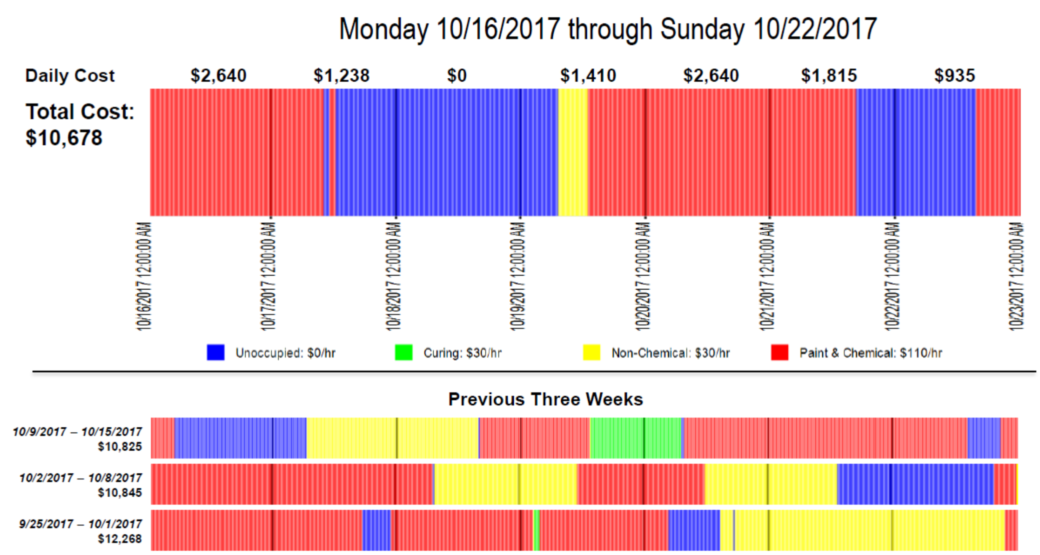

Figure E-5. Example Summary Energy Usage Report.

The primary hypothesis tested in this demonstration was if the CMS system could decrease the electricity and gas usage by 10-20% through training and organizational behavior modification that did not involve financial incentives, but rather through providing an increased awareness of excess building energy consumption. The team believed that the core of this savings would be derived by more specifically mapping tasks to operational modes and by providing sustained tracking, assessment, and reporting. In this way, the team believed that the building's ICS would more often be operated in the correct mode and energy consumption would be reduced.

The test design involved a comparison of before and after electricity usage, gas usage, and required costs to determine the effectiveness of the CMS system. The test phases included pretest preparation, baseline measurements, equipment installation, calibration, commissioning, data collection, and data analysis. The baseline measurements were determined from reports from Robins Air Force Base regarding the electricity usage and gas usage as well as historical usage and scheduling data.

PERFORMANCE ASSESSMENT

Analysis of the data indicate that the CMS did not change the behaviors of B59 staff and thus energy consumption did not achieve the performance targets. However, the potential energy savings at B59 are still significant, and estimated to be on the order of 17% of fan energy and 10% of chiller-energy.

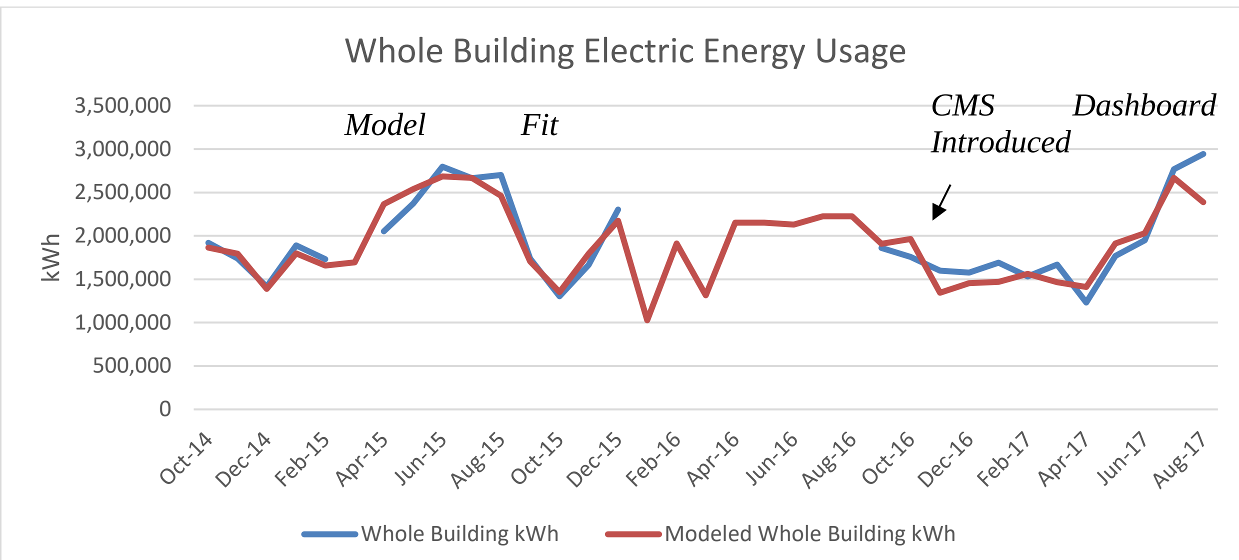

Figure E -6. Predicted and Actual Whole-Building Electricity Usage Before and After the Installation of the CMS.

COST ASSESSMENT

While training sessions with the B59 management and supervisors were held, and the potential for cost savings quantified, at the end of the day, relying on non-financial and social incentives appears to have failed. This leads the team to believe that a financial incentive program to reward use of the CMS would likely yield more positive results, and thus Building Lifecycle Cost scenarios were modeled with financial incentives to understand at which point an incentive program would begin to cost more than the potential energy savings.

IMPLEMENTATION ISSUES

The primary implementation issue during the demonstration period was the general lack of usage of the CMS. Despite frequent visits by the project team and solicitation of feedback on the performance of the system, it appears that the CMS did not in and of itself result in a change in organizational behavioral modification. It is believed that quickly after installation of the digital signs, fatigue set in and the dashboards and reports developed became something that did not trigger attention.

A significant implementation challenge encountered by the team was the lack of experience with the DoD Risk Management Framework (RMF), which resulted in the extended duration of the demonstration due to the time required to obtain Authorization to Operate (ATO). Recently developed RMF framework training programs, Environmental Security Technology Certification Program (ESTCP) publications, including the current ESTCP Installation Energy and Water web portal provides a wealth of requirements documents, manuals, plans, memos, resources, tools, templates, and checklists that would have been invaluable to the investigative team at the beginning of the project.

1.0 INTRODUCTION

This project, with collaboration from Robins Air Force Base (AFB) located near Warner Robins, Georgia, was designed demonstrate/validate (Dem/Val) the technology of providing real-time energy use information and feedback to personnel at the Building 59 (B59) Corrosion Control Facility (CCF) using a Climate Management System (CMS) in order to identify and realize energy savings by operating the building in the correct building mode and other utilities saving opportunities generally related to energy management rather than inherent equipment inefficiencies.

This section provides a general overview of the project, including project background, objectives, and technical/cost drivers and DoD initiatives for this technology demonstration.

1.1 BACKGROUND

Many DoD facilities include climate-controlled buildings. Industrial buildings in particular may require energy intensive heating and cooling, and these requirements may vary depending on operations. Furthermore, CCFs pose multiple climate control challenges. For example, depainting and painting aircraft in a hangar requires careful monitoring and control of lighting, air flow, temperature, relative humidity, and concentrations of particulate matter (PM) and volatile organic compounds (VOCs), not only to optimize conditions for depainting and painting but also to ensure the health, safety, and comfort of personnel.

Minimizing energy use in CCFs can be especially challenging because of the intensity and breadth of environmental control requirements including (i) lighting control; (ii) generating hot water and steam; (iii) providing breathing air; (iv) removing hazardous air pollutants; (v) heating; (vi) cooling and (vii) meeting air flow standards, all changing with work flow. It is important to manage this energy use carefully.

The 225,000 ft^2 B59 CCF at Robins AFB includes two 65,000 ft^2 hangar bays used to depaint and paint aircraft; a small-parts paint bay; common central facility systems; and a process equipment plant. B59 is designed to optimize paint removal and application for C-5, C-17, and other similar-sized aircraft, and increase the level of health and safety for Base employees. B59 uses approximately $1.7M of electricity and $250K of gas per year, or about 8% and 7%, respectively, of the Robins AFB totals ($20.3M and $3.6M, respectively, FY2011)[1].

Generally, the hardware, sensors, and building controls in B59 are designed, sized, and installed properly and, when functioning, operate well to condition B59 as designed. However, observations indicate that lighting is maintained, steam and hot water boilers run, and conditioned air is moved at full flow through hangars even in the absence of aircraft. Therefore, there are energy savings opportunities in B59 related to energy management.

[1] "The Robins Energy Plan" O.L. Hicks, Jr. Base Civil Engineer, Robins AFB, Feb 2012"

One energy savings opportunity is to maintain B59 in the correct building mode to match the required environmental conditions, based upon the tasks being performed at the time; not doing so is estimated to cost $150K/year in the depaint hangar alone according to a recent audit.[2] For example: (i) lighting could be reduced in the absence of personnel; (ii) air flow could be reduced and/or the rate of recycled air increased when PM and VOC concentrations are low; (iii) compressors, chillers, fans, and boilers could be turned off when not used; and (iv) air conditioning could be coordinated with weather forecasts and plans to open hangar doors to move aircraft, all while keeping the hangars at the correct temperature and humidity for product quality, maintaining safe conditions, and meeting air quality standards.

Additionally, an energy audit, a retro-commissioning audit,[3] and our own investigation identified dozens of other issues that could be addressed to improve the operation and energy efficiency in the B59 facility (Appendix C). This list illustrates the variety of issues in this specific CCF, which we presume to be present in other DoD CCFs and industrial facilities. Many issues cannot be solved by conventional upgrades (e.g. more efficient boilers, chillers, or fan motors). Instead, most energy efficiency gains through behavior change, which is affected by training, accountability, and other operational factors. Such changes can be addressed through thoughtful coordination and communication between personnel with varying roles and responsibilities (Appendix D). Planes are painted based on Technical Orders and Process Orders, while the building is operated based on the building specific systems and operations manual. One of the potential benefits of this CMS is to codify the operational mode of the building based on Technical and Process orders.

In summary, tools that improve the sensing, tracking, processing and communication of information among B59 personnel would allow for continuous "retro-commissioning" of the facility for better operation of existing hardware to ultimately decrease energy use while maintaining or improving workflow, product quality, and worker health and safety. The CMS was designed to increase the ability to identify, prioritize, and communicate needed maintenance, system upgrades, and other energy savings opportunities.

1.2 OBJECTIVE OF THE DEMONSTRATION

The Department of Energy (DoE), as part of the U.S. Council for Energy Efficient Manufacturing (CEEM), has detailed the objectives of an effective energy management standard and discussed components that make up the best energy management principles, including:[4]

- Management systems must be coupled with technology and O&M practices
- Communication of goals, tactics, and achievements throughout the facility
- Identification of key performance indicators
- Delegation of responsibility and accountability

[2] "Engineering Energy Analysis", 402 Maintenance Wing, Robins AFB, Contract No. W912DY-05-D-0002, July 2012.

[3] "Retro-Commissioning Audit, Robins Air Force Base, Building 59, Final Report", June 2011.

[4] U.S CEEM includes DoE, industry partners, the U.S. Department of Commerce (DoC) and the Environmental Protection Agency (EPA), www1.eere.energy.gov/manufacturing/pdfs/webcast_2009-0122_energy_mngmnt_stnds.pdf

- Sustained tracking, assessment, and reporting of energy use and technology application
- Continuous investigation of potential energy reduction projects
- Establishment of an internal recognition and reward program for achieving energy goals

The CMS is designed to address each of these energy management principles. It couples technology with O&M practices by requiring the site personnel to change the mode or it will be recorded in the wrong mode for management to see. By providing a numerical value of time percentage operated in the wrong building mode it encourages site personnel to define the results and expectations and converse over issues hindering the goal or expectation. Through a system of delegation of responsibility, accountability will be defined among the personnel. Tactics can be developed to allow for modification and improvement of the system. The CMS identifies the key performance indicators as the record of electricity and water usage in the facility prior the installation of the CMS compared to after the installation. It does not control any of the operation but uses a sustained tracking of operations to allow for later assessment and reporting of the energy use and use of the technology. The implementation of this system can allow for continuous investigation of energy reduction projects as can be used for internal recognition for achieving energy goals.

With the DoE objectives in mind, the overall technical objective was to demonstrate the cost and energy savings capabilities of an innovative CMS in a challenging CCF environment, resulting in environmental conditions that also maintain or improve personnel health and safety, work flow, and product quality while meeting mission and environmental regulations.

Specific technical objectives, therefore, included: (i) establishing current energy use and work practice baselines, including inventorying existing hardware and software; (ii) designing a CMS with commercial components to address the technical, economic, and personnel-related challenges; (iii) assessing CMS performance through operation of no less than 12 months during a variety of weather conditions; (iv) validating capital and O&M cost data for operations; and (v) providing high quality data and analysis, including technical feasibility and realistic cost/benefit estimates to guide full-scale installation of similar systems at other DoD CCFs or other complex industrial sites, including non-DoD sites.

Additionally, achieving a high degree of user satisfaction was identified as critical in distinguishing this CMS from traditional control systems. Only by changing the current culture of how energy is managed in B59 can the direct energy-related metrics be improved in the long term. Therefore, user satisfaction was continually monitored throughout the project and was used to help determine many of the features, including desired data inputs and outputs, of the CMS.

In addition to the technical objectives, another key objective of this project is to develop the CMS as a behavior-based tool that can be deployed at other CCFs and DoD buildings independent of the type of HVAC system that are already installed.

1.3 DRIVERS

The primary driver for this demonstration project is helping DoD achieve the goal of reducing energy use as mandated by Executive Order (EO) 13693, which has superseded EO 13423 and EO 13514.

EO 13423, “Strengthening Federal Environmental, Energy, and Transportation Management”, signed by President Bush on January 24, 2007, set goals in the areas of energy efficiency, acquisition, renewable energy, toxics reductions, recycling, renewable energy, sustainable buildings, electronics stewardship, fleets, and water conservation. In addition, EO 13514, “Federal Leadership in Environmental, Energy and Economic Performance”, signed by President Obama on October 5, 2009, strengthened EO 13514, which requires agencies to meet a number of energy, water, and waste reduction targets.

EO 13693, “Planning for Federal Sustainability in the Next Decade”, signed by President Obama on March 19, 2015, continues to call for Federal leadership in energy, environmental water, fleet, buildings, and acquisition management that will continue to drive national greenhouse gas reductions and support preparations for the impacts of climate change.

Another driver for this project is the Energy Policy Act of 2005. Title I: Energy Efficiency of this policy is to develop and implement a cost-effective energy conservation and management plan for all facilities administered by Congress. Other driving forces include Air Force regulations and the Whole Building Design Guide. The reducing of energy consumption contributes to each driver as it pushes for smart energy usage.

2.0 TECHNOLOGY DESCRIPTION

This section describes the CMS technology and discusses the advantages and potential limitations associated with this technology.

2.1 TECHNOLOGY OVERVIEW

Real-time monitored and controlled systems are particularly well suited for complex situations where timing, magnitude, duration, quality, and changing fluid flows (e.g., water and/or air) are critically important to achieving the desired or required performance. The general approach, then, is to implement technology that better allows personnel to follow the ISO-50001 energy management system model developed by ANSI (Plan-Do-Check-Act). The CMS, using the existing Industrial Control System (ICS), UNCC algorithms, and other analyses, focused on using energy and related data to help Robins personnel: (i) establish baselines, objectives and targets; prioritize actions; and develop action plans ("Plan"); (ii) implement energy plans; communicate data, analyses, and results; and train B59 stakeholders ("Do"); (iii) measure performance; report system status; and identify issues ("Check"); and (iv) improve performance through continuous retro-commissioning ("Act"). This comprehensive Plan-Do-Check-Act approach to energy management was designed to improve energy management based on a conventional control system.

The CMS, shown on Figure 2-1, is designed to augment the existing ICS with a system that gathers, processes, manages, analyzes, and communicates building use and energy use data with customized, intuitive graphics and familiar computer interfaces. The CMS is distinct from conventional energy management approaches that may not always address the hurdles of matching building use with available ICS modes of operation.

Research has shown that behavior-based approaches in a residential setting have the potential to reduce energy usage by using personalized and immediate feedback.[5] Therefore, a core project concept is that if the feedback about energy use is detailed and delivered quickly enough, B59 occupants and managers can learn about how their specific actions affect their consumption levels and adapt their behaviors.

[5] Todd, Annika, Elizabeth Stuart, Steven R. Schiller, and Charles A. Goldman. Evaluation, Measurement, and Verification (EM&V) of Residential Behavior-Based Energy Efficiency Programs: Issues and Recommendations, 2012.

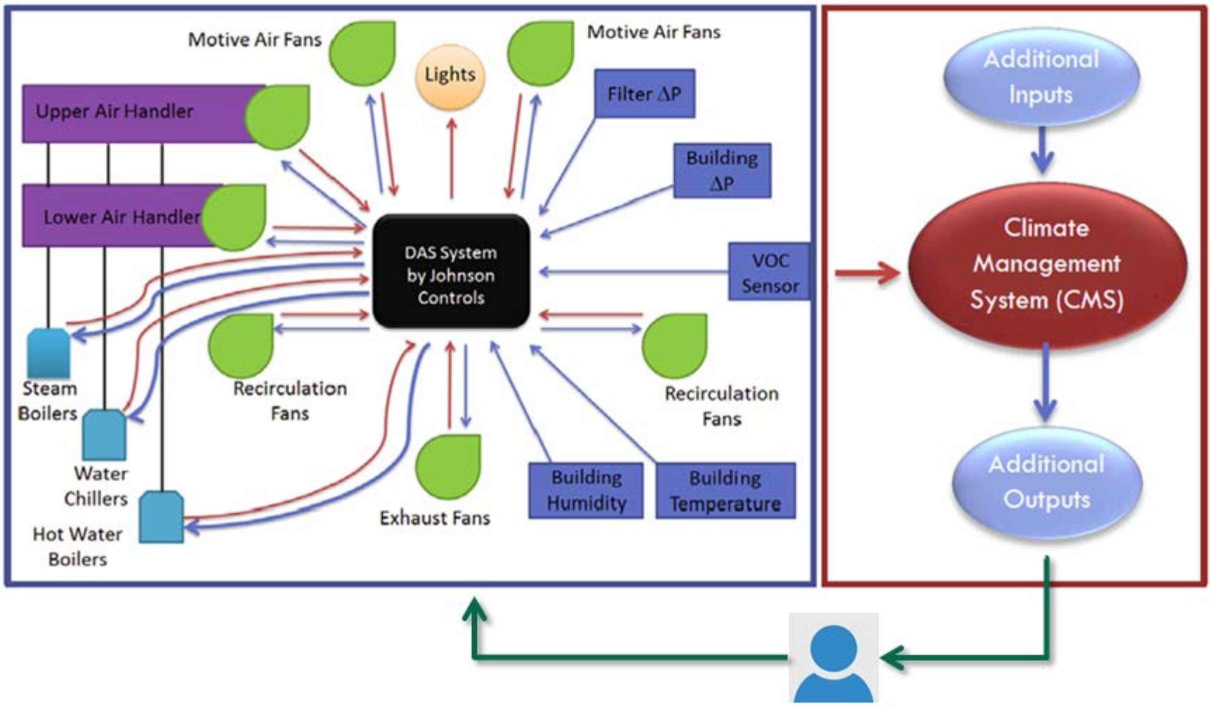

Figure 2-1. Schematic of Interactions Between Existing System (blue box) and the CMS (red box)

The design consists of delivering a real-time dashboard and a summary report. The real-time performance dashboard, displays whether the Johnson Controls system is operating in the right mode based on the current task. The summary report, for use by supervisors and other management providing analysis related to overall performance and energy usage. The dashboard was displayed on large monitors in a highly visible location, the hallway outside the office of the painting supervisor that is immediately next to the entrance to the hangar. These CMS was designed to process the additional inputs listed in Table 2-1 and produce the outputs listed in Table 2-2. Example dashboards are shown in Section 2.2.

The current system is an overlay and has no ability to control the existing system; it is only to alert the working personnel if it is being operated in the wrong building mode. After this initial installation, the opportunity to have the CMS control the system is an option. This technology has the potential to improve system performance through its ability to guide operators in changing the controls per required activity.

Table 2-1. Additional Inputs

Additional Inputs	Comments
Operations scheduler	Planes are scheduled for depaint/paint weeks/months in advance
Fan speed	System does not know if fan blades are turning, only if motor is running – if the fan belts are broken, the blades don't turn but the system doesn't know
External meteorological data	For better planning to know when to turn on the system to cool down or heat up the building
Building occupancy	The building does not know if people are present and what kinds of people are present (painters, mechanics, etc.) which could help determine how to treat the air, shut down lights, etc.
Maintenance schedule & logs	Example: A chemical dosing pump to treat chlorine in water for the RO system failed, meaning the RO membranes would fail faster. The plan to fix was not clear nor who was aware of the ramifications
Utility Use Data (electricity, gas, water)	Data is compiled monthly for utilities through smart meters and data could be better disseminated
Personnel schedules	Related to availability of key personnel at key times
State and condition of equipment	Incorporates the non-intrusive load monitor data

Table 2-2. Additional Outputs

Additional Outputs (e.g. text messages, emails, displays on flat panels, flashing lights)	Dashboard Type
Current Task, Current Mode, Correct Mode, Wasted Energy in money	Real-time Performance
Utility Use Reports (electricity, gas, water)	Monthly Performance

In addition to identifying and communicating opportunities for improved control functionality through the existing ICS, the CMS analysis provides an analytics framework necessary for fault detection and diagnosis (FDD), with a focus on offline tools that reduce the need for real time data. Traditional building designs lead to 20% or more wasted energy due to improperly operated or poorly maintained equipment. Such waste often goes unnoticed if the system performs the desired functions, albeit at greater cost. The team developed algorithms for identifying such issues, which are presented in Section 6.3.

2.2 TECHNOLOGY DEVELOPMENT

The CMS was designed to address both behavior-based energy change and opportunities stemming from equipment health. To achieve behavioral energy savings and track the health of equipment, the team has developed the system presented schematically in Figure 2-2. The existing ICS, developed by JCI, is a building automation system with the Metasys® Application and Data Server (ADS) at its heart. The ADS stores settings for various equipment throughout the building (i.e. chillers, air handlers, etc.) and contains an SQL database to which various points in the system are logged at 15-minute intervals. Example points include valve status, water temperature, and fan speed.

The ADS also communicates directly with the Network Automation Engines (NAEs) located throughout the building.

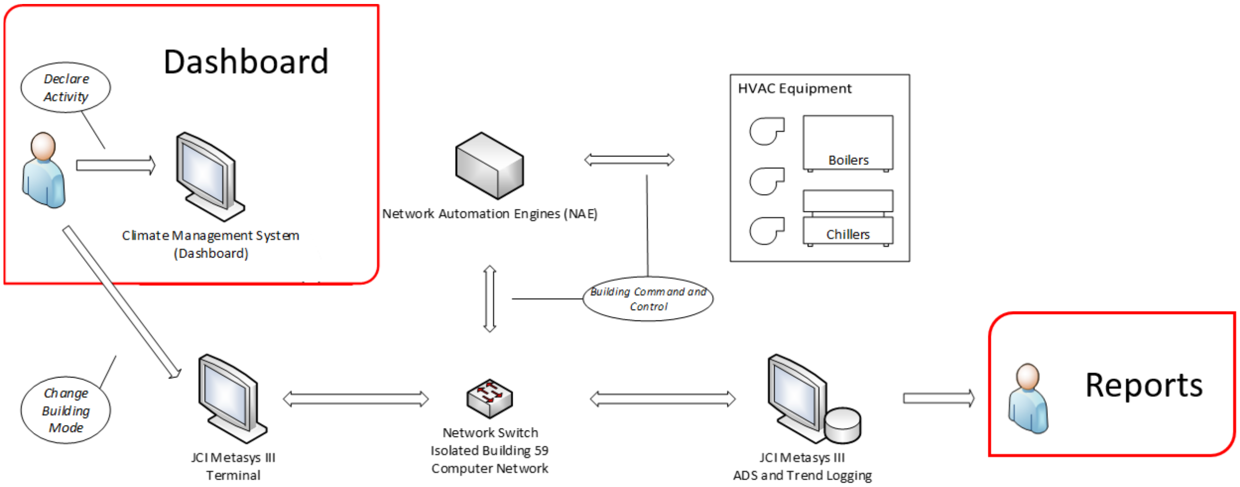

Figure 2-2. Diagram of Existing ICS and CMS Components

These devices communicate directly with the various the field controllers for individual system components such as fans and valves. Users interact with the system *via* terminals in the painting and depainting control rooms immediately adjacent to hangars. From these terminals, users can set the building mode. As noted in the section on baseline characterization, the building has four modes (Unoccupied, Non-Chemical, Paint & Chemical, and Cure). Note that modes are generally selected by paint staff at the beginning of each shift.

During the baseline characterization stage, the team noticed that operators often did not select the appropriate mode for the activity to be performed on a given shift. For instance, during the process of preparing an aircraft to be painted, operators often selected "Paint & Chemical" when conditions imposed by the less energy-intensive "Unoccupied" or "Non-Chemical" modes would be sufficient for the scheduled set of tasks.

To address this behavior-based factor, CMS desktop software was installed on paint shift supervisor desktops and dashboards were displayed on monitors installed in a highly visible location, the hallway outside the office of the painting supervisor that is immediately next to the entrance to the hangar. The supervisor was asked, when beginning a new shift, to input the specific activity to be performed and was guided to set the building to the appropriate mode based on the task being performed. The list of possible activities includes those related to paint preparation or actual painting (masking, sanding, priming, top coating, curing, and sealing). Figures 2-3 and 2-4 show screenshots of the dashboards to be displayed on the CMS terminals to assist decisions by the paint crews.

After review of information assurance (IA) requirements, discussed in section 4.3, the team limited its deployment to paint shift supervisors' desktop computer, rather than the existing "closed-loop" and isolated JCI enclave. Since the CMS is only providing guidance and has no actual control, failure of the CMS system would likely not cause any immediate risk since the systems are logically separated and do not communicate.

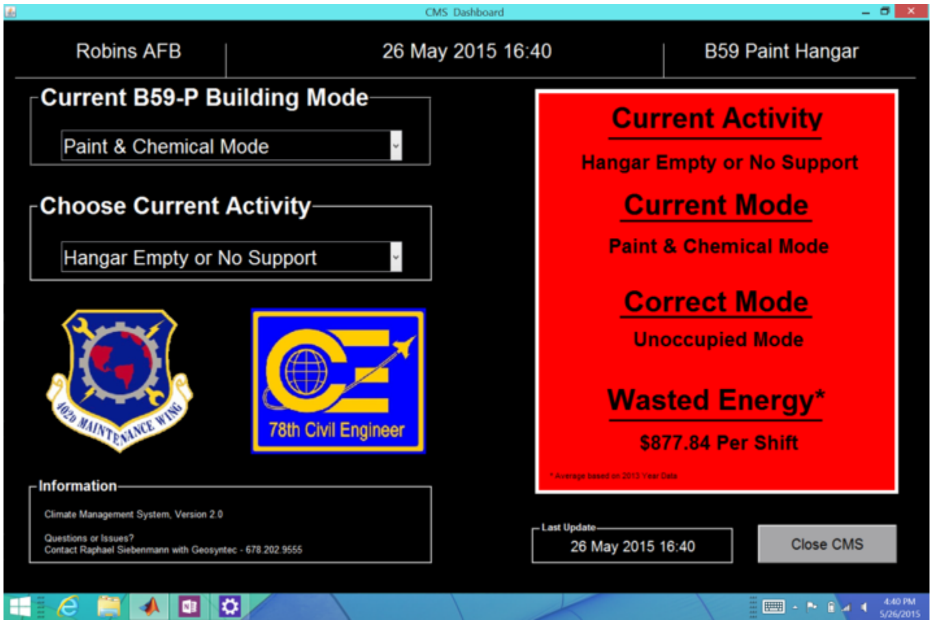

Figure 2-3. Screenshot of the Dashboard to Be Displayed on the CMS Terminal in Building 59.

The red box indicates that the wrong mode has been selected for the current activity.

The dashboards shown in Figures 2-2 and 2-3 provide information needed by the painters during day-to-day operations.

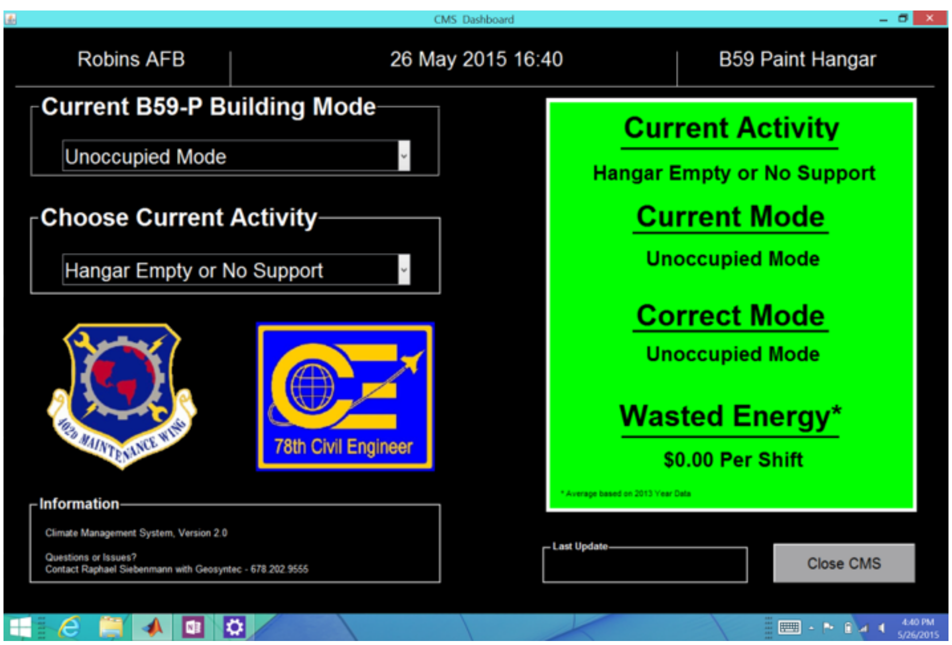

Figure 2-4. Screenshot of the Initial Dashboard to Be Displayed on the CMS Terminal in Building 59.

The green box indicates that the correct mode has been selected for the current activity.

In addition to a real-time dashboard, the team worked with B59's management to develop a summary report, for use by supervisors and other management providing analysis related to overall performance and energy usage. 15-minute interval data from the JCI system was periodically downloaded, typically on a one-week frequency, but occasionally more or less frequently, to extract fan speed, mode usage, and other information. Data were reduced, summarized, and reported to appropriate staff at B59.

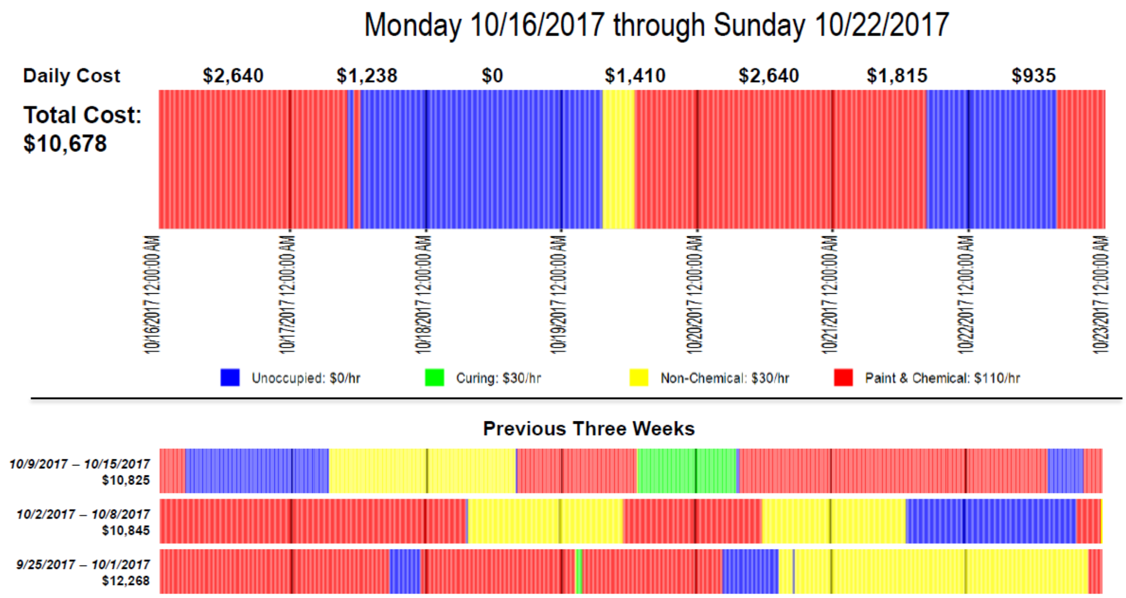

Figure 2-5. Example Summary Energy Usage Report.

The report provides a color-coded representation of mode usage for the current week of reporting, along with data from the previous three weeks, therefore allowing management to quickly compare mode usage to the tasks that were performed during a given week.

2.3 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

The primary advantage of the CMS is that augmentation of existing ICSs, rather than replacement, allows the CMS to be readily translated to other Department of Defense (DoD) facilities. The majority of ICSs operate on "refresh" rate of 20 years, meaning that the physical components including boilers, chillers, fans, and associated sensor networks are replaced on a 20-year cycle. Since the primary purpose of the CMS is to gather building use information and make base personnel more aware of how their use of the existing ICS affects energy consumption rather than direct control of the existing CMS, the system can be installed side-by-side without disrupting the existing ICS.

The primary limitation of the technology is reliance on organizational acceptance and organizational behavioral change in a challenging environment. As discussed in Section 8.0 the team observed an overall a lack of positive participation from B59 personnel and fatigue with the system set in quickly. Communication and close coordination with all levels of stakeholders, including upper management, shift supervisors, and operators, is required to ensure the CMS is successfully integrated into facility operations.

3.0 PERFORMANCE OBJECTIVES

3.1 SUMMARY OF PERFORMANCE OBJECTIVES

The performance objectives of this demonstration plan consist of a combination of quantitative and qualitative performance objectives. Individual performance objectives, metrics, data requirements, and success criteria are provided in Tables 3-1 and 3-2 below.

Table 3-1. Quantitative Performance Objectives

Performance Objective	Quantitative Metric	Data Requirements	Success Criteria
Electricity Usage	Electricity (kWh)	Meter readings of electricity used by B59	> 10-20% reduction from baseline (> $170-$340K/yr, FY2014 costs)
Gas Usage	Gas (MMBtu)	Meter readings of gas used by B59	> 10-20% reduction from baseline (> $25-$50K/yr, FY2014 costs)
Water Usage	Water (Gallons)	Meter readings of water used by B59	> 10% reduction from baseline
Usability	Training (Hours)	Training hours required of system users	< 4 hours to learn to enter & retrieve data
Availability	Operational Time (Hours)	Amount of time the system is operational or ready to operate	> 95% operational (after installation and commissioning)
Scalability	Installations (Number)	Number and description of DoD CCFs that have the same energy management challenges	Identification of 10+ specific DoD CCF installations where this management system is applicable
Cost Performance	Savings to Investment Ratio (Number)	Cost to install and maintain the system	Savings to Investment Ratio > 1

Table 3-2. Qualitative Performance Objectives

Performance Objective	Qualitative Metric	Data Requirements	Success Criteria
Security	Expert Opinion	Review of the vulnerability and potential consequences of the energy data streams to hacking	No major vulnerabilities identified
Behavior Change	Survey Results	Results describing behavior changes with regard to how energy is managed	Increase in awareness and participation in energy usage tracking and/or management
User Satisfaction	Degree of Satisfaction	Likert Scale Survey	Increase in satisfaction over current controls system and energy related data communication

3.2 PERFORMANCE OBJECTIVES DESCRIPTIONS

The assessment procedures evaluated the energy savings for different building modes over an extended period. By associating savings with specific activities, a more accurate description of how the savings occur and how much savings can be predicted for the future.

Section 3.1 outlined the primary technical performance objectives. Each of these were analyzed as follows:

- Electricity usage: The target reduction in electricity usage was tracked using the meter data available from base staff. Analysis will be performed using the processes outlined in the International Performance Measurement & Verification Protocol[6] (IPMVP).
- Gas usage: The target reduction in gas usage was tracked using the meter data available from base staff. Analysis will be performed using the processes outlined in the (IPMVP).
- Water usage: The target reduction in gas usage was tracked using the meter data available from base staff. Analysis will be performed using the processes outlined in the (IPMVP).
- Persistence: Persistence was gauged based on how often it is operating in the correct mode and the transferability to different department staff or other air force bases.
- Usability: Usability was one of the most important indicators to track. To do so, the team from Geosyntec and UNCC jointly led the initial training process and examined the logs on the CMS. These logs will indicate whether or not users are selecting the appropriate modes.
- Availability: Availability was gauged by analyzing logs on the CMS terminal.
- Scalability: Scalability was addressed through discussions with Air Force staff about the specifics of other Corrosion Control Facilities.
- Cost Performance: A Savings to Investment Ratio (SIR), the ratio of the present value of an energy savings stream with respect to the present value of the cost of making the energy efficiency improvement, was used to evaluate the CMS. The SIR was developed using the tools described in Section 7.3
- Security: the team worked with base IA officers to ensure that no vulnerabilities were introduced by the CMS.
- Behavior Change: the team compared baseline behavior to behavior during the study period to detect changes in the frequency of operating in the correct mode.
- User Satisfaction: a satisfaction survey was developed to evaluate energy use awareness and user satisfaction with the system before and after deployment of the CMS.

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[6] *International Performance Measurement and Verification Protocol: Concepts and Options for Determining Energy and Water Savings Volume I*, EVO-10000 -1.2007, Efficiency Valuation Organization.

4.0 FACILITY/SITE DESCRIPTION

The CMS demonstration took place at B59 at Robins AFB in Warner Robins, Georgia (Figure 4-1).

Figure 4-1. Location of Building 59 (B59) at Robins Air Force Base in Warner Robins, GA

4.1 GENERAL FACILITY/SITE SELECTION CRITERIA

Site selection was based on overall energy use and potential for improvement through management rather than infrastructure changes. As the largest CCF located at Robins AFB, B59 alone accounts for about 10% of electricity and gas use at Robins AFB to heat, cool, humidify, dehumidify, and move air through the two main hangars and auxiliary rooms to meet Technical Order (TO) specifications for painting and depainting aircraft. The cost of the electricity and gas represent a substantial portion of the Base's roughly $20M annual energy expenditure. In addition, savings in water use related to humidification appear possible.

4.2 DEMONSTRATION FACILITY/SITE LOCATION AND OPERATIONS

B59 is an $80M 225,000 square foot (sq. ft.) Paint/Depaint Facility constructed in 2007, which is operated by the 402d Air Maintenance Wing. The building is used for painting and depainting aircraft and consists primarily of two 65,000 sq. ft. hangars. It is the first Air Force hangar to be designed for air recirculation (80%) in compliance with NFPA 33, 29 CFR 1910.107(d) and 29 CFR 1910.100[7].

[7] Building 59 Systems and Operations Manual, 7/23/2012.

The air flows from ceiling ductwork and has vents on the side walls for air exhaust or return. Each room contains two air-handling systems that each has three air handling units each along with an exhaust fan system. This building also contains industrial equipment for the process and has an office and administration space which can hold air handling units. The building plant supplies its own water in the building including chilled water, steam, and hot water. Based on demand, the chillers and boilers can be turned on and off. All HVAC conditions are monitored and controlled inside the building at the Metasys® terminal.

While technically one building, each hangar is operated as a separate HVAC zone. One hangar, 59 Paint, referred to as Building 59P, is used for painting, while the other, 59 Depaint, referred to as Building 59D, is used for depainting. Building 59P has four modes: Unoccupied, Non-Chemical, Paint & Chemical, and Cure. Building 59 D has two modes: Unoccupied and Stripping. These modes are further described in Section 5.2.

The existing ICS consists of Metasys® LON devices from Johnson Controls, Inc. (JCI) that allow for the control and monitoring capability. The controls network consists of 22 air handling units, 26 fans, 20 pumps, 5 chillers, 5 boilers, 1 cooling tower, 4 small DX units, and 6 unit heaters. This includes about 198 analog points, 228 digital points, and 9523 input points from industrial equipment. The additional information is required track the health of the various fans, pumps, chillers, and boilers. Electric and gas usage is monitored by meters in the building. Examples of critical control technologies and air handling equipment are shown in Figures 4-2 to 4-4.

Figure 4-2. Bldg. 59; Left: Metasys N2 Controller, Right: Johnson Controls Occupancy Mode Controller

Figure 4-3. B-59; Left: Large Multi-floor Air Handling Unit Systems are used to condition the air to the Paint/Depaint Space, Right: One of Two Paint/Depaint Spaces

Figure 4-4. B-59; Left: Packaged Units Supply many of the Office Spaces, Right: Exhaust Fans

4.3 SITE-RELATED PERMITS AND REGULATIONS

The DoD has extensive information security and information assurance (IA) requirements that may impact development of the technology by requiring compliance with Installation, Department or Federal regulations. In addition to their complexity, IA rules and regulations for ICS are continually evolving. The following policies, rules, and regulations were relevant to the ICS and the CMS during the demonstration period:

- Department of Defense Information Assurance Certification and Accreditation Process (DIACAP) and Platform Information Technology (IT) programs
- DoD's memorandum on Real Property-related Industrial Control System Cybersecurity, dated March 19, 2014
- Department of Defense Instruction (DoDI) 8500.01, *Cybersecurity,* dated March 14, 2014
- DoDI 8510.01, *Risk Management Framework*, dated March 12, 2014
- Handbook for Self-Assessing Security Vulnerabilities and Risks of Industrial Control Systems on DoD Installation, dated December 19, 2012
- Air Force Civil Engineer Support Agency: Engineering Technical Letter (ETL) 11-1: *Civil Engineer Industrial Control System Information Assurance Compliance,* dated March 30, 2011

Based on a review of these regulations, the team discussed the CMS design and IA requirements with Base Point of Contact (POC) and several other key personnel in a number of meetings prior to implementation of the demonstration including:

- Richard Slife, Chief of Environmental and Ergonomics Office, 402d Maintenance Wing (POC)
- Andre Swoopes, 78th Communications Directorate (ABW/SC)
- Judah Bradley, Industrial Energy Manager, 802d Maintenance Support Squadron
- David Bury, Energy Manager, 78th Civil Engineering Group
- Roy Bowden, HVAC shop supervisor, 78th Civil Engineering Squadron
- Steve Chasteen, Information Assurance, 78th Air Base Wing
- Kevin Schlageter, Engineer, 78th Civil Engineering Squadron
- Keith Radcliffe, Johnson Controls

An IT Mission Needs Statement (MNS) was prepared and submitted for Functional Requirements Review Board (FRRB) approval on May 25, 2015 and an FRRB meeting was held on July 14, 2015. The MNS describes the operation problem requirement that 78 ABW/SC Investment Portfolio Managers, IT Subject Matter Experts use to build investment documents. These documents provide key information to the 78 ABW/SC Portfolio Investment Review Board (PIRB) to aid in the review and approval of the subjective decisions. The MNS contains quantitative information to establish and justify the need and validate the investment.

Approval was granted on November 6, 2015, for the CMS software and installation of two digital Signs (DSS). The DSS, as described in Section 2.2 provided immediate visual feedback from the behavior-based solution designed and implemented for the ESTCP project at Building 59.

Approval for installation of the CMS software was confirmed on August 10, 2016. The CMS software installation on paint and depaint shift supervisors' computers was completed by the ABW/SC and subsequently verified by the Geosyntec and UNCC Team.

As part of the CMS design and implementation, we followed the following IA best practices:

- Role based logon vs "guest" accounts and password protection per 8.1.3 of ETL 11-1
- Establishing a patching protocol
- Enabling audit logging and reviewing logs frequently to detect anomalous activity
- Disabling unnecessary connection points on the CMS hardware, i.e. disabling USB ports

4.4 PROPERTY TRANSFER OR DECOMMISSIONING

Following successful implementation of this demonstration, the CMS was transferred per Principal Investigator's Guide to Military Installations. DD Form 1354 was prepared as per instructions in Unified Facilities Criteria (UFC) 1-300-08.

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5.0 TEST DESIGN

This section provides the detailed description of the system design and testing procedure to address the performance objectives described in Section 4.0. The fundamental problem and demonstration question are provided below:

- Fundamental Problem: Building Energy use in B59 could be optimized and this demonstration attempted to solve the problem by providing a set of tools to B59 personnel that allowed them to more effectively match building use with ICS operations to use only the required amount of energy depending on operation. It augmented the existing ICS by providing energy use information in a more user-friendly and potentially compelling way.
- Demonstration Question: Does implementing the CMS reduce electricity, gas, and water usage by 10-20% while maintaining proper indoor environmental conditions?

5.1 CONCEPTUAL TEST DESIGN

The primary hypothesis tested in this demonstration was if the CMS system could decrease the electricity and gas usage by 10-20% through training and organizational behavior modification that did not involve financial incentives, but rather through providing an increased awareness of excess building energy consumption. The team believed that the core of this savings would be derived by more specifically mapping tasks to operational modes and by providing sustained tracking, assessment, and reporting. In this way, the team believed that the building's ICS would more often be operated in the correct mode and energy consumption would be reduced.

The CMS system acted as the independent variable that was customized to the system and the only change in the system was for testing purposes. The expectation was that the inclusion of the CMS would decrease energy usage without any other changes to the system or operation.

The primary dependent variables measured were the electricity and gas usage of the building. These variables were be observed and compared to the values recorded prior to the installation of the CMS.

The controlled variables include the building size and operations. Painting, depainting, and curing were not affected by the CMS system. The operating personnel were asked to interact with the interface to select the current activity, with this task requiring less than one minute and thus should not be considered an onerous additional task or time requirement for the personnel.

The test design involved a comparison of before and after electricity usage, gas usage, and required costs to determine the effectiveness of the CMS system. The test phases included pretest preparation, baseline measurements, equipment installation, calibration, commissioning, data collection, and data analysis. Section 5.2 details the baseline characterization, Section 5.4 details the design and layout of system components, Section 5.4 details the operational testing, and data collection is discussed in Section 5.5.

The baseline measurements were determined from reports from Robins Air Force Base regarding the electricity usage and gas usage as well as historical usage and scheduling data.

5.2 BASELINE CHARACTERIZATION

To understand the opportunities for energy savings, the team from Geosyntec and UNCC reviewed the existing ICS, analyzed available energy use data from B59, and reviewed TOs and Process Orders (POs) associated with painting and depainting the aircraft in B59. Four modes are programmed into the ICS, and each of these is designed to meet a different set of conditioning requirements. Table 5-1 lists the various modes currently used in Building 59P and provides set points for the associated flow rate, temperature, and humidity values. Note that flow rates are varied largely as a means to control the air exchange rate in the hangar. The temperature and humidity values are intended to ensure that painting occurs at optimal conditions. All values in the table correspond to actual control set points/ranges in the current ICS.

Table 5-1. Actual Operational Modes & Corresponding Set Points/Ranges in Building 59P.

Hangar	Mode	Max Flow (CFM)	Min Flow (CFM)	Observed Flow (CFM)	Summer Temp (°F)	Winter Temp (°F)	Relative Humidity (%)
Paint	Unoccupied	0	0	0	N/A	50	N/A
Paint	Non-Chemical	660,000	388,000	~500,000	78	68	35-60
Paint	Paint & Chemical	1,320,000	650,000	~1,000,000	78	68	35-60
Paint	Cure	660,000	388,000	~500,000	86	68	35-55
Depaint	Unoccupied	0	0	0	N/A	50	30
Depaint	Stripping	48,000	N/A	~48,000	78	68	30

An analysis of operating modes and actual activities was performed to quantify energy savings opportunities. Energy-intensive modes such as "Paint & Chemical" appeared to be used far more often than expected. Initially, it was hypothesized that this could be caused by aircraft scheduling issues. Upon a review of the facility schedule, however, it appears that paint staff often operates the building in the "Paint & Chemical" mode far more often than the TOs and POs require.

To quantify the savings potential from proper mode selection, the team analyzed the "Waterfall," data, i.e. the plane schedule, and 15-minute interval data collected between May 1, 2013 and Dec. 31, 2013. This assessment provided an opportunity to quantify the apparent disconnect between actual operations and the choices available in the ICS. Specifically, nine additional tasks are used besides painting itself: towing, sanding, masking, sealing, washing, priming, coating, curing, and stenciling. However, as indicated in Table 5-1, the JCI system only has four operational modes: Unoccupied, Non-Chemical, Paint & Chemical, and Cure. The results of the operational mode analysis by aircraft are shown on Figure 5-1, indicating that the building was maintained in a more energy intensive mode over 50% of the time that most aircraft were at the facility.

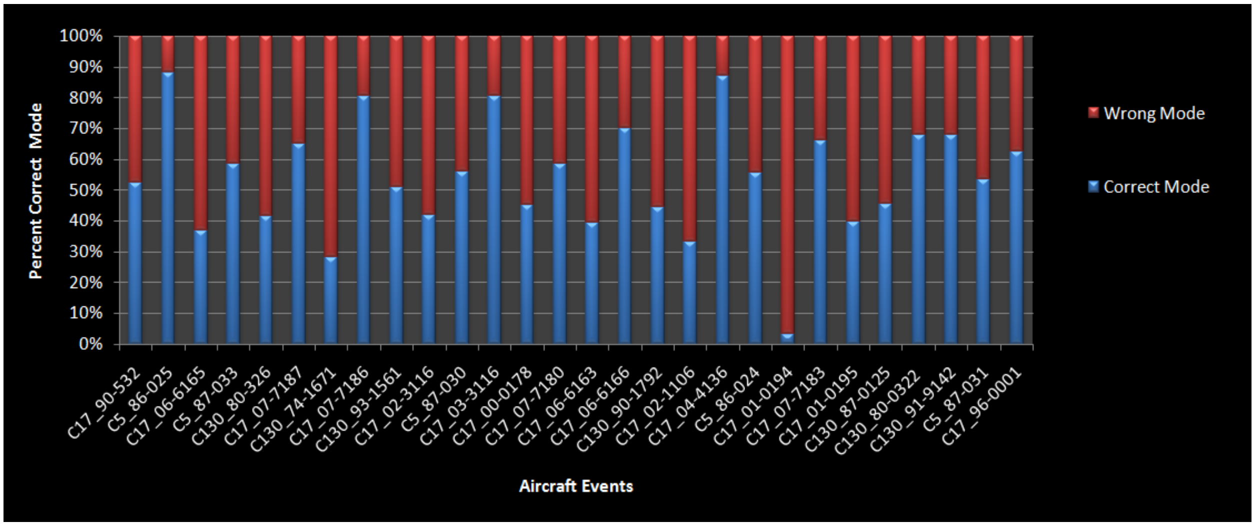

Figure 5-1. Operational Mode Analysis by Aircraft.

Analysis of data and documentation provided by base personnel during the initial analysis period allowed the team to also understand how energy is consumed in Building 59. At present, well over 50% of the energy consumed in Building 59 is used by fans, and these fans operate at fixed power levels, with the level determined by the operating mode. In this context, fan energy is thus decoupled from external factors such as weather and is heavily impacted by the behaviors indicated in Figure 5-1. Table 5-2 details the potential energy savings resulting from fan operation alone. Had the building been operated consistently in the correct mode between May 1, 2013 and Dec. 31, 2013, reduced consumption from fan operation would have led to an 18% reduction in electricity costs ($225K) during that same period of May 1, 2013 and Dec. 31, 2013. Unnecessary fan operation appears to be driven primarily by occupant behaviors that can be addressed through education and behavior change informed by feedback from the designed CMS.

Table 5-2. Estimated Potential Fan Energy Savings Between May 1, 2013 and Dec 31, 2013

Hangar Condition		Potential Savings	% of Total
Paint	Aircraft in Hangar	$172,729	14%
	Hangar Unoccupied	$6,665	0.5%
Depaint	Aircraft in Hangar	$11,146	1%
	Hangar Unoccupied	$34,868	3%
	Summary	**$225,408**	**18%**

Again, the savings potential described above is with respect to fan operation alone and provides a lower bound for opportunities. Potential opportunities with respect to equipment health were analyzed based on JCI trend data records. Figure 5-2 shows one such example. As noted in Table 5-1, the control system for Building 59P is designed to operate at a fixed temperature point, rather than a temperature range, in both the summer and in the winter. To maintain set point temperature, Figure 5-2 indicates that the controller often simultaneously heats and cools the space during the shoulder seasons.

Such energy savings opportunities can be easily spotted by relatively simple analytic routines and have been shown to drive median cost reductions on the order of \$0.29/ft^2 (Mills, 2009)[8]. Other equipment-related issues have been identified, but none have been exhaustively studied at this time. It is likely that, if fixed, such issues should reduce energy costs by as much as 30% based on results from similar studies.

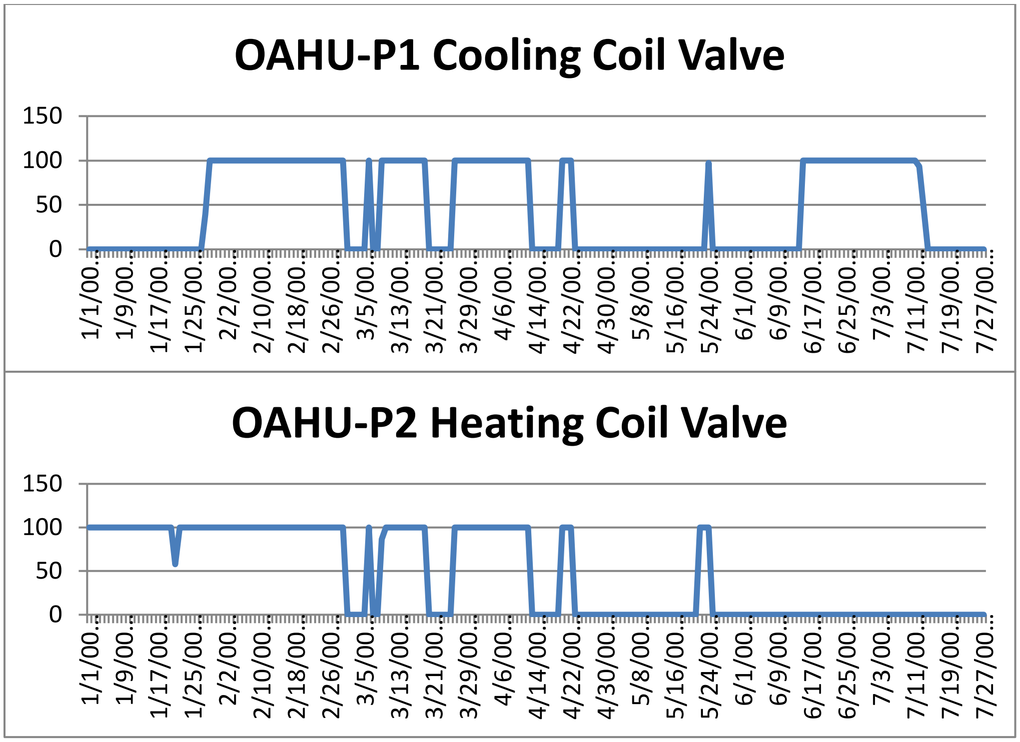

Figure 5-2. Trend Lines Showing the Status of the Heating & Cooling Valves in Two Different Air-handling Units in Building 59 during the First Half of 2014.

The y-axis is in units of % open.

5.3 DESIGN AND LAYOUT OF SYSTEM COMPONENTS

The CMS is intended to address both behavior-based energy change and opportunities stemming from equipment health. To achieve behavioral energy savings and track the health of equipment, the team has developed the system described in Section 2.2 and presented schematically in Figure 2-2.

To address the behavior-based factor, CMS desktop software was installed on paint shift supervisor desktops and dashboards were displayed on monitors installed in a highly visible location, the hallway outside the office of the painting supervisor that is immediately next to the entrance to the hangar. The supervisor was asked, when beginning a new shift, to input the specific activity to be performed. The list of possible activities includes those related to paint preparation or actual painting (masking, sanding, priming, top coating, curing, and sealing). Figures 2-3 and 2-4 show screenshots of the dashboards to be displayed on the CMS terminals to assist decisions by the paint crews.

[8] E. Mills, "Building commissioning: A golden opportunity for reducing energy costs and greenhouse gas emissions." Available: http://cx.lbl.gov/documents/2009-assessment/lbnl-cx-cost-benefit.pdf

In addition to a real-time dashboard, the team worked with B59's management to develop a summary report, shown on Figure 2-5, for use by supervisors and other management providing analysis related to overall performance and energy usage. 15-minute interval data from the JCI system was periodically downloaded, typically on a one-week frequency, but occasionally more or less frequently, to extract fan speed, mode usage, and other information. Data were reduced, summarized, and reported to appropriate staff at B59.

5.4 OPERATIONAL TESTING

During the course of this project, the team sought to achieve energy savings through two different approaches, list in order of importance:

- Behavior based program
- Fault detection and diagnosis

This section describes the general framework developed to address these approaches. The rollout was implemented as follows:

1. Kickoff meeting with the Flight Chief and shift supervisors to describe project status and gather initial feedback on design and implementation.
2. Initial training with engineering and painting teams to describe the project and provide training on CMS and terminal use, including key inputs to keep track of building operation.
3. Installation, start-up, and commissioning.
4. Additional training with engineering and painting teams to solicit feedback, reinforce goals of the project, and provide additional training as needed.
5. Monitor during demonstration period to collect building usage after CMS installation and begin FDD algorithm development.
6. Update the CMS with data gathered during baseline building usage and begin providing feedback on the correct mode of operation. Improvement of dashboards to include FDD and additional reporting capabilities.

For CMS installation, start-up, and commissioning, both Geosyntec and UNCC were onsite to ensure all the parts are installed and working.

During the monitoring period, Geosyntec and UNCC worked to quantify the effectiveness of the CMS at reducing energy consumption. The measurement and verification process involved the monitoring of the variables provided in Section 5.5. Section 6 describes how this data was used to measure the effectiveness of the CMS at impacting the behavior of base personnel and thus energy consumption.

A timeline of training and data collection activities is provided below on Figure 5-3.

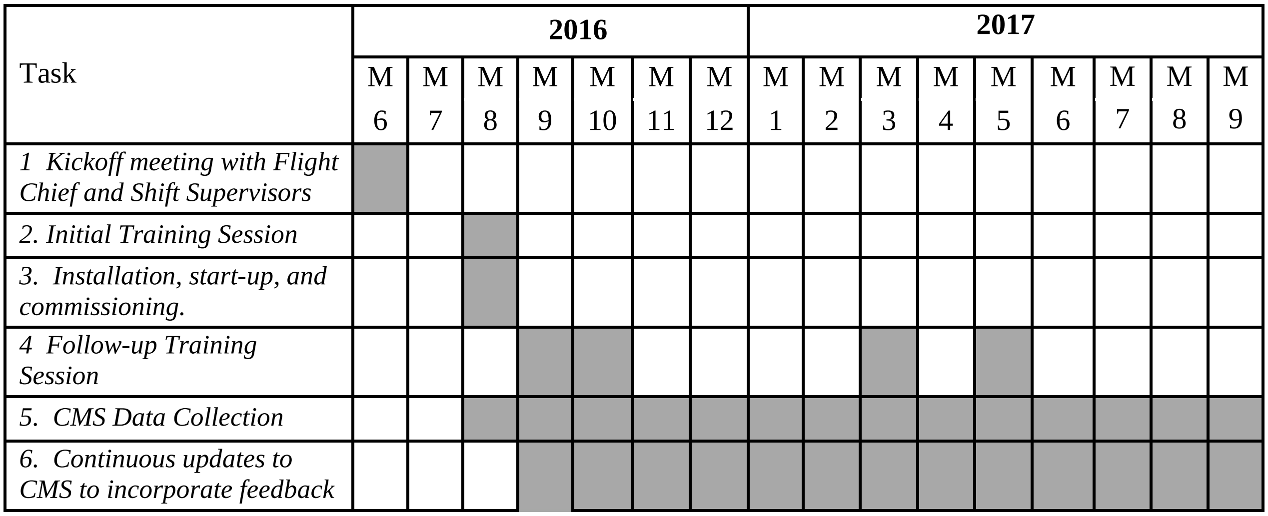

Figure 5-3. Training and Data Collection Schedule

5.5 SAMPLING PROTOCOL

Geosyntec and UNCC monitor several data streams to evaluate the effectiveness of the proposed scheme. Table 5-3 provides a list of the variables to be monitored, as well as a listing of the systems which record them, the frequency at which they are recorded, and the means by which data is physically obtained from the base.

Table 5-3. List of Monitored Variables

Data Stream	System(s)	Monitoring Frequency	How Acquired
Electrical energy consumption	8 GE submeters located throughout Building 59	15 minutes	Data transferred *via* modem to central location on base / Base staff provides data *via* email
Electrical power demand	8 GE submeters located throughout Building 59	15 minutes	Data transferred via modem to central location on base / Base staff provides data *via* email
Natural gas consumption	Submeter for Building 59	Daily (intended, but often less frequent since recorded manually)	Data recorded manually on certain shifts / Base staff provides data *via* email
Waterfall schedules	Maintained by base staff	Shift-by-shift recording of activities	Recorded monthly by base staff / Base staff provides data *via* email
Equipment status indicators	Building Automation System (variables recorded providing indications of air/water temperatures, valve and fan settings, etc.)	15 minutes	Data logged in SQL database in Building 59 / Demo team regularly burns CDs with copies of the database info
Equipment electrical current (Electrical current is measured on several critical pieces of equipment, i.e. chillers)	HOBO U12 Data Loggers	15 minutes	Data is acquired by demo team *via* laptop connection to data logger on a regular basis

During the demonstration, the data obtained from each of the streams identified in Table 5-3 allowed the team to quantify the effectiveness of its approach. The primary data streams for validation were the electrical energy, gas consumption, and waterfall schedules. Other data streams, such as equipment status information from the BAS, were helpful for identifying the rationale for observed changes in energy consumption.

Data from the CMS was backed up for archiving purposes during period visits by the Geosyntec and/or UNCC team. These tasks were typically performed monthly.

5.6 EQUIPMENT CALIBRATION AND DATA QUALITY ISSUES

The CMS collected time stamped building usage and mode data. Building usage data from the CMS were compared to the Waterfall on a monthly basis and operational mode data from the CMS were be compared to the mode data in the JCI. Data analysis was performed as described in Section 6.2 to identify calibration and data quality issues.

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6.0 PERFORMANCE ASSESSMENT

This section summarizes the performance assessment. First, we describe some of the assumptions that underlie the expected performance. Subsequently, we analyze the actual system performance. Since the CMS is intended to drive behavioral change, we focus specifically on measures of behavioral change and then examine energy metrics, specifically electricity consumption, that would be impacted by behavioral change. Finally, we present a summary of the potential energy savings and list several potential opportunities for savings in Building 59 that were outside of the scope of this project. Note that these data sets were generated from the raw data sources indicated in Section 5. In addition, monthly electricity data was used to develop validation models.

6.1 OVERVIEW

Building 59 is one of the highest energy consumers at RAFB. Although the building and its operations are somewhat complex, its energy requirements are a straightforward function of a limited number of independent variables. Fundamentally, the building is used to paint and de-paint large cargo-carrying aircraft. The chemicals and processes required to perform these functions impose two primary constraints on the use of energy. First, for paint and other chemicals to be properly applied to the aircraft, building systems must maintain a strict set of dry bulb temperatures and relative humidity levels. Second, for building staff to remain safe and healthy during the required processes, a significant volume of outside air must be introduced and moved through the building. Figure 6-1 shows how these requirements should relate to energy consumption. While an aircraft is in the building, there are certain specific tasks that may be performed during any given shift. For example, staff may be sanding the aircraft, preparing it for painting, or actively applying paint. During any one of these activities, staff should select one of a limited set of building modes. In 59P, there are four mode choices that determine two specific items:

- The air flow, and hence the number of fans that are turned on
- Whether or not the chiller and boiler plant are engaged and functional

In 59D, on the other hand, there are only two mode choices – one that engages the fans and loads the chiller plant and one that does not. Once a mode combination has been selected, the variable speed drives on the fans engage at a pre-determined level and the fan power is set. When operating in modes that require space conditioning, the load on the chiller and boiler plant are largely a function of outside air temperature and the state of maintenance in the facility. This latter point is explored more deeply below, but there are occasionally conditions when as many as 5 chillers are required even though the environmental conditions would not seem to fully dictate the need. In addition, the building has additional loads such as lighting and office equipment that provide a base level of consumption.

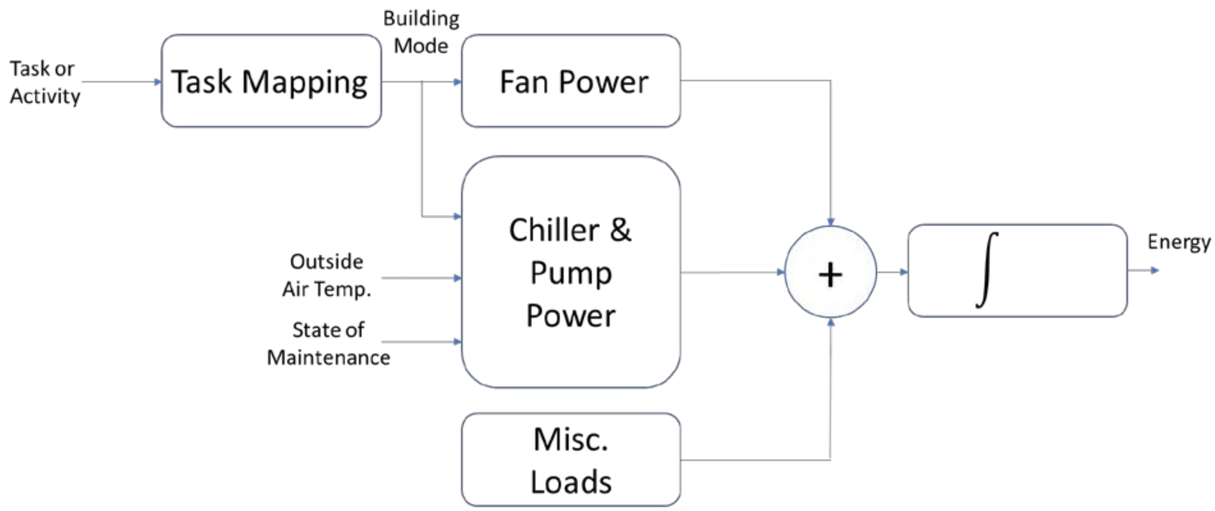

Figure 6-1. The Energy Flow through Building 59.

Excess energy consumption, i.e. wasted energy, in B59 is largely a function of two elements: the central plant operation and task mapping. The first driver of energy waste, control of the central energy plant and the associated fluid-distribution systems does not appear to be well tuned. This issue is evaluated below, but it is not the primary focus of this work and thus it overall contribution to energy waste is not deeply explored. Common indicators of poorly tuned operations were observed, including frequent high levels of simultaneous heating and cooling, low temperature differences between supply and return chilled water, and extremely narrow deadbands for temperature control in the main hangars. The main emphasis of this project is the second driver of energy consumption, which is the “Task Mapping” shown in Figure 6-1. As noted previously, the building has various operational modes, and these dictate air flows and whether the chiller and boiler plant are required. Table 5-1 listed the four modes for Building 59P and the two modes for Building 59D. That table also presented the key operational parameters for each mode, including air flows, dry bulb temperature, and relative humidity. Note that the airflow ranges are relatively large, but extensive observations have indicated that the fans are programmed to provide a nearly constant volume when in any given mode. Whenever the fans are engaged, the only variation in fan power comes from the exhaust fans which modulate their speeds to maintain proper pressurization within the facility. Figure 6-2 shows an example. Note that the outdoor air handling unit fan runs at a constant power and the exhaust fan power varies. This behavior is observed across all fans.

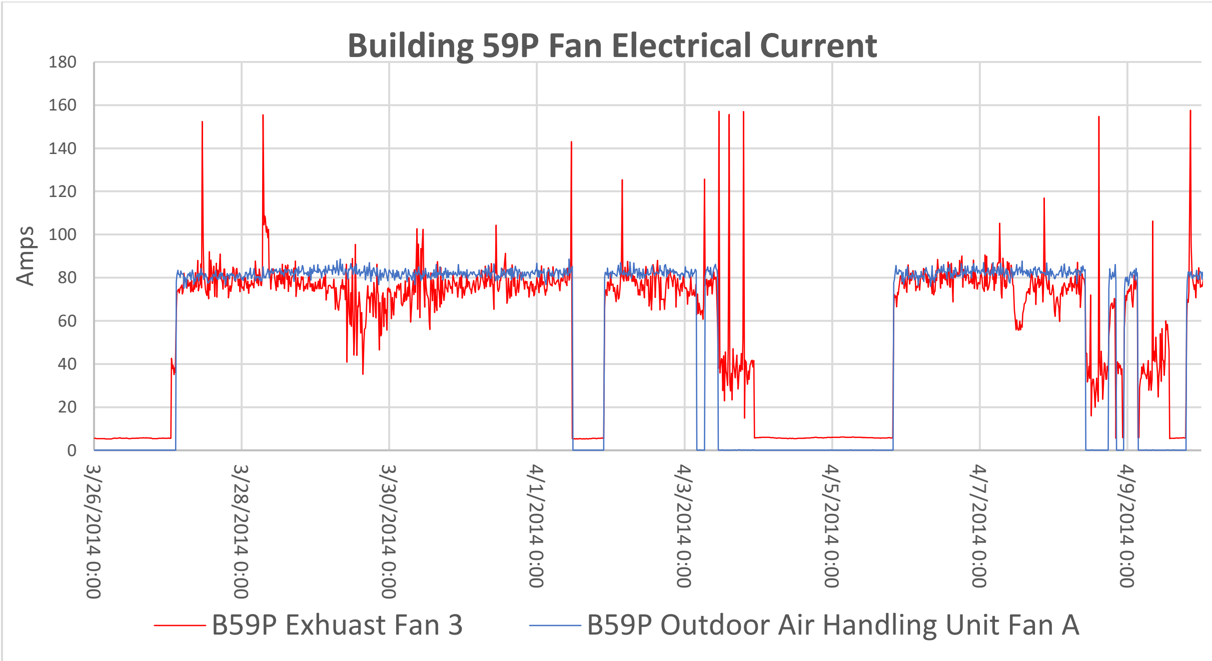

Figure 6-2. Current Drawn by Two Different Fans in B59P.

Note that the exhaust fan varies, and the outdoor air handling unit fan does not. The same is true for all other AHU fans.

Early in the project, the team observed that the "Task Mapping" process appeared to be ad hoc and driven largely by personnel comfort rather than by the needs of the processes performed in the building. Prior to the demonstration period, the project team carefully investigated various task orders and interviewed various base staff. Table 6-1 presents the "ideal" mapping determined through this process. The table is based on the work flow during a nominal job with no major slowdowns or specific difficulties. Each line in the chart lists the tasks to be performed during each shift. It also lists the mode that base staff believe should be used. Given this set of mappings for a nominal, nine-day job, Figure 6-3 shows the percentage of time that the building should be in each mode. By comparison, Figure 6-4 shows the percent of time that Building 59P remains in Paint & Chemical mode, which is the most energy intensive, during all recorded paint jobs in fiscal years 2015, 2016, and 2017 respectively[9]. On average 60% of paint-job time was spent in Paint & Chemical mode, which is significantly higher than the 25% predicted for a nominal job. The core concept of this project was to deploy the CMS Dashboard to drive this 60% closer to its predicted value on a more consistent basis. Given that such a mapping had never been created before, as described in Section 5.1, the hypothesis tested here was that energy waste could be partially eliminated by providing the appropriate awareness to both painters and their supervisors.

The remaining sub-sections quantify the impact of the proposed solution during the demonstration period as well as the potential opportunity from its proper implementation. There is also a discussion about potential additional savings from a more thorough review of the task-mapping process and commentary on the benefits of improved operations.

[9] Note that fiscal year 2015 spans from October 1, 2014 to September 30, 2015, etc.

Table 6-1. The Mapping Between Paint-Job-Related Tasks and Building Modes during a Nominal Paint Job in Building 59P.

	Shift	Activity	Correct Mode
Day 1	Day	Prep/Inspection/Jack	Unoccupied
	Swing	Mask	Non-Chemical
	Owl	Prime & Paint Wheel Wells	Paint & Chemical
Day 2	Day	Demask Wheel Wells & Retract Gears	Unoccupied
	Swing	Demask Wheel Wells & Retract Gears	Unoccupied
	Owl	Demask Wheel Wells & Retract Gears	Unoccupied
Day 3	Day	Sand	Paint & Chemical
	Swing	Sand	Paint & Chemical
	Owl	Sand	Paint & Chemical
Day 4	Day	Sealing & Cure	Non-Chemical
	Swing	Sealing & Cure	Non-Chemical
	Owl	Sealing & Cure	Non-Chemical
Day 5	Day	Wash	Unoccupied
	Swing	Apply PRC/PreKote	Non-Chemical
	Owl	Prime	Paint & Chemical
Day 6	Day	Apply Topcoat/Cure	Paint & Chemical
	Swing	Demask	Non-Chemical
	Owl	Apply Special Coatings/Apply Stencil	Paint & Chemical
Day 7	Day	Apply Stencil	Non-Chemical
	Swing	Apply Stencil	Non-Chemical
	Owl	Apply Stencil	Non-Chemical
Day 8	Day	Wet Tape Test	Non-Chemical
	Swing	After Paint Inspection	Unoccupied
	Owl	After Paint Inspection	Unoccupied
Day 9	Day	Tow for Weight and Balance	Unoccupied

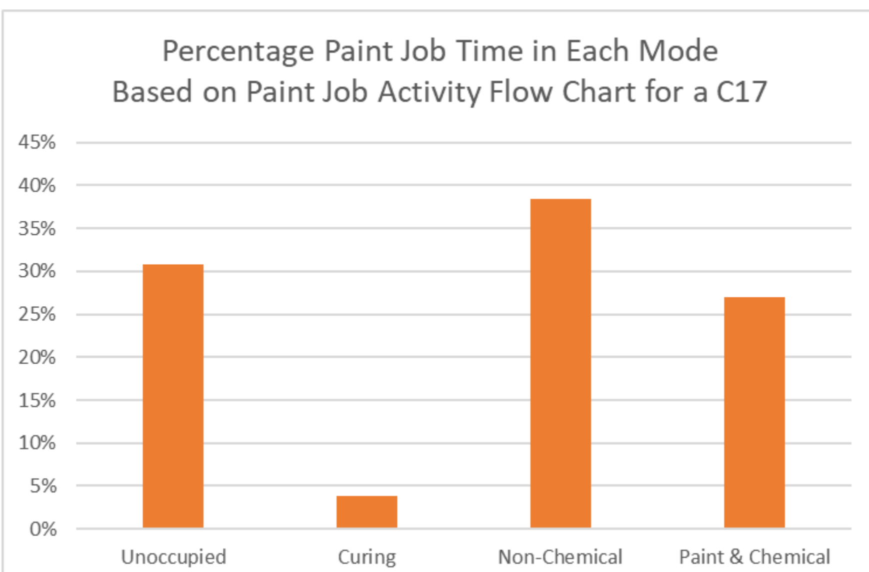

Figure 6-3. Percent of Time in Each Mode during the Nominal Nine-day Paint Job Described in Table 6-1.

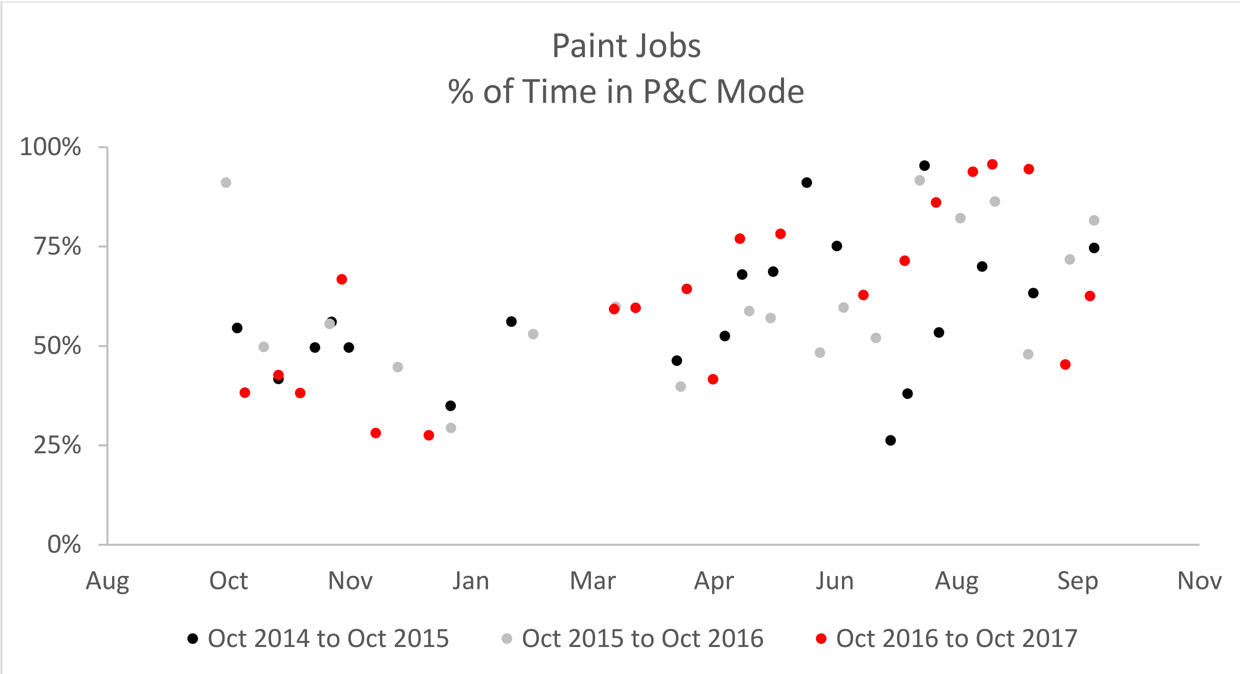

Figure 6-4. Percent of Time in Paint & Chemical Mode in Three Consecutive Fiscal Years.

6.2 IMPACT ANALYSIS

The demonstration period for the CMS Dashboard was Fiscal Year 2017 (October 2016-September 2017). To quantify the impact of the tool, the team compared key measures before and after the deployment of the CMS Dashboard. Given that the key focus was to drive a consistent change in the mapping between tasks and modes, the team compared mode usage in the demonstration period to that in the previous years. In addition, the team also investigated the energy consumption before and after the deployment. As demonstrated here, the tool did not appear to impact mode mapping and thus no measurable energy savings was achieved. Subsequent sections describe the institutional barriers that the team believes made the tool ineffective.

Impact on Mode Usage

Figure 6-4 demonstrates the lack of impact on mode usage. This graph compares the percent of paint-job time spent in Paint & Chemical mode for two years before the deployment to that observed during the demonstration period. Note that there is significant spread in the data and that some amount of seasonal variation is observed. Table 6-2 summarizes the average amount of time spent in Paint & Chemical mode per paint job in each of the three years considered in Figure 6-4. On average, 61% of paint-job time was spent in Paint & Chemical mode in the two years before the CMS Dashboard was introduced, compared to 62% afterward. This finding suggests a clear lack of impact.

Table 6-2. Average Percentage of Each Paint Job Spent in Paint & Chemical Mode.

	Paint Job Time in Paint & Chemical Mode
Oct 1st, 2014 through Sep 30th, 2015	**58%**
Oct 1st, 2015 through Sep 30th, 2016	**61%**
Oct 1st, 2016 through Oct 31st, 2017	**62%**

It is noted that there appears to be a seasonal variation in the use of Paint & Chemical mode. Jobs performed in hotter months tend to have a larger percentage of time in Paint & Chemical mode. Jobs performed during cooler months (October to April) generally utilize this more energy-intensive mode for about 25 to 50% of their duration. This is much closer to the amount expected based on a nominal job schedule.

The seasonal variation apparent in Figure 6-4 can be deceptive, as one might at first expect this variation to be normal. However, as shown by the basic energy flow presented in Figure 6-1 and the interior climate settings summarized in Table 5-1, the mode selection simply determines how much air flow occurs in the hangar and whether space conditioning is required. Table 5-1 shows that the temperature and humidity conditions inside the hangar should be the same when using either paint and chemical mode or non-chemical mode. As a result, energy consumption in any given mode should increase when the outside air temperature is hotter, but mode usage should be unaffected.

Given that human comfort is impacted by air speed[10], it is possible that building staff feel more comfortable in Paint & Chemical mode. That said, the higher air flows may provide an ability to cool the building faster if it was previously unoccupied. Such an operational efficiency may be desired under some conditions. Once cooled, however, there should be no lingering need for the use of Paint & Chemical mode and thus outside air temperature should not have a significant impact on mode usage. The correlation between seasonal outside air temperature and mode usage suggests that facility personnel are unfamiliar with building mode utilization and subsequent energy consumption and costs. Given the energy intensity of such a facility and the significance of energy management for the DoD, a higher level of training and technical support should be expected to guide decision making.

Mode usage data was further evaluated to identify potentially underlying reasons why the mode usage had not changed and if there are activities during which building staff are especially unlikely to use the a more energy intensive mode. Knowing the latter could help to focus appropriate educational programs. Figure 6-5 shows the distribution of activities by shift during the two years observed between October 2015 and November 2017. This distribution was generated from the "Waterfall" documents created by base staff to plan and log activities by shift.

It should be noted that the waterfall documents often did not contain sufficient detail to determine exact activity in the building on an individual shift basis. Among the 2094 shifts during which an aircraft was actively inside Building 59P during the two years between October 2015 and November 2017, some 1565 lacked comments or comments did not have enough details to determine an exact activity, although the sequence of operations allowed the team to estimate activities.

[10] Reference: ASHRAE Standard 55

In addition, the lack of detailed comments increased during the demonstration period, with some 946 of 1124 shifts not having detailed information, only tow-in and tow-out dates. The provided information does indicate, however, that many shifts are spent dedicated to sealing, sanding, applying topcoat, masking, and stenciling.

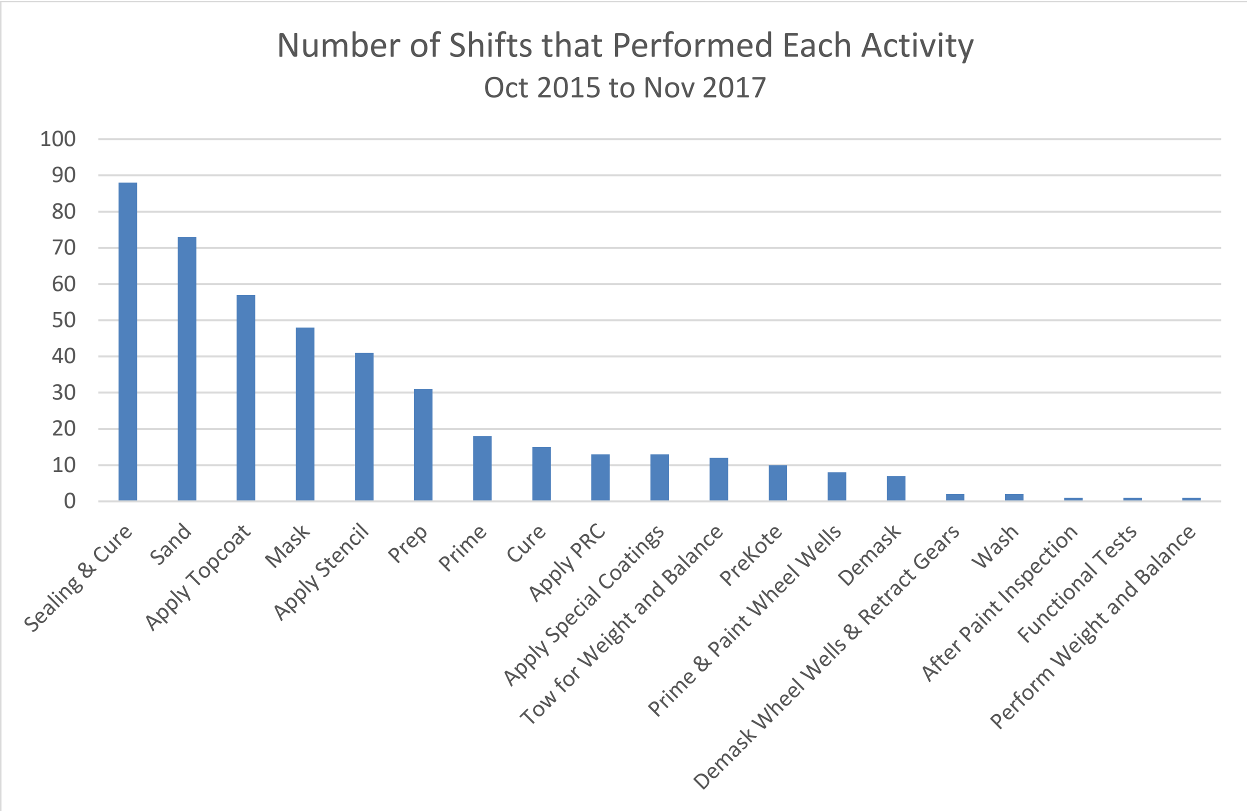

Figure 6-5. Distribution of activities by shift between October 2015 and November 2017.[11]

To explore whether certain activities were more likely to use the incorrect mode, we explored mode selection for the five most common activities. Detailed comments during the demonstration period were provided for shifts between October 2016 and March 2017, thus while representative, the analysis is somewhat truncated. Figure 6-6 through Figure 6-10 compare mode usage for similar tasks performed in the same parts of the year before and after the installation of the CMS Dashboard (i.e. October – March). Several trends are apparent in these graphs. First, mode usage does not appear to be well correlated to task. For example, all modes except "Curing" appear to be almost as likely to be used for a task such as "sealing and curing." Second, it is clear that "Paint and Chemical" mode is often the most frequently used. If one were to explore jobs performed during the warmer months of the year, this frequency would only increase.

[11] This distribution includes only shifts for which comments were provided by base staff. Of the total 2094 shifts, only 529 had associated comments.

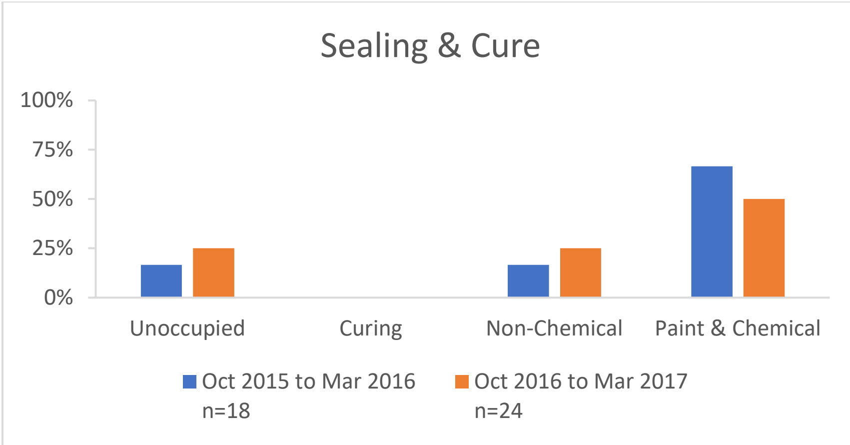

Figure 6-6. Mode Usage for Sealing & Curing for Shifts Occurring between October and March.

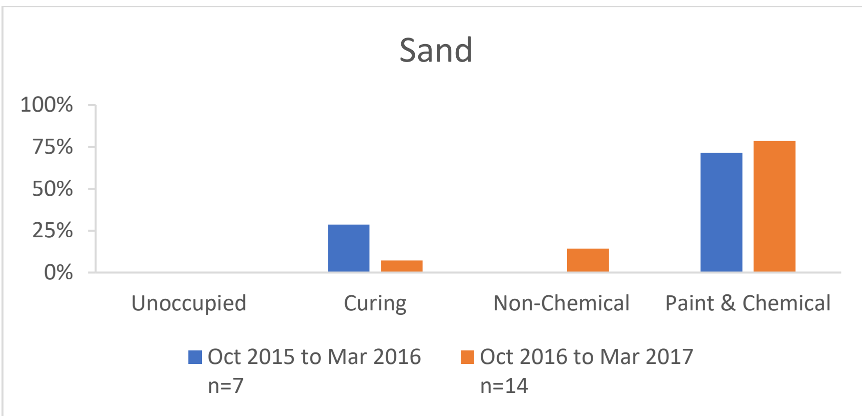

Figure 6-7. Mode Usage for Sanding for Shifts Occurring between October and March.

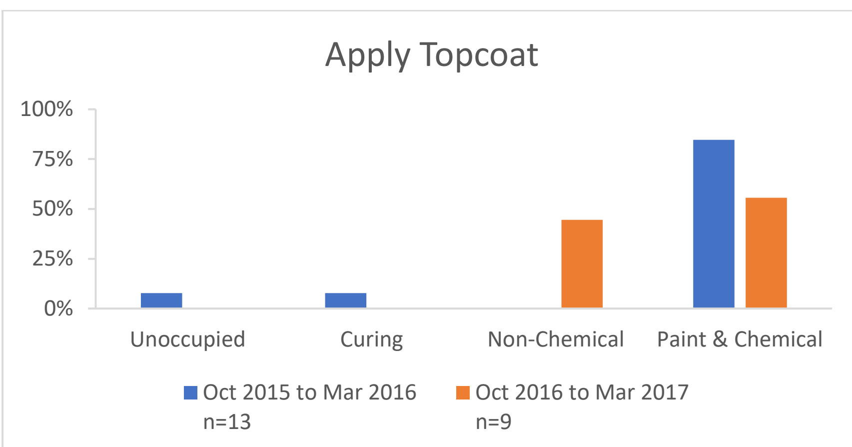

Figure 6-8. Mode Usage for Applying Topcoat for Shifts Occurring between October and March.

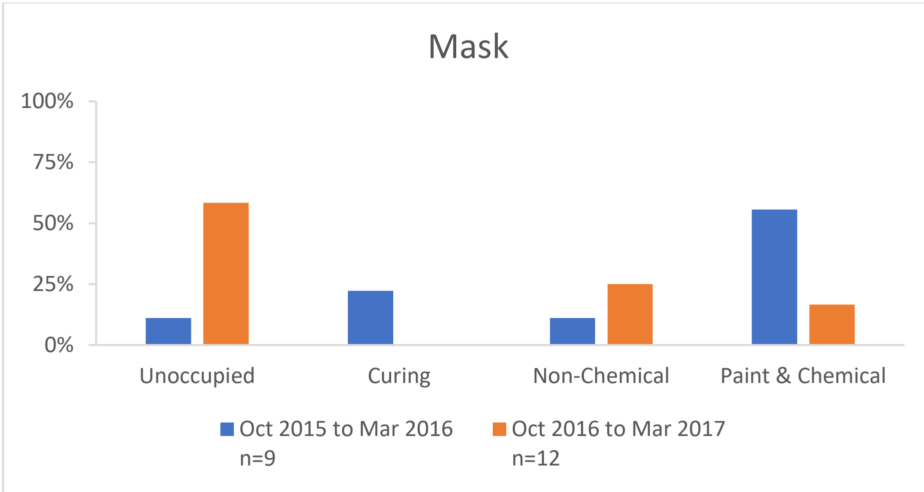

Figure 6-9. Mode Usage for Masking for Shifts Occurring between October and March.

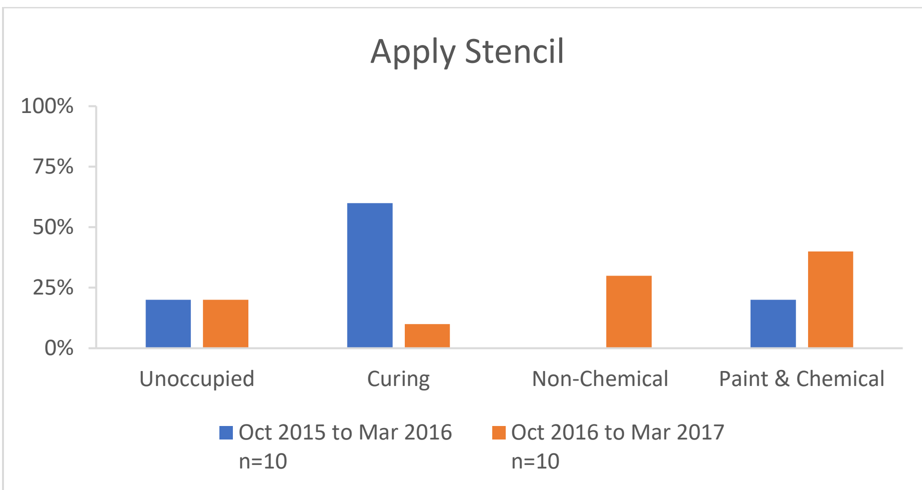

Figure 6-10. Mode Usage for Applying Stencils for Shifts Occurring between October and March.

Figure 6-6 through Figure 6-10 do suggest a general drop in the usage of more energy-intensive modes before and after the installation of the CMS Dashboard, but the reasons for the change are unknown. There are several interesting questions that arise from these trends. Most importantly, it appears that mode selection tends to be driven more significantly by forces other than the task to be performed. For instance, if we examine a task such as "masking," we note a significant increase in the percentage of shifts that used unoccupied mode before and after the CMS Dashboard was installed. This change was unexpected and is not, in fact, recommended by the Dashboard. During our initial analysis, we noted that tasks such as "masking" were often performed in an unoccupied state and analysis of materials safety data sheets for chemicals used during this activity did not indicate that any special ventilation requirements were needed. That said, we noted that base staff often used other more energy-intensive modes.

To help drive greater acceptance of the proper task mapping, the “non-chemical” mode was recommended by the CMS for many activities such as “masking.” Although increased use of the “unoccupied” mode for this task represents a positive change in energy usage, it also indicates that mode selections are not consistent with tasks that are being performed. The team believes that the change in the mode usage for this task was likely driven by the fact that masking was performed on mild days during the demonstration period or during shifts when more energy-conscience supervisors were present.

Impact on Electricity Consumption

As noted previously, electricity consumption in Building 59 during any given shift should be a function of the task or activity performed during that shift. As a result, annual energy consumption should depend on production levels. In other words, in years when more aircraft are painted, energy consumption should rise. Figure 6-1 indicates that fan energy is the most direct measure of the change in energy consumption since fan power is primarily a function of mode selection. Thus, fan energy is weather-independent. If production levels in two different years are exactly identical, then a difference in fan energy would most probably be caused by mode selections. Table 6-3 compares Building 59P fan-energy consumption in FY2016 and FY2017. The first column indicates the total number of “job days” in each year. As we define it, “job days” are days on which an aircraft is in the building. At any given time, there are several “job types” that might be underway. Broadly speaking, there are three job types:

- Painting: This category includes two types of jobs. The first is full paint jobs that begin with a fully de-painted aircraft. The other type is a touch-up jobs that involves some form of small touch-up on a previously painted aircraft.
- De-painting: This category includes jobs in which paint is being removed from the aircraft using a chemical process. This occasionally occurs in Building 59P.
- Other: There are several other jobs that might occur although much less frequently. The first type is a “sand/scuff.” This typically involves a short sanding and scuffing to remove paint from some parts of the aircraft. This is typically followed by a “paint job.” The other type of process that sometimes occurs in the Building 59P is a washing process. These job types occur far less frequently than the first two.

Table 6-3 shows that production levels are relatively high, with nearly every day of the year listed as a "job day." Since we were primarily focused on the act of painting, we specifically examined "paint job days." These are days in which task logs or extrapolated task logs indicate that building staff are performing activities associated with the painting category. Note that most days fall into this group. On these days, fan energy consumption should largely be a function of mode usage. If appropriate modes were selected, then the amount of fan energy per day should have been different in the two years. Given that mode selection behaviors did not change, we did not expect a significant change in fan energy.

Table 6-3. Comparison Between Fan Energy Used per Paint-job Day in FY 2016 and FY2017 in Building 59P.

	Total Job Days	Total Paint Job Days	% Paint Job Days	Total Fan Energy Used on Paint Job Days (kWh)	Fan Energy Per Paint Job Day (kWh)
10/1/2015 to 9/30/2016	347	248	71.5%	5,215,176	21,029
10/1/2016 to 9/30/2017	354	299	84.5%	6,410,329	21,439

To complete a comparison of electricity consumption, we developed a weather-normalized whole-building energy model compliant with the IPMVP approach. Monthly data from FY 2015 and FY 2016 was used to develop a baseline model. An analysis of the data indicated that there were four independent variables. These include the following:

- Average outside air temperature (OAT) during the given month
- Number of job days in each major category each month. Since there are three major categories, we utilized three independent variables:
  - Number of "Paint Job Days" and “Other Job Days” in Building 59P
  - Number of "Depaint Job Days" in Building 59P
  - Number of hours spent in the "Stripping" mode in Building 59D

Again, since the type of activity reflects production and production relates to energy, these additional variables needed to be included. Fifteen monthly values were used, and a multi-variate regression was performed.

Table 6-4 presents the relevant model parameters, and Table 6-5 presents the relevant regression statistics. These values suggest confidence in the model fit.

Figure 6-11 compares the predicted and actual whole-building energy consumption before and after the installation of the CMS. Note that both the predicted energy and the actual energy remain relatively close to each other during the demonstration period. Once again, this result is expected since the behavior noted above did not change.

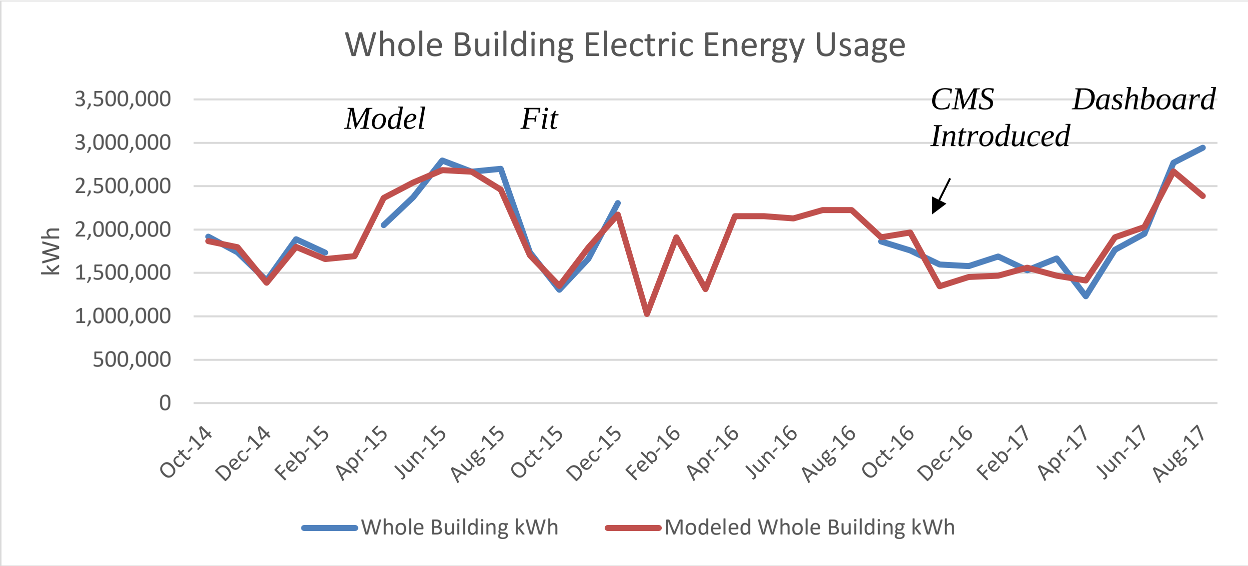

Figure 6-11. Predicted and Actual Whole-building Electricity Usage Before and After the Installation of the CMS.

Table 6-4. Parameter Values from the Inverse Energy Model

	Coefficients
Intercept	-1,075,846
B59P Paint Job & Other Job Days	30,911
B59P Depaint Job Days	28,062
B59D - Hours in Stripping	1,876
Av OAT	23,511

Table 6-5. Regression Statistics from the Multi-variate Regression for Monthly Electricity

Regression Statistics	
Multiple R	0.956131871
R Square	0.914188155
Adjusted R Square	0.879863417
Standard Error	160161.5104
Observations	15

6.3 ENERGY SAVINGS POTENTIAL IN BUILDING 59 AND THE NEED FOR IMPROVED AUTOMATION

The results presented in the previous sections indicate that the CMS did not change the behaviors of B59 staff and thus energy consumption did not achieve the performance targets. Several reasons for this are discussed in Section 8, however potential energy savings at B59 are still significant. Therefore, this section describes both the potential for energy savings simply from improved building usage as well as from improved commissioning.

To predict the potential savings from improved building usage, the team returned to Figure 6-1. As shown by this figure, the energy consumption in Building 59P is a function of outside air temperature, the state of maintenance, and the mapping between tasks and modes. The core thesis of this project was that the CMS could impact that mapping. Had it been able to do so, Figure 6-1 indicates that there would have been two potential changes:

- Fan energy, which is approximately constant in any given mode, would have decreased.
- Chiller energy, which is weather-dependent, would also have decreased since the modes that require conditioning would have been used less frequently.

To compute the potential savings from these two sources, the team developed a more detailed model for both fan energy and chiller energy. Since fan energy is weather-independent, we simply note that improved mode usage would have directly led to lower energy consumption. Table 6-1 lists the appropriate mode for each task. These suggestions are the same as the ones loaded into the CMS and developed based on Task Orders and discussions with base staff. To compute potential fan energy savings, the team did the following:

- Step 1: Compute actual fan energy consumption by shift
- Step 2: Compute the predicted fan energy consumption if the appropriate mode had been selected in each shift.

Figure 6-12 demonstrates this process. The top graph shows the actual fan energy consumption by shift from September 30, 2015 to September 30, 2017. As mentioned earlier, detailed shift activities were not available for many of the shifts, and thus there are significant time periods for which no data was available. For clarity, these gaps in the x-axis are removed from Figure 6-12. Note that the middle graph shows fan energy based on correct mode usage for the same time periods. The bottom graph shows the potential savings, which is the difference between the top and bottom graphs. Across the period shown in Figure 6-12, the fan energy savings is 16.9%.

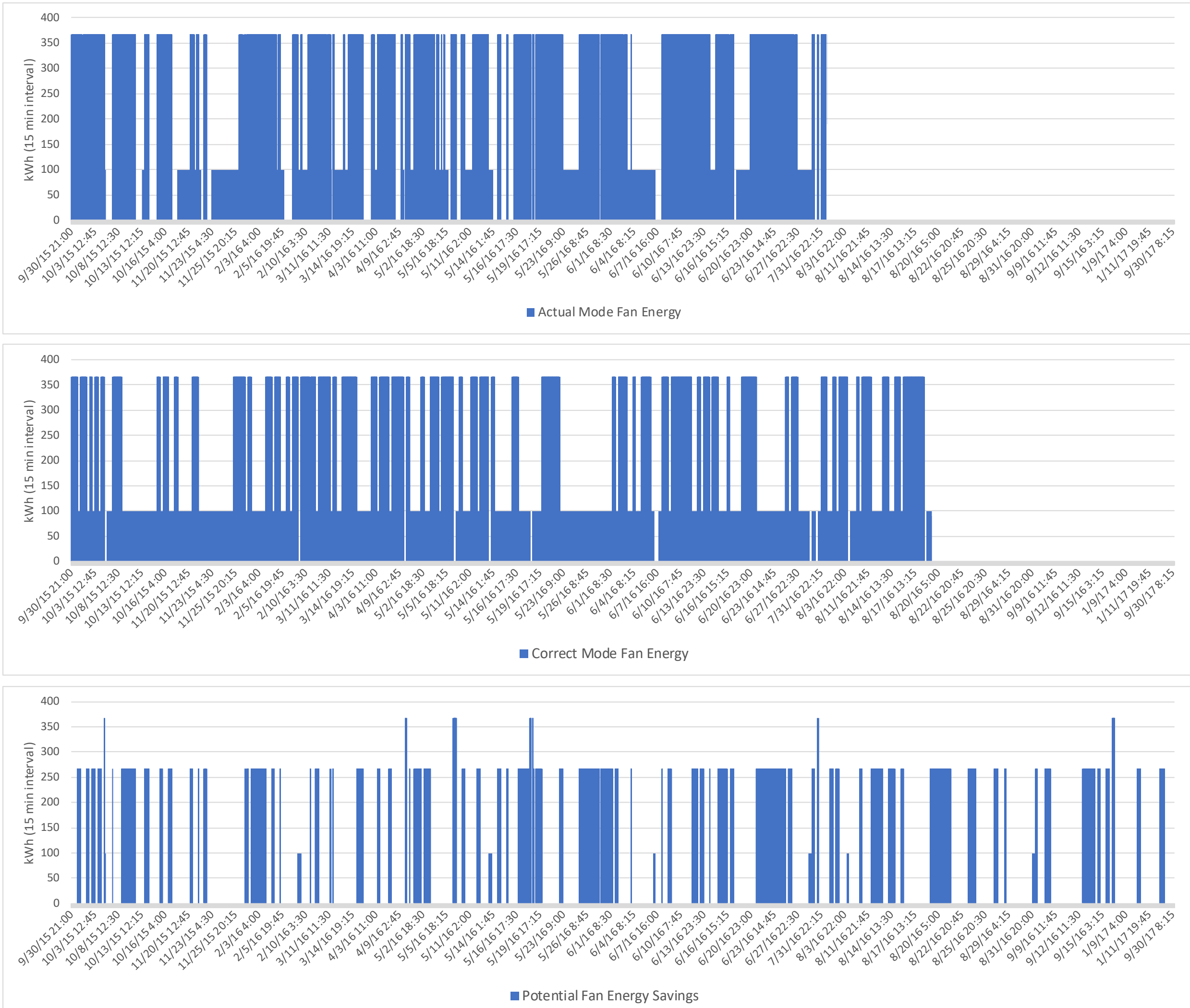

Figure 6-12. Potential Savings in Fan Energy Between September 30, 2015 and September 30, 2017.

Top: Actual fan energy consumption by shift. Middle: Predicted energy consumption based on appropriate mode selection. Bottom: The difference between the first two graphs (i.e. the savings).

Chiller-plant energy is significantly more complicated than fan energy. First, the amount of energy required to cool the building should be weather dependent. Second, an investigation of Building 59P found that the number of chillers operational at any given time did not always correlate with load. For instance, the team found cool-weather conditions in which all 5 chillers were operational and warm-weather conditions when fewer chillers were operational. This behavior is consistent with our field observations, in which we found that the chiller plant was often in need of repairs.

To accurately model chiller plant energy, the team developed a series of regression models whose dependent variable was daily chiller plant energy and whose independent variables were the following:

- Average daily outdoor air temperature (OAT)
- Number of chillers operational (This was obtained from the Building Automation System)

- Building 59P mode
- Building 59D mode

A separate second-order regression model was created for each combination of B59P mode, B59D mode, and the number of chillers active. Table 6-6 presents the models and correlation coefficients for each case. Note that the "x" variable in each model is the average daily outside air temperature.

Table 6-6. Regression Models for Each Combination of Modes and Number of Chillers.

The variable "x" is the average daily outdoor air temperature.

B59P Mode	B59D Mode	# of Chillers	Model	R^2	# of Samples
Unoccupied	Non-Stripping	1	-	-	1
Unoccupied	Non-Stripping	2	0.2071x^2 - 27.04x + 1049.5	0.11	76
Unoccupied	Non-Stripping	3	-	-	3
Unoccupied	Non-Stripping	4	-	-	5
Unoccupied	Non-Stripping	5	-	-	0
Unoccupied	Stripping	1	-	-	0
Unoccupied	Stripping	2	0.4844x^2 - 52.074x + 1740.6	0.73	22
Unoccupied	Stripping	3	0.5434x^2 - 56.297x + 1789.7	0.76	65
Unoccupied	Stripping	4	0.3316x^2 - 29.354x + 1055.3	0.77	70
Unoccupied	Stripping	5	0.3602x^2 - 34.95x + 1413.9	0.53	157
Curing	Non-Stripping	1	-	-	0
Curing	Non-Stripping	2	-	-	2
Curing	Non-Stripping	3	-0.0534x^2 + 11.435x - 139.01	0.07	35
Curing	Non-Stripping	4	2.0389x^2 - 247.36x + 7859.6	0.55	28
Curing	Non-Stripping	5	-0.5454x^2 + 89.137x - 2950.8	0.76	17
Curing	Stripping	1	-	-	3
Curing	Stripping	2	0.3604x^2 - 32.157x + 1009.5	0.83	29
Curing	Stripping	3	0.0391x^2 + 10.431x - 242.86	0.44	133
Curing	Stripping	4	0.4143x^2 - 38.333x + 1341.6	0.31	69
Curing	Stripping	5	0.8614x^2 - 94.688x + 3182.6	0.89	44
Non-Chemical	Non-Stripping	1	-	-	0
Non-Chemical	Non-Stripping	2	0.4855x^2 - 72.52x + 3219.3	0.28	23
Non-Chemical	Non-Stripping	3	-0.5269x^2 + 86.414x - 3080	0.73	14
Non-Chemical	Non-Stripping	4	-0.2785x^2 + 50.567x - 1713	0.41	97
Non-Chemical	Non-Stripping	5	-0.281x^2 + 47.632x - 1432.2	0.17	103
Non-Chemical	Stripping	1	-	-	0
Non-Chemical	Stripping	2	0.4855x^2 - 72.52x + 3219.3	0.28	23
Non-Chemical	Stripping	3	-0.0127x^2 + 15.04x - 323.51	0.62	85
Non-Chemical	Stripping	4	0.2707x^2 - 18.912x + 756.22	0.93	105
Non-Chemical	Stripping	5	0.1473x^2 - 3.3692x + 402.31	0.71	134
Paint & Chemical	Non-Stripping	1	0.6327x^2 - 67.393x + 1926.1	0.77	22
Paint & Chemical	Non-Stripping	2	0.3309x^2 - 32.658x + 1082.1	0.54	77
Paint & Chemical	Non-Stripping	3	0.2896x^2 - 22.214x + 659.04	0.75	197
Paint & Chemical	Non-Stripping	4	-0.1168x^2 + 37.4x - 1394.6	0.66	520
Paint & Chemical	Non-Stripping	5	-1.0876x^2 + 180.77x - 6559.6	0.54	305
Paint & Chemical	Stripping	1	0.3805x^2 - 55.494x + 2192.5	0.10	65
Paint & Chemical	Stripping	2	-0.0653x^2 + 13.774x - 102.78	0.35	204
Paint & Chemical	Stripping	3	-0.0621x^2 + 24.698x - 730.88	0.79	607
Paint & Chemical	Stripping	4	-0.2713x^2 + 55.1x - 1707.7	0.70	232
Paint & Chemical	Stripping	5	-0.2574x^2 + 64.156x - 2196	0.71	771

Figure 6-13 compares predicted chiller-plant energy consumption to actual chiller-plant energy consumption using the models presented in Table 6-6. The graphs demonstrate the performance over three different periods in 2015. These three periods collectively represent the baseline period for our model. Note the qualitatively close agreement in all three cases. The total CV(RMSE) over this period was 12.7%, which represents exceptional accuracy according to the standards presented in the IPMVP. Note also that the model was most accurate during the summer months when the greatest savings potential exists.

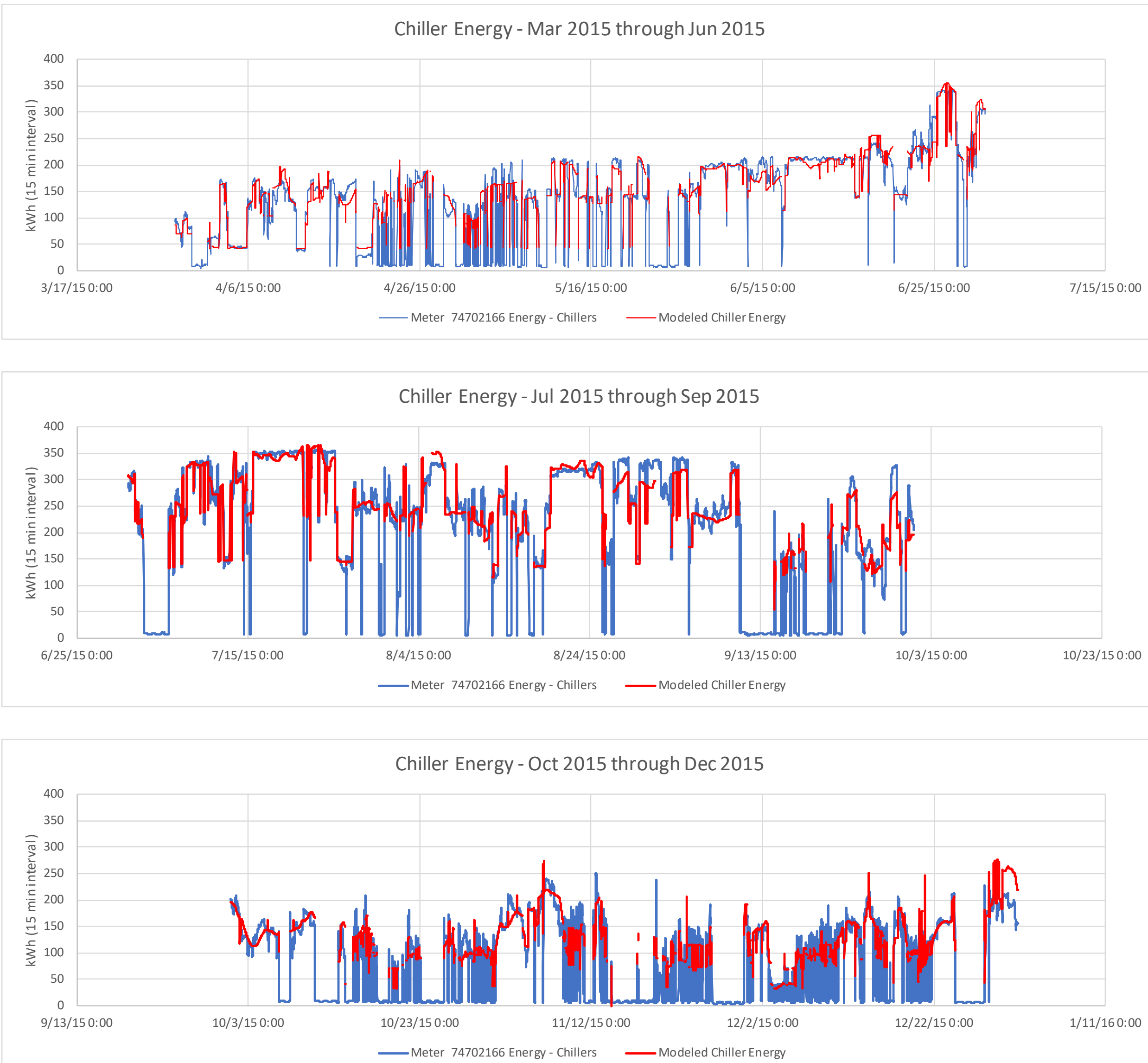

Figure 6-13. Predicted and Actual Chiller-plant Energy Consumption for Three Different Periods in 2015.

To compute the potential savings from improved mode usage, we compared actual chiller-plant energy consumption to that predicted if the correct modes outlined in Table 6-1 had been selected.

Figure 6-14 shows the difference over parts of FY2016. The blue line shows actual or modeled energy consumption based on the actual modes. The orange line shows the predicted consumption assuming correct modes had been selected. Additionally, because of gaps in the available activity logs (i.e. the waterfalls), several time periods are missing from Figure 6-14. In all, only about 20% of the data was available. Across this data, some 10.2% of chiller energy could have been saved. The team thus concluded that proper mode selection would yield a 10.2% drop in chiller-plant energy each year.

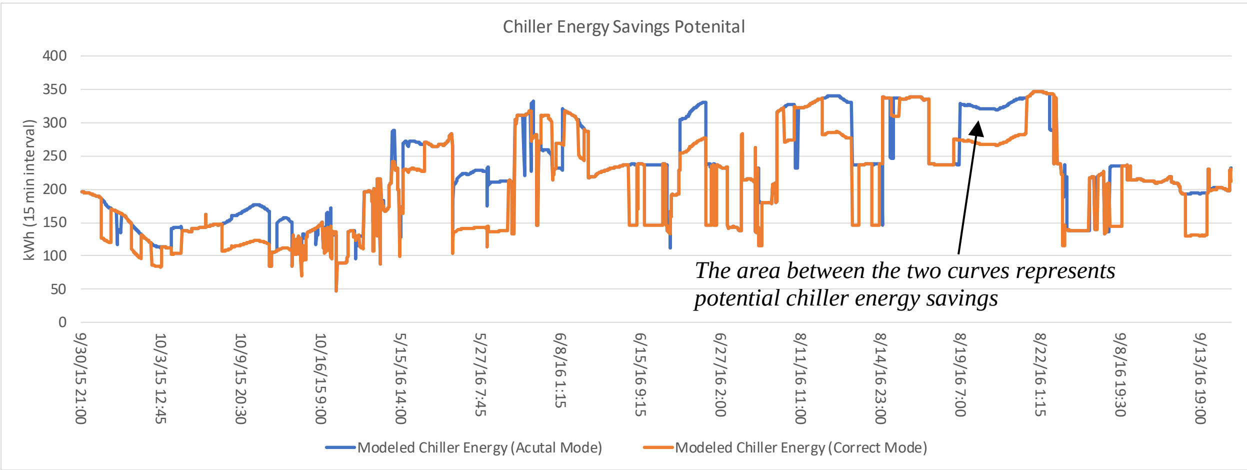

Figure 6-14. Actual Chiller Plant Energy (blue) and Potential Chiller Energy (orange) if Proper Modes Had Been Selected.

Table 6-7 summarizes the estimated annual energy-savings potential based on the two models presented above. In the case of chiller-plant energy, the annualized consumption was calculated using the models described above. In the case of the fan energy, the values were calculated using the known modes. The data needed to generate the modeled energy, which includes modes and the number of operational chillers, was available for nearly all of calendar years 2015-17 so annual values were calculated for these years. The savings were estimated assuming the 16.9% fan-energy savings and 10.2% chiller-energy savings values noted above.

It should be noted that the predicted savings noted in Table 6-7 are lower than those presented in Table 5-2. When the baseline savings were originally calculated for the Demonstration Plan, the team had been informed that "non-chemical" mode was acceptable for "sanding." This activity occurs quite commonly, and base staff now believe that the building should be in "paint & chemical" mode when performing it. This change accounts for most of the difference between this prediction and the original presented in Table 5-2. Regardless, Table 6-7 shows that significant potential savings are achievable simply from improving mode selections.

Table 6-7. Annual Chiller and Fan Energy Savings Estimate

Annual Chiller Energy (kWh)	
CY 2015	5,079,479
CY 2016	6,071,874
CY 2017	6,331,359
Annual Average	5,827,571
Annual Savings % Estimate	10.2%
Annual Savings Estimate	594,412
Combined Chiller and Fan Energy Savings Estimate (kWh)	1,910,482
Annual $ Savings (0.075 $/kWh)	$143,286

Annual Fan Energy - B59P (kWh)	
CY 2015	7,615,762
CY 2016	7,369,621
CY 2017	8,376,804
Annual Average	7,787,396
Annual Savings % Estimate	16.9%
Annual Savings Estimate	1,316,070

Energy-Savings Potential from Improved Controls

In addition to savings opportunities created by improved mode selection, there are also opportunities to reduce energy consumption by improving building control sequences. Figure 6-15 provides one particularly poignant example. The graph shows critical trends from one of Building 59P's outdoor air handling units (OAHU) and hangar space temperature for a single day in March 2016. During this entire period, the hangar was in "Paint & Chemical" mode and the OAHU was supplying the maximum amount of air flow to the hanger. When in this mode, separate AHUs provide recirculated air to the hanger and the OAHU's cooling and heating valves modulate to maintain the hangar's thermostat setpoint. The OAHU's supply air temperature thus varies based on the heating/cooling requirements of the hangar. Figure 6-16 shows a diagram of a representative OAHU for reference.

In Figure 6-15, we note that the hangar temperature was below the thermostat setpoint and little conditioning was needed from the cooling coil valve in the early morning. Around 7AM, the hangar setpoint changed from 78F to 68F. It is unclear why the setpoint changed since the hangar did not change modes. At this point, the hangar space temperature was well above the setpoint, so the OAHU aggressively cooled by opening its cooling coil valve to 100%. The cooling coil remained 100% open even after the space temperature reached the thermostat setpoint at about 10:00 AM. Shortly after this, the reheat valve opened, and the supply air temperature greatly increased. The space temperature responded and rose above the thermostat setpoint. The heating coil valve position then cycled open and closed to keep the space temperature close to the thermostat setpoint. All the while, the cooling coil valve was 100% open. This behavior represents an extremely inefficient way to maintain a setpoint, and a controls vendor should be asked to review the control sequence.

Additional inefficiency is noted around 3PM, when the hangar thermostat setpoint changed from 68F to 78F. The heating coil valve responded by opening and aggressively heating the supply air. At the same time, the cooling coil valve remained 100% open. The hangar space temperature responds by rising. Before the hangar space temperature has reached the new setpoint, the heating coil valve closed completely, and the hangar temperature remained about 5F below the 78F setpoint. Once the heating valve closed, the cooling-coil valve also began to close, but it quickly opened to 100% again after the heating-coil valve completely closed.

This behavior represents three critical inefficiencies often observed in Building 59P:

- The lack of a thermostat deadband
  - This is the difference in degrees between when cooling and heating happens
  - A small deadband results in cycling between heating and cooling
  - Building 59P appears to condition the hangar temperature to a very narrow deadband around the current setpoint
  - A deadband of at least 3F is recommended
- The sudden change of hangar thermostat setpoint
  - It is not clear why the hangar thermostat setpoint changes frequently while not changing modes
  - This behavior results in aggressive cooling followed directly by aggressive heating
- Simultaneous heating and cooling
  - Often the cooling coil valve remains at 100% open even when the heating valve is open in response to the hangar space temperature being below the thermostat setpoint

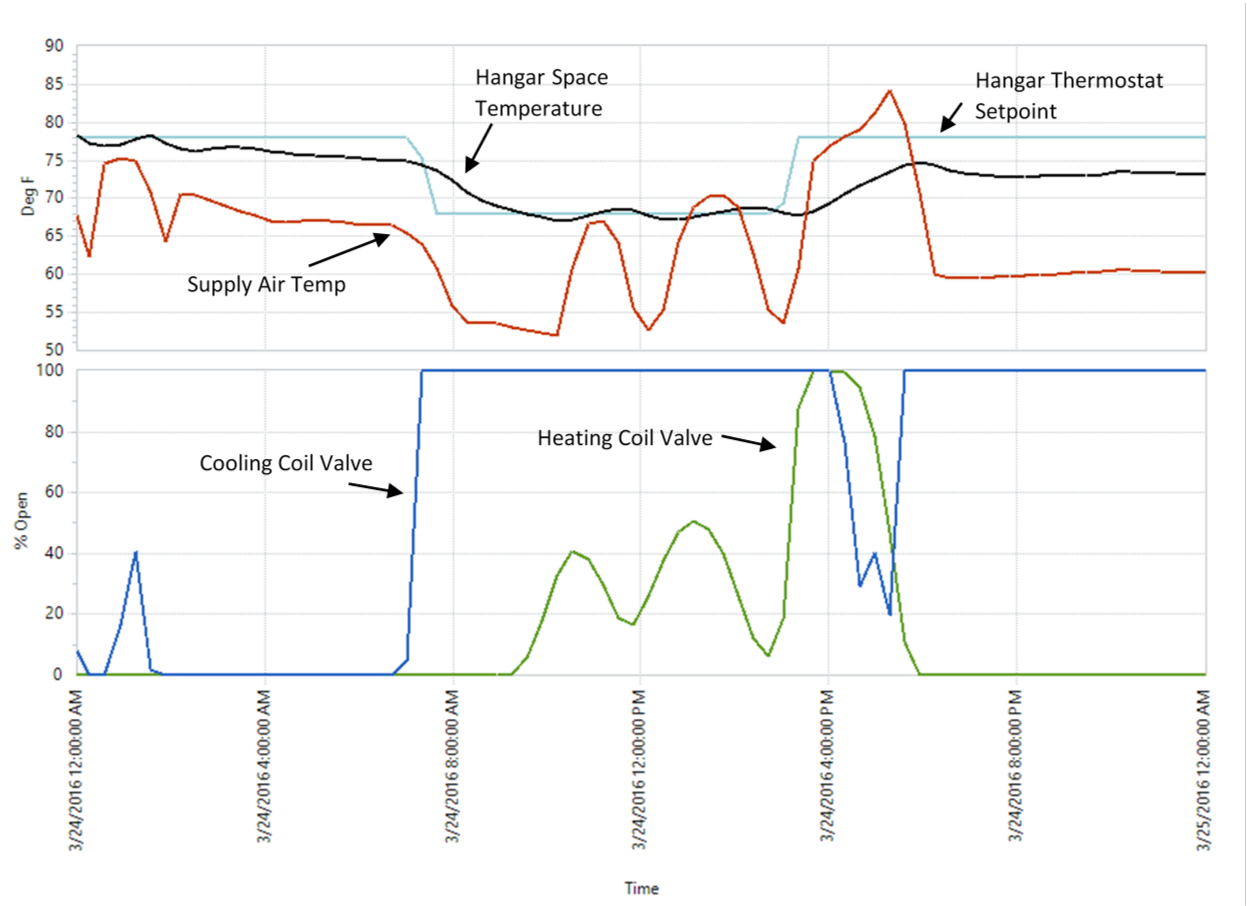

Figure 6-15. Critical Control Signals for One of Building 59P's Outdoor AHU's on a Day in March 2016.

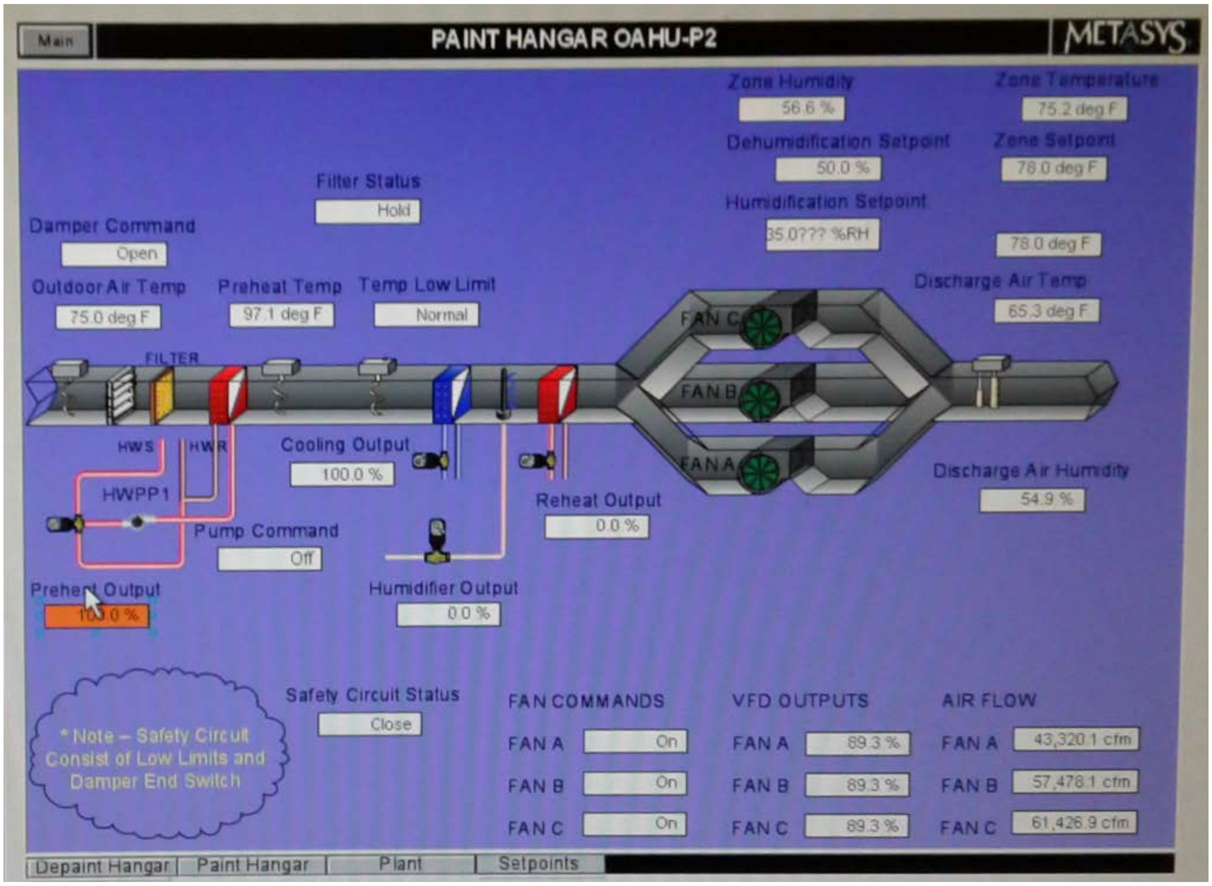

Figure 6-16. Screenshot Showing the Layout of One of the Outside Air Handling Units in Building 59P.

7.0 COST ASSESSMENT

7.1 COST MODEL

A cost model for the CMS is provided in Table 7-1.

Figure 7-1. CMS Cost Elements

Cost Element	Data Tracked During the Demonstration
Hardware capital costs	Estimates made based on component costs for demonstration
Installation costs	Labor and material required to install
Facility operational costs	Reduction in energy required vs. baseline data
Maintenance	• Frequency of required maintenance • Labor and material per maintenance action
Hardware lifetime	Estimate based on components degradation during demonstration
Operator training	Estimate of training costs required

7.1.1 Hardware Capital Costs

The hardware capital costs are attributed to the computers, monitors, peripherals, and back-up power supplies installed alongside the JCI Metasys® terminals. Two sets of digital signage systems were purchased per RAFB requirements for approximately $5,000.

7.1.2 Installation Costs

Installation costs were developed based on the labor and material required to install the CMS, as well as the estimated time required for RAFB personnel involved in IA review and approval. While the installation costs of the digital signage system are estimated to be minimal, i.e. a few thousand dollars, the level of effort required for testing and deployment of the software would likely be on the order of $100,000. This estimate is based on "RMF Work Breakdown Structure" provided in ESTCP's recent Risk Management Framework (RMF) 101 for Managers (Noblis, 2017).

7.1.3 Facility Operational Costs

The decrease in facility operational costs were evaluated as part of the performance assessment detailed in Section 6.0. The CMS implementation did not result in decreased energy consumption.

However, as described in Section 6, potential costs savings exist and BLCC scenarios were developed assuming a financial incentive program. Two incentive programs were modeled, one with a SIR (Savings to Investment Ratio) of 1.0 and a second with an SIR of 2.0, which could potentially reduce operational costs by 1.9M kWh.

7.1.4 Maintenance

Maintenance of the CMS will include labor and material costs associated with periodically backing up data from the CMS. In addition, since the CMS is a tool for a broader behaviorally based energy savings program, the maintenance costs will include an estimate of the time required to review the data and reports produced by the CMS. The level of effort required to download energy data from the JCI and prepare a report is conservatively estimated to require $1,000 a month, with approximately one half of that effort required by RAFB IT to perform installation of software and conduct periodic testing of the digital signs.

7.1.5 Hardware lifetime

It is expected that the hardware for the CMS will have an effective lifetime of two years, with the CMS software having lifetime of approximately five years. During the demonstration period it was observed that one of the digital signage systems had suffered a short circuit and required replacement. Therefore, for modeling, the lifetime of the CMS hardware is expected to lower than with the typical lifetime of similar equipment.

7.1.6 Operator Training

As described in Section 5.4, the team anticipates holding two separate training sessions to explain the purpose of the demonstration project and to train operators on the use of the CMS. It is estimated that each training session will take between one and two hours. It is estimated that an annual training program would be established, with an estimated cost of $10,000.

7.2 SCALING

Costs for scaling the CMS to other CCFs are estimated to be similar to the costs for installing and maintaining the CMS at B59. The primary reason for the lack of cost efficiency is that the need to develop, test, and deploy a software solution at a separate facility will require separate RMF evaluations.

There likely exists significant potential for improving building mode usage at other CCFs in the DoD. For many facilities, the CMS can provide a simple and straightforward way to track and report energy usage. However, as discussed in Section 8.0, it is recommended that future implementation of behavior-based programs include financial incentives, as is appropriate on a facility by facility basis. The cost analysis in Section 7.3 provides example of financial incentive models that could be used.

Because the CMS demonstration did not meet the performance goals using non-financial incentives, it is more than likely that energy managers at CCFs and other facilities with large energy footprints will opt for using alternative strategies, such as performance-based contracts with outside vendors or utilities to reduce energy consumption.

7.3 COST ANALYSIS AND COMPARISON

The FEMP (Federal Energy Management Program) analysis template in the NIST BLCC was used to calculate the SPB (Simple Payback) and SIR (Savings to Investment Ratio) for the CMS at Building 59. The BLCC cost analysis has been included as Appendix E.

A baseline scenario was compared to the CMS program as implemented, which resulted in no energy savings, as well as two additional hypothetical scenarios where financial incentives are provided to operators of B59. Meaningful SIR, Adjusted Internal Rate of Return (AIRR) and payback could not be computed for the CMS as implemented, as the program was not able to document energy savings. Under the first hypothetical scenario, an annual incentive program with a budget of $83,000 was modeled to achieve an SIR of 1.0. This scenario achieves an AIRR of 3.56% and a simple payback period of four years. Under the second scenario, an annual incentive program with a budget of $57,000 was modeled to achieve an SIR of 2.0. This scenario achieves an AIRR of 18.28% and a simple payback period of two years. The purpose of the hypothetical financial incentive program scenarios is to provide a range of potential incentive costs to understand at which point an incentive program would begin to cost more than the potential energy savings.

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8.0 IMPLEMENTATION ISSUES

The primary implementation issue during the demonstration period was the general lack of usage of the CMS. Despite frequent visits by the project team and solicitation of feedback on the performance of the system, it appears that the CMS did not in and of itself result in a change in organizational behavioral modification. It is believed that quickly after installation of the digital signs, fatigue set in and the dashboards and reports developed became something that did not trigger attention.

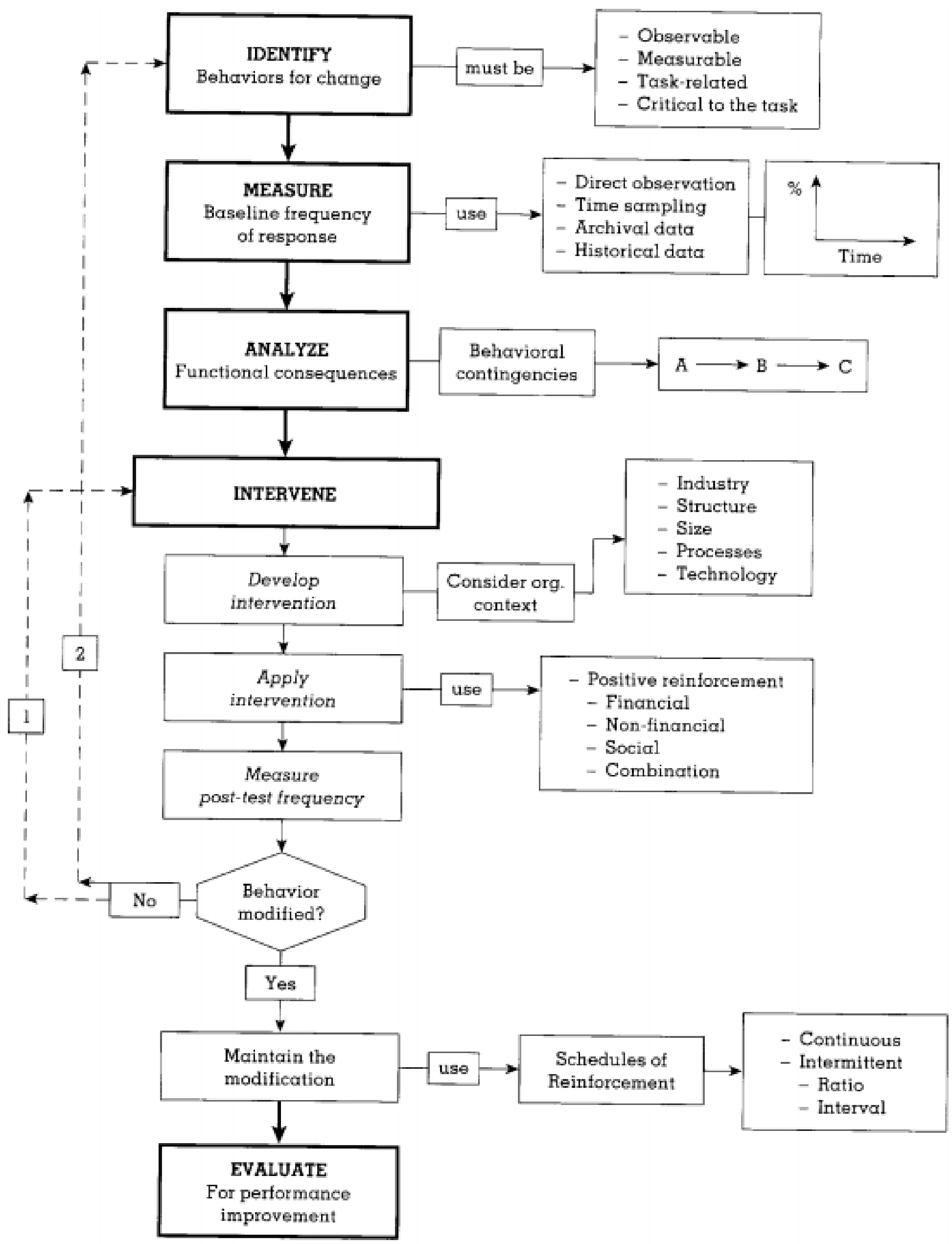

Figure 8-1. Organizational Behavior Modification Application Model (Luthans, Stajkovic, 1999)

An Organizational Behavior Modification Application Model is provided on Figure 8-1. It illustrates the key steps in changing organizational behavior, namely identifying behaviors for change, measuring baseline frequency, analyzing functional consequences, intervening, and evaluating if the behavior was modified. The typical methods for providing positive reinforcement are financial, non-financial, social, and a combination of the three.

While training sessions with the B59 management and supervisors were held, and the potential for cost savings quantified, at the end of the day, relying on non-financial and social incentives appears to have failed. This leads the team to believe that a financial incentive program to reward use of the CMS would likely yield more positive results, and thus these scenarios were modeled and described in Section 7.3.

The second implementation challenge encountered by the team was the lack of experience with the DoD RMF, which resulted in the extended duration of the demonstration due to the time required to obtain Authorization to Operate (ATO). Recently developed RMF framework training programs, ESTCP publications, including the current ESTCP Installation Energy and Water web portal provides a wealth of requirements documents, manuals, plans, memos, resources, tools, templates, and checklists that would have been invaluable to the investigative team at the beginning of the project.

9.0 REFERENCES

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10. Noblis. Risk Management Framework (RMF) 101 for Managers. October, 2017.

11. Luthans, Fred & Stajkovic, Alex. Reinforce for Performance: The Need to Go beyond Pay and Even Rewards. Academy of Management Perspectives. 13. 49-57. 10.5465/AME.1999.1899548.

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APPENDIX A POINTS OF CONTACT

Point of Contact	Organization	Phone & E-mail	Role in Project
Mr. Raphael Siebenmann	Geosyntec Consultants	678-202-9555 RSiebenmann@Geosyntec.com	Lead PI
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Mr. Richard Slife	RAFB, 402d	478-926-0209 richard.slife@us.af.mil	DoD Liaison
Mr. Steve Battle	RAFB, 402d	478-327-2952 steven.battle@us.af.mil	Energy Engineer
Ms. Judy Middlebrooks	RAFB, 78th	478-327-4531 judith.middlebrooks.1@us.af.mil	Energy Engineer
Mr. Judah Bradley	RAFB, 802d	478-222-8684 judah.bradley.3@us.af.mil	Energy Engineer
Mr. Keith Radcliff	Johnson Controls	478-319-0597 Roy.K.Radcliff@jci.com	ICS Vendor

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APPENDIX B DRAFT RECOMMENDED MODES

Activity	From Technical Order 1-1-8		Recommended Mode
	Description	Required Engineering Controls	
Hangar Empty or No Support	N/A	N/A	Unoccupied
Tow In and Configure	N/A	N/A	Non-Chemical
Masking	Masking	None	Non-Chemical
Sanding	Sanding	HEPA-Ventilated Sander	Non-Chemical
Dust Removal	Dust Removal	HEPA-Vacuum	Non-Chemical
Sealing	N/A	N/A	Non-Chemical
Corrosion Removal (Alodine)	Corrosion Coating (Alodine)	General Dilution Ventilation	Non-Chemical
Alodine Wipe	Alodine Wipe	General Dilution Ventilation	Non-Chemical
Solvent Wiping	Solvent Wiping	General Dilution Ventilation	Non-Chemical
PreKote / Wash	N/A	N/A	Non-Chemical
Mixing	Mixing	General Dilution Ventilation	Non-Chemical
Thinning	Thinning	General Dilution Ventilation	Non-Chemical
Priming	Spray Application	Paint Spray Booth/Facility	Paint & Chemical
Top Coating	Spray Application	Paint Spray Booth/Facility	Paint & Chemical
Curing	Curing	General Dilution Ventilation	Curing
Touch Ups	N/A	N/A	Non-Chemical
Stenciling	N/A	N/A	Non-Chemical
Tow Out	N/A	N/A	Unoccupied

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APPENDIX C SELECTION OF B59 ISSUES

Issue	Description
Incorrect Building Mode	Mode (see Table 5-1) controlled by shift supervisor or proxy, but shift supervisors report that Mode change is subject to delays or even forgotten, resulting in energy inefficiencies; no way to alert others if Mode is on incorrect setting
Recirculation pump for the chillers	Runs continuously. A software bug meant to save energy by turning off the pump when not needed does not always turn the pump back on again, so Maintenance switched the pump to manual mode to always keep it on
Outside cooling towers	Each section of the cooling tower is dedicated to one of five 70 ton chillers; if that section fails, the chiller cannot direct water to other sections and is automatically turned off and the building loses 20% of its cooling capacity
One steam boiler always on	Runs constantly due to steam valve leak (resulting in constant demand); plus, one specific Maintenance person (day shift, M-F) has technical knowledge to turn boiler on and off, so boiler is left on when key Maintenance person is absent
Refrigerant monitoring	Fuses missing from the electrical panel o f t he refrigerant monitoring system so monitoring is not conducted
Maintenance scheduling	No apparent schedule for performing preventative maintenance work, so work can be delayed or not completed at all, resulting in equipment inefficiencies & failures
Control systems	Not monitored in one central location; system not always well understood by users; changes/upgrades only possible through outside contractor
Alarms	Not monitored in one central location; not reported to key individuals; do not effectively communicate urgency and consequences of inaction; VOCs not currently monitored, even though operations plan indicated paint equipment is to shut down if VOC thresholds are exceeded13
Safety lockouts	There does not appear to be a defined process in place to alert and protect maintenance personnel working on equipment inside the building. Multiple entities can turn equipment and modes on and off from multiple locations, possibly resulting in injuries and dangerous situations
Fans	Fans currently completely stop to switch between Modes (Table 1), resulting in energy inefficiencies and 10-15 minute breaks in production. Fans are not monitored for speed/motion, so fans can be moving when restarted, breaking multiple fan belts ($1,000/occurrence, occurred up to twice a week, Summer 2012). Fan motor runs even with broken belts so controls system does not know fanning is not being provided.
Humidity sensors	Inlet humidity sensors fail; no alarms or notification; system injects steam at 100% of maximum, resulting in more water & gas use and requires more cooling. Higher humidity can slow paint curing.

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APPENDIX D SELECTION OF B59 ROLES AND RESPONSIBILITIES

Organization & Position	Roles & Responsibilities
CES Zone 1 – HVAC Supervisor	Chillers and air compressors > 100 tons
CES Zone 1 – Boilers Supervisor	Boilers > 100 tons
CES Zone 1 – HVAC Supervisor	All equipment < 100 tons
CES – Civil Engineer	Maintains the facility envelope
WR-ALC/AMXSS – Scheduler	Schedules aircraft's time in facility
WR-ALC/AMXSS – Supervisor	Shop Operations
WR-ALC/AMXSS – Flight Chief	Building 59 Facility Operations
WR-ALC/AMXSS – Operators	Paint/depaint activities
78 CEG – Energy	Energy usage for the CEG
WR-ALC/QPE – Chief	Building 59 Environmental and Ergonomics
WR-ALC/QPE – Air Coordinator	Environmental compliance
WR-ALC/QPE – Project Manager	WR-ALC/QPE support
Contractor – Project Manager	WR-ALC/QPE support
Bioenvironmental – Ventilation Program Manager	Ventilation for worker health and safety

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APPENDIX E BLCC MODEL

NIST BLCC 5.3-18: Input Data Listing

Consistent with Federal Life Cycle Cost Methodology and Procedures, 10 CFR, Part 436, Subpart A

General Information

File Name:	C:\ProgramFiles\BLCC5.3-2018\projects\B59-CMS.xml
Date of Study:	Sun Apr 15 22:25:54 EDT 2018
Analysis Type:	FEMP Analysis, Energy Project
Project Name:	CMS Installation
Project Location:	Georgia
Analyst:	Raphael Siebenmann
Comment:	Installation of Climate Management System at Building 59 at Robins AFB.
Base Date:	April 1, 2018
Service Date:	April 1, 2019
Study Period:	5 years 0 months (April 1, 2018 through March 31, 2023)
Discount Rate:	3%
Discounting Convention:	End-of-Year

Discount and Escalation Rates are REAL (exclusive of general inflation)

Alternative: Baseline

Energy: Electricity

Annual Consumption:	13,600,000.0 kWh
Price per Unit:	$0.07500
Demand Charge:	$0
Utility Rebate:	$0
Location:	Georgia
Rate Schedule:	Industrial
State:	Georgia

Usage Indices

From Date	Duration	Usage Index
April 1, 2019	Remaining	100%

Escalation Rates

From Date	Duration	Escalation
April 1, 2018	1 year 0 months	1.87%
April 1, 2019	1 year 0 months	1.89%
April 1, 2020	1 year 0 months	-0.21%
April 1, 2021	1 year 0 months	-0.85%

April 1, 2022	1 year 0 months	-0.43%
April 1, 2023	1 year 0 months	0.16%
April 1, 2024	1 year 0 months	0.75%
April 1, 2025	1 year 0 months	0.37%
April 1, 2026	1 year 0 months	0.16%
April 1, 2027	1 year 0 months	0.05%
April 1, 2028	1 year 0 months	0.27%
April 1, 2029	1 year 0 months	0.16%
April 1, 2030	1 year 0 months	0.16%
April 1, 2031	1 year 0 months	0.11%
April 1, 2032	1 year 0 months	-0.11%
April 1, 2033	1 year 0 months	-0.21%
April 1, 2034	1 year 0 months	-0.26%
April 1, 2035	1 year 0 months	-0.11%
April 1, 2036	1 year 0 months	-0.05%
April 1, 2037	1 year 0 months	0.05%
April 1, 2038	1 year 0 months	0.11%
April 1, 2039	1 year 0 months	-0.05%
April 1, 2040	1 year 0 months	0%
April 1, 2041	1 year 0 months	-0.11%
April 1, 2042	1 year 0 months	-0.21%
April 1, 2043	1 year 0 months	0.05%
April 1, 2044	1 year 0 months	0%
April 1, 2045	1 year 0 months	-0.27%
April 1, 2046	1 year 0 months	-0.05%
April 1, 2047	1 year 0 months	0.53%
April 1, 2048	Remaining	0.05%

Component:

Initial Investment

Initial Cost (base-year $):	$0
Annual Rate of Increase:	0%
Expected Asset Life:	0 years 0 months
Residual Value Factor:	0%

Cost-Phasing

Cost Adjustment Factor: 0%

Years/Months (from Date)	Date	Portion
0 years 0 months	April 1, 2018	100%

Alternative: Operation of CMS - No Financial Incentives

Energy: Electricity

Annual Consumption:	13,600,000.0 kWh
Price per Unit:	$0.07500
Demand Charge:	$0
Utility Rebate:	$0
Location:	Georgia
Rate Schedule:	Industrial
State:	Georgia

Usage Indices

From Date	Duration	Usage Index
April 1, 2019	Remaining	100%

Escalation Rates

From Date	Duration	Escalation
April 1, 2018	1 year 0 months	1.87%
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April 1, 2022	1 year 0 months	-0.43%
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April 1, 2024	1 year 0 months	0.75%
April 1, 2025	1 year 0 months	0.37%
April 1, 2026	1 year 0 months	0.16%
April 1, 2027	1 year 0 months	0.05%
April 1, 2028	1 year 0 months	0.27%
April 1, 2029	1 year 0 months	0.16%
April 1, 2030	1 year 0 months	0.16%
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April 1, 2032	1 year 0 months	-0.11%
April 1, 2033	1 year 0 months	-0.21%
April 1, 2034	1 year 0 months	-0.26%
April 1, 2035	1 year 0 months	-0.11%

April 1, 2036	1 year 0 months	-0.05%
April 1, 2037	1 year 0 months	0.05%
April 1, 2038	1 year 0 months	0.11%
April 1, 2039	1 year 0 months	-0.05%
April 1, 2040	1 year 0 months	0%
April 1, 2041	1 year 0 months	-0.11%
April 1, 2042	1 year 0 months	-0.21%
April 1, 2043	1 year 0 months	0.05%
April 1, 2044	1 year 0 months	0%
April 1, 2045	1 year 0 months	-0.27%
April 1, 2046	1 year 0 months	-0.05%
April 1, 2047	1 year 0 months	0.53%
April 1, 2048	Remaining	0.05%

Component:

Initial Investment

Initial Cost (base-year $):	$105,000
Annual Rate of Increase:	0%
Expected Asset Life:	5 years 0 months
Residual Value Factor:	0%

Cost-Phasing

Cost Adjustment Factor: 0%

Years/Months (from Date)	Date	Portion
0 years 0 months	April 1, 2018	100%

Replacement: Digital Signage

Years/Months:	1 year 0 months
Amount:	$2,500
Annual Rate Of Increase:	0%
Expected Asset Life:	1 year 0 months
Residual Value Factor:	0%

Recurring OM&R: Training

Amount:	$10,000
Annual Rate of Increase:	3%

NIST BLCC 5.3-18: Input Data Listing

Consistent with Federal Life Cycle Cost Methodology and Procedures, 10 CFR, Part 436, Subpart A

General Information

File Name:	C:\ProgramFiles\BLCC5.3-2018\projects\B59-CMS.xml
Date of Study:	Sun Apr 15 22:25:54 EDT 2018
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Alternative: Baseline

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April 1, 2028	1 year 0 months	0.27%
April 1, 2029	1 year 0 months	0.16%
April 1, 2030	1 year 0 months	0.16%
April 1, 2031	1 year 0 months	0.11%
April 1, 2032	1 year 0 months	-0.11%
April 1, 2033	1 year 0 months	-0.21%
April 1, 2034	1 year 0 months	-0.26%
April 1, 2035	1 year 0 months	-0.11%
April 1, 2036	1 year 0 months	-0.05%
April 1, 2037	1 year 0 months	0.05%
April 1, 2038	1 year 0 months	0.11%
April 1, 2039	1 year 0 months	-0.05%
April 1, 2040	1 year 0 months	0%
April 1, 2041	1 year 0 months	-0.11%
April 1, 2042	1 year 0 months	-0.21%
April 1, 2043	1 year 0 months	0.05%
April 1, 2044	1 year 0 months	0%
April 1, 2045	1 year 0 months	-0.27%
April 1, 2046	1 year 0 months	-0.05%
April 1, 2047	1 year 0 months	0.53%
April 1, 2048	Remaining	0.05%

Component:

Initial Investment

Initial Cost (base-year $):	$0
Annual Rate of Increase:	0%
Expected Asset Life:	0 years 0 months
Residual Value Factor:	0%

Cost-Phasing

Cost Adjustment Factor: 0%

Years/Months (from Date)	Date	Portion
0 years 0 months	April 1, 2018	100%

Alternative: Operation of CMS - No Financial Incentives

Energy: Electricity

Annual Consumption:	13,600,000.0 kWh
Price per Unit:	$0.07500
Demand Charge:	$0
Utility Rebate:	$0
Location:	Georgia
Rate Schedule:	Industrial
State:	Georgia

Usage Indices

From Date	Duration	Usage Index
April 1, 2019	Remaining	100%

Escalation Rates

From Date	Duration	Escalation
April 1, 2018	1 year 0 months	1.87%
April 1, 2019	1 year 0 months	1.89%
April 1, 2020	1 year 0 months	-0.21%
April 1, 2021	1 year 0 months	-0.85%
April 1, 2022	1 year 0 months	-0.43%
April 1, 2023	1 year 0 months	0.16%
April 1, 2024	1 year 0 months	0.75%
April 1, 2025	1 year 0 months	0.37%
April 1, 2026	1 year 0 months	0.16%
April 1, 2027	1 year 0 months	0.05%
April 1, 2028	1 year 0 months	0.27%
April 1, 2029	1 year 0 months	0.16%
April 1, 2030	1 year 0 months	0.16%
April 1, 2031	1 year 0 months	0.11%
April 1, 2032	1 year 0 months	-0.11%
April 1, 2033	1 year 0 months	-0.21%
April 1, 2034	1 year 0 months	-0.26%
April 1, 2035	1 year 0 months	-0.11%

April 1, 2035	1 year 0 months	0.11%
April 1, 2036	1 year 0 months	-0.05%
April 1, 2037	1 year 0 months	0.05%
April 1, 2038	1 year 0 months	0.11%
April 1, 2039	1 year 0 months	-0.05%
April 1, 2040	1 year 0 months	0%
April 1, 2041	1 year 0 months	-0.11%
April 1, 2042	1 year 0 months	-0.21%
April 1, 2043	1 year 0 months	0.05%
April 1, 2044	1 year 0 months	0%
April 1, 2045	1 year 0 months	-0.27%
April 1, 2046	1 year 0 months	-0.05%
April 1, 2047	1 year 0 months	0.53%
April 1, 2048	Remaining	0.05%

Component:

Initial Investment

Initial Cost (base-year $):	$105,000
Annual Rate of Increase:	0%
Expected Asset Life:	5 years 0 months
Residual Value Factor:	0%

Cost-Phasing

Cost Adjustment Factor: 0%

Years/Months (from Date)	Date	Portion
0 years 0 months	April 1, 2018	100%

Replacement: Digital Signage

Years/Months:	1 year 0 months
Amount:	$2,500
Annual Rate Of Increase:	0%
Expected Asset Life:	1 year 0 months
Residual Value Factor:	0%

Recurring OM&R: Training

Amount:	$10,000
Annual Rate of Increase:	3%

Usage Indices

From Date	Duration	Factor
April 1, 2019	Remaining	100%

Recurring OM&R: Data Retrieval Reporting

Amount:	$12,000
Annual Rate of Increase:	3%

Usage Indices

From Date	Duration	Factor
April 1, 2019	Remaining	100%

Alternative: Operation of CMS - Financial Incentives Applied - SIR Goal of 1

Energy: Electricity

Annual Consumption:	11,700,000.0 kWh
Price per Unit:	$0.07500
Demand Charge:	$0
Utility Rebate:	$0
Location:	Georgia
Rate Schedule:	Industrial
State:	Georgia

Usage Indices

From Date	Duration	Usage Index
April 1, 2019	Remaining	100%

Escalation Rates

From Date	Duration	Escalation
April 1, 2018	1 year 0 months	1.87%
April 1, 2019	1 year 0 months	1.89%
April 1, 2020	1 year 0 months	-0.21%
April 1, 2021	1 year 0 months	-0.85%
April 1, 2022	1 year 0 months	-0.43%
April 1, 2023	1 year 0 months	0.16%
April 1, 2024	1 year 0 months	0.75%
April 1, 2025	1 year 0 months	0.37%
April 1, 2026	1 year 0 months	0.16%

Usage Indices

From Date	Duration	Factor
April 1, 2019	Remaining	100%

Recurring OM&R: Data Retrieval Reporting

Amount:	$12,000
Annual Rate of Increase:	3%

Usage Indices

From Date	Duration	Factor
April 1, 2019	Remaining	100%

Alternative: Operation of CMS - Financial Incentives Applied - SIR Goal of 1

Energy: Electricity

Annual Consumption:	11,700,000.0 kWh
Price per Unit:	$0.07500
Demand Charge:	$0
Utility Rebate:	$0
Location:	Georgia
Rate Schedule:	Industrial
State:	Georgia

Usage Indices

From Date	Duration	Usage Index
April 1, 2019	Remaining	100%

Escalation Rates

From Date	Duration	Escalation
April 1, 2018	1 year 0 months	1.87%
April 1, 2019	1 year 0 months	1.89%
April 1, 2020	1 year 0 months	-0.21%
April 1, 2021	1 year 0 months	-0.85%
April 1, 2022	1 year 0 months	-0.43%
April 1, 2023	1 year 0 months	0.16%
April 1, 2024	1 year 0 months	0.75%
April 1, 2025	1 year 0 months	0.37%
April 1, 2026	1 year 0 months	0.16%

April 1, 2027	1 year 0 months	0.05%
April 1, 2028	1 year 0 months	0.27%
April 1, 2029	1 year 0 months	0.16%
April 1, 2030	1 year 0 months	0.16%
April 1, 2031	1 year 0 months	0.11%
April 1, 2032	1 year 0 months	-0.11%
April 1, 2033	1 year 0 months	-0.21%
April 1, 2034	1 year 0 months	-0.26%
April 1, 2035	1 year 0 months	-0.11%
April 1, 2036	1 year 0 months	-0.05%
April 1, 2037	1 year 0 months	0.05%
April 1, 2038	1 year 0 months	0.11%
April 1, 2039	1 year 0 months	-0.05%
April 1, 2040	1 year 0 months	0%
April 1, 2041	1 year 0 months	-0.11%
April 1, 2042	1 year 0 months	-0.21%
April 1, 2043	1 year 0 months	0.05%
April 1, 2044	1 year 0 months	0%
April 1, 2045	1 year 0 months	-0.27%
April 1, 2046	1 year 0 months	-0.05%
April 1, 2047	1 year 0 months	0.53%
April 1, 2048	Remaining	0.05%

Component:

Initial Investment

Initial Cost (base-year $):	$105,000
Annual Rate of Increase:	0%
Expected Asset Life:	5 years 0 months
Residual Value Factor:	0%

Cost-Phasing

Cost Adjustment Factor: 0%

Years/Months (from Date)	Date	Portion
0 years 0 months	April 1, 2018	100%

Replacement: Digital Signage

Years/Months: 1 year 0 months

Amount: $2,500

Annual Rate Of Increase: 0%

Expected Asset Life: 1 year 0 months

Residual Value Factor: 0%

Recurring OM&R: Training

Amount: $10,000

Annual Rate of Increase: 3%

Usage Indices

From Date	Duration	Factor
April 1, 2019	Remaining	100%

Recurring OM&R: Data Retrieval Reporting

Amount: $12,000

Annual Rate of Increase: 3%

Usage Indices

From Date	Duration	Factor
April 1, 2019	Remaining	100%

Recurring OM&R: Incentive Program

Amount: $83,000

Annual Rate of Increase: 3%

Usage Indices

From Date	Duration	Factor
April 1, 2019	Remaining	100%

Alternative: Operation of CMS - Financial Incentives Applied - SIR Goal of 2

Energy: Electricity

Annual Consumption: 11,700,000.0 kWh

Price per Unit: $0.07500

Demand Charge: $0

Utility Rebate: $0

Location: Georgia

Rate Schedule: Industrial

State: Georgia

State: Georgia

Usage Indices

From Date	Duration	Usage Index
April 1, 2019	Remaining	100%

Escalation Rates

From Date	Duration	Escalation
April 1, 2018	1 year 0 months	1.87%
April 1, 2019	1 year 0 months	1.89%
April 1, 2020	1 year 0 months	-0.21%
April 1, 2021	1 year 0 months	-0.85%
April 1, 2022	1 year 0 months	-0.43%
April 1, 2023	1 year 0 months	0.16%
April 1, 2024	1 year 0 months	0.75%
April 1, 2025	1 year 0 months	0.37%
April 1, 2026	1 year 0 months	0.16%
April 1, 2027	1 year 0 months	0.05%
April 1, 2028	1 year 0 months	0.27%
April 1, 2029	1 year 0 months	0.16%
April 1, 2030	1 year 0 months	0.16%
April 1, 2031	1 year 0 months	0.11%
April 1, 2032	1 year 0 months	-0.11%
April 1, 2033	1 year 0 months	-0.21%
April 1, 2034	1 year 0 months	-0.26%
April 1, 2035	1 year 0 months	-0.11%
April 1, 2036	1 year 0 months	-0.05%
April 1, 2037	1 year 0 months	0.05%
April 1, 2038	1 year 0 months	0.11%
April 1, 2039	1 year 0 months	-0.05%
April 1, 2040	1 year 0 months	0%
April 1, 2041	1 year 0 months	-0.11%
April 1, 2042	1 year 0 months	-0.21%
April 1, 2043	1 year 0 months	0.05%
April 1, 2044	1 year 0 months	0%
April 1, 2045	1 year 0 months	-0.27%
April 1, 2046	1 year 0 months	-0.05%
April 1, 2047	1 year 0 months	0.53%

April 1, 2048	Remaining	0.05%

Component: Copy of:

Initial Investment

Initial Cost (base-year $):	$105,000
Annual Rate of Increase:	0%
Expected Asset Life:	5 years 0 months
Residual Value Factor:	0%

Cost-Phasing

Cost Adjustment Factor: 0%

Years/Months (from Date)	Date	Portion
0 years 0 months	April 1, 2018	100%

Replacement: Copy of: Copy of: Digital Signage

Years/Months:	1 year 0 months
Amount:	$2,500
Annual Rate Of Increase:	0%
Expected Asset Life:	1 year 0 months
Residual Value Factor:	0%

Recurring OM&R: Training

Amount:	$10,000
Annual Rate of Increase:	3%

Usage Indices

From Date	Duration	Factor
April 1, 2019	Remaining	100%

Recurring OM&R: Data Retrieval Reporting

Amount:	$12,000
Annual Rate of Increase:	3%

Usage Indices

From Date	Duration	Factor
April 1, 2019	Remaining	100%

Recurring OM&R: Incentive Program

Amount:	$57,000
Annual Rate of Increase:	3%

Usage Indices

From Date	Duration	Factor
April 1, 2019	Remaining	100%

NIST BLCC 5.3-18: Detailed LCC Analysis

Consistent with Federal Life Cycle Cost Methodology and Procedures, 10 CFR, Part 436, Subpart A

General Information

File Name:	C:\ProgramFiles\BLCC5.3-2018\projects\B59-CMS.xml
Date of Study:	Sun Apr 15 22:26:19 EDT 2018
Analysis Type:	FEMP Analysis, Energy Project
Project Name:	CMS Installation
Project Location:	Georgia
Analyst:	Raphael Siebenmann
Comment:	Installation of Climate Management System at Building 59 at Robins AFB.
Base Date:	April 1, 2018
Service Date:	April 1, 2019
Study Period:	5 years 0 months (April 1, 2018 through March 31, 2023)
Discount Rate:	3%
Discounting Convention:	End-of-Year

Discount and Escalation Rates are REAL (exclusive of general inflation)

Alternative: Baseline

Initial Cost Data (not Discounted)

Initial Capital Costs

(adjusted for price escalation)

Initial Capital Costs for All Components: $0

Component:

Cost-Phasing

Date	Portion	Yearly Cost
April 1, 2018	100%	$0
	------------	------------
Total (for Component)		$0

Energy Costs: Electricity

(base-year dollars)

Average Annual Usage	Price/Unit	Average Annual Cost	Average Annual Demand	Average Annual Rebate
13,600,000.0 kWh	$0.07500	$1,020,000	$0	$0

Life-Cycle Cost Analysis

	Present Value	Annual Value
Initial Capital Costs	$0	$0

Energy Costs		
Energy Consumption Costs	$3,795,846	$829,359
Energy Demand Charges	$0	$0
Energy Utility Rebates	$0	$0
	-----------	-----------
Subtotal (for Energy):	$3,795,846	$829,359
Water Usage Costs	$0	$0
Water Disposal Costs	$0	$0
Operating, Maintenance & Repair Costs		
Component:		
Annually Recurring Costs	$0	$0
Non-Annually Recurring Costs	$0	$0
	-----------	-----------
Subtotal (for OM&R):	$0	$0
Replacements to Capital Components		
Component:	$0	$0
	-----------	-----------
Subtotal (for Replacements):	$0	$0
Residual Value of Original Capital Components		
Component:	$0	$0
	-----------	-----------
Subtotal (for Residual Value):	$0	$0
Residual Value of Capital Replacements		
Component:	$0	$0
	-----------	-----------
Subtotal (for Residual Value):	$0	$0
Total Life-Cycle Cost	$3,795,846	$829,359

Emissions Summary

Energy Name	Annual	Life-Cycle
Electricity:		

CO_2	9,307,007.74 kg	37,202,549.76 kg
SO_2	62,417.76 kg	249,500.16 kg
NO_x	11,464.49 kg	45,826.56 kg

Total:

CO_2	9,307,007.74 kg	37,202,549.76 kg
SO_2	62,417.76 kg	249,500.16 kg
NO_x	11,464.49 kg	45,826.56 kg

Alternative: Operation of CMS - No Financial Incentives

Initial Cost Data (not Discounted)

Initial Capital Costs

(adjusted for price escalation)

Initial Capital Costs for All Components: $105,000

Component:

Cost-Phasing

Date	Portion	Yearly Cost
April 1, 2018	100%	$105,000
	------------	------------
Total (for Component)		$105,000

Energy Costs: Electricity

(base-year dollars)

Average Annual Usage	Price/Unit	Average Annual Cost	Average Annual Demand	Average Annual Rebate
13,600,000.0 kWh	$0.07500	$1,020,000	$0	$0

Life-Cycle Cost Analysis

	Present Value	Annual Value
Initial Capital Costs	$105,000	$22,942
Energy Costs		
Energy Consumption Costs	$3,795,846	$829,359
Energy Demand Charges	$0	$0
Energy Utility Rebates	$0	$0
	------------	------------
Subtotal (for Energy):	$3,795,846	$829,359
Water Usage Costs	$0	$0

Water Disposal Costs	$0	$0
Operating, Maintenance & Repair Costs		
Component:		
Annually Recurring Costs	$88,000	$19,227
Non-Annually Recurring Costs	$0	$0
	-----------	-----------
Subtotal (for OM&R):	$88,000	$19,227
Replacements to Capital Components		
Component:	$2,356	$515
	-----------	-----------
Subtotal (for Replacements):	$2,356	$515
Residual Value of Original Capital Components		
Component:	$0	$0
	-----------	-----------
Subtotal (for Residual Value):	$0	$0
Residual Value of Capital Replacements		
Component:	$0	$0
	-----------	-----------
Subtotal (for Residual Value):	$0	$0
Total Life-Cycle Cost	$3,991,203	$872,043

Emissions Summary

Energy Name	Annual	Life-Cycle
Electricity:		
CO_2	9,307,007.74 kg	37,202,549.76 kg
SO_2	62,417.76 kg	249,500.16 kg
NO_x	11,464.49 kg	45,826.56 kg
Total:		
CO_2	9,307,007.74 kg	37,202,549.76 kg
SO_2	62,417.76 kg	249,500.16 kg
NO_x	11,464.49 kg	45,826.56 kg

Alternative: Operation of OMS - Financial Incentives Applied - SIR Goal of 1

Alternative: Operation of CMS - Financial Incentives Applied - SIR Goal of 1

Initial Cost Data (not Discounted)

Initial Capital Costs

(adjusted for price escalation)

Initial Capital Costs for All Components: $105,000

Component:

Cost-Phasing

Date	Portion	Yearly Cost
April 1, 2018	100%	$105,000
	------------	------------
Total (for Component)		$105,000

Energy Costs: Electricity

(base-year dollars)

Average Annual Usage	Price/Unit	Average Annual Cost	Average Annual Demand	Average Annual Rebate
11,700,000.0 kWh	$0.07500	$877,500	$0	$0

Life-Cycle Cost Analysis

	Present Value	Annual Value
Initial Capital Costs	$105,000	$22,942
Energy Costs		
Energy Consumption Costs	$3,265,544	$713,493
Energy Demand Charges	$0	$0
Energy Utility Rebates	$0	$0
	-----------	-----------
Subtotal (for Energy):	$3,265,544	$713,493
Water Usage Costs	$0	$0
Water Disposal Costs	$0	$0
Operating, Maintenance & Repair Costs		
Component:		
Annually Recurring Costs	$420,000	$91,766
Non-Annually Recurring Costs	$0	$0
	-----------	-----------
Subtotal (for OM&R):	$420,000	$91,766

Replacements to Capital Components

Component:	$2,356	$515
	------------	------------
Subtotal (for Replacements):	$2,356	$515

Residual Value of Original Capital Components

Component:	$0	$0
	------------	------------
Subtotal (for Residual Value):	$0	$0

Residual Value of Capital Replacements

Component:	$0	$0
	------------	------------
Subtotal (for Residual Value):	$0	$0

Total Life-Cycle Cost	$3,792,901	$828,716

Emissions Summary

Energy Name	Annual	Life-Cycle
Electricity:		
CO_2	8,006,764.01 kg	32,005,134.72 kg
SO_2	53,697.63 kg	214,643.52 kg
NO_x	9,862.83 kg	39,424.32 kg
Total:		
CO_2	8,006,764.01 kg	32,005,134.72 kg
SO_2	53,697.63 kg	214,643.52 kg
NO_x	9,862.83 kg	39,424.32 kg

Alternative: Operation of CMS - Financial Incentives Applied - SIR Goal of 2

Initial Cost Data (not Discounted)

Initial Capital Costs

(adjusted for price escalation)

Initial Capital Costs for All Components: $105,000

Component: Copy of:
Cost-Phasing

Date	Portion	Yearly Cost
April 1, 2018	100%	$105,000

----------- -----------

Total (for Component)	$105,000

Energy Costs: Electricity

(base-year dollars)

Average Annual Usage	Price/Unit	Average Annual Cost	Average Annual Demand	Average Annual Rebate
11,700,000.0 kWh	$0.07500	$877,500	$0	$0

Life-Cycle Cost Analysis

	Present Value	Annual Value
Initial Capital Costs	$105,000	$22,942
Energy Costs		
Energy Consumption Costs	$3,265,544	$713,493
Energy Demand Charges	$0	$0
Energy Utility Rebates	$0	$0
	-----------	-----------
Subtotal (for Energy):	$3,265,544	$713,493
Water Usage Costs	$0	$0
Water Disposal Costs	$0	$0
Operating, Maintenance & Repair Costs		
Component: Copy of:		
Annually Recurring Costs	$316,000	$69,043
Non-Annually Recurring Costs	$0	$0
	-----------	-----------
Subtotal (for OM&R):	$316,000	$69,043
Replacements to Capital Components		
Component: Copy of:	$2,356	$515
	-----------	-----------
Subtotal (for Replacements):	$2,356	$515
Residual Value of Original Capital Components		
Component: Copy of:	$0	$0
	-----------	-----------

Subtotal (for Residual Value):	$0	$0

Residual Value of Capital Replacements

Component: Copy of:	$0	$0
	------------	------------
Subtotal (for Residual Value):	$0	$0

Total Life-Cycle Cost	$3,688,901	$805,993

Emissions Summary

Energy Name	Annual	Life-Cycle
Electricity:		
CO_2	8,006,764.01 kg	32,005,134.72 kg
SO_2	53,697.63 kg	214,643.52 kg
NO_x	9,862.83 kg	39,424.32 kg
Total:		
CO_2	8,006,764.01 kg	32,005,134.72 kg
SO_2	53,697.63 kg	214,643.52 kg
NO_x	9,862.83 kg	39,424.32 kg

NIST BLCC 5.3-18: Comparative Analysis

Consistent with Federal Life Cycle Cost Methodology and Procedures, 10 CFR, Part 436, Subpart A

Base Case: Baseline

Alternative: Operation of CMS - No Financial Incentives

General Information

File Name:	C:\ProgramFiles\BLCC5.3-2018\projects\B59-CMS.xml
Date of Study:	Sun Apr 15 22:27:18 EDT 2018
Project Name:	CMS Installation
Project Location:	Georgia
Analysis Type:	FEMP Analysis, Energy Project
Analyst:	Raphael Siebenmann
Comment	Installation of Climate Management System at Building 59 at Robins AFB.
Base Date:	April 1, 2018
Service Date:	April 1, 2019
Study Period:	5 years 0 months(April 1, 2018 through March 31, 2023)
Discount Rate:	3%
Discounting Convention:	End-of-Year

Comparison of Present-Value Costs

PV Life-Cycle Cost

	Base Case	Alternative	Savings from Alternative
Initial Investment Costs:			
Capital Requirements as of Base Date	$0	$105,000	-$105,000
Future Costs:			
Energy Consumption Costs	$3,795,846	$3,795,846	$0
Energy Demand Charges	$0	$0	$0
Energy Utility Rebates	$0	$0	$0
Water Costs	$0	$0	$0
Recurring and Non-Recurring OM&R Costs	$0	$88,000	-$88,000
Capital Replacements	$0	$2,356	-$2,356
Residual Value at End of Study Period	$0	$0	$0
	------------	------------	------------
Subtotal (for Future Cost Items)	$3,795,846	$3,886,203	-$90,356
	------------	------------	------------
Total PV Life-Cycle Cost	$3,795,846	$3,991,203	-$195,356

Net Savings from Alternative Compared with Base Case

PV of Non-Investment Savings	-$88,000
- Increased Total Investment	$107,356

Net Savings	-$195,356

NOTE: Meaningful SIR, AIRR and Payback can not be computed unless incremental savings and total savings are both positive.

Energy Savings Summary

Energy Savings Summary (in stated units)

Energy Type	-----Average Base Case	Annual Alternative	Consumption----- Savings	Life-Cycle Savings
Electricity	13,600,000.0 kWh	13,600,000.0 kWh	0.0 kWh	0.0 kWh

Energy Savings Summary (in MBtu)

Energy Type	-----Average Base Case	Annual Alternative	Consumption----- Savings	Life-Cycle Savings
Electricity	46,405.1 MBtu	46,405.1 MBtu	0.0 MBtu	0.0 MBtu

Emissions Reduction Summary

Energy Type	-----Average Base Case	Annual Alternative	Emissions----- Reduction	Life-Cycle Reduction
Electricity				
CO_2	9,307,007.74 kg	9,307,007.74 kg	0.00 kg	0.00 kg
SO_2	62,417.76 kg	62,417.76 kg	0.00 kg	0.00 kg
NO_x	11,464.49 kg	11,464.49 kg	0.00 kg	0.00 kg
Total:				
CO_2	9,307,007.74 kg	9,307,007.74 kg	0.00 kg	0.00 kg
SO_2	62,417.76 kg	62,417.76 kg	0.00 kg	0.00 kg
NO_x	11,464.49 kg	11,464.49 kg	0.00 kg	0.00 kg

NIST BLCC 5.3-18: Comparative Analysis

Consistent with Federal Life Cycle Cost Methodology and Procedures, 10 CFR, Part 436, Subpart A

Base Case: Baseline

Alternative: Operation of CMS - Financial Incentives Applied - SIR Goal of 1

General Information

File Name:	C:\ProgramFiles\BLCC5.3-2018\projects\B59-CMS.xml
Date of Study:	Sun Apr 15 22:27:45 EDT 2018
Project Name:	CMS Installation
Project Location:	Georgia
Analysis Type:	FEMP Analysis, Energy Project
Analyst:	Raphael Siebenmann
Comment	Installation of Climate Management System at Building 59 at Robins AFB.
Base Date:	April 1, 2018
Service Date:	April 1, 2019
Study Period:	5 years 0 months(April 1, 2018 through March 31, 2023)
Discount Rate:	3%
Discounting Convention:	End-of-Year

Comparison of Present-Value Costs

PV Life-Cycle Cost

	Base Case	Alternative	Savings from Alternative
Initial Investment Costs:			
Capital Requirements as of Base Date	$0	$105,000	-$105,000
Future Costs:			
Energy Consumption Costs	$3,795,846	$3,265,544	$530,302
Energy Demand Charges	$0	$0	$0
Energy Utility Rebates	$0	$0	$0
Water Costs	$0	$0	$0
Recurring and Non-Recurring OM&R Costs	$0	$420,000	-$420,000
Capital Replacements	$0	$2,356	-$2,356
Residual Value at End of Study Period	$0	$0	$0
	-----------	-----------	------------
Subtotal (for Future Cost Items)	$3,795,846	$3,687,901	$107,946
	-----------	-----------	------------
Total PV Life-Cycle Cost	$3,795,846	$3,792,901	$2,946

Net Savings from Alternative Compared with Base Case

PV of Non-Investment Savings	$110,302
- Increased Total Investment	$107,356

Net Savings $2,946

Savings-to-Investment Ratio (SIR)

SIR = 1.03

Adjusted Internal Rate of Return

AIRR = 3.56%

Payback Period

Estimated Years to Payback (from beginning of Service Period)

Simple Payback occurs in year 4

Discounted Payback occurs in year 4

Energy Savings Summary

Energy Savings Summary (in stated units)

Energy Type	-----Average Base Case	Annual Alternative	Consumption----- Savings	Life-Cycle Savings
Electricity	13,600,000.0 kWh	11,700,000.0 kWh	1,900,000.0 kWh	7,594,798.1 kWh

Energy Savings Summary (in MBtu)

Energy Type	-----Average Base Case	Annual Alternative	Consumption----- Savings	Life-Cycle Savings
Electricity	46,405.1 MBtu	39,922.0 MBtu	6,483.1 MBtu	25,914.5 MBtu

Emissions Reduction Summary

Energy Type	-----Average Base Case	Annual Alternative	Emissions----- Reduction	Life-Cycle Reduction
Electricity				
CO2	9,307,007.74 kg	8,006,764.01 kg	1,300,243.73 kg	5,197,415.04 kg
SO2	62,417.76 kg	53,697.63 kg	8,720.13 kg	34,856.64 kg
NOx	11,464.49 kg	9,862.83 kg	1,601.66 kg	6,402.24 kg
Total:				
CO2	9,307,007.74 kg	8,006,764.01 kg	1,300,243.73 kg	5,197,415.04 kg
SO2	62,417.76 kg	53,697.63 kg	8,720.13 kg	34,856.64 kg
NOx	11,464.49 kg	9,862.83 kg	1,601.66 kg	6,402.24 kg

NIST BLCC 5.3-18: Comparative Analysis

Consistent with Federal Life Cycle Cost Methodology and Procedures, 10 CFR, Part 436, Subpart A

Base Case: Baseline

Alternative: Operation of CMS - Financial Incentives Applied - SIR Goal of 2

General Information

File Name:	C:\ProgramFiles\BLCC5.3-2018\projects\B59-CMS.xml
Date of Study:	Sun Apr 15 22:28:12 EDT 2018
Project Name:	CMS Installation
Project Location:	Georgia
Analysis Type:	FEMP Analysis, Energy Project
Analyst:	Raphael Siebenmann
Comment	Installation of Climate Management System at Building 59 at Robins AFB.
Base Date:	April 1, 2018
Service Date:	April 1, 2019
Study Period:	5 years 0 months(April 1, 2018 through March 31, 2023)
Discount Rate:	3%
Discounting Convention:	End-of-Year

Comparison of Present-Value Costs

PV Life-Cycle Cost

	Base Case	Alternative	Savings from Alternative
Initial Investment Costs:			
Capital Requirements as of Base Date	$0	$105,000	-$105,000
Future Costs:			
Energy Consumption Costs	$3,795,846	$3,265,544	$530,302
Energy Demand Charges	$0	$0	$0
Energy Utility Rebates	$0	$0	$0
Water Costs	$0	$0	$0
Recurring and Non-Recurring OM&R Costs	$0	$316,000	-$316,000
Capital Replacements	$0	$2,356	-$2,356
Residual Value at End of Study Period	$0	$0	$0
	-----------	-----------	------------
Subtotal (for Future Cost Items)	$3,795,846	$3,583,901	$211,946
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Total PV Life-Cycle Cost	$3,795,846	$3,688,901	$106,946

Net Savings from Alternative Compared with Base Case

PV of Non-Investment Savings	$214,302
- Increased Total Investment	$107,356

Net Savings $106,946

Savings-to-Investment Ratio (SIR)

SIR = 2.00

Adjusted Internal Rate of Return

AIRR = 18.28%

Payback Period

Estimated Years to Payback (from beginning of Service Period)

Simple Payback occurs in year 2

Discounted Payback occurs in year 2

Energy Savings Summary

Energy Savings Summary (in stated units)

Energy	-----Average	Annual	Consumption-----	Life-Cycle
Type	Base Case	Alternative	Savings	Savings
Electricity	13,600,000.0 kWh	11,700,000.0 kWh	1,900,000.0 kWh	7,594,798.1 kWh

Energy Savings Summary (in MBtu)

Energy	-----Average	Annual	Consumption-----	Life-Cycle
Type	Base Case	Alternative	Savings	Savings
Electricity	46,405.1 MBtu	39,922.0 MBtu	6,483.1 MBtu	25,914.5 MBtu

Emissions Reduction Summary

Energy	-----Average	Annual	Emissions-----	Life-Cycle
Type	Base Case	Alternative	Reduction	Reduction
Electricity				
CO_2	9,307,007.74 kg	8,006,764.01 kg	1,300,243.73 kg	5,197,415.04 kg
SO_2	62,417.76 kg	53,697.63 kg	8,720.13 kg	34,856.64 kg
NO_x	11,464.49 kg	9,862.83 kg	1,601.66 kg	6,402.24 kg
Total:				
CO_2	9,307,007.74 kg	8,006,764.01 kg	1,300,243.73 kg	5,197,415.04 kg
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