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ESTCP Project EW-201261

MAY 2014

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FirstFuel Software

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14. ABSTRACT
The Rapid Building Assessment demonstration project focused on determining whether FirstFuel's end-to-end solution can enable the DoD to scale energy efficiency initiatives across its large and varied building portfolio. FirstFuel analytics were applied to 100 Department of Defense (DoD) buildings in total across five different DoD specific categories ofbuilding types and 11 locations. The successful achievement of the performance objectives suggest that the FirstFuel RBA can present significant advantages for the DoD over traditional approaches to onsite energy audits and continuous performance monitoring. Traditional audits are too costly and time-consuming to deliver savings at scale, and yield reports that are often difficult to use for efficiency prioritization and planning. In contrast, FirstFuel's remote audits can be accomplished at a fraction of the cost and time, without a site visit, and at minimal complication to the site managers, while simultaneously yielding performance analysis results similar to ASHRAE Level II onsite audits (the comparison onsite used in this demonstration project). In addition, the FirstFuel remote analytics solution was found to be compatible with approximately 90% of the DoD's building portfolio.

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Rapid Building Assessment, Remote Energy Assessment, FirstFuel, Energy Audits

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List of Acronyms

AMI: Advanced Metering Infrastructure

ASHRAE: American Society of Heating Refrigeration and Air Conditioning Engineers

DoD: Department of Defense

ECM: Energy Conservation Measures

ESCO: Energy Service Company

ESTCP: Environmental Security Technology Certification Program

FTP: File Transfer Protocol

GIS: Geographical Information Systems

GSA: General Services Administration

IPMVP: International Performance Measurement and Verification Protocol

JBLM: Joint Base Lewis-McChord

JCI: Johnson Controls Energy Services Group

kBtu: Thousand British Thermal Units

kWh: Kilowatt Hour

M&V: Monitoring and Verification

NAVFAC EXWC: Naval Facilities Engineering Command and Expeditionary Warfare Center

NOAA: National Oceanic and Atmospheric Administration

PGE: Pacific Gas & Electric

RBA: Remote Building Analytics

REST: Representational state transfer

ROI: Return on Investment

SasS: Software-as-a-Service

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Executive Summary

Background

In recent years, the Department of Defense (DoD) has launched several initiatives to reduce its fossil fuel use by improving energy efficiency (i.e. reducing wasted energy). Reducing the amount of energy used and wasted across the DoD's portfolio of buildings is a significant opportunity and key to reducing emissions and energy consumption across the U.S. However, identifying and profiling the energy savings potential of individual buildings presents significant challenges for the DoD's large and diverse building portfolio.

FirstFuel Software is a Boston-based commercial energy analytics company that provides a breakthrough solution with the potential to address this large-scale challenge. The company's Remote Building Analytics ("RBA") platform is an analytics-driven energy information service designed to help large government agencies and utilities rapidly and cost-effectively target, prioritize, quantify, enable and track energy savings in heterogeneous building portfolios, at scale. The platform utilizes advanced, proprietary statistical methods and data mining techniques to deliver an end-to-end efficiency solution that is being deployed at over 15 government agencies and utilities across North America and Europe.

Requiring only hourly utility electric meter data, the building type, and address, FirstFuel produces a remote set of building-specific performance insights and customized recommendations at an end-use consumption level that can be utilized by agencies such as the DoD at the management, site, and/or building level to identify opportunities, plan and execute efficiency projects. In addition, FirstFuel's analytics can track the efficiency measures enacted by building managers/operators and quantify their effectiveness over time. All of these services are performed remotely, and require no onsite visits or additional metering device installations. FirstFuel analytics have been independently and repeatedly validated by third-parties across many dimensions of performance (e.g. accuracy, speed, cost, scale, impact potential). The FirstFuel methodology produces completely unique analysis on each building and each ECM is verified based on actual building performance. These results are much more comparable to onsite audits than to automated energy analysis solutions that use 'like-building' analysis, benchmarking and/or simulation models to try to infer how a building might be performing.

Furthermore, the results from each building can be shown in an aggregated view that provides detailed energy consumption, savings recommendations, and efficiency performance tracking views across a building portfolio. This aggregated 'roll-up' view of the results from remote audits and continuous performance monitoring enables the ongoing management of commercial energy efficiency. No other company offers all of these proven services on a seamless, integrated Software-as-a-Service (SaaS) platform.

Demonstration Project:

The Rapid Building Assessment demonstration project focused on determining whether FirstFuel's end-to-end solution can enable the DoD to scale energy efficiency initiatives across its large and varied building portfolio. FirstFuel analytics were applied to 100 Department of Defense (DoD) buildings in total across five different DoD specific building types. Specifically, FirstFuel worked with 11 installations across the country to conduct the performance analysis.

Performance Objectives and Results:

The FirstFuel demonstration project was designed around three specific Performance Objectives: (1) Cost, (2) Scalability, and (3) Accuracy. To support the DoD's evaluation of these primary Performance Objectives, a third-party engineering firm, The Cadmus Group, conducted ASHRAE Level II on-site audits across 16 of the DoD buildings.

The table below provides details of the performance objectives and the results of FirstFuel's Remote Building Analytics platform (Hereafter 'RBA').

Performance Objective	Success Criteria	Results
FirstFuel RBA Cost	• The average cost for the FirstFuel RBAs performed on the 16 ASHRAE Level II audited buildings (Types 1-5) will be less than or equal to $3,000/building, or $0.12/sq. ft.(whichever is higher)	• FirstFuel met this cost performance objective through its analysis
FirstFuel RBA Scalability	• RBAs for Type 1 buildings completed in 25% of the time of Cadmus ASHRAE Level II Audits. • RBAs for Type 2-5 completed in 50% of the time of Cadmus ASHRAE Level II Audits.	• FirstFuel exceeded these criteria

Performance Objective	Success Criteria	Results
FirstFuel RBA Accuracy	• RBA finds 80% of the ECMs found in Building Type 1 ASHRAE Level II audits. • RBA finds 60% of the ECMs found in Building Types 2-5 • RBA finds recommendations NOT found in Type 1 Building ASHRAE Level II onsite audits. • FirstFuel's continuous performance monitoring satisfies ASHRAE Guideline 14	• RBA found 61% of the ECMs found in Building Type 1 ASHRAE Level II audits (1), which accounted for 16% more savings than the savings found in the same onsite audits.[1] • RBA found 65% of the ECMs found in Building Type 2-5 ASHRAE Level II audits, which accounted for 37% more savings than the savings found in the same onsite audits.[2] • RBA found 18 recommendations NOT found in Type 1 building ASHRAE Level II onsite audits • FirstFuel's continuous performance monitoring satisfied ASHRAE Guideline 14.
Customer Satisfaction	• 75% overall customer satisfaction compared to the Cadmus ASHRAE Level II audits	• Greater than 75% customer satisfaction compared to the ASHRAE Level II audits for 1 of the 2 sites visited[3]

The results of this project and achievement of the performance objectives suggest that the FirstFuel RBA can present significant advantages over the DoD's traditional approach to onsite energy audits and continuous performance monitoring. For example, traditional walk-through audits run between $5,000-$10,000, and take several weeks or more to complete, including multiple days on-site. These traditional audits are too costly and time-consuming to deliver savings at scale, and yield large reports that are often difficult to use as an efficiency prioritization and planning tool. In contrast, FirstFuel's remote audits can be accomplished in hours, regardless of size or type of building and at a fraction of the cost, without a site visit, while simultaneously yielding performance analysis results similar to ASHRAE Level II onsite audits (the comparison onsite used in this demonstration project). In addition, the FirstFuel remote analytics solution was found to be compatible with approximately 90% of the DoD's building portfolio.

More specifically, the FirstFuel ESTCP demonstration suggests that DoD will find significant value in using FirstFuel's tool to launch, manage and track major energy efficiency initiatives across its vast portfolio of buildings, primarily through:

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[1] The ASHRAE LII onsite audits identified 421,909 kWh of savings in the 6 Type 1 buildings. FirstFuel RBA identified 491,196 kWh of savings in the same buildings.
[2] The ASHRAE LII onsite audits identified 289,561 kWh of savings in the 6 Type 2-5 buildings. FirstFuel RBA identified 396,220 kWh of savings in the same buildings.
[3] Survey was not completed by the second of the two sites visited

- Immediately implementing low/no cost operational savings uniquely identified through the FirstFuel platform
- Significantly reducing the time and cost relative to traditional on-site audits across a range of building types specific to the Department of Defense.
- Providing DOD on-site energy managers with an insightful, intuitive tool to focus and refine their energy savings efforts, compare their buildings to others within the portfolio, and share insights with others that drive more effective energy management
- Tracking energy performance and savings over time to track progress of long-term efforts, aid reporting, validate the effectiveness of energy conservation projects, and maintain the persistence of savings.

In addition to the advantages listed above, the FirstFuel customer delivery model suggests an advantage in overall effectiveness. By providing the use of an intuitive online web portal, interactive Efficiency Planning Webinars with FirstFuel energy engineering experts, and dynamic performance monitoring/tracking features, FirstFuel's integrated approach enables a deeper level of continuous insight and engagement than a static audit report and monitoring tools which lack features, ongoing engagement and a human element to keep users interested and active. Early results suggest that this new approach to efficiency engagement will increase site managers' ability and propensity to act on recommended energy conservation measures.

Because FirstFuel does not require any onsite devices or visits, the platform can be deployed rapidly and with no further installation cost, to all DoD buildings with interval meters. Given the widespread deployment of such meters throughout both the Army and Navy branches, with extensive work underway for almost complete coverage of Advanced Metering Infrastructure (AMI) in all service branches, the FirstFuel RBA platform provides the optimal combination of effectiveness and leverage of existing or planned infrastructure investments.

1.0 Introduction

Energy efficiency is the "first fuel" the Department of Defense (DoD) is addressing, and FirstFuel's demonstration was designed to test the validity of its approach to remote building assessments while also helping the DoD to meet its energy efficiency goals.

1.1 Background

In recent years, the DoD has launched several initiatives to reduce its fossil fuel use by improving energy efficiency (i.e. reducing wasted energy).[4] Reducing the amount of energy used and wasted across the DoD's portfolio of buildings is a significant opportunity and key to reducing emissions and energy consumption across the U.S. However, identifying and profiling the energy efficiency savings potential of individual buildings presents significant challenges for a building portfolio as large and diverse as that of the DoD.

Over the course of the 16 month project, FirstFuel worked with 11 DoD installations to perform remote audits on 100 buildings utilizing FirstFuel's Remote Building Analytics (RBA) platform. In order to evaluate the technology on a range of DoD specific buildings, FirstFuel divided the 100 buildings assessed into five building type categories. The first type consisted of 30 "Type "1 buildings, which were building types that FirstFuel's RBA was already optimized to analyze—company headquarters and administrative buildings. Seventy (70) buildings made up the four other buildings types that are specific to the DoD.

The table below explains the breakdown of building category by "Type" for the purposes of this demonstration:

	Building Type	**Number of RBAs**
1	Offices, municipal, schools, training facilities	30
2	Barracks, dining facilities, mess halls	31
3	Warehouses, Shipping Centers, Commissaries	18
4	Rec centers, auditoriums, chapels	12
5	Motor pools, hangars, garages--facilities with lighter process and specific equipment loads	9
	Total Sites	**100**

Table 1: RBA Demonstration Building Types

[4] "Fact Sheet: DoD's Energy Efficiency and Renewable Energy Initiatives. Environmental and Energy Study Institute. http://www.eesi.org/dod_eere_factsheet_072711

FirstFuel performed R&D to customize the RBA software in order to provided end-use analysis for buildings of this type.

The experience and outcome of this ESTCP demonstration suggests that DoD will find significant value in using FirstFuel's tool to track the energy performance of its vast portfolio of buildings, primarily through:

- Immediately implementing low to no cost operational savings uniquely identified through the platform.
- Reducing the time and cost relative to traditional onsite audits across a range of building types specific to the Department of Defense.
- Using the platform for onsite energy managers to focus and refine their energy savings efforts, compare their buildings to others within the portfolio, and share insights with others to more effectively manage energy consumption.
- Use of the platform to track performance and savings over time which both helps with reporting efforts and validates the effectiveness of energy conservation measures.

1.2 Objective of the Demonstration

FirstFuel's demonstration examined how the DoD could measure the impact of energy audits across hundreds of buildings. In order to test this question, FirstFuel performed remote building assessments across 100 DoD buildings. To conduct each remote audit, FirstFuel utilized four pieces of information: 1 year of historical electric interval consumption data, weather data from the building's closest weather station, GIS information from the building's location, and a building information survey completed by DoD site energy managers. The weather and GIS data were sourced by FirstFuel, and not provided by the DoD.

The project's objectives were designed around measuring the time, cost, and accuracy of FirstFuel's remote audits, as compared to ASHRAE Level II onsite audits. FirstFuel demonstrated the that remote audits could be done at one third the cost when compared to the onsite approach, and three to five times faster versus ASHRAE Level II onsite audits. While the ECMs between the two approaches did not match up to the expected success criteria of 80% in the Type 1 buildings, the FirstFuel approach did find 16% more savings compared to the onsite audits in these buildings, suggesting that number of ECMs as a metric may be a less important than the savings found. For example, ECMs recommended via onsite audits may not be uncovered by the FirstFuel RBA (or vice versa) because omissions may reflect a different set of energy management objectives or scope. By their very nature, onsite audits are more likely to capture smaller value capital improvements, because they result from visual confirmation, whereas analytics based approaches, like FirstFuel's, are likely to capture larger value operational ECMs.

1.3 Regulatory Drivers

FirstFuel's ESTCP Rapid Building Assessment Proposal addresses the following drivers:

Driver		**Explanation**
Energy Policy Act, 2005, Section 103	Mandate for using advanced meters to reduce electricity in federal buildings by October, 2012	FirstFuel's software platform provides a straightforward way for the DoD to use the data generated from the advanced meters to identify and encourage reductions in electricity consumption.
Executive Order (EO) 13123	"Greening the Government through Efficient Energy Management"	This executive order set energy management goals for the Federal Government. The inefficient use of energy wastes defense funds. The success of FirstFuel's project offers the DoD a way to identify areas to reduce energy waste in a manner that is cost effective and timely.
Strategic Sustainability Performance Plan, 2011; Pg I-14	"decisions made at the facility level are not always in the best long term interests of the Department as a whole, including its sustainability objectives. DoD needs to ensure that personnel working on site-level projects bring a broad perspective to the decision-making process that considers objectives of the Department beyond those of the site alone."	The project may contribute to the driver by giving energy site managers insight into the energy consumption of different DoD buildings, thereby allowing DoD to make strategic decisions in their entire building portfolio and comparing the performance of buildings within the DoD.

Driver		Explanation
Memorandum of Understanding between U.S. Department and Energy and U.S. Department of Defense Concerning Cooperation in Strategic Partnership to Enhance Energy Security; 2010; Section IV. Activities	"Expand cooperation related to energy management practice and knowledge exchange, working to ensure that Federal Leadership is in compliance with all statutory and Executive Order goals and objectives…Encourage the sharing of data, including, but not limited to, data on internal energy management projects and technical assistance projects."	The project may contribute to the support of the MOU between the DOE and the DoD as the RBAs can be made available for viewing through the online portal. Leaders from both the DoD and DOE may use the insights gained from the building assessments and subsequent energy consumption monitoring to learn about how the certain DoD buildings consume energy and use the portfolio view to identify the biggest opportunities for energy savings.

2.0 Technology Description

2.1 Technology Overview

Core Technology
FirstFuel's Remote Building Analytics (RBA) platform combines interval meter data with hourly weather and climate data and geographical information systems (GIS) mapped building characteristics to provide a consistent, reliable view of how energy is used inside a building. The platform utilizes advanced, proprietary statistical methods and data mining techniques based on FirstFuel's patent pending technology. The core technology utilizes a unique approach based on "inverse modeling," which examines each building and data set independently. The technology infers the building's energy use utilizing only its own unique consumption patterns and signatures. The platform infers the building's energy use breakdown without the use of outside databases/benchmarks of "like" buildings, traditional energy simulation models (e.g. eQuest, DOE-2, EnergyPlus), or models that compare a building's interval usage data to a simulated model of the building operating at 'optimal performance'. This enables FirstFuel platform users to view energy analysis and recommendations that each have been individually verified based on actual building performance, as opposed to automated content based on how their building should be performing. The output from FirstFuel's inverse model is a highly accurate breakdown of the actual hour-by-hour consumption across end-uses for the building. This inverse-modeling approach enables a level of simultaneous individual building analysis customization, scale across portfolios, and accuracy of results that is unparalleled in the industry.

The only inputs that the FirstFuel RBA platform requires is 1 year of historical electrical interval data (5/15/30/60 minute building electric consumption data) and the building address. The data can be delivered to FirstFuel seamlessly through a variety of data transfer methods, including encrypted .csv files uploaded to our secure File Transfer Protocol (ftp) server, using Representational state transfer (REST) services, and through Green Button Connect. The electric interval data must represent only the building being analyzed. For example, buildings that are served by a central heating/cooling plant cannot be analyzed unless the building's electric consumption is measured on an interval basis. From there, FirstFuel pulls in additional information about the building including (a) Hourly local weather data, (b) GIS building data, and (c) Additional building data through semantic searches that are publicly available including square feet, occupancy type, etc.

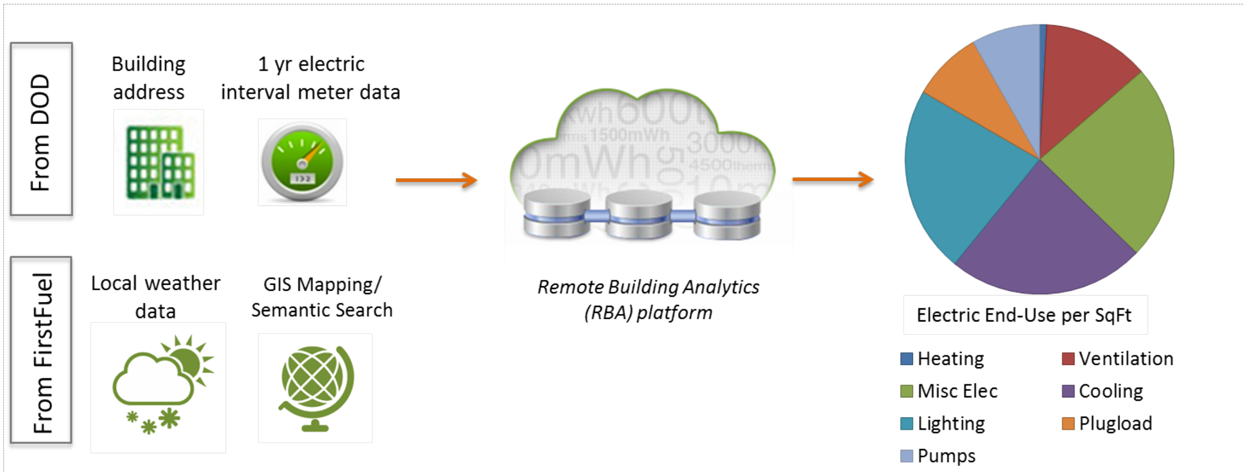


Figure 1: FirstFuel's Inverse Modeling Remote Audit Process

The analytics output includes building-specific performance benchmarks, base lining, load disaggregation, and customized recommendations for actions at the end-user level, as well as predictive projections of each building's potential for energy efficiency. FirstFuel's technology is particularly adept at detecting and detailing operational savings opportunities, and instructing energy administrators or building-level managers regarding how best to implement changes and track performance. When monthly thermal data (natural gas, fuel oil, etc.) is available for the building, FirstFuel is able to perform an analysis of the building's thermal use. The analysis includes a breakdown of the weather related and non-weather related thermal fuel consumption, and energy conservation measures related to thermal energy reductions.

To provide results more consistent with those of ASHRAE Level II equivalent audits, FirstFuel asked the energy site managers to complete a short building information survey for each building analyzed. These surveys provide asset-related information needed for FirstFuel building engineers to make implementation more refined cost & ROI estimates associated with the Energy Conservation Measures (ECMs). While a large majority of the remote energy audit process is automated through analytics, FirstFuel's team of in-house energy engineers verify each ECM to ensure the energy savings recommendations are relevant, customized, and actionable.

Through this approach, FirstFuel creates a level of detail about each building that was previously unavailable without going onsite, including end-use consumption profiles by hour, detailed building operational schedules, setpoints, equipment sequences, ventilation configurations and more. FirstFuel is the only fully remote commercial energy analytics solution that has been independently and repeatedly validated by 3rd parties across many dimensions of performance. FirstFuel's successful technical validations include a Scaled Field Placement completed by PG&E in 2013 as an Emerging Technologies Coordinating Council initiative, the Fraunhofer

Institute (a U.S. DOE-funded study), the Cadmus Group, The Electric Power and Research Institute (EPRI), Johnson Controls Energy Services Group (JCI), and the US DOE's Energy Efficiency Buildings Hub (EEB Hub).

For this project, FirstFuel worked with 11 Department of Defense (DoD) installations across the country to identify buildings for remote audit participation. Participating sites provided just three pieces of information for the remote audits and remote performance monitoring: (1) 1 year of historical electrical interval data (2) the building address and (3) a completed building information survey.

Technology Application

FirstFuel's deploys its Remote Building Analytics platform to customers in an industry leading integrated approach – through an intuitive web-based portal, demonstrated to the end user in a webinar by our skilled team of in-house energy engineers.

The engagement of building operators remains a critical step to accelerating energy efficiency across the federal sector. In this project, FirstFuel's team of in-house energy engineers directly engaged building operators through an Efficiency Planning Session. Conducted via webinar by, FirstFuel discussed the full energy analysis and results, gained acceptance and buy-in around leading energy savings recommendations, and secured initial commitment to act through collaborative dialogue.

Following the webinar, FirstFuel energy engineers can continue to provide on-going coaching to motivate and support action through regular engagement touch-points and by working with 3rd party implementers to ensure that uncovered opportunities translate into projects and energy savings opportunities. The resulting remote audit and customer delivery process incorporates the best of analytics, building engineering experience and local knowledge that cannot be accomplished with the "push of a button" alone.

Following completion of the Efficiency Planning Session, participants were given access to FirstFuel's web-based energy portal for ongoing usage by DoD energy managers. This portal includes all underlying building performance analysis (including leading energy conservation recommendations) and ongoing tracking of energy savings through FirstFuel's remote performance monitoring. The following screenshots provide a snapshot of FirstFuel's web-based energy portal:

Building Information and Current Energy Use:

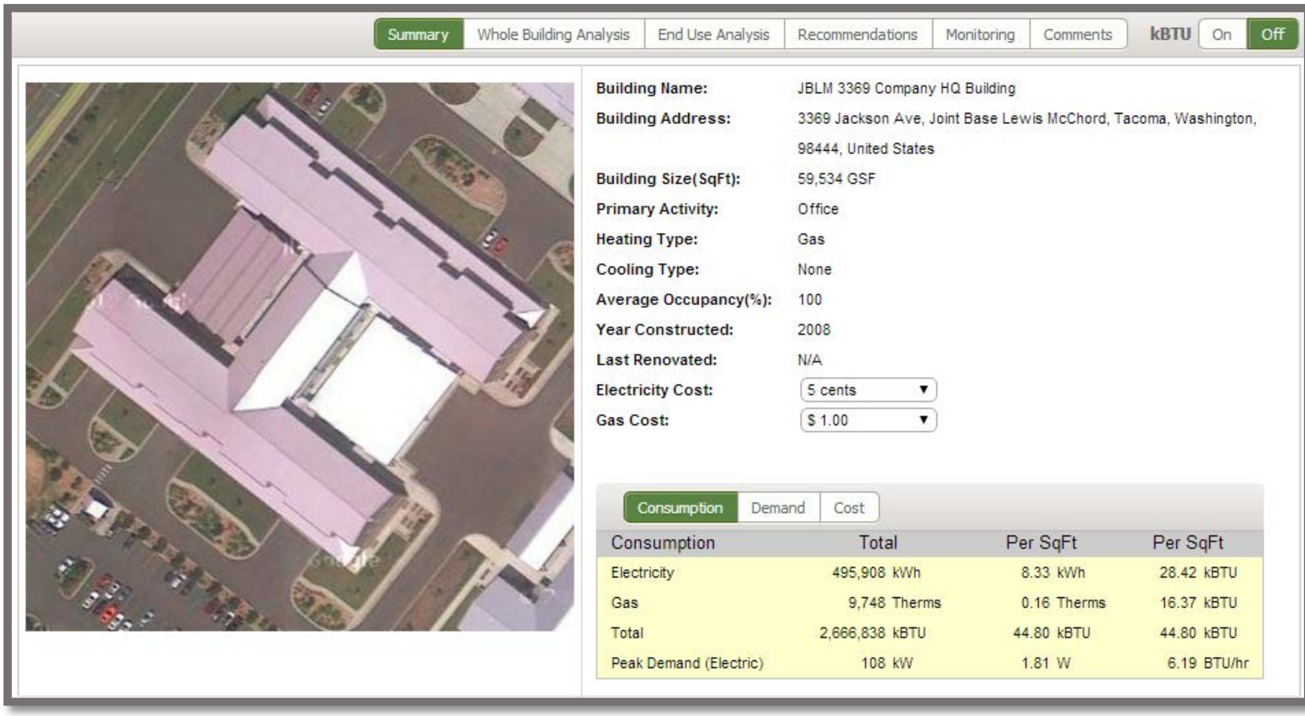
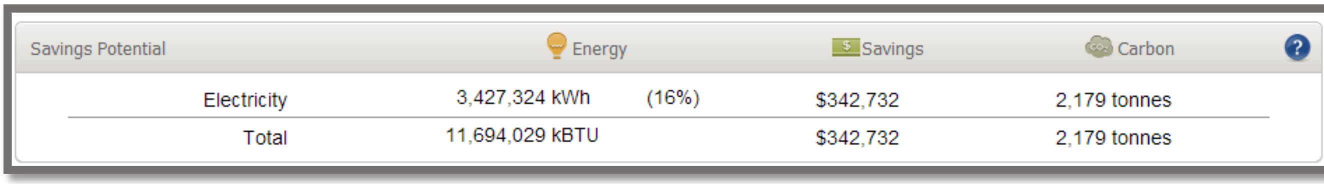


Figure 2: Sample Building Summary Page, Part 1

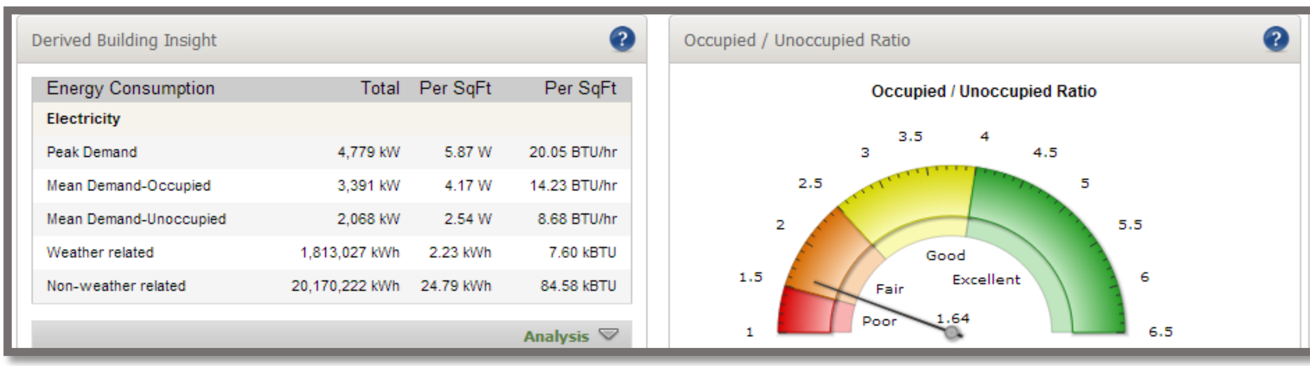
Savings Potential



Savings Potential	Energy		Savings	Carbon
Electricity	3,427,324 kWh	(16%)	$342,732	2,179 tonnes
Total	11,694,029 kBTU		$342,732	2,179 tonnes

Figure 3: Sample Building Summary Page, Part 2

Operational and Occupancy Analysis:



Derived Building Insight

Energy Consumption	Total	Per SqFt	Per SqFt
Electricity			
Peak Demand	4,779 kW	5.87 W	20.05 BTU/hr
Mean Demand-Occupied	3,391 kW	4.17 W	14.23 BTU/hr
Mean Demand-Unoccupied	2,068 kW	2.54 W	8.68 BTU/hr
Weather related	1,813,027 kWh	2.23 kWh	7.60 kBTU
Non-weather related	20,170,222 kWh	24.79 kWh	84.58 kBTU

Figure 4: Sample Whole Building Analysis, Part 1

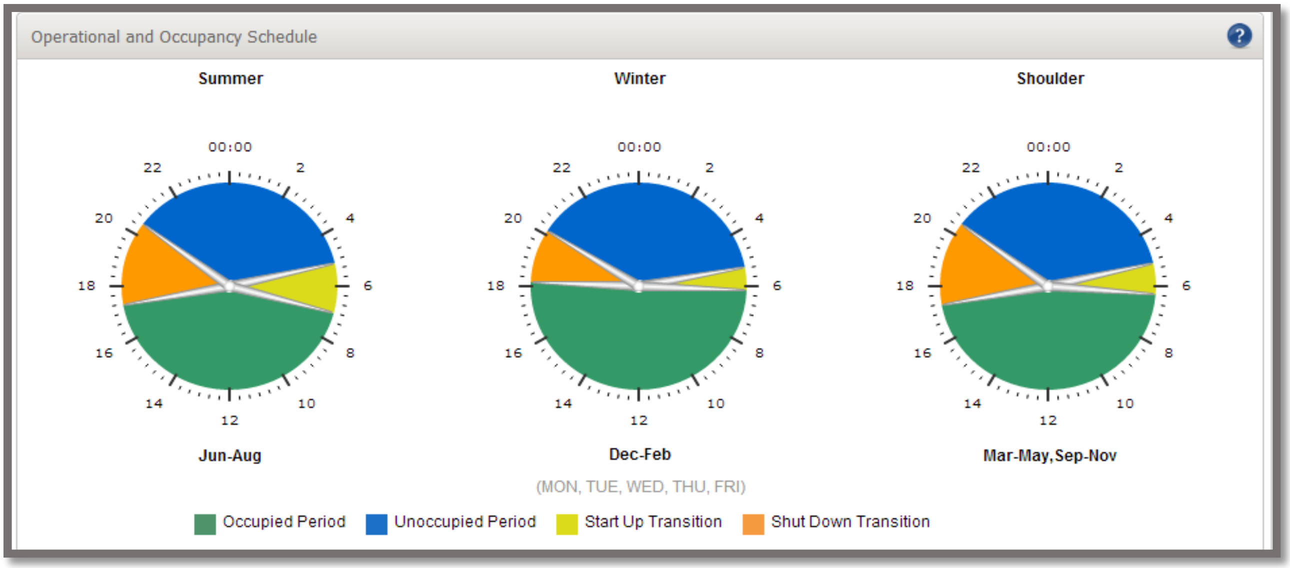


Figure 5: Sample Whole Building Analysis, Part 2

End Use Analysis:

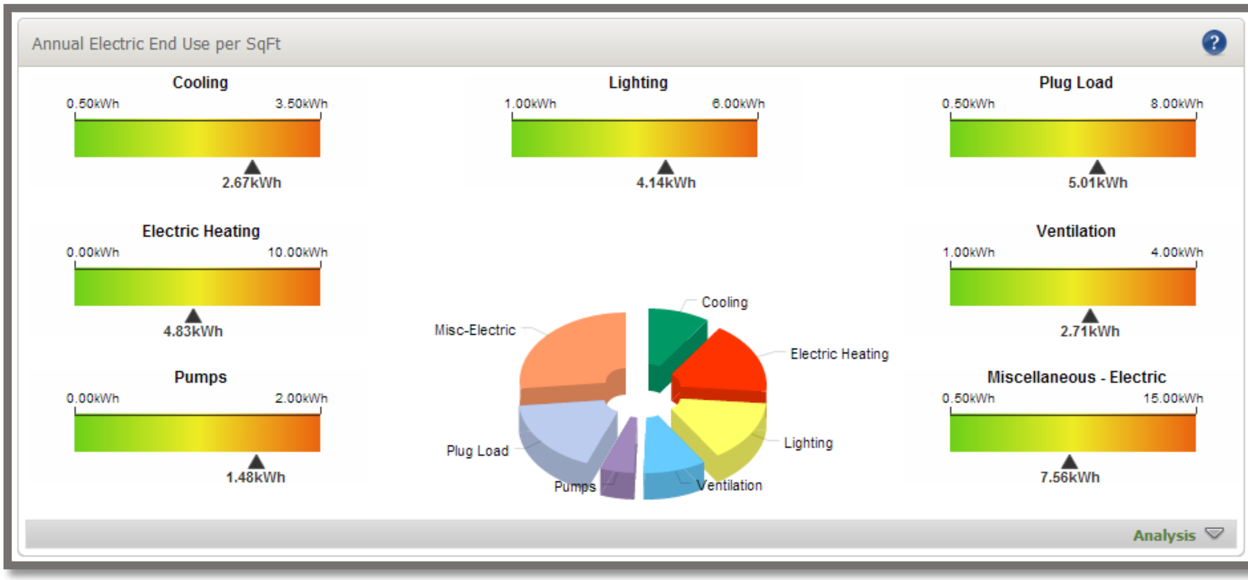
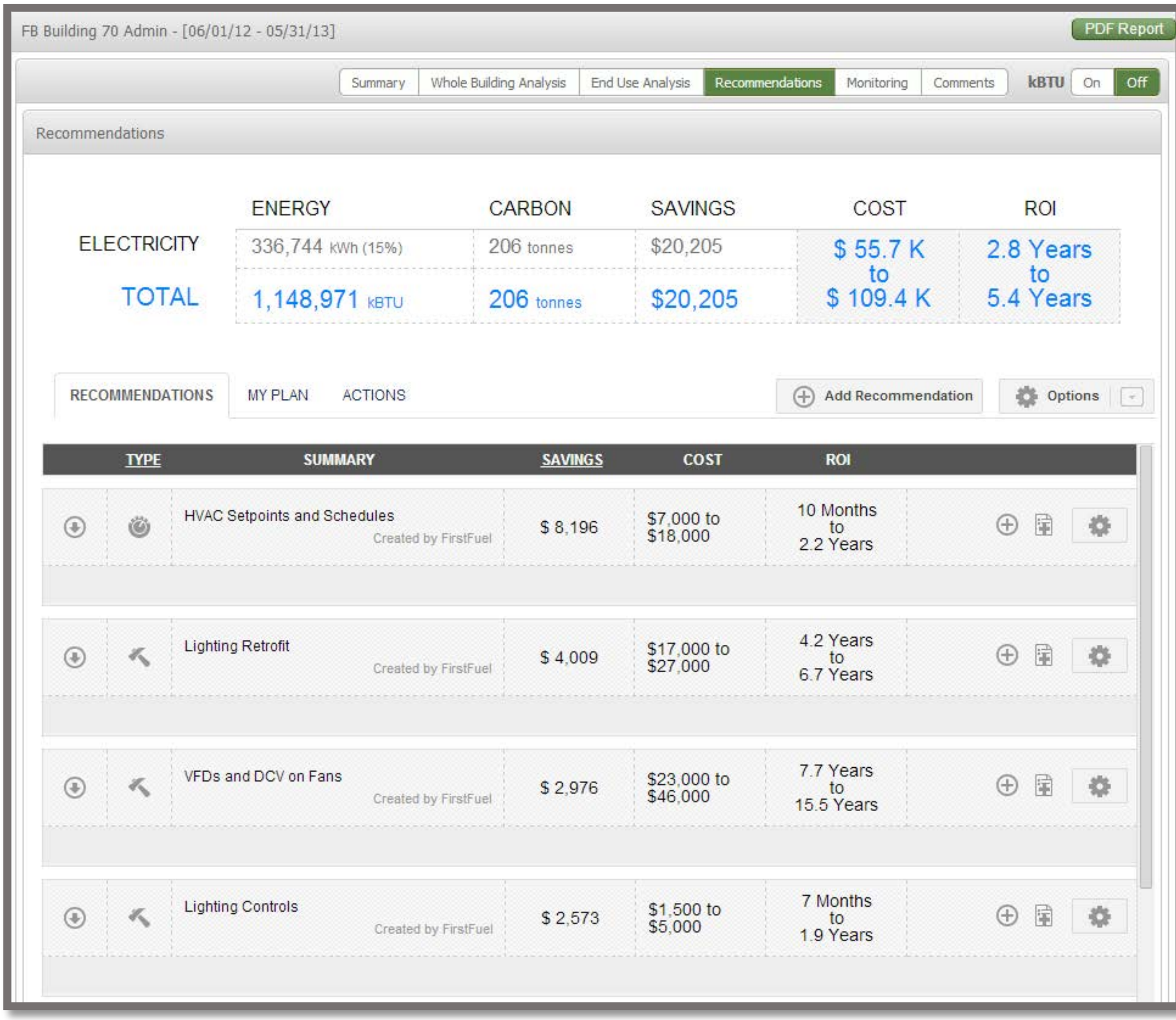


Figure 6: Sample End Use Analysis

Energy Conservation Measures (ECMs):



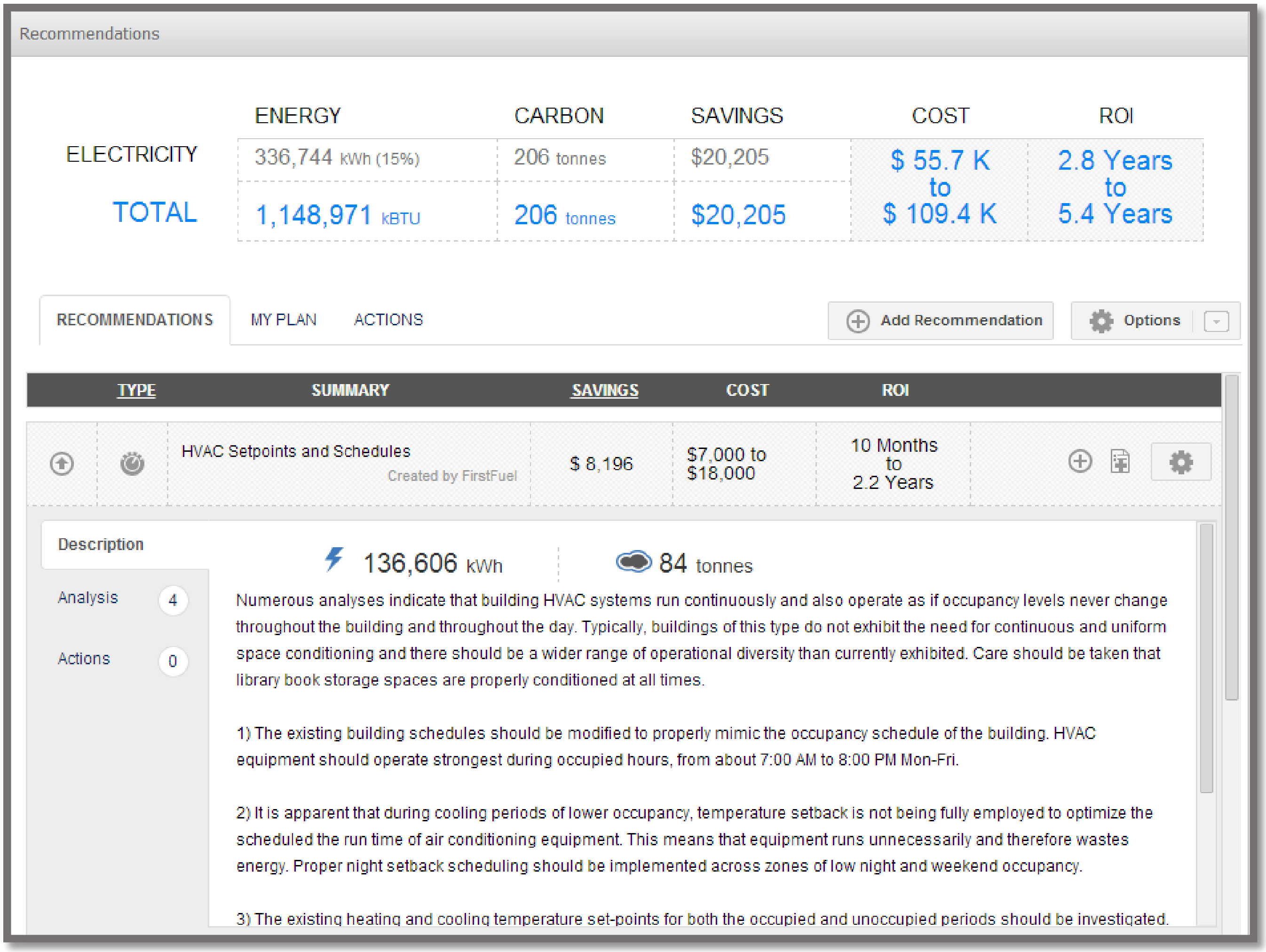


Figure 7: Sample Recommendations

FirstFuel portal users that oversee more than one building have portfolio viewing privileges. Portfolio users are able review the results of the assessments across multiple buildings to identify areas of highest opportunity, by building type, by location or by opportunity type (e.g. lighting, schedule changes, etc.). Below is an example of the DoD portfolio view for potential energy savings sorted by building type:

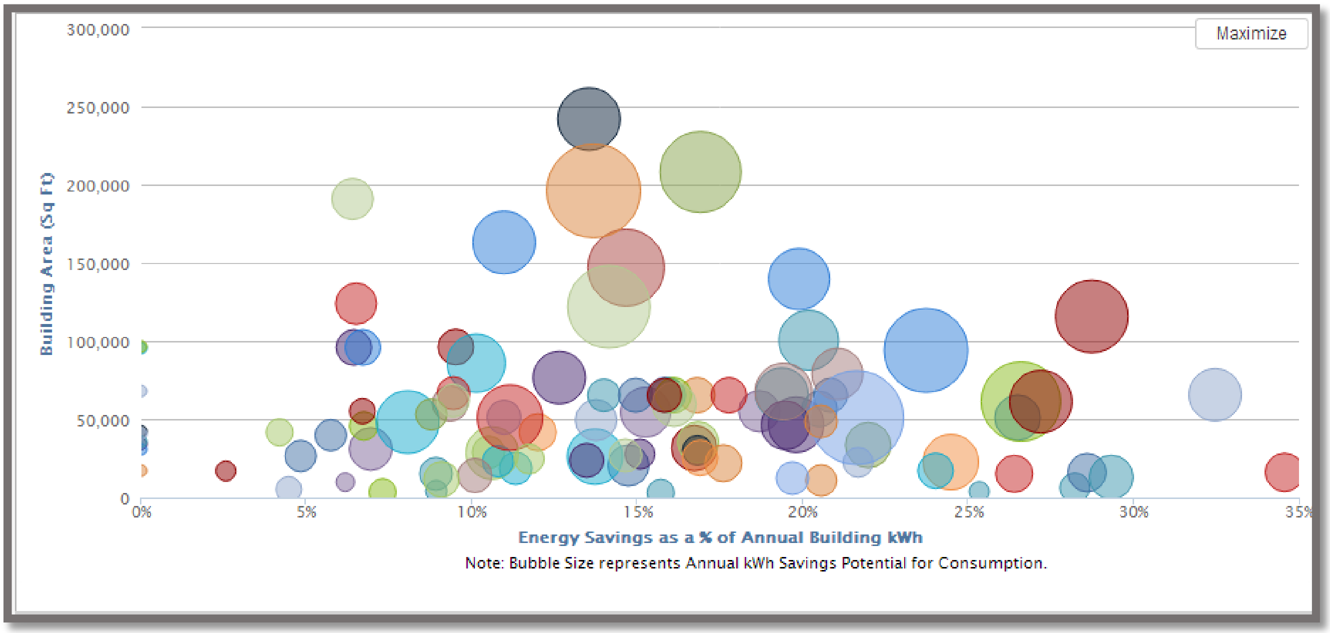


Figure 8: Portfolio View

Sites that provided FirstFuel with post-audit electric consumption data were given access to FirstFuel's continuous performance monitoring service. Similar to the remote audit service, FirstFuel continuous monitoring is conducted without the use of onsite devices or site visits, and requires only regular updates of interval data. With this data, FirstFuel is able to: (1) establish a weather and occupancy-normalized baseline of consumption based on the initial year of data; (2) measure the deviation, at a whole building level, between the baseline and actual consumption, i.e., measure energy savings at a whole building level; (3) correct for major non-efficiency changes in the building during either the initial year of data or in the following years; (4) alert customers on a monthly or quarterly basis to significant changes in the building's energy consumption profile; and (5) demonstrate persistence of operational measures for enhanced savings. Figure 9 below is an example of FirstFuel's continuous performance monitoring:

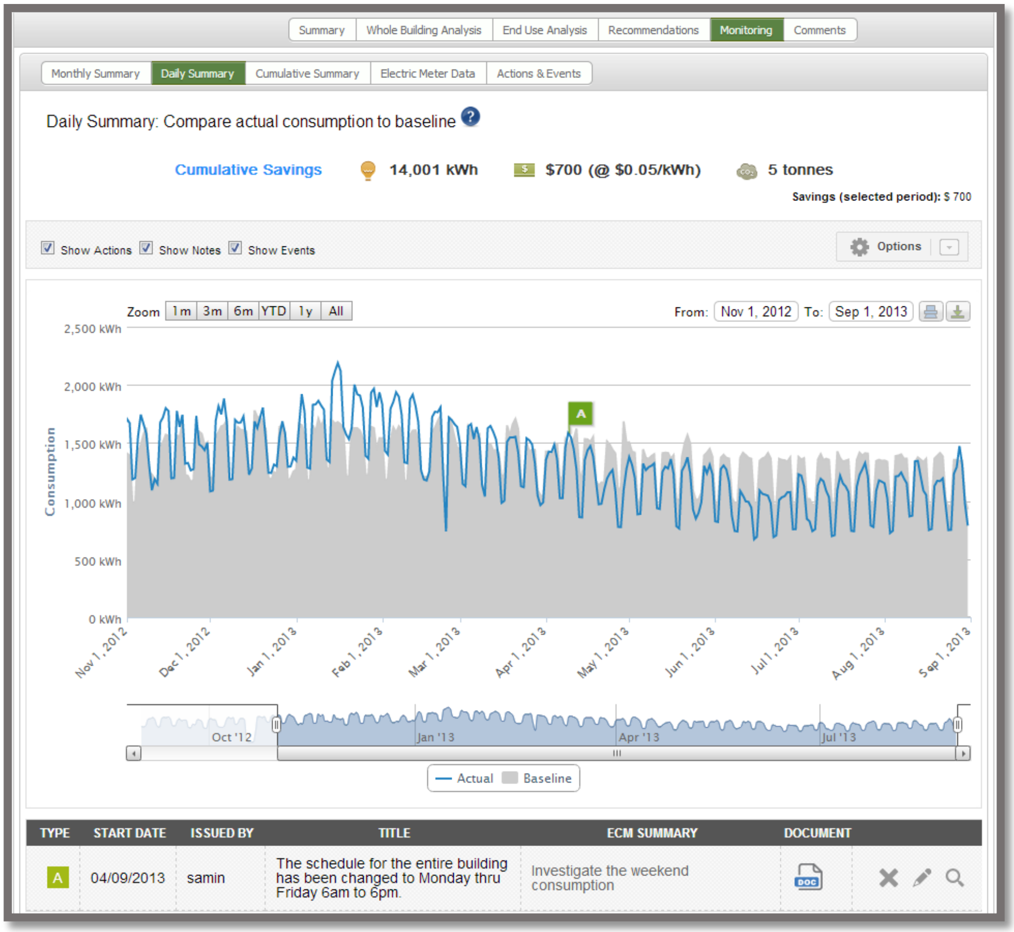


Figure 9: Continuous Performance Monitoring Screenshot

2.2 Technology Development

FirstFuel developed the remote audit technology, now called FirstAudit, through two years of intensive research and development. After launching FirstAudit in mid-2011, FirstFuel has added a suite of additional Software-as-a-Service analytics capabilities to support the entire energy efficiency lifecycle, including portfolio efficiency screening and energy audits to customer engagement and performance monitoring and verification. The timeline below illustrates the chronological summary of the FirstFuel's deployment of the RBA technology to date.

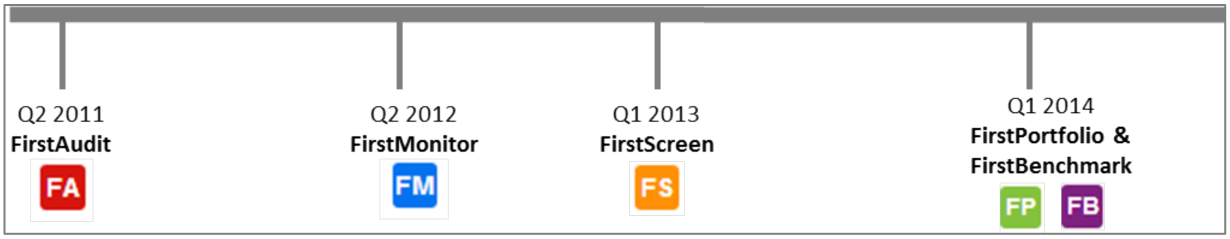


Figure 10: Chronological Summary of FirstFuel's technology deployment

Expected Application of the Technology

Following technical and field evaluation of FirstFuel's RBA platform, the software has been fully commercialized. FirstFuel is engaged in several deployments with customers, including several of the largest North American utilities, the U.S. General Services Administration, and the Washington D.C. Department of General Services. As of January 2014, FirstFuel customers were tracking over $250 million in potential savings on the FirstFuel RBA platform, which includes an identified 14% electricity savings potential across 5.5 million square feet of DoD buildings.

FirstFuel's demonstration involved conducting remote audits on DoD buildings, using FirstFuel's existing RBA technology. Research that occurred as part of the demonstration focused on optimizing the RBA platform for DoD's unique building types in addition to the common commercial building types that were previously available through the platform. Specifically, FirstFuel building engineers spent time researching how each new building type operates in order to incorporate that learning into the key algorithms and processes of the RBA platform, including the end-use disaggregation and other component analytics of the remote audit. To understand the unique features associated with DoD buildings, a team of FirstFuel building engineers conducted building walkthroughs at two sites – Fort Benning and Naval Station Everett – which each hosted several example buildings in the new types. The onsite walkthroughs consisted of visual inspection and discussions with onsite building operators to review the buildings' operational schedules, types of equipment and overall design specifications.

The onsite review and study of DoD specific building types provided FirstFuel's team the necessary information to optimize the RBA platform, analytics and disaggregation engine for these new buildings. The research also yielded the realization that not all DoD buildings can be analyzed using only FirstFuel's traditional RBA tool. A particularly unique feature of DoD buildings' energy consumption is that many buildings are not always occupied throughout the year (e.g. barracks). Because FirstFuel's original audit tool worked by analyzing a building's own unique consumption patterns and signatures over a 12 month period, those buildings with significantly different patterns within the year period required a slightly modified analytics approach. In order to provide end-use level consumption detail for these buildings, FirstFuel's traditional "inverse modeling" approach was supplemented by another proprietary approach, using a high-speed variant of traditional building models, such as DOE-2. The method was also remote and meets similar cost, speed and accuracy specifications to FirstFuel's core methodology, as it still incorporates most aspects of the inverse modeling approach.

2.3 Advantages and Limitations of the Technology

There are three primary alternatives to FirstFuel's remote audit technology in the market today.

1. Traditional onsite energy assessments and audits
2. Remote energy analysis and benchmarking tools
3. Analytics tools requiring onsite devices

The FirstFuel RBA has been designed to present significant advantages over each, and these advantages have been demonstrated successfully in this project.

1. The traditional approach to building energy assessments begins with a walk-through audit. Typical onsite assessments run between $5,000-$10,000, and take several weeks or more to complete, including multiple days onsite. These audits are too costly and time-consuming to deliver savings at scale across the DoD's portfolio of buildings. FirstFuel's remote audits can be accomplished in hours regardless of the size or type of building and at a fraction of the cost, without a site visit, yielding results similar to ASHRAE Level II onsite audits (the comparison onsite used in this demonstration project) that can take weeks to complete.

   In addition to cost and speed advantages, the FirstFuel methodology suggested an advantage in overall effectiveness. Between the use of the online portal, interactive Efficiency Planning Sessions via webinar and the remote monitoring tracking features, the FirstFuel approach creates a more interactive and ongoing engagement than a static audit. Early results suggest that this engagement will increase building managers' ability and propensity to act on the recommended ECMs provided. Key interactive features not available from onsite audits include:

   - Easy access via web portal by multiple stakeholders
   - Updateable and easy to understand dynamic charts, graphs and analysis describing energy performance and ECMs
   - Tracking of overall building performance over time
   - Impact measurement of enacted ECMs

- ECM recommendation, personalized plan creation and documentation features

2. Other remote technologies currently available in the market are inexpensive but do not offer the same level of scalability, accuracy or actionable results as FirstFuel's RBA platform. Although many bill themselves as "remote audits", FirstFuel's inverse modeling approach is the only one to examine each building utilizing only its own unique consumption patterns and signatures. This is analogous to an onsite audit that bases its conclusions on observation and analysis of the actual building in question, rather than on a series of comparisons to other buildings. Using its proprietary approach, FirstFuel analysis is able to include: end-use consumption profiles by hour, detailed building operational schedules, setpoints, equipment sequences, ventilation configurations and more. The net result is a series of ECMs, cost and savings estimates that are uniquely verified for each building. In contrast, other remote technologies offer results that rely only partially on building data, and instead make recommendations based on comparisons to "like" buildings or models that simulate the performance of a particular building operating at maximum efficiency. This approach especially falls short when analyzing DoD type buildings, as the unique building types make "like building" comparisons less accurate or insightful due to the lack of "like buildings" to compare to.

   Taking into consideration the above, it is notable that FirstFuel offers the only remote technology that has been extensively validated by 3rd parties, now including this demonstration project, for its accuracy and comparability to onsite audits. As the DoD investigates the use of tools now and in the future, this demonstration underscores the importance of such validation of both accuracy and actionability of results.

3. Analytics tools that utilize onsite devices are typically more expensive than the FirstFuel solution – ranging from $5,000 installed cost for the lightest devices to over $100,000 for high-end BMS systems or building sub-meters. The "light-device" solutions tend to lack the diagnostic detail found in the FirstFuel RBA, for example end-use level benchmarking and detailed recommendations. These light-device solutions are often classified as a "dashboard" or "energy monitoring" and provide few actionable insights. At the higher end, more detail is provided, but at much higher price, and often foregoing the "whole building" view in favor of much higher detail and control of a few key systems. However, the key advantage of the FirstFuel platform relative to systems that require onsite devices is the speed, cost and ease of implementation – all of which enable scale across of a multitude of building types and sizes. The FirstFuel platform can be deployed rapidly, with no further installation cost, to all DoD buildings with interval meters. Given the already widespread deployment of such meters in both the Army and Navy, with extensive work underway for almost complete coverage of AMI in all service

branches, the FirstFuel RBA platform provides the optimal combination of effectiveness and leverage of existing or planned infrastructure investments.

Through this demonstration we have observed two potential limitations to the demonstrated approach. The first relates to building energy data. Buildings that do not have interval electric consumption data are not applicable for the remote audits. Additionally, for those buildings with significantly less than one years' worth of interval electric consumption, the remote analysis can be difficult or impossible to complete. Such meter data issues are often not discovered until those twelve months are requested, and the undetected problem means the building's analysis cannot be completed until either more data is gathered by the meter or more complete data is gathered from an earlier time period. The second limitation concerns buildings that are not occupied for months at a time, typically while troops are deployed, or buildings that have very low energy consumption. These buildings may present challenges to perform the end use analyses. However, the impact of this limitation is partially mitigated by the finding that these types of buildings often have lower consumption and/or limited energy efficiency opportunities.

One final issue to consider regarding FirstFuel platform advantages and limitations is the total cost of ownership and return to the DoD. When conducting an audit- either onsite or remotely, one of the major cost considerations is the resources that the DoD must offer to complete the assessment. Onsite audits typically require a site manager to accompany the building engineers to each of the buildings. This can mean that a DoD employee is occupied for an entire day for one building walkthrough. In addition, the DoD resource often is asked to pull building drawings and building automation system data. Alternative remote energy analysis and benchmarking solutions bill themselves as "push button", but return results that require extensive additional work to detail actual savings opportunities.

FirstFuel's remote audits require only the time of the site manager to collect the building's data (including completing a building information survey) and participate in a webinar-based Planning Session. As such, a significant advantage of FirstFuel's approach is that it helps to reduce the time and burden that the DoD energy site manager, or their staff, must devote to energy audits.

3.0 Performance Objectives

3.1 Performance Objectives

Table 2: Performance Objectives

Performance Objective	Metric	Data Requirements	Success Criteria	Results
Quantitative Performance Objectives				
Cost of the RBA	RBA price per building and per square foot	• 12 months of historical electric data in interval format for each building • Building Information Survey for each building	• The average cost for the RBAs performed on the 16 ASHRAE Level II audited buildings (Types 1-5) will be less than or equal to \$3,000/building, or \$0.12/sq. ft.(whichever is higher)	• The RBA met or exceeded this criteria
Scalability of the RBA	Hours per engineer per RBA	• 12 months of historical electric data in interval format for each building • Building Information Survey for each building • Results from 12 Cadmus ASHRAE Level II audits	• RBAs for Type 1 buildings completed in 25% of the time of Cadmus ASHRAE Level II Audits. • RBAs for Type 2-5 completed in 50% of the time of Cadmus ASHRAE Level II Audits.	• The RBA met or exceeded this criteria
Accuracy of the RBA	• # of RBA ECMs identified • # of ASHRAE Level II ECMs	• Outputs from the FirstFuel RBAs • Results from 12 Cadmus ASHRAE Level II audits	• RBA finds 80% of the ECMs found in Building Type 1 ASHRAE Level II audits. • RBA finds 60% of the ECMs found in Building Types 2-5 • RBA finds recommendations NOT found in Type 1 Building ASHRAE Level II onsite audits.	• RBA found 61% of the ECMs found in Building Type 1 ASHRAE Level II audits (1), which accounted for 16% more savings than the savings found in the same onsite audits.[5] • RBA found 65% of the ECMs found in Building

[5] The ASHRAE LII onsite audits identified 421,909 kWh of savings in the 6 Type 1 buildings. FirstFuel RBA identified 491,196 kWh of savings in the same buildings.

Performance Objective	Metric	Data Requirements	Success Criteria	Results
Quantitative Performance Objectives				
				Type 2-5 ASHRAE Level II audits, which accounted for 37% more savings than the savings found in the same onsite audits.[6] • RBA found 18 recommendations NOT found in Type 1 building ASHRAIE Level II onsite audits
Accuracy of the Continuous Performance Monitoring	FirstFuel's predictions compared to actual consumption during the monitoring period	• Three months' worth of interval data from the 12 ASHRAE Level II buildings	• FirstFuel's continuous performance monitoring satisfies ASHRAE Guideline 14	• FirstFuel's continuous performance monitoring satisfies ASHRAE Guideline 14
Qualitative Performance Objectives				
Customer Satisfaction	Degree of Satisfaction	• Standard, web-based Likert Scale Survey to include criteria such as: RBA invasiveness, speed, opinion on applicability of results and recommendations, portal ease of use, among others	• 75% overall customer satisfaction compared to the Cadmus ASHRAE Level II audits	• Greater than 75% customer satisfaction compared to the ASHRAE Level II audits for 1 of the 2 sites visited[7]. Responding sites had 39 buildings with remote audits.

[6] The ASHRAE LII onsite audits identified 289,561 kWh of savings in the 6 Type 2-5 buildings. FirstFuel RBA identified 396,220 kWh of savings in the same buildings.
[7] Survey was not completed by the second of the two sites visited

3.2 Performance Objectives Descriptions

Cost of RBA: FirstFuel demonstrated its applicability to the large and disparate DoD building portfolio by showing that its process can be executed much more cost effectively than onsite ASHARE Level II building audits.

> Purpose: To prove the low-cost nature of FirstFuel's RBA methodology compared to onsite ASHRAE Level II audits.
> Metric: The units used to measure this performance objective were cost per building to perform RBAs and the costs of the equivalent ASHRAE Level II onsite audit.
> Data: In order to perform the RBAs, FirstFuel used the 12 months' worth of hourly interval electric meter data. Additionally, FirstFuel's engineers used a completed building information questionnaire, when it was available. This data was then used to complete the remote audit.
> Analytical Methodology: FirstFuel used its standard building price schedule to determine the per-building remote audit cost.
> Success Criteria: FirstFuel's cost per RBA per building would be less than or equal to $3,000/building.
> Results: FirstFuel's cost per RBA met or exceeded this criterion.

Scalability of RBA: FirstFuel demonstrated its applicability to the large and disparate DoD building portfolio by demonstrating that building energy assessments can be performed rapidly, providing a scalable solution for a large portfolio of buildings.

> Purpose: To prove the scalability of FirstFuel's RBA as compared to the traditional approach of onsite ASHRAE Level II audits.
> Metric: Time to complete each RBA and time spent to conduct each ASHRAE Level II audit and produce the final report.
> Data: FirstFuel's building engineers recorded their time spent to perform each RBA, and present the audit using the company's project management software. The data for this Performance Objective also included the average time spent on behalf of the DoD energy site manager to complete the building information survey, and participate in a webinar to review the results of the building. To gather the data for the time spent on the onsite audits and reports, FirstFuel used the cost and time provided in the invoice documents from the Cadmus Group. To account for the DoD energy site manager time for the onsite audits, we used their time spent supervising the walk through of the building.
> Analytical Methodology: FirstFuel's building engineers recorded their time for each remote assessment in the company's project management software. That data, plus the DoD time was then used to analyze the amount of time it took for the completion of the

RBA compared to the time it took for the completion of the onsite audit and the resulting report. The onsite audit time also included the energy site manager's time.
Success Criteria: The success criteria for Type 1 buildings was based on completing a Type 1 RBA in 25% of the time that it took Cadmus to complete the ASHRAE Level II audit for the same Type 1 buildings. For building types 2-5, FirstFuel's success metric was to complete the RBAs in 50% of the time it took Cadmus to complete the ASHRAE Level II audits for the same buildings.
Results: FirstFuel's project exceeded these criteria.

Accuracy of RBAs: FirstFuel demonstrated the validity of its approach to remote building assessments.

Purpose: For technical due diligence and credibility.
Metric: ECMs from the Building Type 1 and audits from each of the ASHRAE Level II audit reports and the RBAs of the same 12 buildings.
Data: The ECMs identified in the FirstFuel RBAs for the 12 buildings and the ECMs identified in the 12 Cadmus ASHRAE Level II onsite audits.
Analytical Methodology: FirstFuel created a table comparing 12 onsite audit ECMs to the ECMs of the 12 RBAs of the same buildings.
Success Criteria:

1. The RBA identifies 80% of the measures/recommendations found in the Cadmus onsite audits for type 1 building, and 60% of the measures/recommendations found in the Cadmus onsite audits for building Types 2-5.
2. The RBA identifies ECMs NOT found in the Type 1 ASHRAE Level II audited buildings.

Results: FirstFuel's RBAs identified 61% of the ECMs that the ASHRAE Level II audits found in the Type 1 buildings, which accounted for 16% more energy savings compared to the ASHRAE Level II audits in the same buildings. For the Type 2-5 buildings, FirstFuel's RBAs identified 65% of the ECMs that the ASHRAE Level II audits found, which accounted for 37% more savings compared to the savings found in the same onsite audits. It is important to recognize that the omissions of ECMs in the RBAs compared to the ASHARE Level II audits may reflect a different, broad approach to energy management, rather than an indication that the RBA "missed" ECMs. The RBA identified 18 measures/recommendations NOT found in the Type 1 building onsite audits.

Accuracy of Continuous Performance Monitoring: FirstFuel will demonstrate the value of our continuous monitoring by proving the accuracy of our predictions for 12 buildings (Types 1-5) compared to the buildings' actual consumption data.

Purpose: For technical due diligence and credibility.
Metric: FirstFuel's baseline predictions in line with actual consumption data.

Data: FirstFuel offered the continuous monitoring to all 100 buildings, however, quarterly data collection proved difficult for many of the sites. Therefore, FirstFuel selected 11 Type 1-5 buildings that represent the range of buildings in the sample set and also had sufficient data from which to compare the predictions and actual performance data after the initial baseline period.

Analytical Methodology: FirstFuel's continuous performance monitoring utilized the whole building approach based on sophisticated weather normalized statistical models of the baseline energy consumption for each of these 11 buildings.

Success Criteria: FirstFuel's continuous performance monitoring satisfies ASHRAE Guideline 14.

Results: FirstFuel's continuous performance monitoring satisfied ASHRAE Guideline 14.

Customer Satisfaction

Purpose: To prove the customer value and satisfaction of FirstFuel's RBA platform compared to onsite audits.

Metric: Degree of satisfaction

Data Requirements: FirstFuel sent a Likert style survey (using an online survey provider, Survey Monkey) to the two site energy managers that Cadmus also visited for the onsite audits. FirstFuel considered satisfied customers those that respond "Neutral", "Agree" and "Strongly Agree" on the web-based online Likert scale survey distributed to the site energy managers.

Analytical Methodology: FirstFuel analyzed the results of the survey using tables and graphs.

Success Criteria: 75% customer satisfaction compared to the Cadmus ASHRAE Level II site audits.

Results: As of this time, only one of the two energy site managers has completed the survey. Therefore, the results are inconclusive.

4.0 Facility/Site Description

4.1 Facility/Site Location and Operations

FirstFuel performed the remote audit (through the RBA platform) on 100 DoD buildings. 30 buildings consisted of offices, municipal/community buildings and schools. The remaining 70 buildings were prevalent types across the broader DoD portfolio, such as barracks, training facilities, and warehouses.

In addition to identifying building types relevant to the DoD, FirstFuel focused on incorporating buildings from sites that represented a range of climate zones. The following map illustrates the 11 DoD sites that participated in the demonstration project:

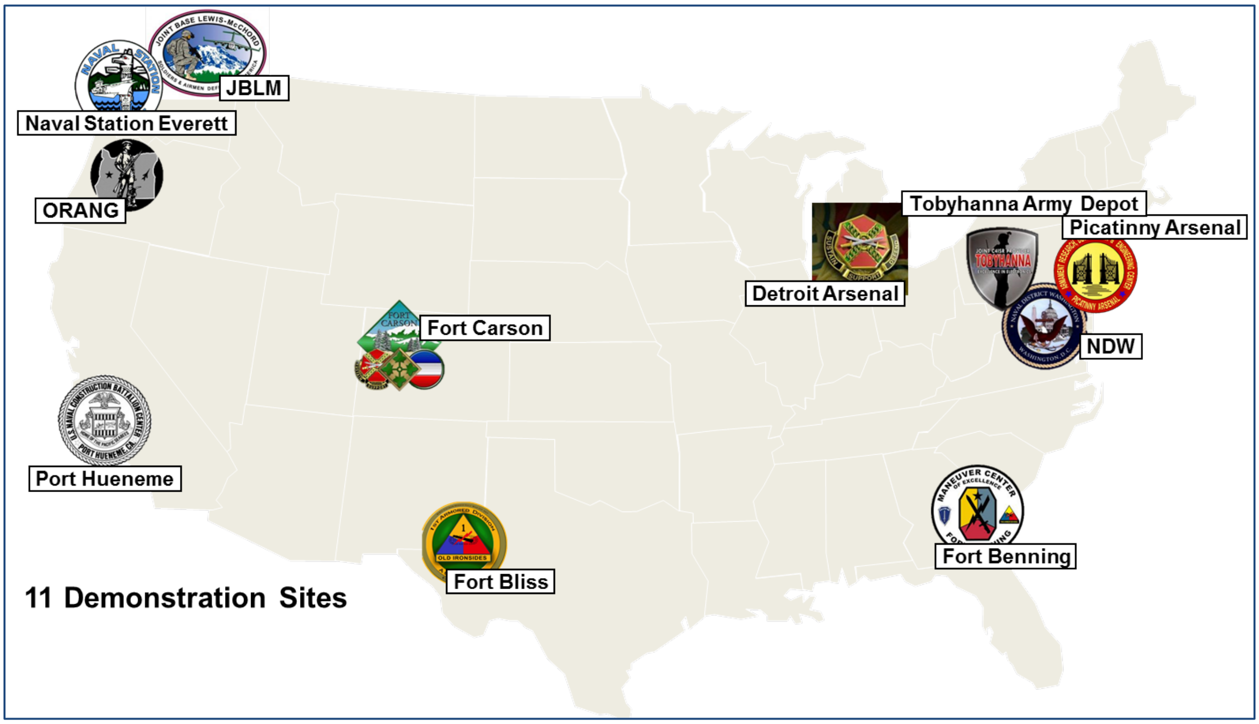


Figure 11: Map of Host DoD Installations

To meet the participation criteria, each site needed to provide FirstFuel with 12 months' worth of historical electric interval data for its building. The interval data had to represent the entire electrical consumption of the building. The table below outlines the number of buildings, by type, from each installation.

FirstFuel RBA Site Partners	Type 1 – Admin	Type 2 – Barracks, Dining	Type 3 – Warehouses	Type 4 – Rec Centers/Auditoriums	Type 5 – Bldgs w/special process loads	Total
Naval Station Everett	7	4	6	3	3	23
Fort Benning	5	22	3	6	3	39
JBLM	1	1	1	-	-	3
Oregon Army National Guard	2	-	-	-	-	2
Picatinny Arsenal	5	-	-	-	-	5
Port Hueneme	4	-	-	-	-	4
Naval District Washington	1	-	-	-	-	1
Tobyhanna Army Depot	2	-	-	-	-	2
Fort Carson	2	4	2	-	1	9
Fort Bliss	1	1	5	2	2	11
Detroit Arsenal			1			1
	30	**31**	**19**	**10**	**9**	**100**

Table 3: Host Installations and Building Count

Cadmus's onsite audits were performed on 16 of the RBA buildings at two sites: Naval Station Everett and Fort Benning. FirstFuel briefly visited both Naval Station Everett and Fort Benning to learn more about DoD specific building types. The following table lists the buildings that were visited at each site:

Installation	Building Number	Building Name/Use	Site Visit Activity
Naval Station Everett	2200	LOGISTICS COMPLEX (FISC)	ASHRAE Level II AUDIT
Naval Station Everett	2202	TRANSIT SHED	ASHRAE Level II AUDIT
Naval Station Everett	1950	FITNESS CENTER	ASHRAE Level II AUDIT
Naval Station Everett	2000	FLEET HQ/ADMIN	ASHRAE Level II AUDIT
Naval Station Everett	2130	GSE SHOP	ASHRAE Level II AUDIT
Naval Station Everett	1980	CHILD DEVELOPMENT CTR	ASHRAE Level II AUDIT
Naval Station Everett	2025	GALLEY	ASHRAE Level II AUDIT
Naval Station Everett	2125	PORT OPERATIONS	ASHRAE Level II AUDIT
Naval Station Everett	1800	LOCATION EXCHANGE	ASHRAE Level II AUDIT
Naval Station Everett	2114	SECURITY/FIRE STATION	ASHRAE Level II AUDIT
Fort Benning	4105	GEN INST BLDG	ASHRAE Level II AUDIT
Fort Benning	6	ENGINEERING ADMIN	ASHRAE Level II AUDIT
Fort Benning	3575	TRAINEE BKS	ASHRAE Level II AUDIT
Fort Benning	4320	DFAC (Dining Facility)	ASHRAE Level II AUDIT
Fort Benning	2653	CHILD DEVELOPMENT CTR	ASHRAE Level II AUDIT
Fort Benning	2827	ENGINEERING ADMIN	ASHRAE Level II AUDIT

4.2 Facility Site Conditions

As long as the buildings satisfy the data criteria [12 months' of historical interval (5/15/ 30/60 minute) electricity data], and they fall under one of five buildings types indicated in Table 1: RBA Demonstration Building Types, then the FirstFuel RBA tool will be able to provide useful outputs, regardless of the climate or other infrastructure on the installation.

5.0 Test Design

Fundamental Problem: The Department of Defense has not yet developed a long-term, highly scalable approach to energy efficiency across its portfolio of buildings. Identifying and profiling energy savings potential presents three fundamental problems for the DoD's building portfolio: achieving scale, uncovering and delivering operational savings opportunities, and measuring and verifying consumption and savings.

FirstFuel Software Demonstration Question: How can the DoD use remote audits to accurately identify and verify Energy Conservation Measures across the DoD's diverse portfolio of buildings?

5.1 Conceptual Test Design

FirstFuel conducted remote audits on 100 buildings that were representative of the DoD's diverse building portfolio. To conduct each remote audit, FirstFuel utilized four pieces of information: 1 year of historical electric interval consumption data, weather data from the building's closest weather station, GIS information from the building's location, and a building information survey completed by DoD energy managers.

The demonstration hypothesis was that FirstFuel's RBA platform would enable the DoD to conduct remote building energy audits across hundreds of buildings using interval meter data in 3x+ lower costs and 3-5x faster speeds compared to traditional ASHRAE Level II onsite audits.

The conceptual test was designed around measuring the time, cost, and accuracy of FirstFuel's 100 remote audits. FirstFuel tracked the time to complete the remote audit (also referred to as the RBA) for each building. The results of 12 of the 16 ASHRAE Level II onsite audits conducted by The Cadmus Group were used to compare energy savings recommendations and help prove the remote audit' accuracy. The remaining four audits (one for each building Type 2-5), were be used to aid the R&D effort associated with optimizing the FirstFuel RBA for those building types.

The buildings included in the demonstration were divided into five types:

Building Types		Percent of DoD's Building Stock[8]
1	Offices, municipal, schools, training facilities	11%
2	Barracks, dining facilities, mess halls	12%
3	Warehouses, Shipping Centers, Commissaries	24%
4	Rec centers & auditoriums	Unknown
5	Facilities with lighter process and specific equipment loads (e.g. large data centers and light manufacturing processes)	13%

While all the building types selected represent the DoD's diverse building portfolio, it is the Type 2-5 building that FirstFuel's platform was not yet optimized for at the start of the demonstration. FirstFuel's team spent time optimizing the process so that the remote audits could be performed effectively.

Design Steps

Step 1: Data Quality Assurance (QA)

Each site's energy manager was responsible for transferring 12 months' of historical interval (5/15/ 30/60 minute) electricity data for 100 buildings to FirstFuel. In addition, they were asked to complete a building information questionnaire that took less than 40 minutes to complete. Please see Appendix C for an example of the building information questionnaire.

Step 2: FirstFuel Remote Audits

The first 30 RBAs were Type 1 buildings. FirstFuel analytics were already optimized for these building types, and therefore required no additional research and development resources to complete. For building Types 2-5, FirstFuel used site visits and building walkthroughs to refine its analytics platform and complete the remote audits for these types of buildings. FirstFuel tracked the time involved to complete the RBA for each building in the deployment.

Step 3: Efficiency Planning Session

Following the completion of each RBA, FirstFuel published the results of the analysis on the online, DoD-specific portal and led an Efficiency Planning Session via webinar for the site's energy manager. The webinar covered the results of the remote audit, focused the energy

[8] http://www.arpa-e.energy.gov/sites/default/files/documents/files/AdvancedBuildings_DOD.pdf

managers on an initial set of recommendation to consider, and included training on how to use the web portal.

The efficiency planning session was also used to get feedback from the building team regarding assumptions made to complete the analysis. Any necessary changes discovered during the webinar, were then made to the audit by FirstFuel's building engineers after the call, and the updated audit was made available directly to the site's building team via the online portal.

Step 4: ASHRAE Level II Onsite Audits

Simultaneously, Cadmus performed the ASHRAE Level II onsite assessments on 16 of the buildings at Fort Benning and Naval Station Everett.

Prior to visiting Fort Benning and Naval Station Everett, Cadmus gathered information and documentation about the buildings from the site managers. This information included:

- Building characteristics, which include details about the shell, mechanical systems, lighting systems, tenant types, operational schedules, and other parameters needed to verify the accuracy of whole building simulation models.
- Building construction and operation information
- Component measure data, such as model numbers

While onsite, Cadmus' field staff gathered data, such as operating schedules, trend data, and other building characteristics and parameters. Where possible, the field staff took one-time spot measurements or performed short-term trend logging for two to four weeks. Cadmus also interviewed the building staff to better understand equipment performance, technical issues, and occupant behavior.

After the site visits, Cadmus wrote an assessment report for each building. The final reports were made available to the sites' energy managers, and the final ECMs were used to compare against the results of the FirstFuel RBA.

Step 5: Data Analysis and Comparison

FirstFuel compiled the time it took to complete each RBA, along with the associated cost and compared it to the time and cost it took to complete the onsite Level II assessments. During this analysis phase, FirstFuel also compared the number of similar recommendations for saving energy between the RBA and the onsite ASHRAE Level II audit.

5.2 Baseline Characterization

The Cadmus Group followed ASHRAE Level II guidelines to conduct the 16 onsite audits Cadmus's data collection included: operating schedules, trend data, and other building characteristics and parameters. Site visits were used to confirm equipment was working as expected, and to interview building operators to better understand how equipment performance and pre-identified technical issues.

For each building, Cadmus obtained square footage data, using site visit data, reported program values, or secondary sources. Then, using available data, Cadmus determined each building's energy-use intensity. The final analysis included trends in building performance and offered potential explanations for outliers.

In contrast, FirstFuel's remote audit process used each building's historical high frequency (5/15/30/60 minutes) consumption data, the corresponding local historical weather data (gathered by FirstFuel via NOAA and other weather agencies) and physical building characteristics (extracted by FirstFuel via online mapping sources) and the building's information survey (as completed by the site manager). Most often, each building's energy data was downloaded from the meter data management system by the person at the site most familiar with the site's advanced metering system. From site to site, the role of who was most familiar with the advanced metering system was not consistent, but it commonly was the person who oversaw building operations and the site's energy service provider contractors. No onsite presence or device installation/tracking was needed to establish the consumption baseline.

To complete the remote audit, FirstFuel used core statistical modeling methodology to disaggregate a building's end uses by employing a combination of Neural Networks, Linear Programming (LP), Ordinary Least Squares (OLS) and other proprietary optimization techniques. The cost estimations associated with the Energy Conservation Measures were derived using the building's completed information survey and recognized facilities' cost data (e.g. RS Means).[9]

[9] RS Means is an industry standard for facility construction cost data, updated annually.

5.3 Design and Layout of System Components

FirstFuel's RBA platform is an "in the cloud" service, meaning that is accessed remotely on via the Internet and is hosted by FirstFuel. The screen shot below is an example of the login screen for the DoD-specific FirstFuel portal:

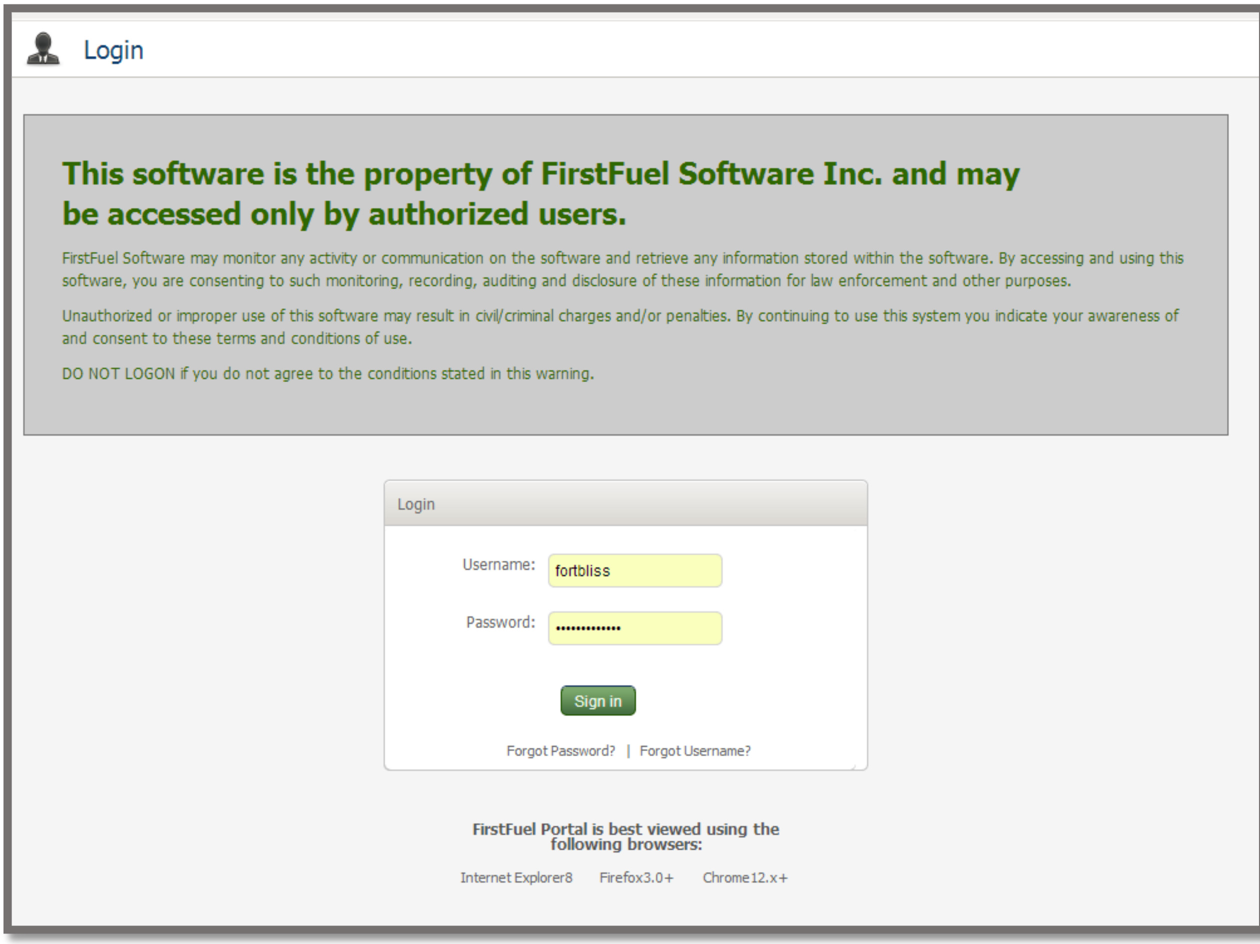


Figure 12: DoD FirstFuel RBA Portal Login Screen

The site's energy managers are given a username and they set their password for their own personal login. Once they've logged in, they are brought to the "Home" tab:

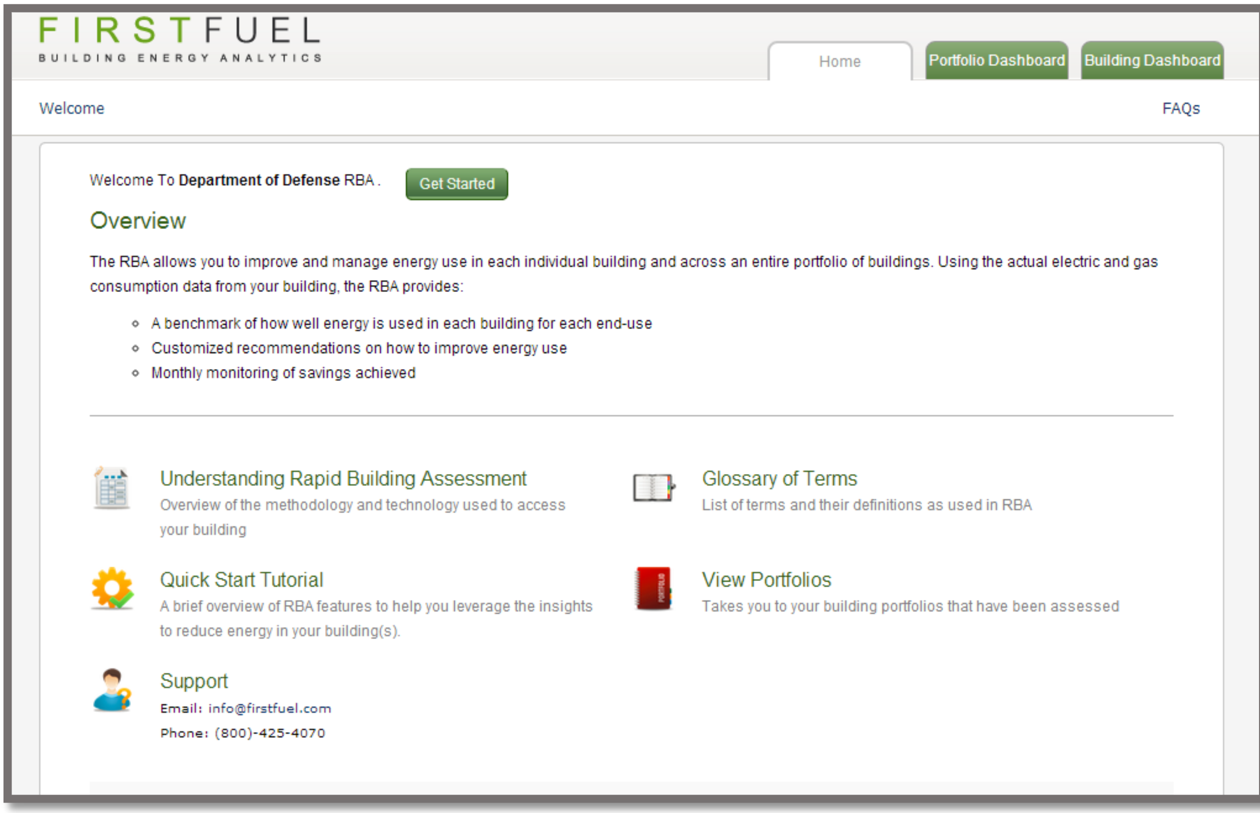


Figure 13: Sample FirstFuel Portal "Home" Tab

The home tab provides resources for understanding the RBA and a Glossary of Terms.

The next tab provides a look at the site's portfolio of analyzed buildings:

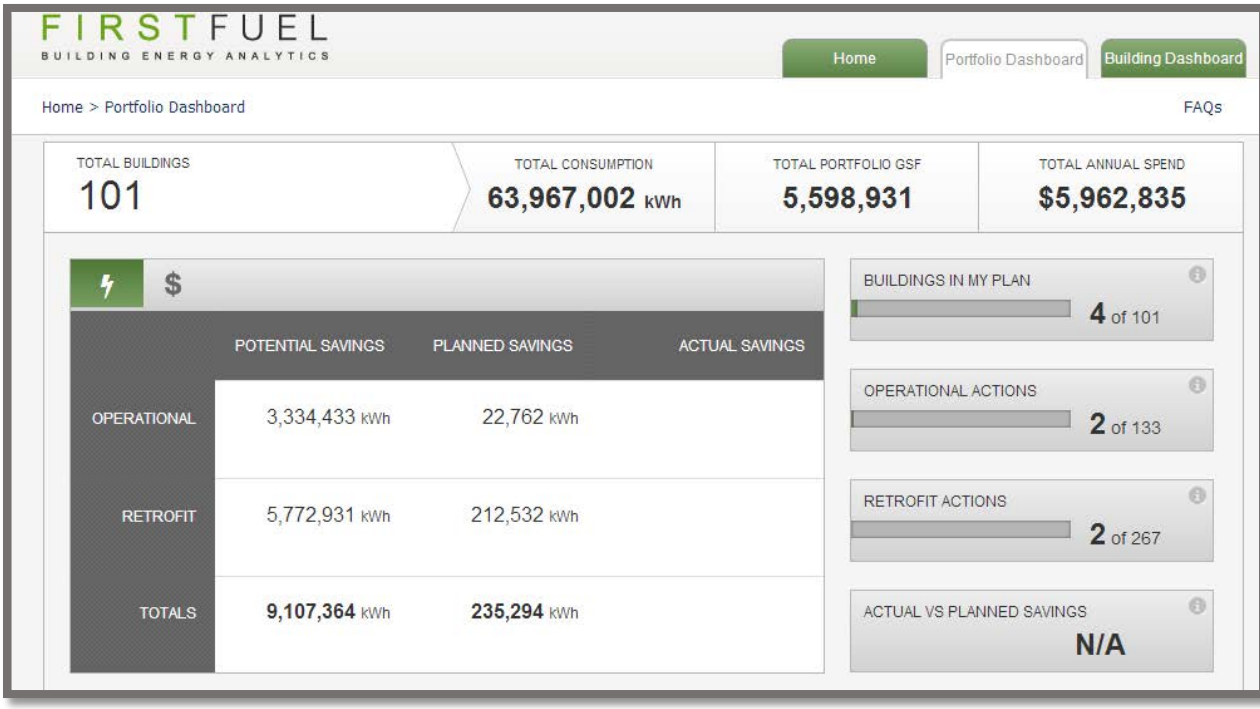


Figure 14: Sample FirstFuel RBA "Portfolio Dashboard" tab

The third, and final tab, is the list of buildings that were analyzed along with key statistics. Clicking on the building's name takes the user to the building's RBA summary page.

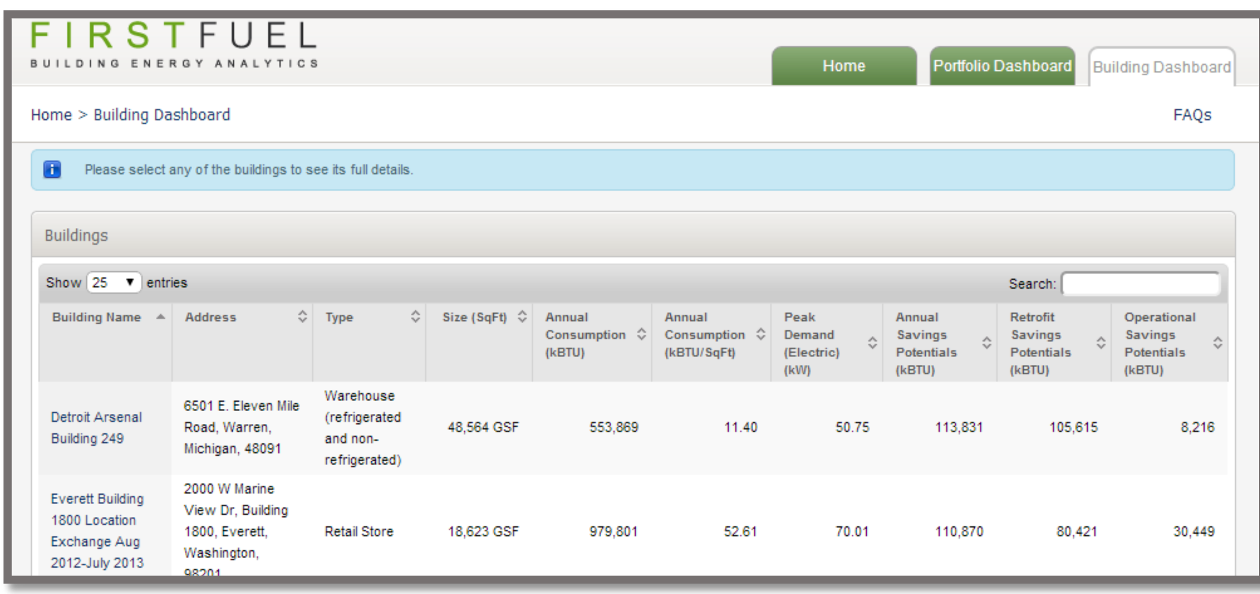


Figure 15: Sample FirstFuel RBA "Building Dashboard" tab

Each building's RBA is analyzed in a similar fashion within their building type and all buildings have the same outputs. In addition, the web-based portal visualizes each building and all analyses the same way.

5.4 Operational Testing

To test cost, speed and performance of the RBAs, FirstFuel first collected data files containing 12 months of electric interval data for each DoD building. FirstFuel received the data as a *.csv or flat file via email, FTP, and via CD-ROM.

FirstFuel used the building's high frequency electrical data, GIS information, and building questionnaire responses to perform the RBA. The time to complete the RBA was officially tracked to properly account for the resources associated with the demonstration activities.

FirstFuel used basic business intelligence techniques and elementary statistics – mean, variance, range, and trend lines to measure the completion time, cost and accuracy (defined by # of measures) comparisons to the ASHRAE Level II audits.

Please see Appendix B for a Gantt chart showing the timeline of project activities.

5.5 Sampling Protocol

Data collected to perform the assessments included: each building's historical high frequency (5/15/30/60 minutes) consumption data (available from the utility or onsite smart meters), corresponding local historical weather data (gathered by FirstFuel via NOAA and other weather agencies) and physical building characteristics (extracted by FirstFuel via online mapping sources) and the building's information survey (as completed by the site manager).

FirstFuel's sample included 100 buildings across 11 distinct DoD sites. See Table 3 in "Section 4.0 Facility Description" for building type distribution and their site locations.

Cadmus collected the following data for 16 buildings where ASHRAE Level II audits were conducted:

- Analyzed building details to accurately characterize the shell, mechanical systems, lighting power density, and other parameters
- Conducted Interviews with facility personnel
- Utilized BAS data (when available) to check operation of sensors, valves, actuators and dampers
- Examined set-back and reset schedules, including whether optimized start and stop were employed

- Examined air and hydronic delivery systems to look for how those systems were adjusted for loads including VSDs on fans and pumps
- Determined the presence of demand control ventilation with CO_2 sensing
- Reviewed lighting controls
- Checked for economizer operation through use of run time logs and interviews
- Reviewed any pertinent files located at the site

The test approach measured five dependent pieces of data:

1) *Time to complete* – All buildings that had onsite audits
2) *Cost* – All buildings
3) *Accuracy* (# of recommendations relative to ASHRAE Level II audits) – 12 buildings that had onsite audits
4) *Remote Monitoring*—11 buildings with sufficient monitoring data
5) *Customer satisfaction* – one online survey[10]

Time to complete – The time to complete each RBA was tracked in FirstFuel's project management system. FirstFuel also tracked the time it took for the site manager to complete the building information, attend the RBA webinar, and to supervise the ASHARE Level II audits. The time to complete the ASHRAE Level II audits, including writing the reports, was tracked by Cadmus and sent to FirstFuel.

Cost – FirstFuel used its standard pricing schedule.

Accuracy – FirstFuel collected the results of the ECMs from Cadmus' reports and recorded them in a spreadsheet that also contained the FirstFuel RBA recommendations.

Continuous Performance Monitoring – FirstFuel's continuous performance monitoring solution relies on electric interval data (5/15/30/60 minute) for each of the three months following the remote audit and the predicted monthly consumption data that FirstFuel generates using a variety of statistical methodologies including but not limited to Mean Bias Error (MBE), R-squared, tests of significance including p-value and confidence interval measures, CVRMSE, etc. to demonstrate the accuracy of both in-sample and out-of-sample fits. The results of the monitoring, both the predicted and the actual consumption, are displayed on the web portal for each DoD building that submitted data.

[10] While customer satisfaction surveys were distributed to the two sites with the ASHRAE Level II onsite audits, only one completed the survey.

FirstFuel demonstrated the value of our baseline model used for continuous performance monitoring by proving the accuracy of our predictions for 11 buildings (Types 1-5) compared to the buildings' actual consumption data. These buildings were selected because they represent the range of buildings in the sample set and they provided sufficient data from which to compare the predictions and actual performance data after the initial baseline period. FirstFuel's model used for continuous performance monitoring meets or exceeds the criteria established in ASHRAE Guideline 14. Guideline 14 was developed by ASHRAE to fill a need for a standardized set of energy (and demand) savings calculation procedures.

For additional information on the continuous performance monitoring results, see Section 6, "Accuracy of FirstFuel Models for Continuous Performance Monitoring".

Customer Satisfaction – A customer satisfaction survey was designed via web-based survey service, using a Likert scale style. The responses were scored along a range of "agree" to "disagree". FirstFuel captured the results/data from the online survey via Excel spreadsheet.

5.6 Sampling Results

The following section provides the results for each of the samples collected and additional information about the remote audit results.

Time to Complete

The table below demonstrates the average amount of time involved on the part of the installation's energy site manager to contribute to the completion of the audit.

	Energy Site Manager
RBA	2
ASHRAE Level II Audit	8

Table 4: Average Hours to Complete One Building Audit

Figure 16: Energy Site manager time for FirstFuel RBA Time vs ASHRAE Level II Audit Time (in hours) for one building

Accuracy

The table below gives the number of ECMs found in the 12 ASHARE Level II onsite audits, the number found by both methodologies and the number found only use the FirstFuel RBA.

Building Site and Type	ASHRAE Level II ECMs	ECMs found in Both	RBA ECMs	ECMs found in RBAs only
Fort Benning (Type 1)	4	3	3	2
Fort Benning (Type 1)	3	1	3	2
Fort Benning (Type 2)	4	3	3	1
Fort Benning (Type 2)	3	3	5	2
Fort Benning (Type 1)	2	1	4	3
NS Everett (Type 1)	7	2	7	5
NS Everett (Type 1)	5	5	6	3
NS Everett (Type 2)	2	1	6	5
NS Everett (Type 4)	2	2	4	2
NS Everett (Type 1)	2	2	5	3
NS Everett (Type 3)	4	2	3	1
NS Everett (Type 5)	5	2	3	1
Totals	**43**	**27**	**52**	**30**

Table 5: ECMs identified in FirstFuel RBAs and ASHRAE Level II audits

As part of the demonstration, FirstFuel also looked at comparing the ECMs between the ASHRAE Level II audits and the RBAs by Type 1 buildings and Type 2-5 buildings. The table below summarizes ECM count by Type 1 buildings and Type 2-5 buildings.

	ASHRAE Level II		FirstFuel RBA		*Both* ASHRAE Level II and FirstFuel RBAs		FirstFuel RBA only	
	Type 1	Type 2-5	Type 1	Type 2-5	Type 1	Type 2-5	Type 1	Type 2-5
ECM Count	23	20	28	24	14	13	18	12

Table 6: ECM Count in FirstFuel RBA and ASHRAE Level II audits by Building Type

Remote Audit Results

Of the 100 buildings analyzed, FirstFuel successfully disaggregated the buildings' energy consumption into its building level end uses of 91 of them. FirstFuel provided targeted energy conservation recommendations for nine buildings that could not be disaggregated; however, savings calculations are not provided, as they are partially dependent on the facility's energy end-use breakdown. The primary challenges of the nine buildings without end-use disaggregation were either a) very low annual energy consumption or b) intermittent occupancy leading to highly irregular data. It should be noted that buildings with very low energy consumption present limited energy efficiency opportunity, by definition, and that buildings with intermittent occupancy also present challenges for accurate onsite audit calculations.

The following charts illustrate the breakdown of average energy use (kWh per square foot) by building type.

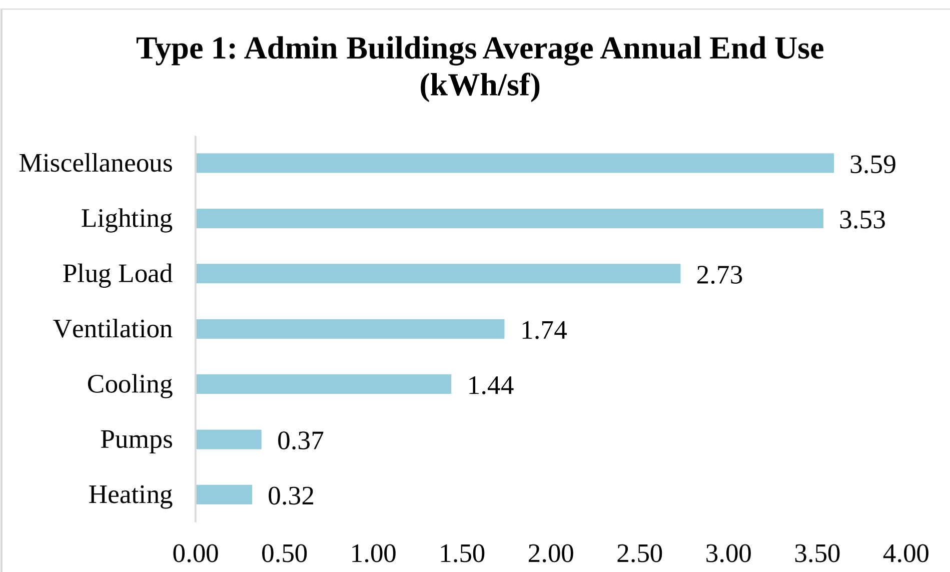


Figure 17: Type 1 Average Annual End Use (kWh/sf)

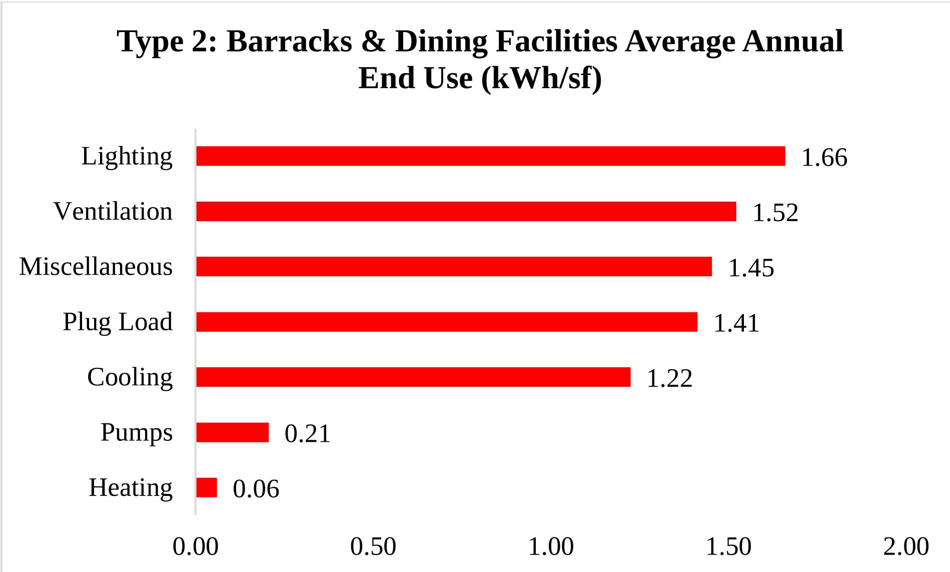


Figure 18: Type 2 Average Annual End Use (kWh/sf)

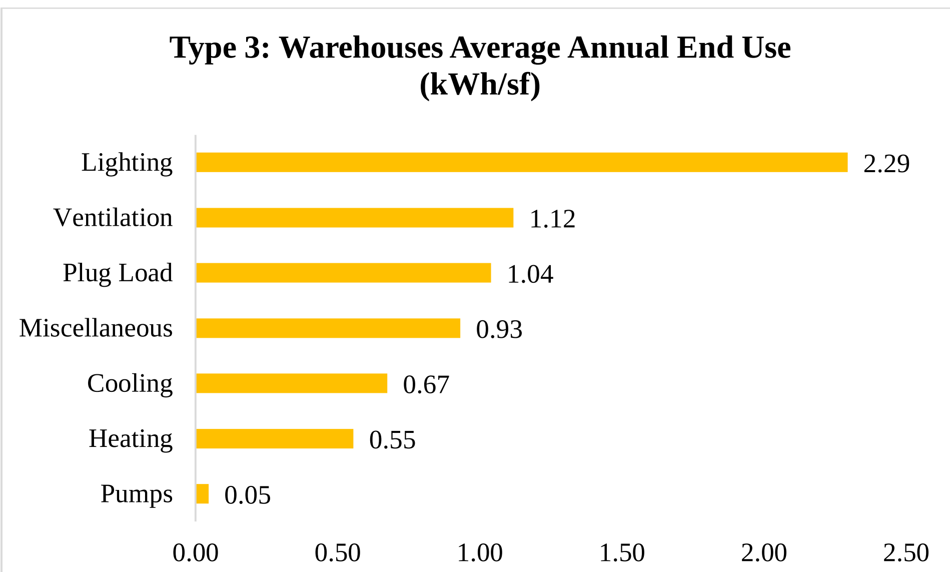


Figure 19: Type 3 Average Annual End Use (kWh/sf)

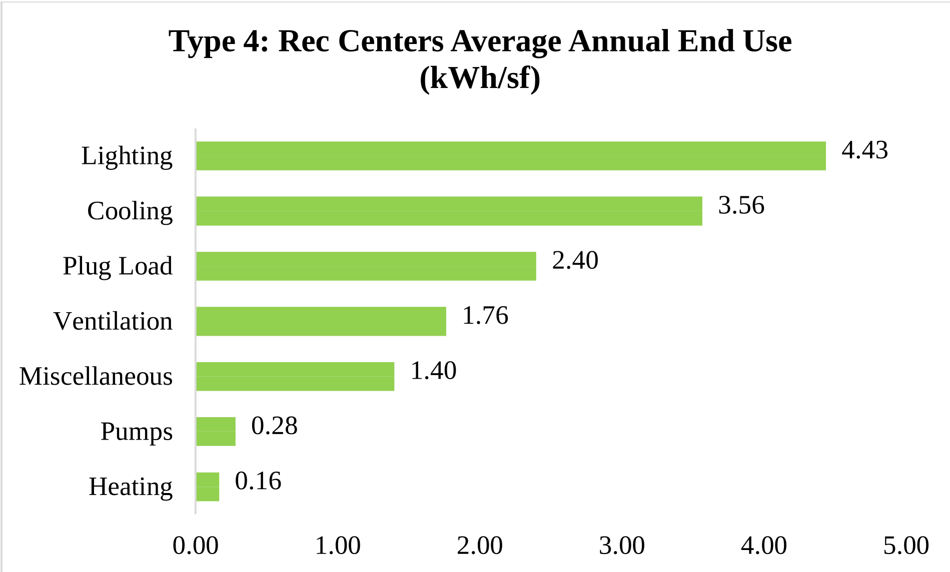


Figure 20: Type 4 Average Annual End Use (kWh/sf)

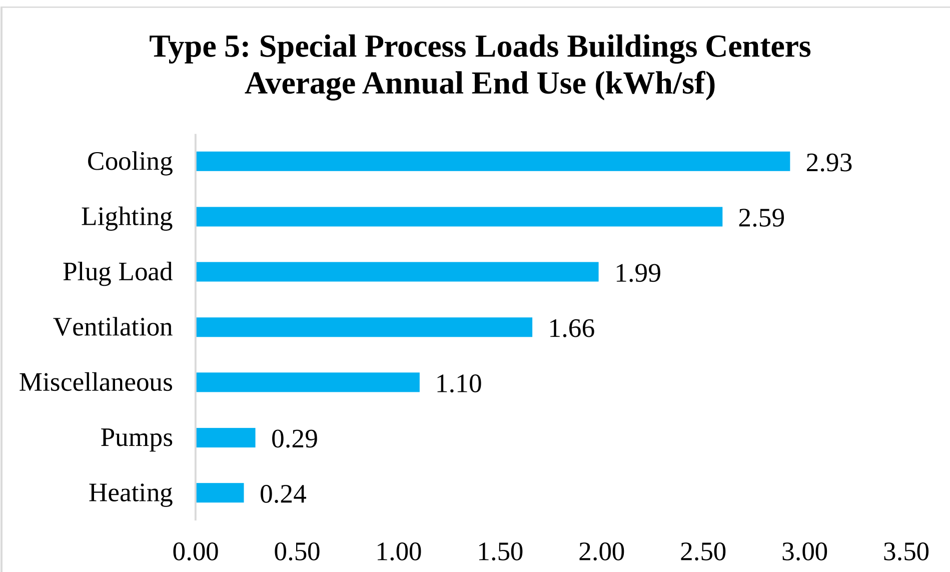


Figure 21: Type 5 Average Annual End Use (kWh/sf)

Across these 100 buildings, FirstFuel's RBA tool identified approximately 8.6 million kWh in energy savings, which represents a potential 14% reduction in energy spending.

The charts below shows how the outcome of the kWh savings per building and per square foot.

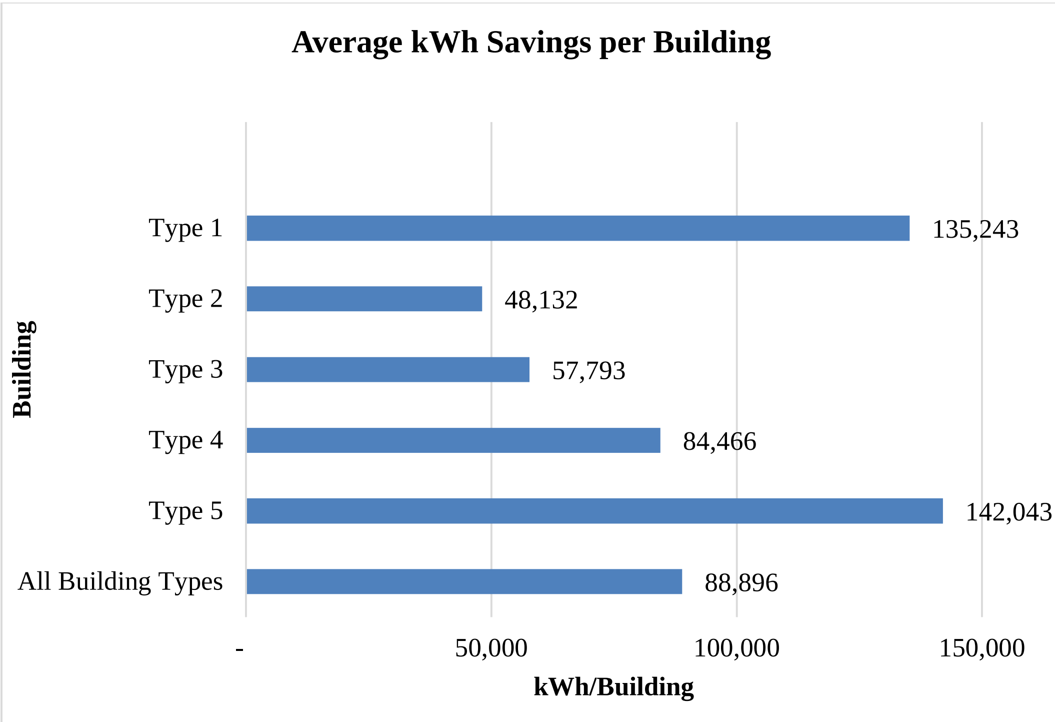


Figure 22: Average kWh Savings Per Building

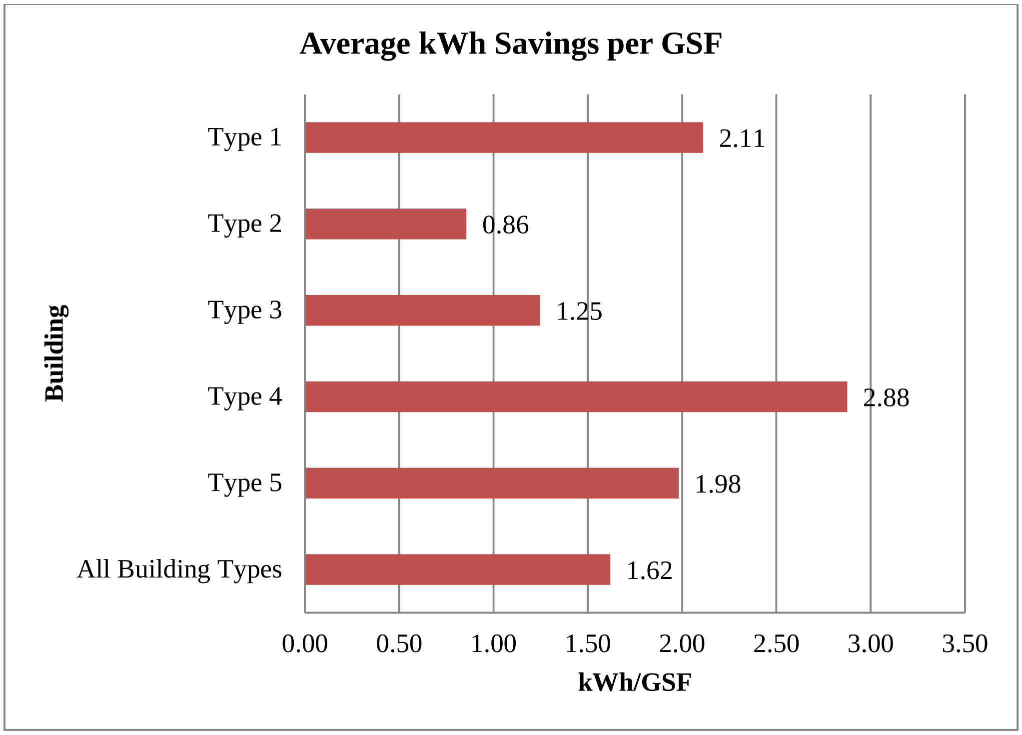


Figure 23: Average kWh Savings per Gross Square Footage (GSF)

Figure 23 demonstrates that the buildings that tended to have the highest savings per square foot were not necessarily the largest.

Figures 24-28, below, illustrate the categories of top energy conservation measures identified within each building type.

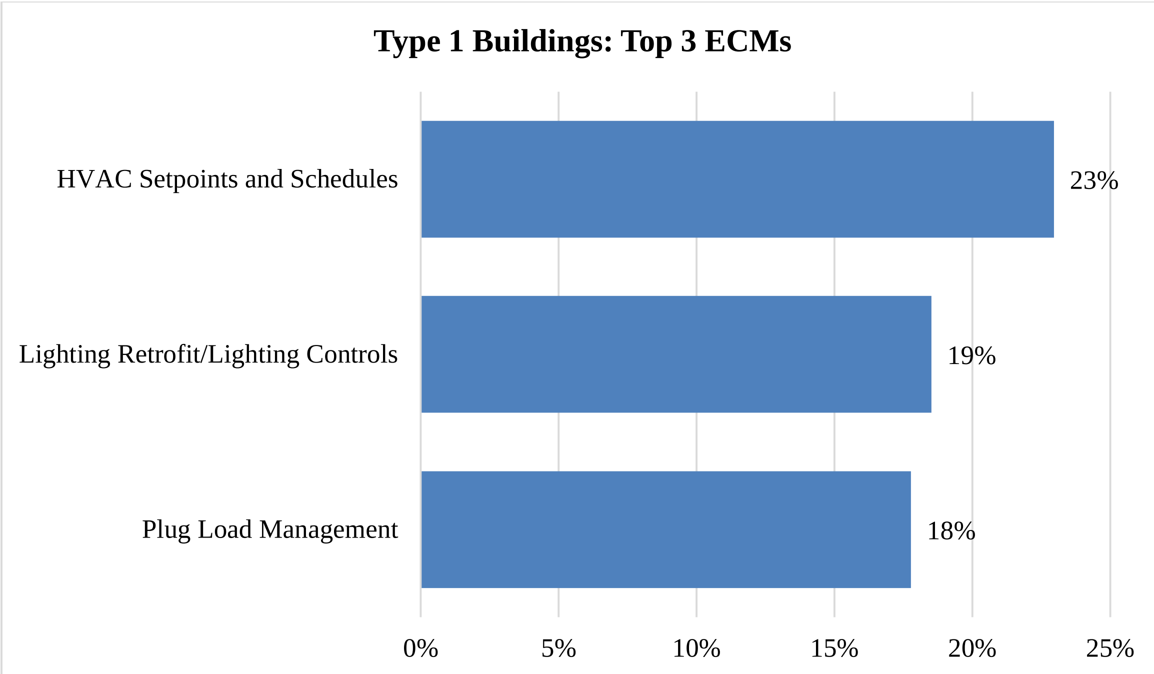


Figure 24: Top 3 ECMs--Type 1 buildings

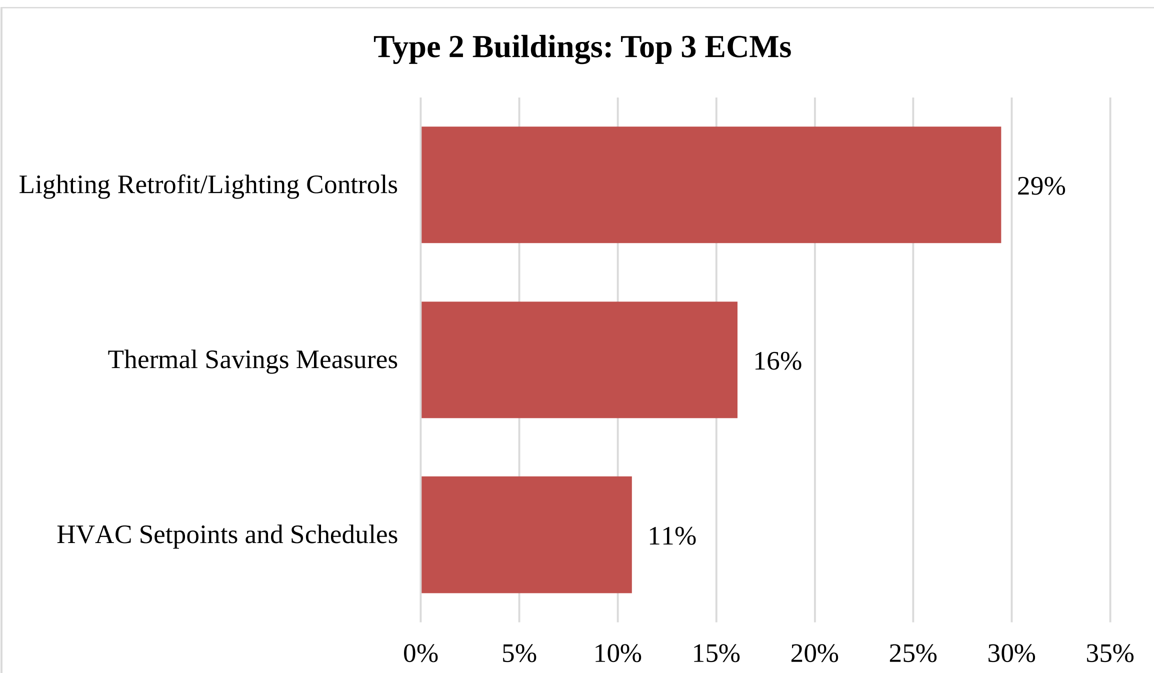


Figure 25: Top 4 ECMs--Type 2 Buildings

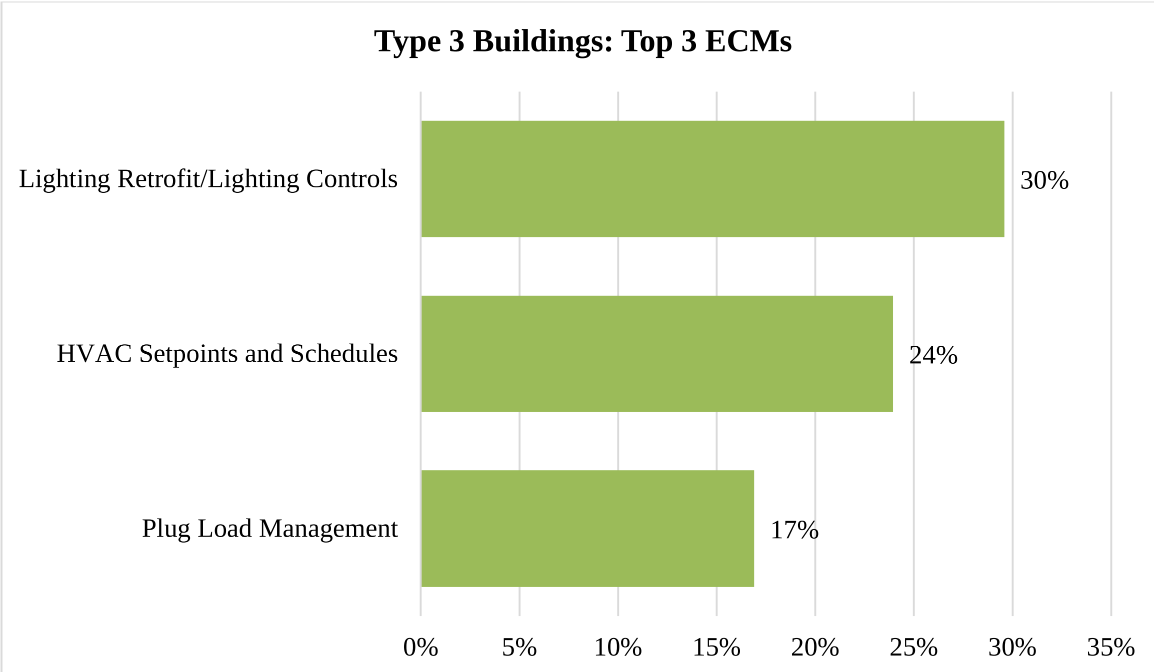


Figure 26: Top 3 ECMs--Type 3 Buildings

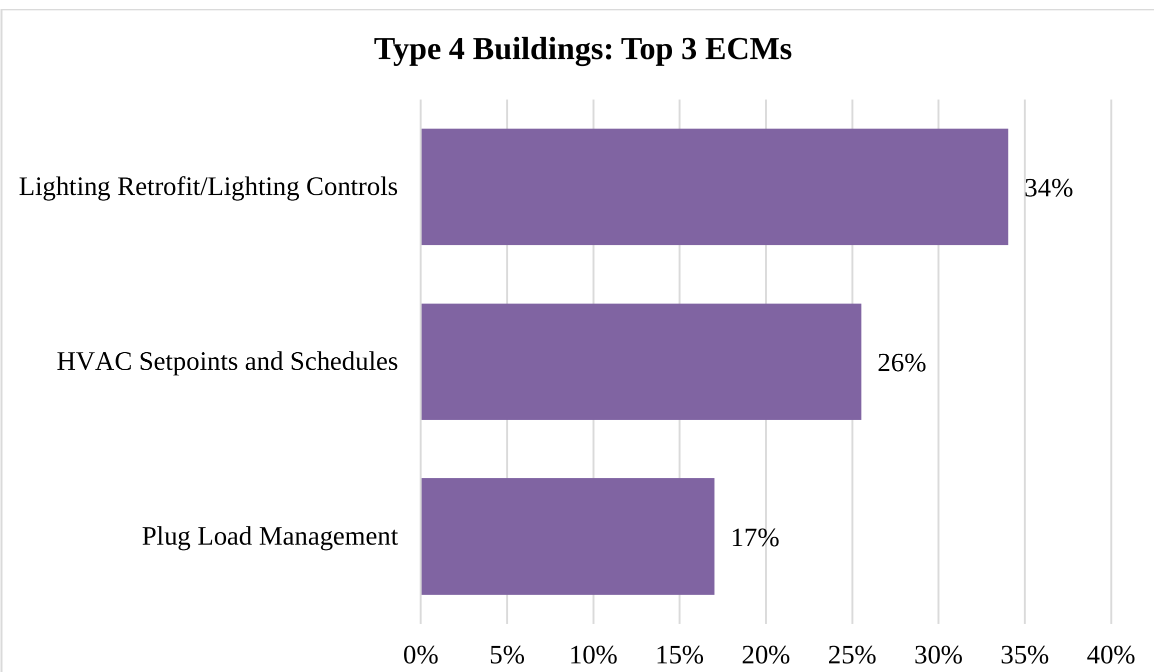


Figure 27: Top 3 ECMs--Type 4 Buildings

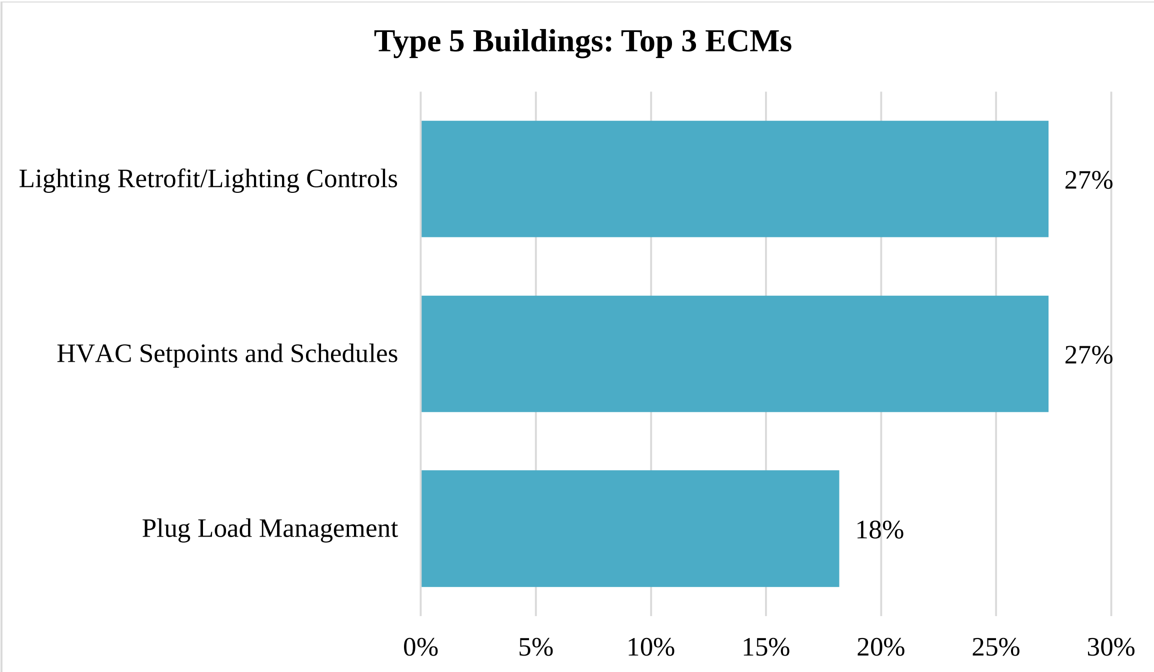


Figure 28: Top 3 ECMs--Type 5 Buildings

Figures 24-28 demonstrate that all five building types had similar recommended measures. Buildings with regular occupancy, but irregular, or sub-optimal building operations are candidates for scheduling adjustments. Type 1 buildings tend to have such regular occupancy patterns, and we found that many of them would benefit from scheduling adjustments. Other types (2-5) included more buildings with irregular occupancy or round-the-clock occupancy, and therefore were not candidates for scheduling improvements. We did find that many of the Type 2-5 buildings would benefit from lighting and plug load related measures.

Additional results collected include the results of the remote building assessments on the 100 DoD buildings. To view the end use analysis breakdowns and recommendations identified by building, please refer to Appendix E.

6.0 Performance Assessment

FirstFuel chose each Performance Objective (PO) with the major project goals in mind: cost, scalability and accuracy. Tools like FirstFuel's RBA platform can help the DoD more rapidly and cost-effectively achieve energy efficiency at scale across its unique portfolio of buildings.

The individual Performance Objective subsections below include the data and graphs obtained during the demonstration to illustrate how the objective was met.

Cost of FirstFuel RBA:

Performance Objective: FirstFuel will demonstrate its applicability to the large and disparate DoD building portfolio by showing that its process can be executed much more cost effectively than traditional ASHRAE Level II onsite building energy assessments.

Success Criteria: FirstFuel's cost per RBA per building would be less than or equal to $3,000/building.

FirstFuel's standard pricing sheet was utilized to the cost of an RBA to the cost of an onsite ASHRAE Level II audit the Cadmus performed on the same DoD building.

Results: FirstFuel's cost per RBA met or exceeded this success criterion.

Scalability of FirstFuel RBA:

Performance Objective: FirstFuel will demonstrate its applicability to the large and disparate DoD building portfolio by demonstrating that building energy assessments can be performed much more rapidly than traditional methods, providing a scalable solution for a large portfolio of buildings.

Success Criteria: 1) RBAs for Type 1 buildings completed in 25% of the time of Cadmus ASHRAE Level II Audits. 2) RBAs for Type 2-5 completed in 50% of the time of Cadmus ASHRAE Level II Audits.

In order to measure the scalability of FirstFuel's RBA platform, we compared the time to complete the remote audits to the time for onsite audits. The time to complete each RBA was tracked in FirstFuel's project management system. FirstFuel also tracked the time it took for the site manager to complete the building information, attend the RBA webinar, and to accompany the ASHRAE Level II auditors on site. The time to complete the ASHRAE Level II audits was tracked by Cadmus and sent to FirstFuel.

Results: The FirstFuel RBA exceeded these criteria.

Accuracy of FirstFuel RBA:

Performance Objective: FirstFuel will demonstrate the validity of its remote audits by comparing the recommendations and energy conservation measures identified in 12 Cadmus ASHRAE Level II audited buildings to the recommendations (both operational and retrofit) uncovered by FirstFuel RBAs.

Success Criteria: 1) The RBA identifies 80% of the measures/recommendations found in the Cadmus onsite audits for type 1 building, and 60% of the measures/recommendations found in the Cadmus onsite audits for building Types 2-5. 2) The RBA identifies measures/recommendations NOT found in the Type 1 Cadmus onsite audits.

Through FirstFuel's technology advancements and customer deployments across the 18 months since the DoD demonstration project, the company has learned that this performance metric is less important and relevant than other metrics. For example, ECMs recommended in onsite audits may not be uncovered by the FirstFuel RBA (or vice versa) because omissions may reflect a different set of energy management objectives or scope. Nevertheless, for the purposes of this demonstration, the table below shows the number of ECMs found in the ASHRAE Level II onsite audit, the FirstFuel RBA, and by both approaches.

The buildings below were selected for the ASHRAE Level II onsite audits and the FirstFuel RBAs based on building data availability and DoD energy site manager preference.

Building Site and Type	ASHRAE Level II ECMs	ECMs found in Both	FirstFuel RBA ECMs	ECMs found in Type I RBAs only
Fort Benning (Type 1)	4	3	3	2
Fort Benning (Type 1)	3	1	3	2
Fort Benning (Type 2)	4	3	3	
Fort Benning (Type 2)	3	3	5	
Fort Benning (Type 1)	2	1	4	3
NS Everett (Type 1)	7	2	7	5
NS Everett (Type 1)	5	5	6	3
NS Everett (Type 2)	2	1	6	
NS Everett (Type 4)	2	2	4	
NS Everett (Type 1)	2	2	5	3
NS Everett (Type 3)	4	2	3	
NS Everett (Type 5)	5	2	3	
Totals	**43**	**27**	**52**	**18**

Table 7: ECM Count - Table

Results: FirstFuel's RBAs identified 61% of the ECMs that the ASHRAE Level II audits found in the Type 1 buildings, which accounted for 16% more energy savings compared to the ASHRAE Level II audits in the same buildings. For the Type 2-5 buildings, FirstFuel's RBAs identified 65% of the ECMs that the ASHRAE Level II audits found, which accounted for 37% more savings compared to the savings found in the same onsite audits. The RBA also identified 18 ECMs that were not found in the Type I ASHRAE Level II audits, and a higher percentage of savings potential overall.

Reasons for ECMs not matching often was a result of different approaches to the audits. For example, in one audit, the ASHRAE Level II audit recommended implementing a supply air temperature reset strategy for each air handling unit. FirstFuel's RBA did not make this recommendation because of the humidity levels in the climate zone. In another case, the ASHRAE Level II audit recommendation de-lamping fixtures to reduce lighting density and installing motion sensors. The FirstFuel RBA for the same building did not include a lighting recommendation because based on the disaggregration, the lighting levels were found to be relatively low.

Accuracy of FirstFuel Models for Continuous Performance Monitoring:

FirstFuel demonstrated the value of our baseline model used for continuous performance monitoring by proving the accuracy of our predictions for 11 buildings (Types 1-5) compared to the buildings' actual consumption data. These buildings were selected because they represent the range of buildings in the sample set and they provided sufficient data from which to compare the predictions and actual performance data after the initial baseline period. FirstFuel's model used for continuous performance monitoring meets or exceeds the criteria established in ASHRAE Guideline 14. Guideline 14 was developed by ASHRAE to fill a need for a standardized set of energy (and demand) savings calculation procedures.

ASHRAE Guideline 14 is titled, "*Measurement of Energy and Demand Savings*" and it describes the procedures that are acceptable for measuring energy when evaluating buildings. This Guideline is based on the "*International Performance Measurement and Verification Protocol*" (IPMVP) which is the globally accepted standard for measuring energy savings. Per the ASHRAE Guideline, "*The purpose of this document is to provide guidelines for reliably measuring the energy and demand savings due to building energy management projects.*"

Guideline 14 comprises four different approaches and the approach the FirstFuel monitoring method falls under is the "Whole Building Performance" method. This approach utilizes meter data for the building as a whole, rather than a subset of building systems. Any change in energy use after one or more energy conservation measures (ECM) therefore is captured by evaluating the post measure consumption relative to how the building would have performed had the change(s) not been made.

To determine how the building would have performed had the ECM not been implemented requires the construction of a model using the pre-ECM energy use data. The Guideline does not prescribe how that model is to be constructed, but it does suggest independent variable selection and prescribes the metrics required to quantify how good the model output correlates to the actual consumption. To comply with the guideline the model uncertainty and bias error must be determined and must be within a prescribed tolerance band. It is up to the modeler to determine how the best model is to be constructed—the better the model, the smaller the uncertainty variable and smaller the bias.

Energy use in a building is generally impacted by two variables, occupancy and weather. Occupancy based load variances include lighting, plug or receptacle load, and depending on how the building is operated HVAC loads. When evaluating energy use on an hour by hour basis, the occupancy variable generally correlates well to day of the week and hour of the day. This is because people generally come and go at the same times for each type of day.

The independent variables in the FirstFuel model therefore are the type of day (weekday, Saturday, Sunday, or Holiday), the hour of the day, the dry bulb temperature, wet bulb temperature, wind velocity, and solar radiation (GHR). This data is used to create a multi-variable model which in turn accurately predicts the hourly electric consumption regardless of how the independent variables vary.

The quality of any model can be evaluated by using the same independent variables from the base period to predict the hourly energy use, and then comparing it to the actual measured use which is known. The Coefficient of Variation of the Root Mean Square Error (CV-RMSE) and Net Mean Bias Error (NMBE) are statistical performance values which the Guideline prescribes for determining the uncertainty and bias in any model.

The ASHRAE Guideline 14 prescribes Coefficient of Variation, CV (or CVRMSE-a measure of the uncertainty in the model) < 30% as a compliance criterion for hourly data for post-retrofit calibration. Additionally, ASHRAE Guideline 14 prescribes that the normalized mean bias error (or NMBE), is < 10% to be compliant for hourly data. For additional details on Monitoring and Verification methodologies, see Appendix D.

The table below presents a summary of the results of the 11 buildings analyzed. Note that in every case, the FirstFuel models are ASHRAE Guideline 14 compliant for the CVRMSE and NVBE measures. In fact, the results demonstrate far less uncertainty and a much lower bias than the ASHRAE thresholds, indicating the FirstFuel model is an excellent predictor of how a building uses energy hour by hour, regardless of weather conditions. Further, the important R^2 metric is in the range of 0.85 for all but two buildings, one of which is below a threshold R-Square of 0.75.

Building Name	CV-RMSE	NMBE	R^2
Everett Building 2000 Fleet HQ-Admin	18.89%	0.20%	0.86
Everett Building 2025 Galley	19.04%	0.10%	0.75
Everett Building 2026 BACHELOR ENLISTED QRTS I	13.52%	0.18%	0.49
Everett Building 2102 Redcom Northwest	21.30%	0.24%	0.84
Everett Building 2120 Fleet Region Readiness Ctr	17.62%	0.29%	0.81
Everett Building 2125 Port Operations	16.98%	0.17%	0.85
FB 2653 Child Development Center	11.74%	0.08%	0.86
Picatinny Building 65 Admin	14.93%	0.25%	0.91
Picatinny Building 92 Admin	26.13%	0.17%	0.86
Port Hueneme Building 1444 Admin Space	10.62%	0.01%	0.88
Everett Building 1980 Child Development Center	18.01%	0.19%	0.87

Table 8: Summary of model performance metrics

The two buildings with low R^2 metrics result because of the unpredictable nature of their occupancy, which can be attributed to the mission of the Naval Station Everett facility that services ships of all sizes and accommodates their crews while ashore. The occupancy of the barracks fluctuates based on the number of sailors ashore and at times are empty. Likewise, the galley operation and loads fluctuates. Regardless of the poor R^2, the CV-RMSE and NMBE are within ASHRAE 14 Guidelines. The poor R^2 could be improved, if the daily number of sailors ashore could be obtained and incorporated in FirstFuel's models.

Performance Objective: FirstFuel will demonstrate the value of our baseline model used for continuous performance monitoring by proving the accuracy of our predictions for 11 buildings (Types 1-5) compared to the buildings' actual consumption data. These buildings were selected because they represent the range of buildings in the sample set and they had sufficient data.

Success Criteria: FirstFuel's model used for continuous performance monitoring meets or exceeds the criteria established in ASHRAE Guideline 14.

Results: FirstFuel's continuous performance monitoring met or exceeded this criterion.

Customer Satisfaction:

Performance Objective: FirstFuel will prove the customer value and satisfaction of FirstFuel's RBA platform compared to ASHRAE Level II onsite audits.

Success Criteria: 75% customer satisfaction compared to the Cadmus ASHRAE Level II site audits.

Results: Only one site responded to the survey provided. That site expressed satisfaction with the FirstFuel RBA approach compared to the ASHRAE Level II onsite audits, however, the results for this performance objective are considered inconclusive. Anecdotally, the FirstFuel approach also received positive feedback or expressions of interest and enthusiasm during the web-based Efficiency Planning Sessions, with few, if any, exceptions.

7.0 Cost Assessment

Since beginning the ESTCP demonstration, FirstFuel has advanced its analytics platform. The advancements include better capabilities and more commercial proof points working across 15 large utilities and government agencies. With the new platform, FirstFuel has updated names for each specific analytics product, or module. These names are as follows:

- **FirstAudit:** Building specific remote audits that deliver customized, actionable energy savings recommendations.
- **FirstMonitor:** Advanced predictive Analytics for efficiency savings monitoring, measuring, and alerting.
- **FirstPortfolio**: Advanced tools for managing building efficiency performance across portfolios.

FirstFuel's RBA platform costs typically range by the number of buildings that will be included in the project and by the buildings' size. The low end costs assume the installation has less than about 50 buildings participating in the FirstFuel RBA deployment and their sizes range from 20,000 to 100,000 gross square feet. The high range assumes that there are 100 buildings in the deployment, and they are between 50,000 and 300,000 gross square feet. On a per building basis, typical remote audits range between $1,000 and $7,000, depending on building size.

7.1 Cost Model

Item	Cost Element	Description	Estimated Costs 50-100 buildings
A	**FirstAudit Costs**	Costs to develop the FirstAudit report.	$50,000-$350,000
B	**Hardware capital costs**	None	$0
C	**Installation costs**	Labor to complete building data survey (about one hour), and Set-Up costs.	$14,000-$29,500
D	**Consumables**	None	$0
E	**Facility operational costs**	None	$0
F	**Annual FirstMonitor**	$1,000 per building per year	$0-100,000/yr.
G	**Maintenance & Support**	Annual Integrated Support $1,000 per building per year.	$50,000-$100,000/yr.
H	**Hardware lifetime**	None	$0
I	**Operator training**	None, Included in above	$0
J	**Salvage Value**	None	$0
K	**Estimated Total Cost of Deployment**	For Year 1	$114,00-$579,500

Table 9: Cost Model

7.2 Cost Drivers

In addition to the RBA platform costs, there are two additional cost drivers that should be considered when selecting FirstFuel's technology for future implementation: data collection and data security. The time and resources required to collect the buildings' data can be minimal, if the site's meter data management system is functional and well-understood. However, if the meter data collection is challenging or not well-understood, additional DoD resources may need to be devoted to data gathering. The second driver to be considered is data security & privacy. Should the DoD require the hosting of FirstFuel's servers behind a DoD firewall (or some other alternative), this will increase the costs and resources necessary to maintain the system.

7.3 Cost Analysis and Comparison

This technical paper illustrates the significant cost advantages that FirstFuel's RBA platform holds over traditional onsite audit methods. While ASHRAE Level II audits vary in terms of approach and rigor, FirstFuel's remote audit technology has been designed to replace these onsite evaluations under certain circumstances. The General Services Administration, for example, utilizes the FirstFuel RBA as an ASHRAE Level II replacement to meet their EISA 432 audit requirement. Rather than sending energy auditors onsite to walk through hundreds of buildings as a means to identify potential energy efficiency projects, which cannot scale, FirstFuel's RBA platform offers DoD installations a highly scalable approach to targeting and driving energy savings projects.

A DoD installation can expect to pay around $0.10-$0.15 a square foot for an ASHRAE Level II audit. FirstFuel's remote audits have been shown to cost significantly less, and have the potential to offer additional benefits, including a more interactive approach and ongoing engagement. Key interactive features not available from onsite audits include:

- Easy access via web portal by multiple stakeholders
- Updateable and easy to understand dynamic charts, graphs and analysis describing energy performance and ECMs
- Tracking of overall building performance over time
- Impact measurement of enacted ECMs
- ECM recommendation, personalized plan creation and documentation features

8.0 Implementation Issues

The biggest issue that FirstFuel encountered during the demonstration was selecting buildings that had sufficient quality meter data. In order to perform the remote analysis, FirstFuel relies on the building's actual consumption data for the entire assessment period (12 months). Often times, meter data would be requested, and the issues with the data would not be discovered until FirstFuel performed the standard Data QA checks. The most common data issues were as follows:

- Meters scaled incorrectly
- Data not properly labeled, and units unclear
- Zero readings
- Random recording resets
- Random Spikes (unrelated to real kW consumption)
- Negative readings
- Repeated readings
- Blank readings

Because the meter data issues were often not discovered until FirstFuel review the data, there was no way to go back and recover sufficient data for the particular buildings. As a result, time was added to the project to identify alternative buildings. Another issue was that sometimes facility personnel were unaware of how to interpret the data or how it was scaled. At many sites, the lack of a centralized resource for building meter data management made it challenging to address questions or issues with the meter data.

To gain better value out of the meters deployed across the DoD, FirstFuel recommends training personnel onsite to manage the meter data system. Furthermore, FirstFuel recommends the DoD adopt a standard across the branches for meter data collection and storage. The standardization may help to reduce the bottleneck of meter data collection efforts as well as the amount of concerns and questions regarding the integrity of the readings. In our professional opinion, these recommendations are important not just for the future success of the FirstFuel project, but for any endeavors seeking to obtain value from the advanced metering investments.

As site managers were made aware of the data discrepancies, they often asked what other installations were doing to address this prevalent issue. While researching solutions for the DoD, FirstFuel came across a United States Department of Energy document called *Metering Data Best Practices*: *A Guide to Achieving Utility Resource Efficiency*[11]. The most helpful and relevant section is "Chapter 6: Meter Communications and Storage" (see Appendix F). This

[11] Full report is available via the Federal Energy Management Program's website: http://www1.eere.energy.gov/femp/pdfs/mbpg.pdf

section outlines meter data storage standards that are in line with FirstFuel's experience of "good" practices. FirstFuel specifically recommends that the DoD adopt the following key guidelines related to meter data recording and storage:

- Interval meter data (5, 15, 30, 60 minutes) be collected and stored for a period of at least 24 months
- Date/time/unit fields should be standard across all meters, buildings, and sites
- Data should be contained in a single, flat file
- Meter communications issues should signal an alert to facility or energy manager so blank values do not go undetected
- Meter database shall allow other applications to reach and access the data
- Applications that access the data should be straight-forward to allow non-technical users to monitor the building's consumption, and download and send files

While the US General Services Administration (GSA) is not immune to data issues, our experience working with their buildings' data has been less prone to delays or roadblocks, thanks, in part, to their centralized management of the meter data collection. Resources throughout the GSA's energy division are trained on how to manage and interpret the building's advanced meter data, and as result issues with recordings are identified in a timely manner and FirstFuel is able to provide the GSA with high quality remote audits and monitoring with minimal time spent on Data QA. While the DoD may be constrained in adopting a policy that all branches can adhere to, standardizing the approach to meter data collection and meter data storage at least within the branches, will go a long way toward helping to achieve the full value of the advanced meter deployment.

APPENDICES

Appendix A: Points of Contact

Table 35: Points of Contact

Point of Contact	Organization	Phone & E-mail	Role in Project
Dr. Yan Lu	Siemens Corporation, Corporate Technology	yanlu@siemens.com 609-734-3549	PI
Sue DeMeo	Siemens Corporation, Corporate Technology	susan.demeo@siemens.com 609-734-4469	Business Contact
Thomas Gruenewald	Siemens Corporation, Corporate Technology	thomas.gruenewald@siemens.com 609-734-3546	PM
Dr. Mohsen Jafari	Rutgers University	jafari@rci.rutgers.edu	PI
Larry Lawrence	US Air Force Academy	Larry.lawrence@us.af.mil 719-333-1447	Site Support

Appendix B: Arnold Hall Chiller Degradation

Introduction

Arnold Hall has two chillers – CH01 and CH02. CH02 has been down for many years. Trend data for CH01 is available for the period 10/04/2012-10/24/2012 and 06/24/2013-08/17/2013. The performance of CH01 was calculated for these periods; significant degradation has been noticed.

COP calculation

The chilled water supply and return temperature, and the chiller power consumption are trended, with a 15-minutes sampling interval. The chilled water flow is not available. However, the primary chilled water pump is constant speed drive rated at 600 GPM. Therefore, it is reasonable to assume the chilled water has 500 GPM constant flow rate if we assume that the pump runs between 75% (450 GPM) and 90% (540 GPM) capacity. Then, the cooling output can be calculated as:

$$P_{cool} = \rho M (T_{CHWRT} - T_{CHWST})$$

where, $\rho = 0.1465 \frac{KW}{GPM^\circ F}$ is the specific heat of chilled water;

and, $M = 500\, GPM$

The instantaneous COP can be calculated as:

$$COP = \frac{P_{cool}}{P}$$

Instantaneous COP needs to be adjusted by corresponding condenser water entering temperature (CWST). **Table 36** from manufacturer document gives the part load power at reduced CWST.

Table 36: Chiller power reduction at reduced CWST

Percent Load	**KW (CWST=85°F)**	**KW**	**A**	**CWST (°F)**
100%	166.56	166.56	1.00000	85
90%	148.09	145.06	0.97954	81
80%	133.79	128.52	0.96061	77
70%	119.88	113.17	0.94403	73
60%	106.61	98.81	0.92684	69
50%	93.36	85.24	0.91302	65
40%	79.8	73.05	0.91541	65
30%	66.14	60.23	0.91064	65
20%	51.63	46.71	0.90471	65

The relation between adjusting factor, A = $KW/KW_{CWST=85°F}$, and CWST can be fitted using a second order polynomial equation.

$$A = f(CWST) = 3.228 \times 10^{-5} CWST^2 - 4.078 \times 10^{-4} CWST + 0.8011$$

$$COP_{adj} = A \cdot COP$$

Figure 28: **CH01 COP** shows the adjusted COP change.

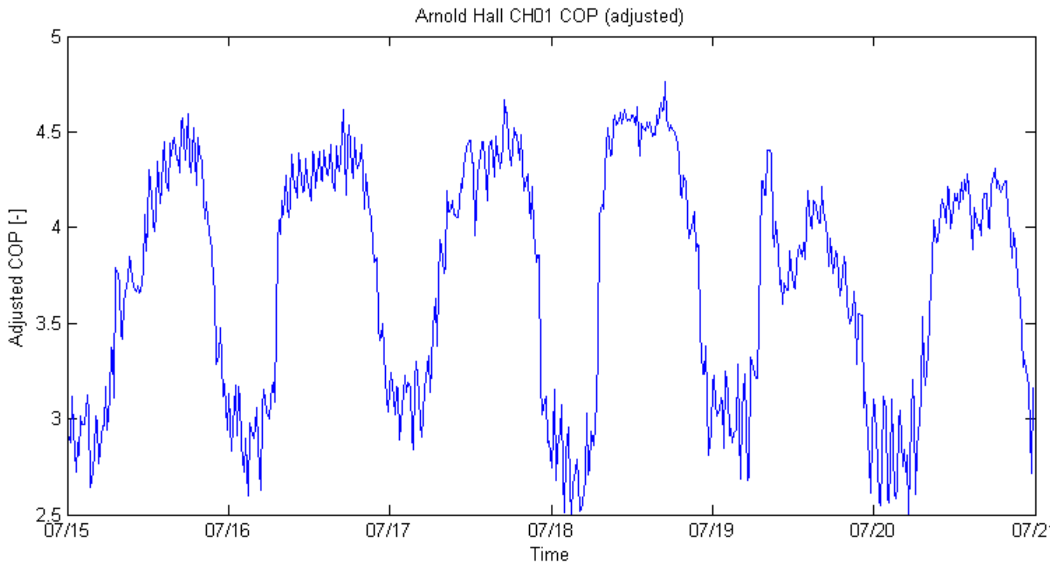


Figure 28: CH01 COP

PLR Calculation

The chiller has rated cooling capacity 300 Ton. That is equivalent to 1055 KW.
Then the chiller part load ratio (PLR) can be calculated as

$$PLR = \frac{P_{cool}}{P_{cool\ capacity}}$$

Figure 28 is the plot of instantaneous COP against PLR. The downward shift of data points is remarkable.

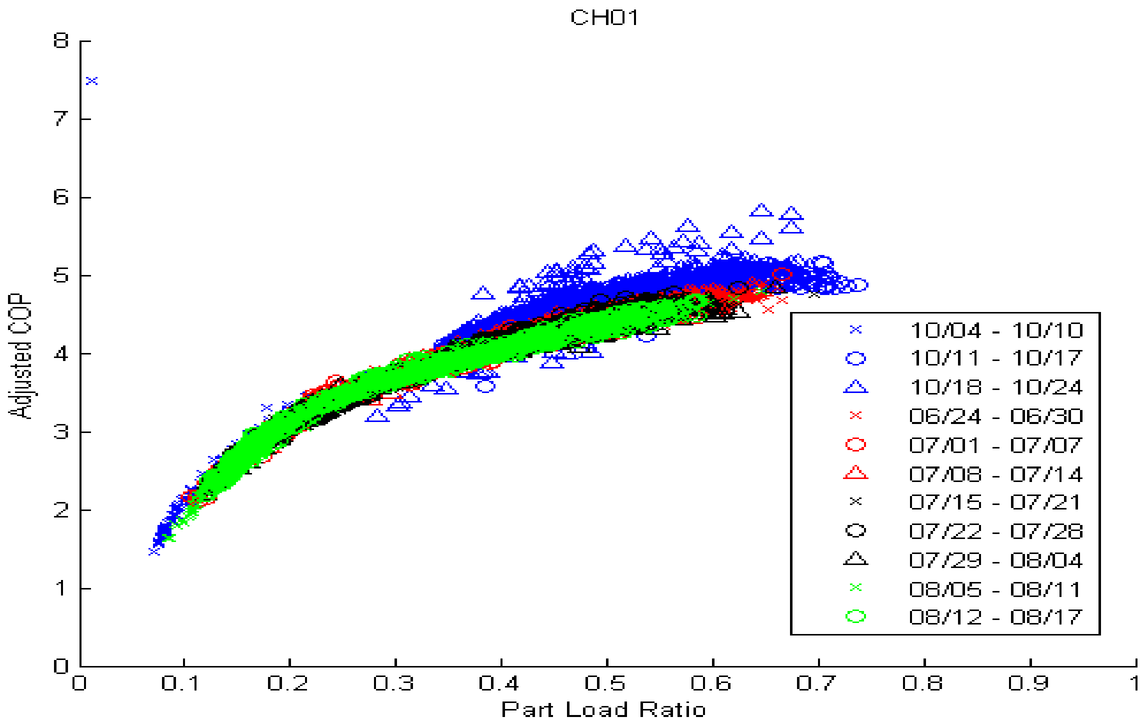


Figure 29: CH01 adjusted COP-PLR scatter plot

Curve fitting and CI calculation

Chiller performance is characterized by its COP-PLR curve. The reference performance data is provided by the manufacturer (Table 37).

Table 37: Chiller reference performance (CWST=85°F)

Percent Load Ratio	COP
100%	6.33
90%	6.41
80%	6.31
70%	6.16
60%	5.94
50%	5.65
40%	5.29
30%	4.79
20%	4.09
19%	4.00

Conventionally, a polynomial equation of power 4 is used to fit COP-PLR curve. The fitted curve is shown as following:

$$COP_{ref} = f(PLR) = -10.91PLR^4 + 28.03PLR^3 - 29.67PLR^2 + 17.27PLR + 1.61$$

Assume chiller performance curve at any time is in the form of

$$COP_{adj} = COP_{ref} CI / 100$$

The fitted curves are shown in Figure 30, and corresponding CI's are shown in Figure 31.

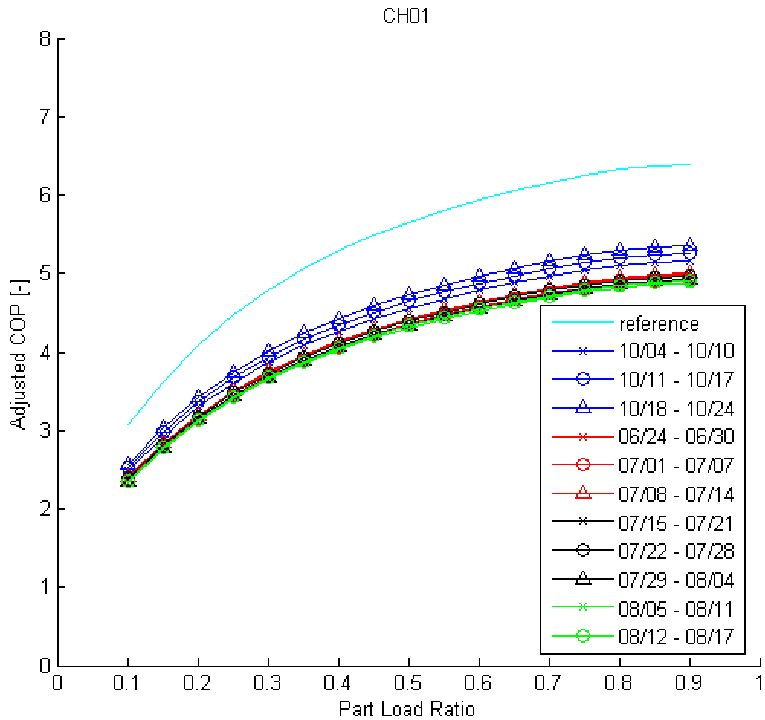


Figure 30: CH08 fitted performance curve

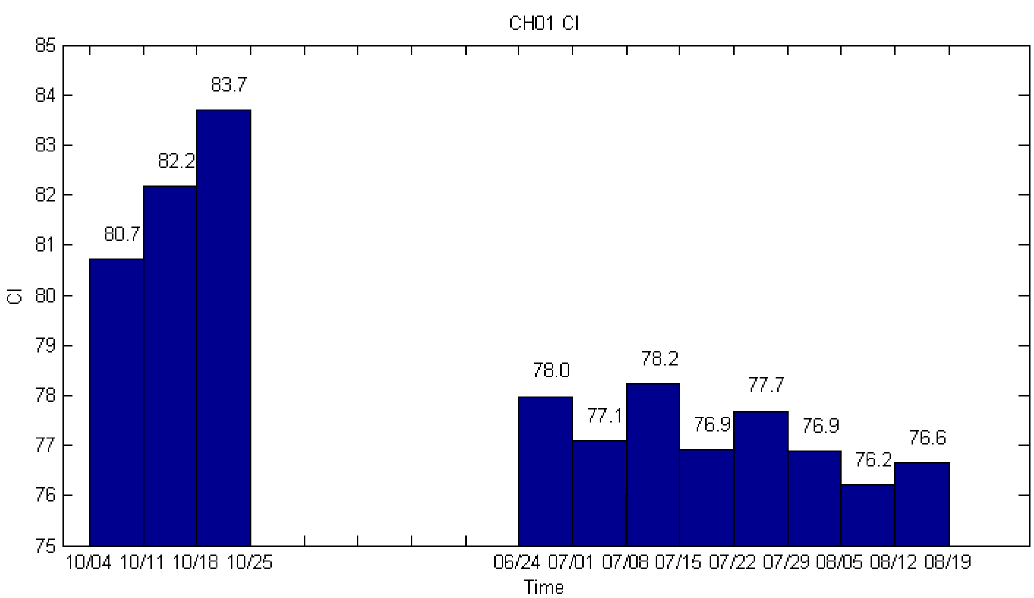


Figure 31: CH01 CI

Appendix C: Optimization Recommended Policies

We considered two different frequencies for each preventive maintenance policy option. Consequently, 12 (=6*2) maintenance options were studied. The "what-if" analysis representing base line case and the optimization ran for 2, 5 and 15 year durations each. For each duration selection, the simulation/co-simulation (with failure generating probability distribution for assets) ran several times (3 or more). This is to ensure that statistically sufficient variations are observed within these runs.

Table 38: Maintenance Policy Options

ID	Description
9.	Reactive Maintenance upon Failure
10.	Reactive Maintenance upon Alarm
11.	Preventive Maintenance Type 1_Age-based ^^^
12.	Preventive Maintenance Type 2_Age-based ^^^
13.	Preventive Maintenance Type 3_Age-based *** ^^^
14.	Preventive Maintenance Type 1_Clock-based ###
15.	Preventive Maintenance Type 2_Clock-based ###
16.	Preventive Maintenance Type 3_Clock-based *** ###

*** Preventive Maintenance Type 3 is the category with the most detailed actions and the highest improvement factor.
^^^ Age-based maintenances are scheduled based on the cumulative load on the assets.
Clock-based maintenances are scheduled based on the calendar.

Two years Optimization results:

Table 39: Year One of Two

Asset	Cooling Peak	Cooling off-Peak	Heating Peak	Heating off-Peak
Chiller	preventive maintenance clock based type 3 every 1 month1 month	preventive maintenance clock based type 3 every 1 months	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF1	preventive maintenance clock based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF2	preventive maintenance age based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF3	preventive maintenance age based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF4	preventive maintenance	Reactive	preventive	Reactive

	age based type 3 every 1 month	maintenance	maintenance clock based type 3 every 1 month	maintenance
SF5	preventive maintenance clock based type 3 every 1 month	Reactive maintenance	Reactive maintenance	Reactive maintenance
SF6	preventive maintenance clock based type 3 every 1 month	preventive maintenance clock based type 3 every 1 month	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF7	preventive maintenance clock based type 3 every 1 month	preventive maintenance clock based type 3 every 1 month	Reactive maintenance	Reactive maintenance
SF8	preventive maintenance age based type 3 every 1 month	preventive maintenance clock based type 3 every 1 month	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF9	preventive maintenance clock based type 3 every 1 month	preventive maintenance clock based type	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF10	preventive maintenance age based type 3 every 1 month	preventive maintenance clock based type	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF11	preventive maintenance clock based type 3 every 1 month	preventive maintenance clock based type 3 every 1 month	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF12	preventive maintenance age based type 3 every 1 month	preventive maintenance clock based type 3 every 1 month	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF13	preventive maintenance clock based type 3 every 1 month	Reactive maintenance	Reactive maintenance	Reactive maintenance

Table 40: Year two of two

Asset	**Cooling Peak**	**Cooling off-Peak**	**Heating Peak**	**Heating off-Peak**
Chiller	preventive maintenance clock based type 3 every 1 month	preventive maintenance clock based type 3 every 1 month	Reactive maintenance	Reactive maintenance

SF1	preventive maintenance clock based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF2	preventive maintenance age based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF3	preventive maintenance age based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF4	preventive maintenance age based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF5	preventive maintenance clock based type 3 every 2 month	Reactive maintenance	Reactive maintenance	Reactive maintenance
SF6	preventive maintenance clock based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF7	preventive maintenance clock based type 3 every 1 month	Reactive maintenance	Reactive maintenance	Reactive maintenance
SF8	preventive maintenance age based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF9	preventive maintenance clock based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF10	preventive maintenance age based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF11	preventive maintenance clock based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF12	preventive maintenance age based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance

SF13	preventive maintenance clock based type 3 every 2 months	Reactive maintenance	Reactive maintenance	Reactive maintenance

Table 41: Year One of Five

Asset	Cooling Peak	Cooling off-Peak	Heating Peak	Heating off-Peak
Chiller	preventive maintenance clock based type 3 every 1 month	preventive maintenance clock based type 3 every 1 month	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF1	preventive maintenance clock based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF2	preventive maintenance age based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF3	preventive maintenance age based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF4	preventive maintenance age based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF5	preventive maintenance clock based type 3 every 1 month	Reactive maintenance	Reactive maintenance	Reactive maintenance
SF6	preventive maintenance clock based type 3 every 1 month	preventive maintenance clock based type 3 every 1 month	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF7	preventive maintenance clock based type 3 every 1 month	preventive maintenance clock based type 3 every 1 month	Reactive maintenance	Reactive maintenance
SF8	preventive maintenance age based type 3 every 1	preventive maintenance	preventive maintenance	Reactive maintenance

	month	clock based type 3 every 1 month	clock based type 3 every 1 month	
SF9	preventive maintenance clock based type 3 every 1 month	preventive maintenance clock based type	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF10	preventive maintenance age based type 3 every 1 month	preventive maintenance clock based type	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF11	preventive maintenance clock based type 3 every 1 month	preventive maintenance clock based type 3 every 1 month	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF12	preventive maintenance age based type 3 every 1 month	preventive maintenance clock based type 3 every 1 month	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF13	preventive maintenance clock based type 3 every 1 month	Reactive maintenance	Reactive maintenance	Reactive maintenance

Table 42: Year Two of Five

Asset	Cooling Peak	Cooling off-Peak	Heating Peak	Heating off-Peak
Chiller	preventive maintenance clock based type 3 every 1 month	preventive maintenance clock based type 3 every 1 month	Reactive maintenance	Reactive maintenance
SF1	preventive maintenance clock based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF2	preventive maintenance age based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF3	preventive maintenance age based type 3 every 1	Reactive maintenance	preventive maintenance	Reactive maintenance

	month		clock based type 3 every 1 month	
SF4	preventive maintenance age based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF5	preventive maintenance clock based type 3 every 2 month	Reactive maintenance	Reactive maintenance	Reactive maintenance
SF6	preventive maintenance clock based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF7	preventive maintenance clock based type 3 every 1 month	Reactive maintenance	Reactive maintenance	Reactive maintenance
SF8	preventive maintenance age based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF9	preventive maintenance clock based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF10	preventive maintenance age based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF11	preventive maintenance clock based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF12	preventive maintenance age based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF13	preventive maintenance clock based type 3 every 2 month	Reactive maintenance	Reactive maintenance	Reactive maintenance

Table 43: Year Three of Five

Asset	Cooling Peak	Cooling off-Peak	Heating Peak	Heating off-Peak
Chiller	preventive maintenance clock based type 3 every 1 month	preventive maintenance clock based type 3 every 1 month	Reactive maintenance	Reactive maintenance
SF1	preventive maintenance clock based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF2	preventive maintenance age based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF3	preventive maintenance age based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF4	preventive maintenance age based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF5	preventive maintenance clock based type 3 every 2 month	Reactive maintenance	Reactive maintenance	Reactive maintenance
SF6	preventive maintenance clock based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF7	preventive maintenance clock based type 3 every 2 month	Reactive maintenance	Reactive maintenance	Reactive maintenance
SF8	preventive maintenance age based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF9	preventive maintenance clock based type 3 every 1	Reactive maintenance	preventive maintenance	Reactive maintenance

	month		clock based type 3 every 1 month	
SF10	preventive maintenance age based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF11	preventive maintenance clock based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF12	preventive maintenance age based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF13	preventive maintenance age based type 3 every 1 month	Reactive maintenance	Reactive maintenance	Reactive maintenance

Table 44: Year Four of Five

Asset	Cooling Peak	Cooling off-Peak	Heating Peak	Heating off-Peak
Chiller	preventive maintenance clock based type 3 every 1 month	preventive maintenance clock based type 3 every 1 month	Reactive maintenance	Reactive maintenance
SF1	preventive maintenance clock based type 3 every 1 month	Reactive maintenance	Reactive maintenance	Reactive maintenance
SF2	preventive maintenance age based type 3 every 1 month	Reactive maintenance	Reactive maintenance	Reactive maintenance
SF3	preventive maintenance age based type 3 every 1 month	Reactive maintenance	Reactive maintenance	Reactive maintenance
SF4	preventive maintenance age based type 3 every 1 month	Reactive maintenance	Reactive maintenance	Reactive maintenance
SF5	preventive maintenance clock based type 3 every 2	Reactive maintenance	Reactive maintenance	Reactive maintenance

	month			
SF6	preventive maintenance clock based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF7	preventive maintenance clock based type 3 every 2 month	Reactive maintenance	Reactive maintenance	Reactive maintenance
SF8	preventive maintenance age based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF9	preventive maintenance clock based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF10	preventive maintenance age based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF11	preventive maintenance clock based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF12	preventive maintenance age based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF13	preventive maintenance clock based type 3 every 2 months	Reactive maintenance	Reactive maintenance	Reactive maintenance

Table 45: Year Five of Five

Asset	Cooling Peak	Cooling off-Peak	Heating Peak	Heating off-Peak
Chiller	preventive maintenance clock based type 3 every 1 month	preventive maintenance clock based type 3 every 1 month	Reactive maintenance	Reactive maintenance
SF1	preventive maintenance clock based type 3 every 1 month	Reactive maintenance	Reactive maintenance	Reactive maintenance
SF2	preventive maintenance age based type 3 every 1 month	Reactive maintenance	Reactive maintenance	Reactive maintenance
SF3	preventive maintenance age based type 3 every 1 month	Reactive maintenance	Reactive maintenance	Reactive maintenance
SF4	preventive maintenance age based type 3 every 1 month	Reactive maintenance	Reactive maintenance	Reactive maintenance
SF5	preventive maintenance clock based type 3 every 2 month	Reactive maintenance	Reactive maintenance	Reactive maintenance
SF6	preventive maintenance clock based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF7	preventive maintenance clock based type 3 every 2 month	Reactive maintenance	Reactive maintenance	Reactive maintenance
SF8	preventive maintenance age based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF9	preventive maintenance clock based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF10	preventive maintenance age based type 3 every 1	Reactive maintenance	preventive maintenance	Reactive maintenance

	month		clock based type 3 every 1 month	
SF11	preventive maintenance clock based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF12	preventive maintenance age based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF13	preventive maintenance clock based type 3 every 2 months	Reactive maintenance	Reactive maintenance	Reactive maintenance

Table 46: Year 6/15

Asset	Cooling Peak	Cooling off-Peak	Heating Peak	Heating off-Peak
Chiller	preventive maintenance clock based type 3 every 1 month	preventive maintenance clock based type 3 every 1 month	Reactive maintenance	Reactive maintenance
SF1	preventive maintenance clock based type 3 every 1 month	Reactive maintenance	Reactive maintenance	Reactive maintenance
SF2	preventive maintenance age based type 3 every 1 month	Reactive maintenance	Reactive maintenance	Reactive maintenance
SF3	preventive maintenance age based type 3 every 1 month	Reactive maintenance	Reactive maintenance	Reactive maintenance
SF4	preventive maintenance age based type 3 every 1 month	Reactive maintenance	Reactive maintenance	Reactive maintenance
SF5	preventive maintenance clock based type 3 every 2 months	Reactive maintenance	Reactive maintenance	Reactive maintenance
SF6	preventive maintenance clock based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF7	preventive maintenance clock based type 3 every 2 month	Reactive maintenance	Reactive maintenance	Reactive maintenance

SF8	preventive maintenance age based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF9	preventive maintenance clock based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF10	preventive maintenance age based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF11	preventive maintenance clock based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF12	preventive maintenance age based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF13	preventive maintenance clock based type 3 every 2 months	Reactive maintenance	Reactive maintenance	Reactive maintenance

Table 47: Year 7/15

Asset	Cooling Peak	Cooling off-Peak	Heating Peak	Heating off-Peak
Chiller	preventive maintenance clock based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF1	preventive maintenance clock based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF2	preventive maintenance age based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF3	preventive maintenance age based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF4	preventive maintenance age based type 3 every 1	Reactive maintenance	preventive maintenance	Reactive maintenance

	month		clock based type 3 every 1 month	
SF5	preventive maintenance clock based type 3 every 2 months	Reactive maintenance	Reactive maintenance	Reactive maintenance
SF6	preventive maintenance clock based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF7	preventive maintenance clock based type 3 every 2 month	Reactive maintenance	Reactive maintenance	Reactive maintenance
SF8	preventive maintenance age based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF9	preventive maintenance clock based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF10	preventive maintenance age based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF11	preventive maintenance clock based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF12	preventive maintenance age based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF13	preventive maintenance clock based type 3 every 2 months	Reactive maintenance	Reactive maintenance	Reactive maintenance

Table 48: Year 8/15

Asset	Cooling Peak	Cooling off-Peak	Heating Peak	Heating off-Peak
Chiller	preventive maintenance clock based type 3 every 1 month	Reactive maintenance	Reactive maintenance	Reactive maintenance
SF1	preventive maintenance clock based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type	Reactive maintenance

			3 every 1 month	
SF2	preventive maintenance age based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF3	preventive maintenance age based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF4	preventive maintenance age based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF5	preventive maintenance clock based type 3 every 2 months	Reactive maintenance	Reactive maintenance	Reactive maintenance
SF6	preventive maintenance clock based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF7	preventive maintenance clock based type 3 every 2 month	Reactive maintenance	Reactive maintenance	Reactive maintenance
SF8	preventive maintenance age based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF9	preventive maintenance clock based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF10	preventive maintenance age based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF11	preventive maintenance clock based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF12	preventive maintenance age based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF13	preventive maintenance clock based type 3 every 2 months	Reactive maintenance	Reactive maintenance	Reactive maintenance

Table 49: Year 9/15

Asset	Cooling Peak	Cooling off-Peak	Heating Peak	Heating off-Peak
Chiller	preventive maintenance clock based type 3 every 1 month	preventive maintenance clock based type 3 every 1 month	Reactive maintenance	Reactive maintenance
SF1	preventive maintenance clock based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF2	preventive maintenance age based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF3	preventive maintenance age based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF4	preventive maintenance age based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF5	preventive maintenance clock based type 3 every 1 month	Reactive maintenance	Reactive maintenance	Reactive maintenance
SF6	preventive maintenance clock based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF7	preventive maintenance clock based type 3 every 1 month	Reactive maintenance	Reactive maintenance	Reactive maintenance
SF8	preventive maintenance age based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF9	preventive maintenance clock based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF10	preventive maintenance age based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type	Reactive maintenance

			3 every 1 month	
SF11	preventive maintenance clock based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF12	preventive maintenance age based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF13	preventive maintenance clock based type 3 every 1 month	Reactive maintenance	Reactive maintenance	Reactive maintenance

Table 50: Year 10/15

Asset	Cooling Peak	Cooling off-Peak	Heating Peak	Heating off-Peak
Chiller	preventive maintenance clock based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF1	preventive maintenance clock based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF2	preventive maintenance age based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF3	preventive maintenance age based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF4	preventive maintenance age based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF5	preventive maintenance clock based type 3 every 2 months	Reactive maintenance	Reactive maintenance	Reactive maintenance
SF6	preventive maintenance clock based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF7	preventive maintenance clock based type 3 every 2	Reactive maintenance	Reactive maintenance	Reactive maintenance

	month			
SF8	preventive maintenance age based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF9	preventive maintenance clock based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF10	preventive maintenance age based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF11	preventive maintenance clock based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF12	preventive maintenance age based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF13	preventive maintenance clock based type 3 every 2 months	Reactive maintenance	Reactive maintenance	Reactive maintenance

Table 51: Year 11/15

Asset	Cooling Peak	Cooling off-Peak	Heating Peak	Heating off-Peak
Chiller	preventive maintenance clock based type 3 every 1 month	preventive maintenance clock based type 3 every 1 month	Reactive maintenance	Reactive maintenance
SF1	preventive maintenance clock based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF2	preventive maintenance age based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF3	preventive maintenance age based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF4	preventive maintenance	Reactive	preventive	Reactive

	age based type 3 every 1 month	maintenance	maintenance clock based type 3 every 1 month	maintenance
SF5	preventive maintenance clock based type 3 every 2 months	Reactive maintenance	Reactive maintenance	Reactive maintenance
SF6	preventive maintenance clock based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF7	Reactive maintenance	preventive maintenance clock based type 3 every 2 months	Reactive maintenance	Reactive maintenance
SF8	preventive maintenance age based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF9	preventive maintenance clock based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF10	preventive maintenance age based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF11	preventive maintenance clock based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF12	preventive maintenance age based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF13	preventive maintenance clock based type 3 every 2 months	Reactive maintenance	Reactive maintenance	Reactive maintenance

Table 52: Year 12/15

Asset	Cooling Peak	Cooling off-Peak	Heating Peak	Heating off-Peak
Chiller	preventive maintenance clock based type 3 every 1 month	preventive maintenance clock based type 3 every 1 month	Reactive maintenance	Reactive maintenance

SF1	preventive maintenance clock based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF2	preventive maintenance age based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF3	preventive maintenance age based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF4	preventive maintenance age based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF5	preventive maintenance clock based type 3 every 2 months	Reactive maintenance	Reactive maintenance	Reactive maintenance
SF6	preventive maintenance clock based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF7	preventive maintenance clock based type 3 every 2 months	Reactive maintenance	Reactive maintenance	Reactive maintenance
SF8	preventive maintenance age based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF9	preventive maintenance clock based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF10	preventive maintenance age based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF11	preventive maintenance clock based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF12	preventive maintenance age based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance

SF13	preventive maintenance clock based type 3 every 2 months	Reactive maintenance	Reactive maintenance	Reactive maintenance

Table 53: Year 13/15

Asset	Cooling Peak	Cooling off-Peak	Heating Peak	Heating off-Peak
Chiller	preventive maintenance clock based type 3 every 1 month	preventive maintenance clock based type 3 every 1 month	Reactive maintenance	Reactive maintenance
SF1	preventive maintenance clock based type 3 every 1 month	preventive maintenance clock based type 3 every 1 month	Reactive maintenance	Reactive maintenance
SF2	preventive maintenance age based type 3 every 1 month	preventive maintenance clock based type 3 every 1 month	Reactive maintenance	Reactive maintenance
SF3	preventive maintenance clock based type 3 every 1 month	preventive maintenance clock based type 3 every 1 month	Reactive maintenance	Reactive maintenance
SF4	preventive maintenance age based type 3 every 1 month	preventive maintenance clock based type 3 every 1 month	Reactive maintenance	Reactive maintenance
SF5	preventive maintenance clock based type 3 every 2 months	Reactive maintenance	Reactive maintenance	Reactive maintenance
SF6	preventive maintenance clock based type 3 every 1 month	preventive maintenance clock based type 3 every 1 month	Reactive maintenance	Reactive maintenance
SF7	preventive maintenance clock based type 3 every 2 months	Reactive maintenance	Reactive maintenance	Reactive maintenance
SF8	preventive maintenance age based type 3 every 1 month	preventive maintenance clock based type 3 every 1 month	Reactive maintenance	Reactive maintenance
SF9	preventive maintenance clock based type 3 every 1 month	preventive maintenance clock based type 3 every 1 month	Reactive maintenance	Reactive maintenance

SF10	preventive maintenance age based type 3 every 1 month	preventive maintenance clock based type 3 every 1 month	Reactive maintenance	Reactive maintenance
SF11	preventive maintenance clock based type 3 every 1 month	preventive maintenance clock based type 3 every 1 month	Reactive maintenance	Reactive maintenance
SF12	preventive maintenance age based type 3 every 1 month	preventive maintenance clock based type 3 every 1 month	Reactive maintenance	Reactive maintenance
SF13	Reactive maintenance	Reactive maintenance	Reactive maintenance	Reactive maintenance

Table 54: Year 14/15

Asset	Cooling Peak	Cooling off-Peak	Heating Peak	Heating off-Peak
Chiller	preventive maintenance clock based type 3 every 1 month	preventive maintenance clock based type 3 every 1 month	Reactive maintenance	Reactive maintenance
SF1	preventive maintenance clock based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF2	preventive maintenance age based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF3	preventive maintenance age based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF4	preventive maintenance age based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF5	preventive maintenance clock based type 3 every 2 months	Reactive maintenance	Reactive maintenance	Reactive maintenance
SF6	preventive maintenance clock based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type	Reactive maintenance

			3 every 1 month	
SF7	preventive maintenance clock based type 3 every 2 months	Reactive maintenance	Reactive maintenance	Reactive maintenance
SF8	preventive maintenance age based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF9	preventive maintenance clock based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF10	preventive maintenance age based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF11	preventive maintenance clock based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF12	preventive maintenance age based type 3 every 1 month	Reactive maintenance	preventive maintenance clock based type 3 every 1 month	Reactive maintenance
SF13	preventive maintenance clock based type 3 every 2 months	Reactive maintenance	Reactive maintenance	Reactive maintenance

Table 55: Year 15/15

Asset	Cooling Peak	Cooling off-Peak	Heating Peak	Heating off-Peak
Chiller	preventive maintenance clock based type 3 every 1 month	preventive maintenance clock based type 3 every 1 month	Reactive maintenance	Reactive maintenance
SF1	preventive maintenance clock based type 3 every 1 month	preventive maintenance clock based type 3 every 1 month	Reactive maintenance	Reactive maintenance
SF2	preventive maintenance age based type 3 every 1 month	preventive maintenance clock based type 3 every 1 month	Reactive maintenance	Reactive maintenance
SF3	preventive maintenance clock based type 3 every 1	preventive maintenance	Reactive maintenance	Reactive maintenance

	month	clock based type 3 every 1 month		
SF4	preventive maintenance age based type 3 every 1 month	preventive maintenance clock based type 3 every 1 month	Reactive maintenance	Reactive maintenance
SF5	preventive maintenance clock based type 3 every 2 months	Reactive maintenance	Reactive maintenance	Reactive maintenance
SF6	preventive maintenance clock based type 3 every 1 month	preventive maintenance clock based type 3 every 1 month	Reactive maintenance	Reactive maintenance
SF7	preventive maintenance clock based type 3 every 2 months	Reactive maintenance	Reactive maintenance	Reactive maintenance
SF8	preventive maintenance age based type 3 every 1 month	preventive maintenance clock based type 3 every 1 month	Reactive maintenance	Reactive maintenance
SF9	preventive maintenance clock based type 3 every 1 month	preventive maintenance clock based type 3 every 1 month	Reactive maintenance	Reactive maintenance
SF10	preventive maintenance age based type 3 every 1 month	preventive maintenance clock based type 3 every 1 month	Reactive maintenance	Reactive maintenance
SF11	preventive maintenance clock based type 3 every 1 month	preventive maintenance clock based type 3 every 1 month	Reactive maintenance	Reactive maintenance
SF12	preventive maintenance age based type 3 every 1 month	preventive maintenance clock based type 3 every 1 month	Reactive maintenance	Reactive maintenance
SF13	preventive maintenance clock based type 3 every 2 months	Reactive maintenance	Reactive maintenance	Reactive maintenance

Appendix D: Building Energy Simulation model

The EnergyPlus model was built to run what-if (baseline case) and optimization scenarios. The following components were included in the EnergyPlus model of Arnold Hall.

Building Zones

41 zones were identified during the development of the building energy simulation model. Most zones are located at the Main Level (Ground Level). The ballroom has one zone in the basement level, and the auditorium has more zones at Levels 1~4. The zone map for the Main Level (Ground Level) is shown in the following figure.

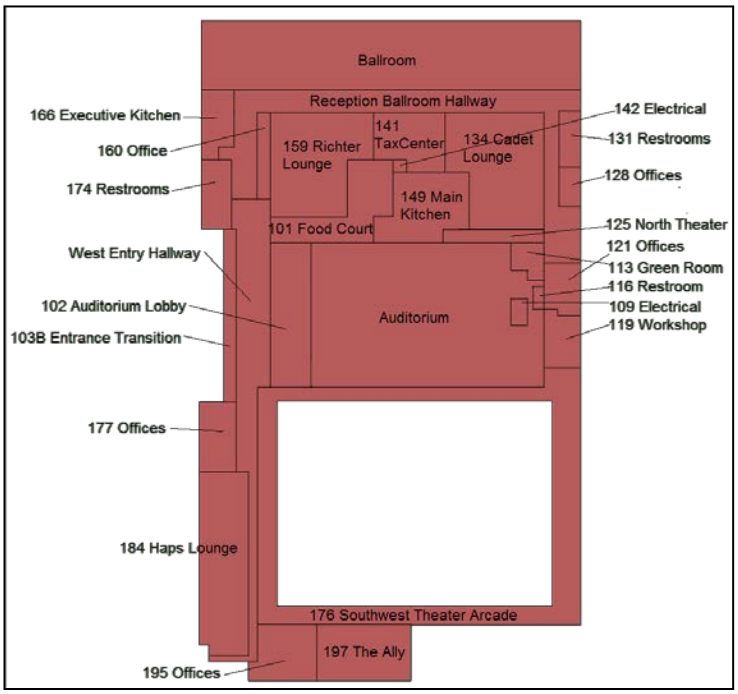


Figure 32: Zone Map - the Main Level (Ground Level)

Plants

The heating water for Arnold Hall is provided by a central plant within the same USAFA campus. However, in the simulation, a natural gas boiler is modeled as an equivalent surrogate. This boiler has nominal capacity of 478.9KW and nominal thermal efficiency of 0.89. There are two 300-ton chillers providing chilled water to both Arnold Hall and one adjacent building (Harmon Hall). Metering that measures the flow to and from the Harmon branch is not available. In the simulation, an electric chiller is modeled as an equivalent surrogate. The simulated chiller has reference capacity of 703.3KW and reference COP of 5.5. There are two cooling towers providing condenser water. In the simulation, one cooling tower is modeled as an equivalent surrogate.

Air Handling Units

Twelve (12) air handling units have been identified as providing conditioned air to the zones. The correlation between zones and AHUs is summarized in Table 56.

Table 56: Air Handling Units

AHU	Type	Served Area	Served Zone Names
AHU-1A	VAV/Dual Duct/Dual Deck	Misc.	Richter Lounge, Tax Center, Food Court, Main Kitchen, Southwest Theater Arcade, Restrooms(131,116)
AHU-1C	CAV	Auditorium	Auditorium Behind, Auditorium, Corridor
AHU-1D	CAV	Auditorium	Rehearsal & Dressing Room, Backstage
AHU-2	CAV	Auditorium	Auditorium
AHU-3	VAV	Misc.	Green Room, Workshop
AHU-4	VAV	Misc.	Offices (177,195), Ally
AHU-5	VAV	Haps Lounge	Haps Lounge
AHU-6	CAV	Misc.	Entrance Transition, Auditorium Lobby, West Entry Hallway
AHU-7	VAV	Ballroom	Ballroom
AHU-8	VAV	Cadet Lounge	Cadet Lounge
AHU-9	VAV	Misc.	Executive Kitchen, Offices (121,128,160), Restroom(174)
AHU-10	VAV	Ballroom	Reception Ballroom Hallway

For each air-handling unit in the simulation, 1 supply fan and 1 return fan are modeled.

Appendix E: Business Value Model (BVM)

BEAM Configuration maps the missions assigned to a building to the building's assets based on Business Value Models: *BVM-I*, *BVM-II* or *BVM-III*. The following **Table 57** lists data assumptions for the BVM model. Some data are input based on information received from the building owner/operator, which were obtained through the interview process.

Table 57: BVM Data Assumptions

#	Assumption	Description	Data/Model Source
1	Productivity loss or business value loss due to asset failure: Quantifiable Economic Consequence of Asset Failure (Loss)	Building occupants' productivity as well as activities performed in the building are correlated with performance of building energy assets such as components of HVAC system namely chiller, supply and return fans; thus, any deviation from optimal performance of such components (including asset failures) results in loss of productivity or business value gained through activities held in the building. This concept is used in defining consequence of asset failure in monetary terms. (i.e. Asset Business Value in BVM-II & -III)	BVM Survey Questionnaires
2	Building Zoning: Thermal zoning concept	In order to effectively map building missions to energy assets, zoning is performed based on thermal zoning (Control Zones) concept used in building energy simulation. Control Zones (zones with independently controlled equipment) are defined based on placement of Air Terminal Units (i.e., VAV boxes) within the building.	Building Simulation Model (EnergyPlus Model)
3	Building Mission/Business Objectives and Functions	Building missions are accomplished through various functions carried out in building zones. Functions performed across the building can be defined according to functional zones within the building. Functional zones are defined based on the type(s) of activities performed in them. Each functional zone may be operational for one or more mission.	BVM Survey Questionnaires

#	Assumption	Description	Data/Model Source
4	Seasonality	4 seasons are considered in BVM-III business value calculation: Peak Cooling, Off-Peak Cooling, and Peak Heating & Off-Peak Heating. Peak and Off-Peak seasons are defined based on cooling and heating demands. Such seasons include various intensive and un-intensive occupancy patterns throughout the year.	BVM Survey Questionnaires
5	Duration of Asset Unavailability Due to Failure (Loss)	This duration is defined in days. This number is used to derive monetary consequence per failure of assets.	BVM Survey Questionnaires or default unavailability duration
6	Polynomial Regression Function between Relative Productivity and PMV in BVM-II.	It is assumed that office work consists of typical office tasks such as typing, proof reading, etc…; Thus the function introduced by Lan et al. 2011, can be used: $RP = -0.0351PMV^3 - 0.5294PMV^2 - 0.215PMV + 99.865$	Regression function from Lan et al., 2011
7	Employees' Annual Income or Income Contribution as Reference for Economic Loss Due to Productivity	It is assumed that since employees are hired to produce value for the organization, their average annual income may be used to approximate an economic value for loss of productivity due to asset failure	BVM Survey Questionnaires
8	Risk Priority Number (RPN): FMEA's risk measure used in BVM-I for asset criticality score calculation.	In order to define criticality of an asset such as supply fan to performance of its associated asset system (AHU), FMEA's RPN $\in [0,100]$ is used which is defined based on assets fault types, each fault's occurrence probability $\in [0,10]$ & each fault's consequence on performance of asset system $\in [0,10]$	Historical data on asset faults, BVM Survey Questionnaires

According to the seasonality concept in BVM model Peak and off-Peak seasons are defined based on cooling and heating demands. Table 58 shows the start date and end date for each defined season.

Table 58: Seasons Start date and End date

Season	Start Date	End Date
Cooling season	April - 1	October - 15
Cooling Peak season	June - 1	August - 31
Heating season	October - 16	March - 31
Heating Peak season	December - 1	February - 15

Note that, as Table 58 shows, in the cooling season we consider two cooling off-peak seasons, one of them before cooling peak season (April-1 to May-31) and the other one after cooling peak season (September-1 to October-15). The same approach is taken for the heating season.

Based on the inputs received from users about average annual income for task related zones, average business value gained through activities in non- task related zones and duration of asset unavailability due to failure (in days), business value for each asset is calculated. The following table shows these values which are used as penalty cost per failure for the assets.

Table 59: Seasonal BVM values

Asset	Cooling Peak($)	Cooling off-Peak ($)	Heating Peak ($)	Heating off-Peak ($)
Chiller	4,406,350	2,566,336	0	0
SF1	995,800	1,159,943	1,019,021	954,514
SF2	85,800	99,943	168,771	288,514
SF3	7,800	9,086	15,343	26,229
SF4	85,800	99,943	168,771	288,514
SF5	0	0	0	0
SF6	65,520	76,320	64,440	56,160
SF7	0	0	0	0
SF8	449,800	523,943	482,021	486,514
SF9	46,800	54,514	92,057	157,371
SF10	126,100	146,886	248,043	424,029
SF11	481,520	560,891	524,726	543,017
SF12	296,400	345,257	296,629	267,086
SF13	0	0	0	0

As you see chiller has the most business value which is reasonable since chiller is serving all of the 41 zones of the building. So the failure of chiller in cooling season will impact the functionality of whole building.

Appendix F: BEAM Configuration Tool User Manual

BVM tool User Manual

USAFA Arnold Hall Case Study

Pre-Requisites

- Firefox browser is the preferred browser for BVM tool application.
- Apache Tomcat 7.0 has been started.
- Copy "BeamIII_3_3.war" into the webapps folder of Apache Tomcat, (in my machine, it is C:\Program Files\Apache Software Foundation\Tomcat 7.0\webapps) and rename it as "BeamII.war";
- Use IP address http://localhost:8080/BeamII/ to load the BVM tool.

Step1: BVM tool log in

User name: beam

Password: beam

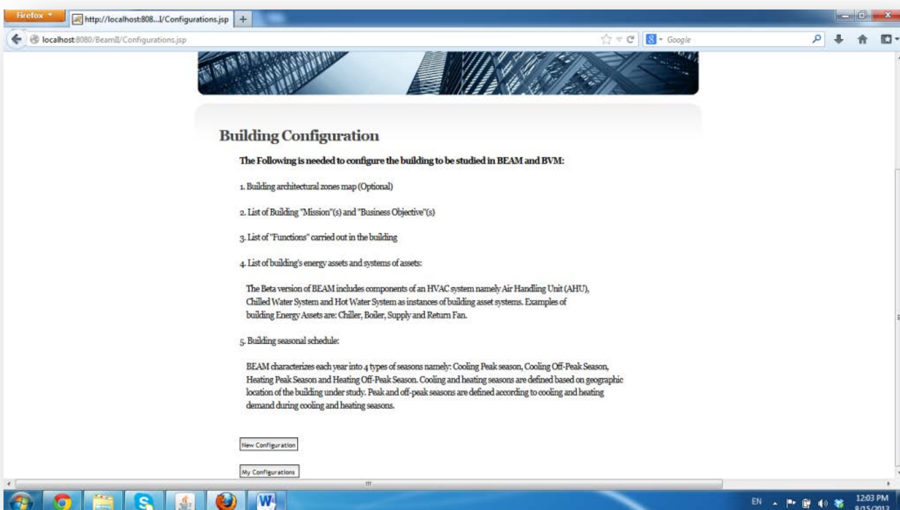
Note: this user name and password cannot be changed.

Step2. Building Configuration

Click "New Configuration" to start configuration process

Click "My Configuration" to load a previously existing configuration

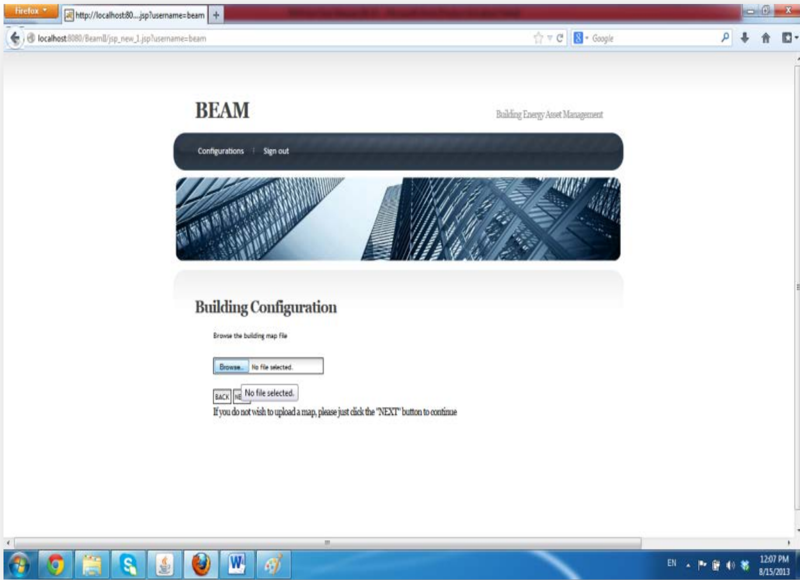
Here, we click "New Configuration" to start a new configuration process. Here we use Arnold Hall as an example.



Step 2.1: Browse building zone map

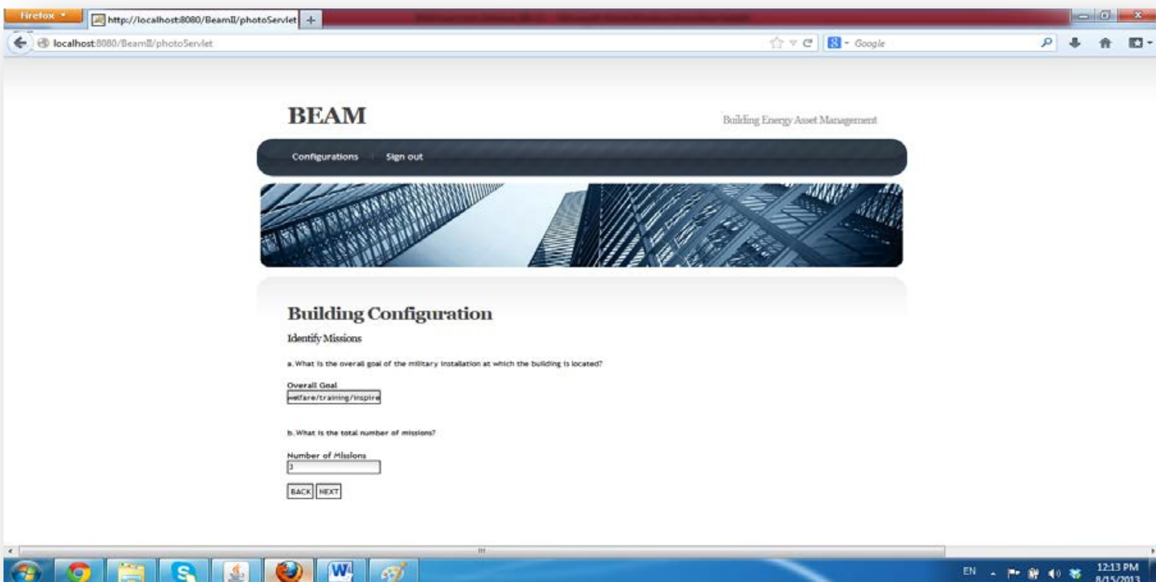
Notes:

- Zone maps should be in *.png format
- No error occurs if no map is uploaded



Step 2.2: Identify Goal of military installation and Number of Missions

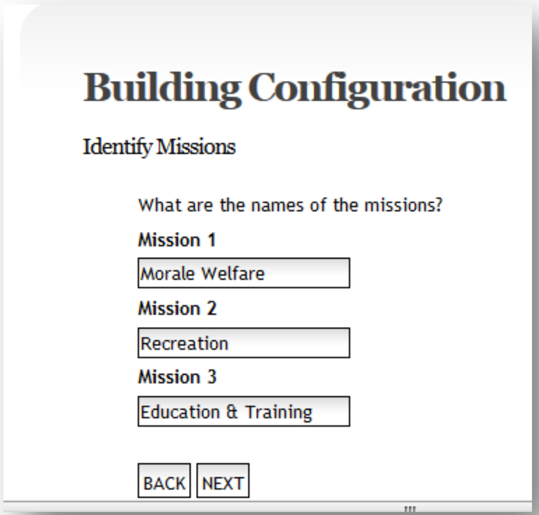
Type "welfare/training/inspire" as the overall goal and "3" as the number of missions.



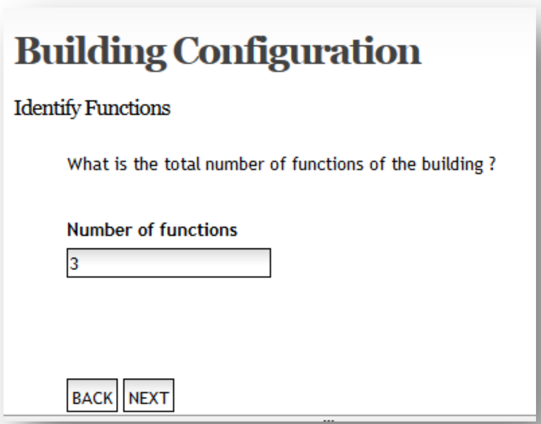
Notes:

- "Overall Goal" is a text indication high level purpose of the building.
- "Missions" are specific business objectives which ensure realization of building "Overall Goal".
- Suggested number of missions for USAFA Arnold hall: <u>3 Missions</u>

Step 2.3: Identify Missions (Input three missions indicated below)



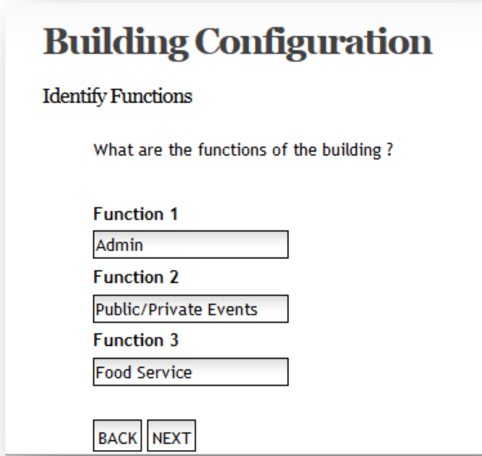
Step 2.4: Identify Functions



Notes:

- Functions are set of actions carried out in the building zones that help accomplish individual building "Missions".
- BVM3 tool supports 3 types of functions. (since it is defined specifically for USAFA Arnold hall)
- If more than 3 functions are defined no error is generated; however the tool automatically reads and uses only the first 3.

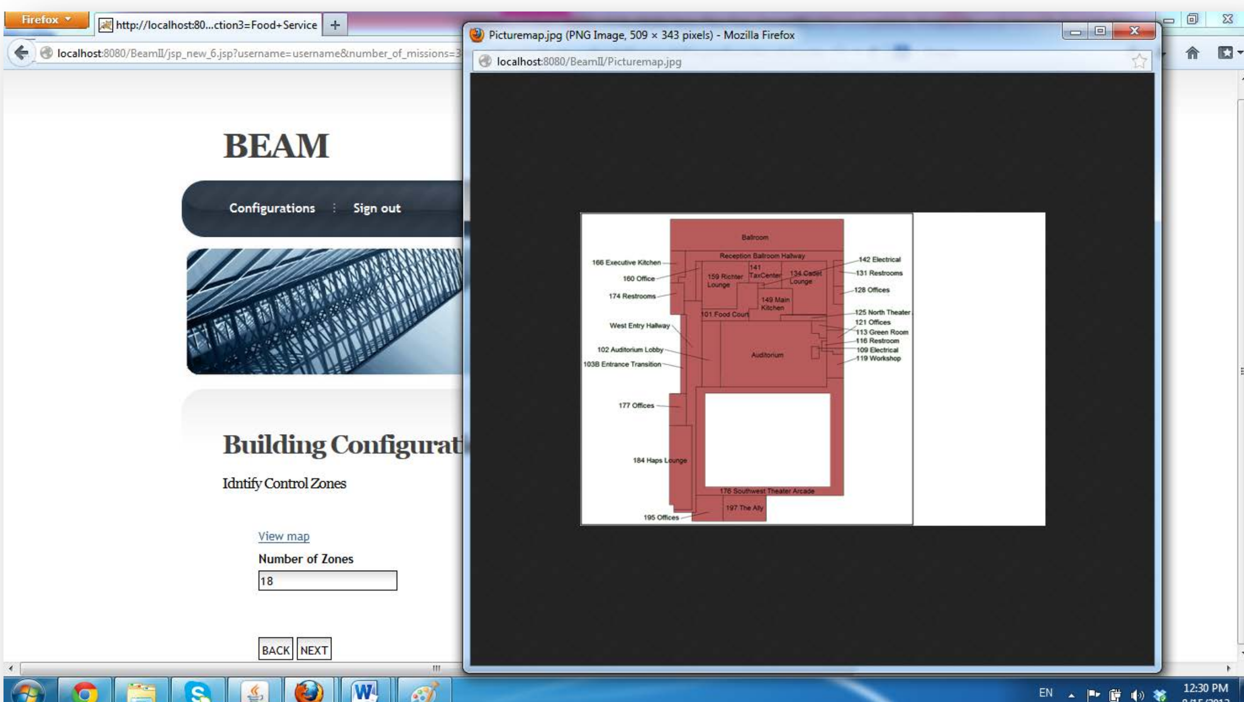
Step 2.5: Identify Function names



Notes:

- The sequence of data entry is important here. In other words, always use “Admin” as first and “Food Service” as last “Function” input. Since the BVM3 questionnaires are designed according to this sequence. The question types are different for each “Function” type.

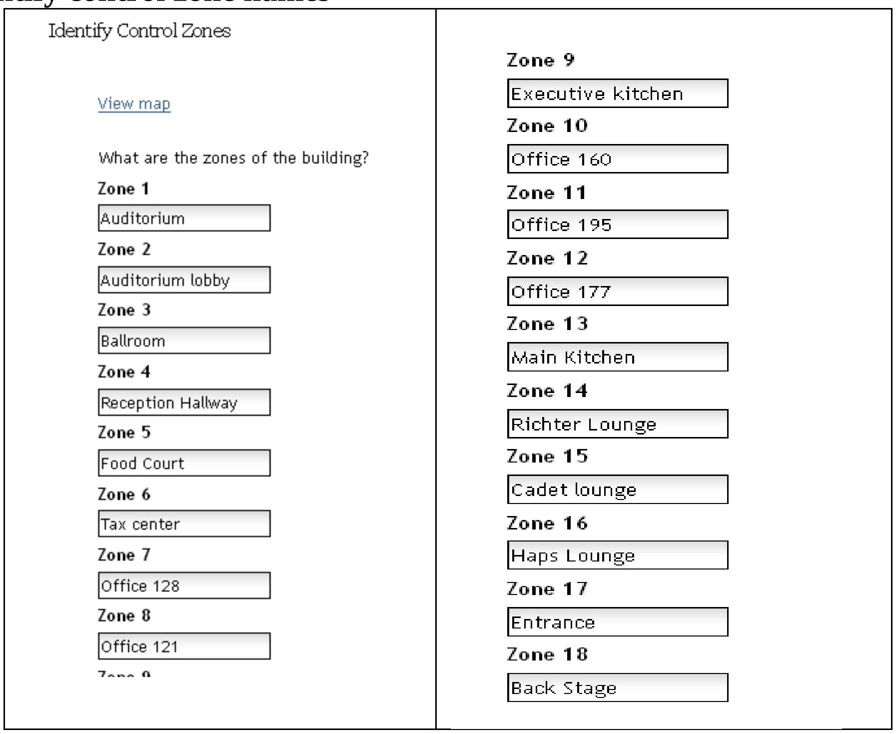
Step 2.6: Identify control zones



Notes:

- If in step 2.1 building map was uploaded, user can view this map now by clicking "View Map"
- Suggested number of zones for USAFA : 18 zones

Step 2.7: Identify control zone names



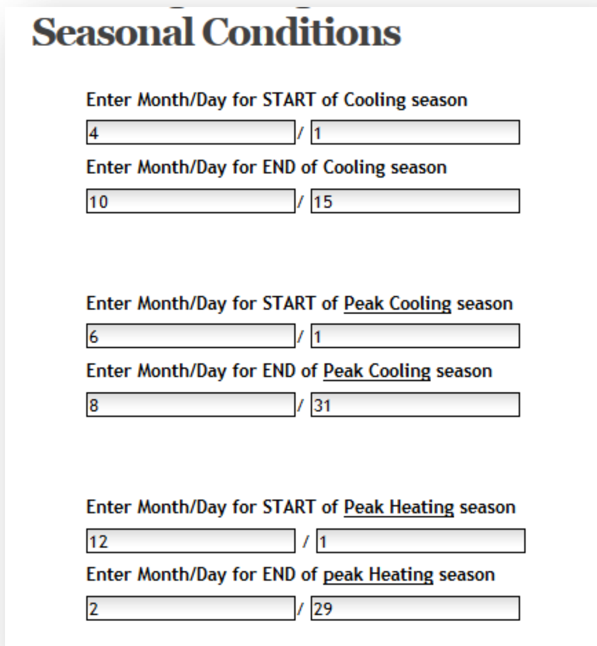
A complete list of zones for USAFA and the associated asset systems is listed in **Table 60** below. **Table 60** is also going to be used in step 3.12 for zone asset Association.
The data entry is in no particular order. Click NEXT to proceed.

Table 60: List of zones, associated asset systems and functions assigned

Zone Name	Associated asset System	Associated Functions
Auditorium lobby	Chilled Water System, AHU-6	Public/Private Events
Auditorium	Chilled Water System, AHU-1C, AHU-2	Public/Private Events
Ballroom	Chilled Water System, AHU-7	Public/Private Events
Reception Hallway	Chilled Water System, AHU-10	Public/Private Events
Food Court	Chilled Water System, AHU-1A	Food Service
Tax center	Chilled Water System, AHU-1A	Admin
Office 128	Chilled Water System, AHU-9	Admin
Office 121	Chilled Water System, AHU-9	Admin
Executive kitchen	Chilled Water System, AHU-9	Food Service
Office 160	Chilled Water System, AHU-1A	Admin
Office 195	Chilled Water System, AHU-4	Admin

Office 177	Chilled Water System, AHU-4	Admin
Main Kitchen	Chilled Water System, AHU-1A	Food Service
Richter Lounge	Chilled Water System, AHU-1A	Public/Private Events
Cadet lounge	Chilled Water System, AHU-8	Public/Private Events
Haps Lounge	Chilled Water System, AHU-5	Public/Private Events
Entrance	Chilled Water System, AHU-6	Admin
Back Stage	Chilled Water System, AHU-1D	Public/Private Events

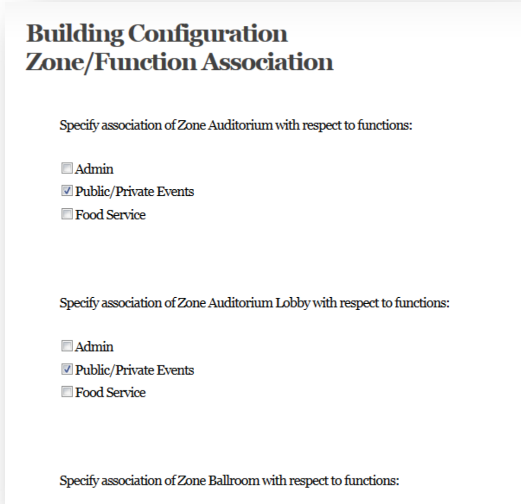
Step 2.8: Building seasonal conditions (please input the following data and click NEXT):



Notes:

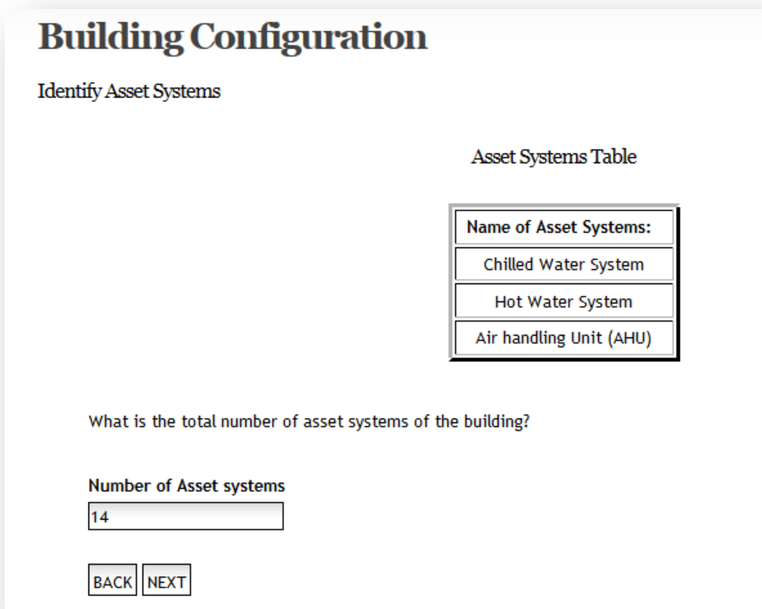
- Dates should be input as displayed for instance 4-1 for April 1st NOT 04-01

Step 2.9: Zone/Function Association



Notes: More than 1 "Function" can be associated with each zone; therefore more than one box can be marked for each zone. Please use **Table 60** to associate each zone with its functions.

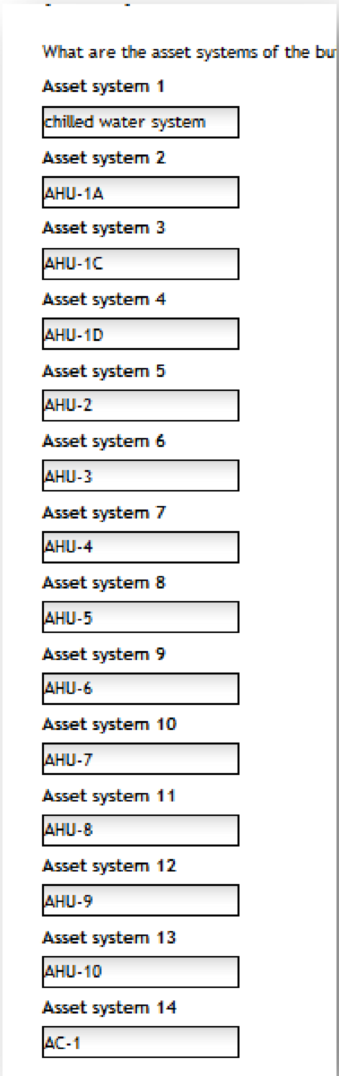
Step 2.10: Identify Asset Systems



Notes:

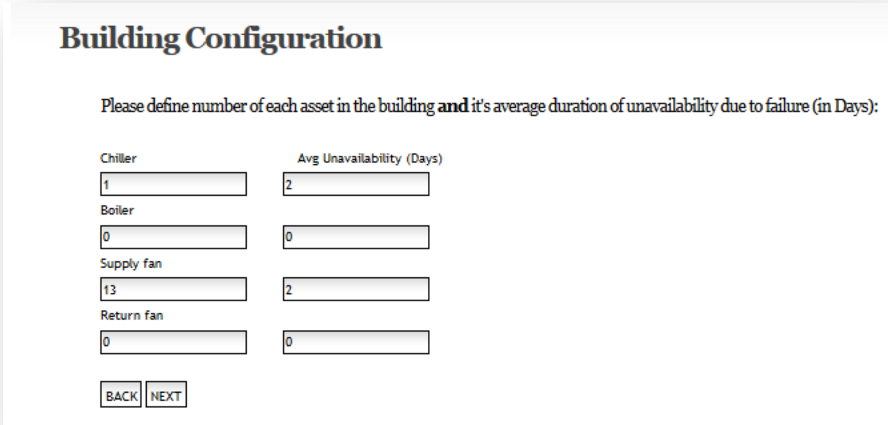
- The Assets systems supported in BVM tool are the ones listed in the Asset Systems Table in the above snapshot for Step 2.10.
- Number of Asset systems in USAFA Arnold Hall=14

Step 2.11: Identify Asset System Names and click NEXT



Note: The data entry does not have particular order

Step 2.12:
Number of each asset in the building and average duration of unavailability due to failure



Notes:

- Average Unavailability is in days
- If an asset does not exist in a building inputs are zero.

Step 2.13: Asset-Asset System Association.
The Following **Table 61** can be used for USAFA associations:

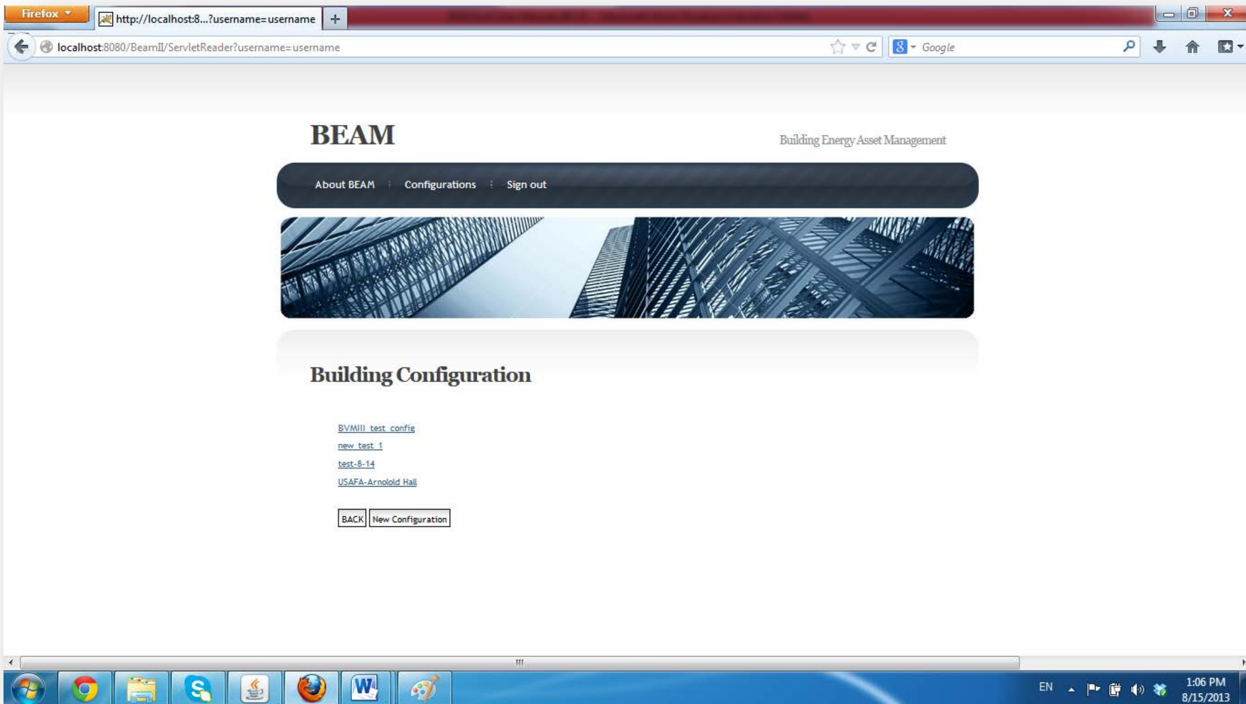
Table 61: Asset System/Asset Association

Asset System	Asset
Chilled Water System	chiller1
AHU-1A	supply Fan1
AHU-1C	supply Fan2
AHU-1D	supply Fan3
AHU-2	supply Fan4
AHU-3	supply Fan5
AHU-4	supply Fan6
AHU-5	supply Fan7
AHU-6	supply Fan8
AHU-7	supply Fan9
AHU-8	supply Fan10
AHU-9	supply Fan11
AHU-10	supply Fan12
AC-1	supply Fan13

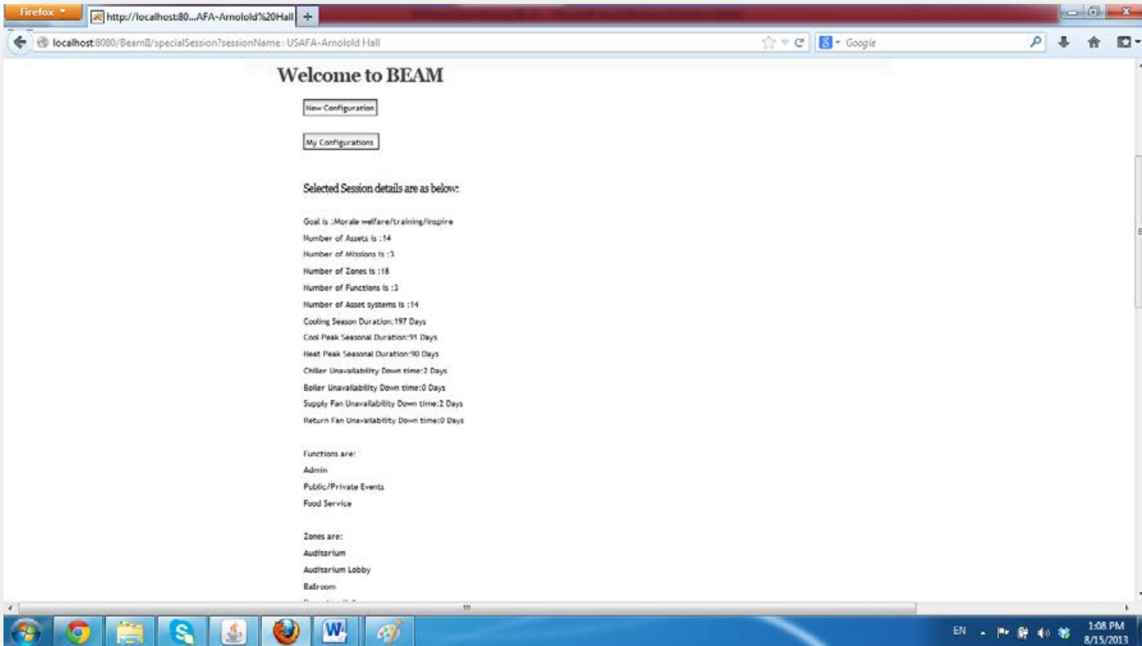
Step 2.14:
Assign a configuration name (say “Beam_Test_8_17”) and save the configuration.

Step 3: Using BVM questionnaires (BVM-I, -II or –III)

Step 3.1:
User can build a new configuration or choose to upload and use the already saved configuration from the list. Here **we will upload** “Beam_Test_8_17” just saved by clicking “My Configurations”. Snapshot below shows the configurations saved on a machine at RU. Click the displayed link “Beam_Test_8_17” in the next window.

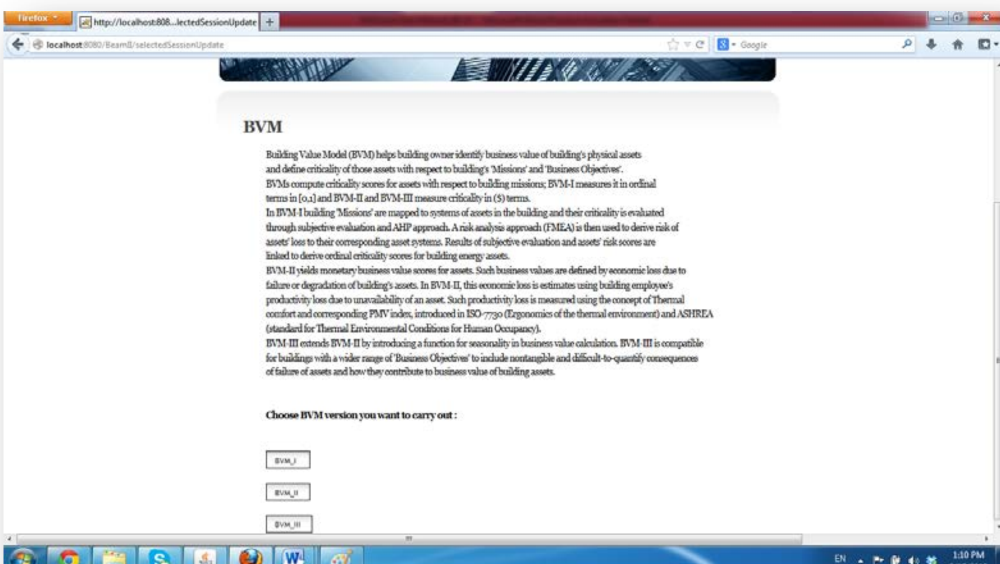


Step 3.2:
Upon choosing a configuration, the data saved for the configuration is displayed to the user, see Example snapshot below):

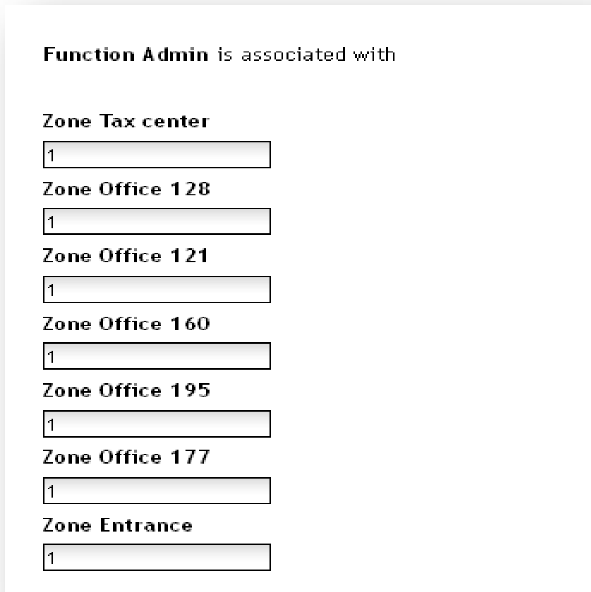


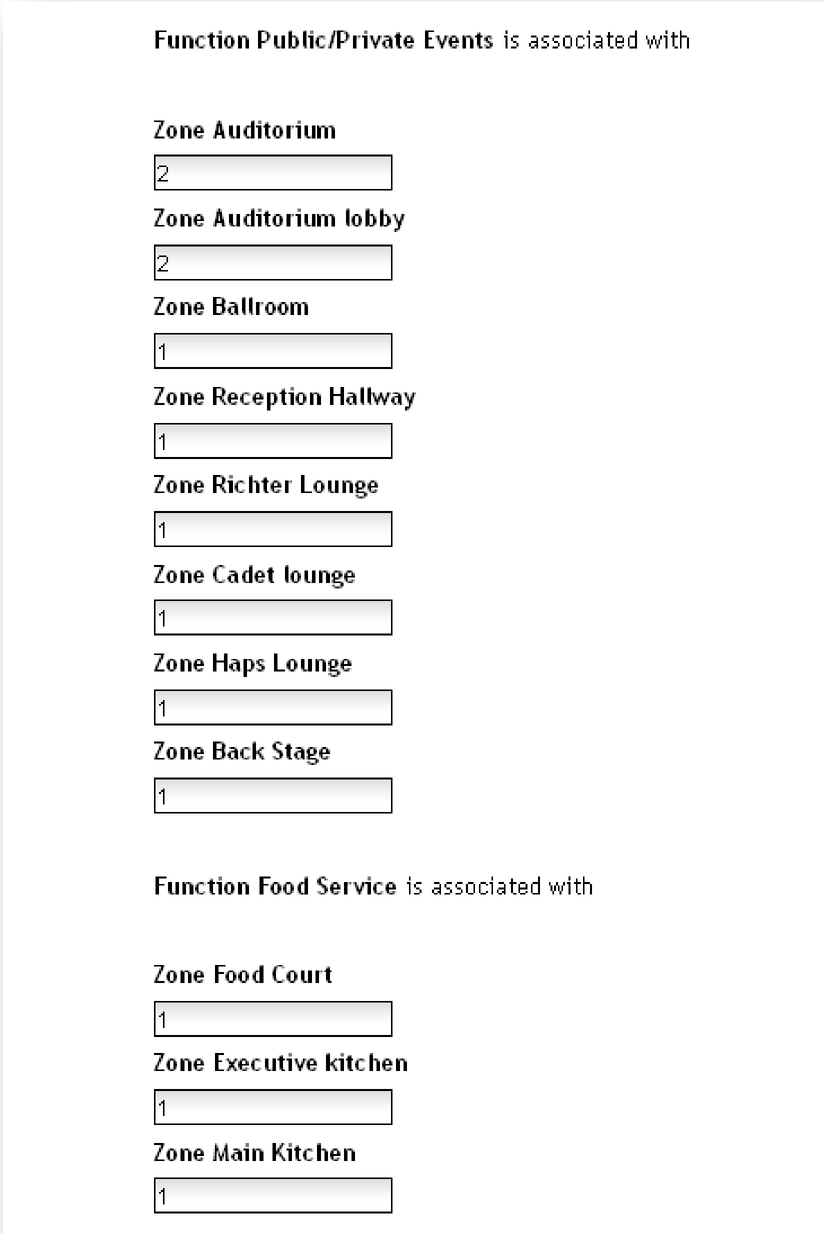
The user then can click the "Use these values for BVMs" button (please scroll to the bottom) to use the values in configuration for BVM questionnaire.

Step 3.3:
User can choose to select either BVM-I, -II or III by clicking on the buttons:



Step 3.4: for USAFA, BVM-III is going to be selected:
In this step the number of intensive occupation periods for zones associated with each function is defined. For instance an "Auditorium" can have 2 intensive occupation periods. One in summer and one in winter: Input "2" in the zone Auditorium and Zone Auditorium Lobby, input "1" in all other zones.




Function Public/Private Events is associated with

Zone Auditorium

2

Zone Auditorium lobby

2

Zone Ballroom

1

Zone Reception Hallway

1

Zone Richter Lounge

1

Zone Cadet lounge

1

Zone Haps Lounge

1

Zone Back Stage

1

Function Food Service is associated with

Zone Food Court

1

Zone Executive kitchen

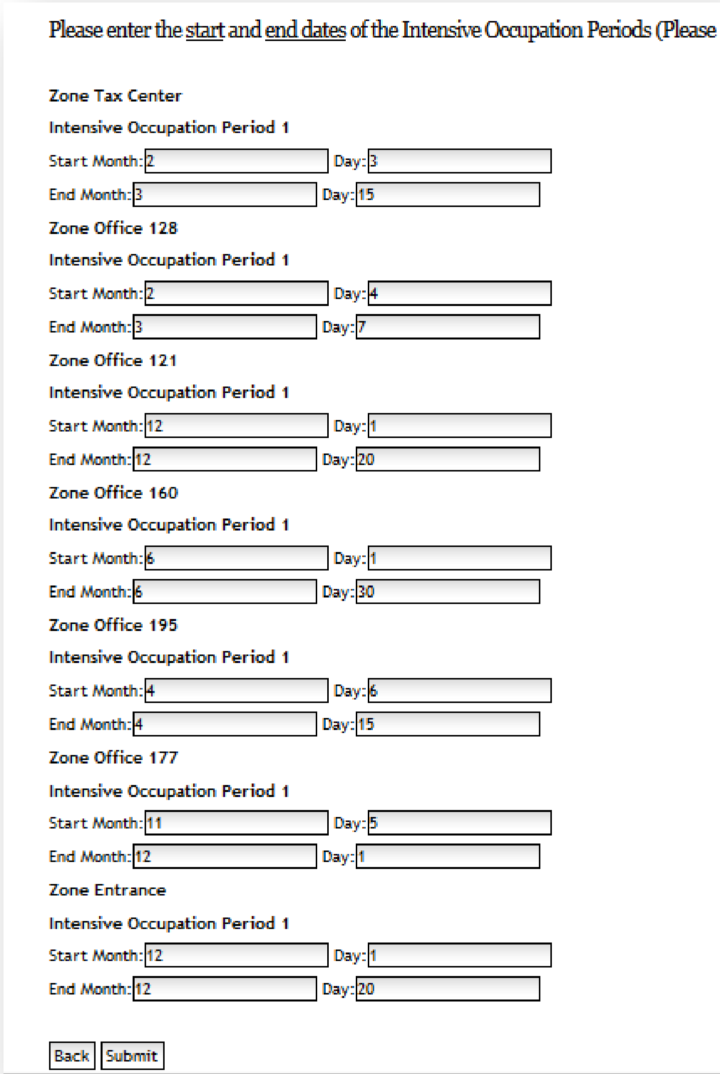
1

Zone Main Kitchen

1

Steps 3.5 & 3.6 are questionnaire specific to zones associated with "Admin Function"

Step 3.5: Intensive occupation period for zones associated with "Admin Function"



Please enter the start and end dates of the Intensive Occupation Periods (Please I

Zone Tax Center
Intensive Occupation Period 1
Start Month: 2 Day: 3
End Month: 3 Day: 15

Zone Office 128
Intensive Occupation Period 1
Start Month: 2 Day: 4
End Month: 3 Day: 7

Zone Office 121
Intensive Occupation Period 1
Start Month: 12 Day: 1
End Month: 12 Day: 20

Zone Office 160
Intensive Occupation Period 1
Start Month: 6 Day: 1
End Month: 6 Day: 30

Zone Office 195
Intensive Occupation Period 1
Start Month: 4 Day: 6
End Month: 4 Day: 15

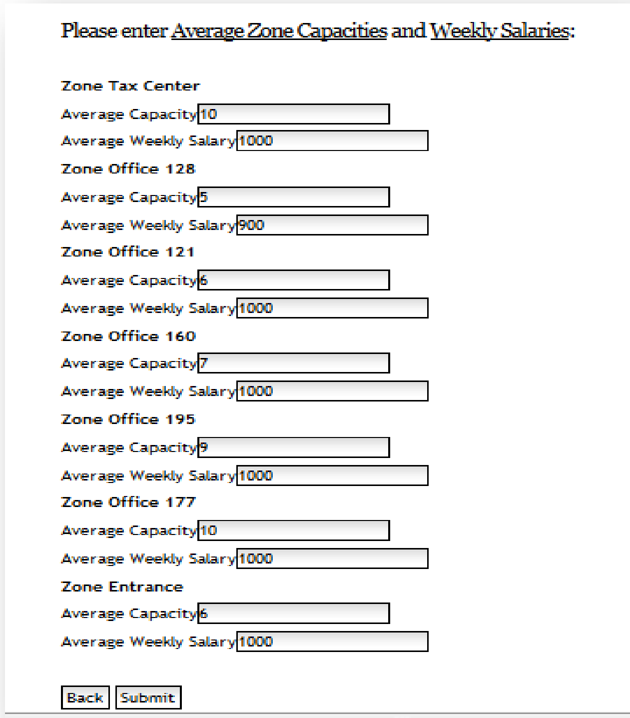
Zone Office 177
Intensive Occupation Period 1
Start Month: 11 Day: 5
End Month: 12 Day: 1

Zone Entrance
Intensive Occupation Period 1
Start Month: 12 Day: 1
End Month: 12 Day: 20

Back Submit

Note: follow instructions in step 2.8 for date entry

Step 3.6:
Average Weekly Salary and Average Zone capacity for zones associated with "Admin Function":



Notes:

- Salary is in dollars
- The numbers are dummy numbers and NOT USAFA data.

Steps 3.7& 3.8 are questionnaire specific to zones associated with “Public/Private Events Function”

Step 3.7:
Similar to step 3.5, intensive occupation periods are defined for zones Associated with “Public/Private Events Function”. Snapshot below shows part of the data entry and not the complete zones.
Data are dummy numbers and NOT USAFA data

Zone Auditorium

Intensive Occupation Period 1

Start Month: 12 Day: 24

End Month: 1 Day: 5

Zone Auditorium

Intensive Occupation Period 2

Start Month: 8 Day: 1

End Month: 8 Day: 15

Zone Auditorium lobby

Intensive Occupation Period 1

Start Month: 4 Day: 1

End Month: 6 Day: 31

Zone Auditorium lobby

Intensive Occupation Period 2

Start Month: 12 Day: 24

End Month: 1 Day: 5

Zone Ballroom

Intensive Occupation Period 1

Start Month: 12 Day: 23

End Month: 1 Day: 5

Zone Reception Hallway

Intensive Occupation Period 1

Start Month: 3 Day: 1

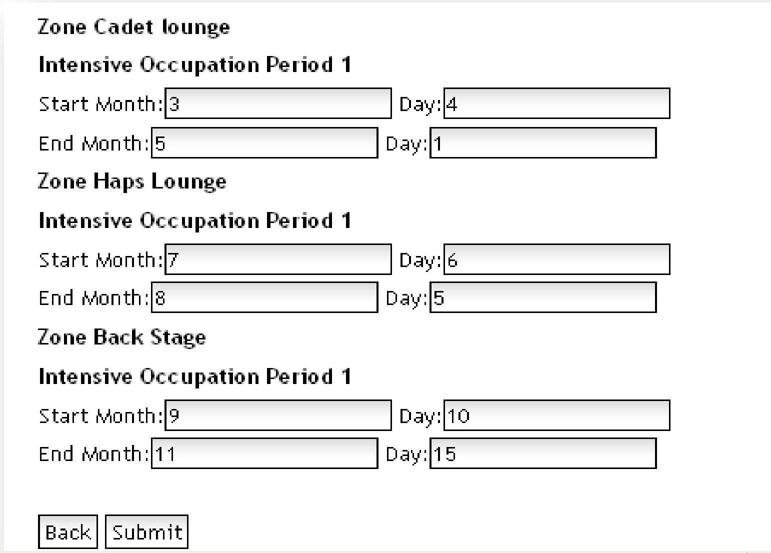
End Month: 5 Day: 20

Zone Richter Lounge

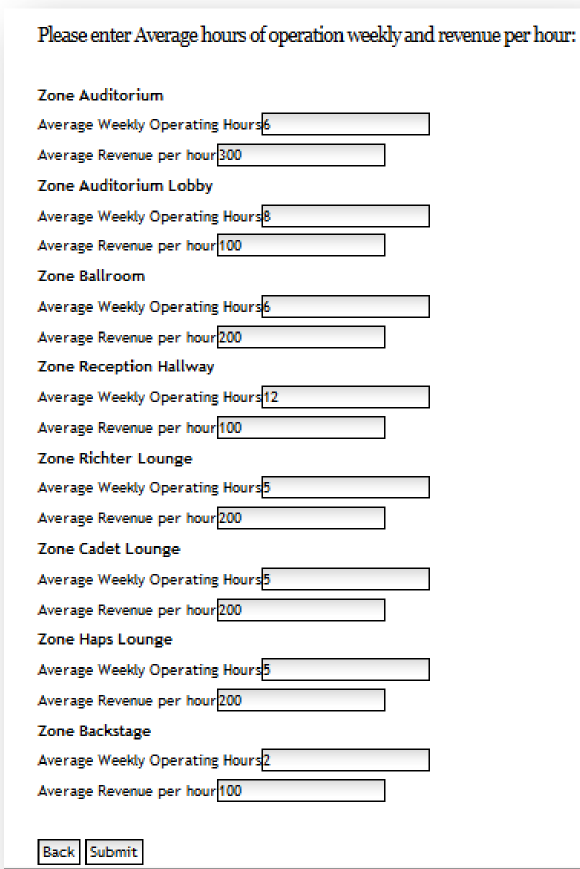
Intensive Occupation Period 1

Start Month: 6 Day: 1

End Month: 8 Day: 20

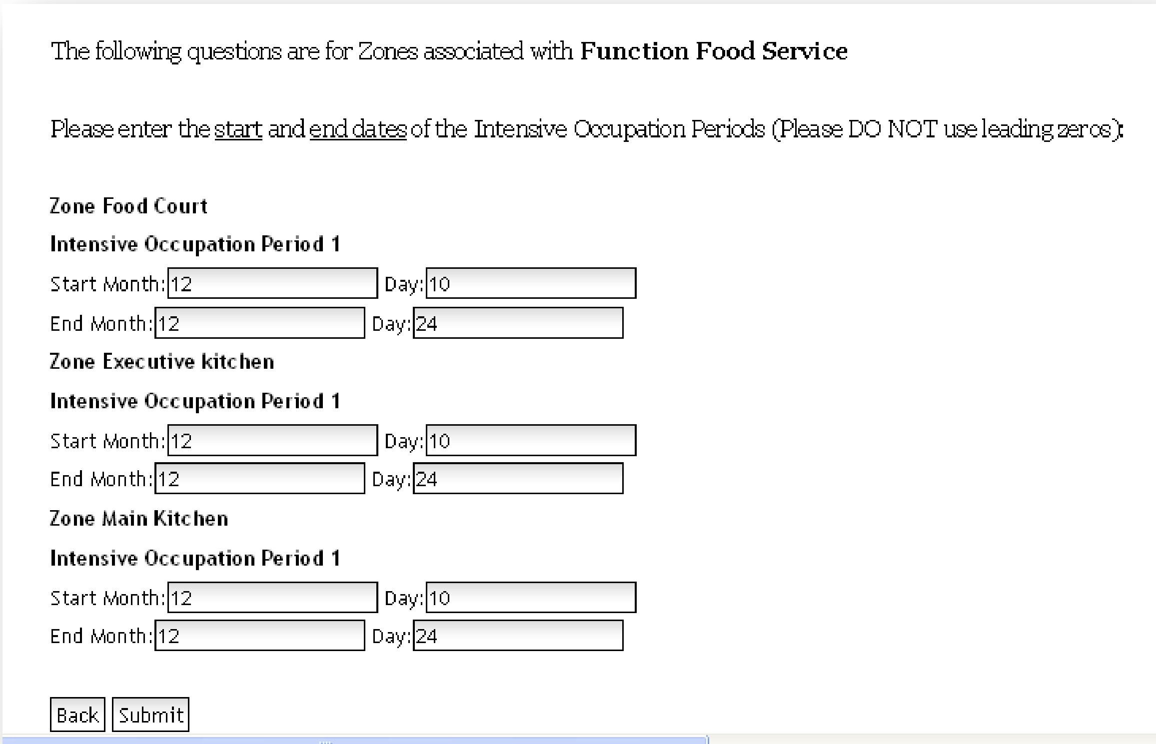


Step 3.8: "Average hours of operation" and "revenue per hour" for zones Associated with "Public/Private Events Function".

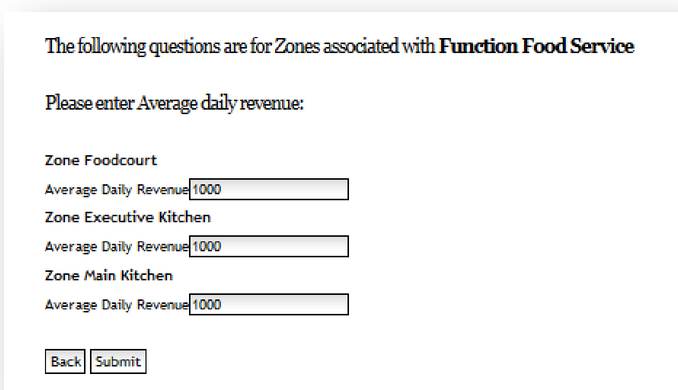


Steps 3.9& 3.10 are questionnaire specific to zones associated with “Food Service Function”

Step 3.9:
Similar to step 3.5 & 3.7, intensive occupation periods are defined for zones Associated with “Food Services Function”. Snapshot below shows part of the data entry and not the complete zones.
Data are dummy numbers and NOT USAFA data



Step3.10: “Average daily revenue” for zones Associated with “Food service Function”.



Step3.11: Zone/Asset Association:

Please use **Table 62** below for zone asset association for USAFA, based on the configuration defined in step 2. Click NEXT.

Table 62: Zone Asset Association

Zone Name	Associated asset System
Auditorium lobby	Chiller1, Supply fan 8
Auditorium	Chiller1, Supply Fan 2, Supply Fan 4
Ballroom	Chiller1, Supply Fan 9
Reception Hallway	Chiller1, Supply Fan 12
Food Court	Chiller1, Supply Fan 1
Tax center	Chiller1, Supply Fan 1
Office 128	Chiller1, Supply Fan 11
Office 121	Chiller1, Supply Fan 11
Executive kitchen	Chiller1, Supply Fan 11
Office 160	Chiller1, Supply Fan 1
Office 195	Chiller1, Supply Fan 6
Office 177	Chiller1, Supply Fan 6
Main Kitchen	Chiller1, Supply Fan 1
Richter Lounge	Chiller1, Supply Fan 1
Cadet lounge	Chiller1, Supply Fan 10
Haps Lounge	Chiller1, Supply Fan 7
Entrance	Chiller1, Supply Fan 8
Back Stage	Chiller1, Supply Fan 3

More than one asset can serve one zone so multiple boxes can be marked for each zone.

Step 3.12:

Asset seasonal Business Values are displayed. The Business Values should be non-negative. If any of the assets are not associated with any zone defined in the configuration the Business Value will be zero. Example: Supply fan 5's business Value in this example is zero since Supply fan 5 (Associated with AHU-3) is not associated with any zone in configuration. The same condition holds for Supply fan 13(Associated with AC-1). Also, you can find BVM3.xml data


Final BVM-III Business Values

For Asset chiller1:

For Peak Cooling Season

$1513100.0

For Off-Peak Cooling Season

$879742.8571428572

For Peak Heating Season

$0.0

For Off-Peak Heating Season

$0.0

For Asset supplyfan1:

For Peak Cooling Season

$777200.0

For Off-Peak Cooling Season

$884514.2857142857

For Peak Heating Season

$895285.7142857143

For Off-Peak Heating Season

$1026057.1428571428

file in the Apache Tomcat installation

For Asset supplyfan2:

For Peak Cooling Season

$48000.0

For Off-Peak Cooling Season

$61257.14285714286

For Peak Heating Season

$49942.85714285714

For Off-Peak Heating Season

$54628.571428571435

For Asset supplyfan3:

For Peak Cooling Season

$121200.0

For Off-Peak Cooling Season

$142514.2857142857

For Peak Heating Season

$143285.7142857143

For Off-Peak Heating Season

$400057.14285714284

For Asset supplyfan4:

For Peak Cooling Season

$48000.0

For Off-Peak Cooling Season

$61257.14285714286

For Peak Heating Season

$49942.85714285714

For Off-Peak Heating Season

$54628.571428571435

For Asset supplyfan5:

For Peak Cooling Season

$0.0

For Off-Peak Cooling Season

$0.0

For Peak Heating Season

$0.0

For Off-Peak Heating Season

$0.0

For Asset supplyfan6:

For Peak Cooling Season

$331800.0

For Off-Peak Cooling Season

$355400.0

For Peak Heating Season

$288000.0

For Off-Peak Heating Season

$249600.0

For Asset supplyfan7:

For Peak Cooling Season

$60000.0

For Off-Peak Cooling Season

$76571.42857142858

For Peak Heating Season

$62428.57142857141

For Off-Peak Heating Season

$68285.71428571429

For Asset supplyfan8:

For Peak Cooling Season

$171600.0

For Off-Peak Cooling Season

$214400.0

For Peak Heating Season

$174800.0

For Off-Peak Heating Season

$191200.00000000003

For Asset supplyfan9:

For Peak Cooling Season

$74400.0

For Off-Peak Cooling Season

$94285.71428571428

For Peak Heating Season

$75942.85714285713

For Off-Peak Heating Season

$81942.85714285716

For Asset supplyfan10:

For Peak Cooling Season

$60000.0

For Off-Peak Cooling Season

$76571.42857142858

For Peak Heating Season

$62428.57142857141

For Off-Peak Heating Season

$68285.71428571429

For Asset supplyfan11:

For Peak Cooling Season

$313500.0

For Off-Peak Cooling Season

$378142.85714285716

For Peak Heating Season

$360185.71428571426

For Off-Peak Heating Season

$598571.4285714286

For Asset supplyfan12:

For Peak Cooling Season

$72000.0

For Off-Peak Cooling Season

$91885.71428571428

For Peak Heating Season

$74914.28571428572

For Off-Peak Heating Season

$81942.85714285716

For Asset supplyfan13:

For Peak Cooling Season

$0.0

For Off-Peak Cooling Season

$0.0

For Peak Heating Season

$0.0

For Off-Peak Heating Season

$0.0

Appendix G: BEAM Runtime Tool Installation & User Manual

Runtime Tools for Building Energy Asset Management (BEAM)

BEAM Setup

Prerequisites Software

<u>Install .NET libraries</u>

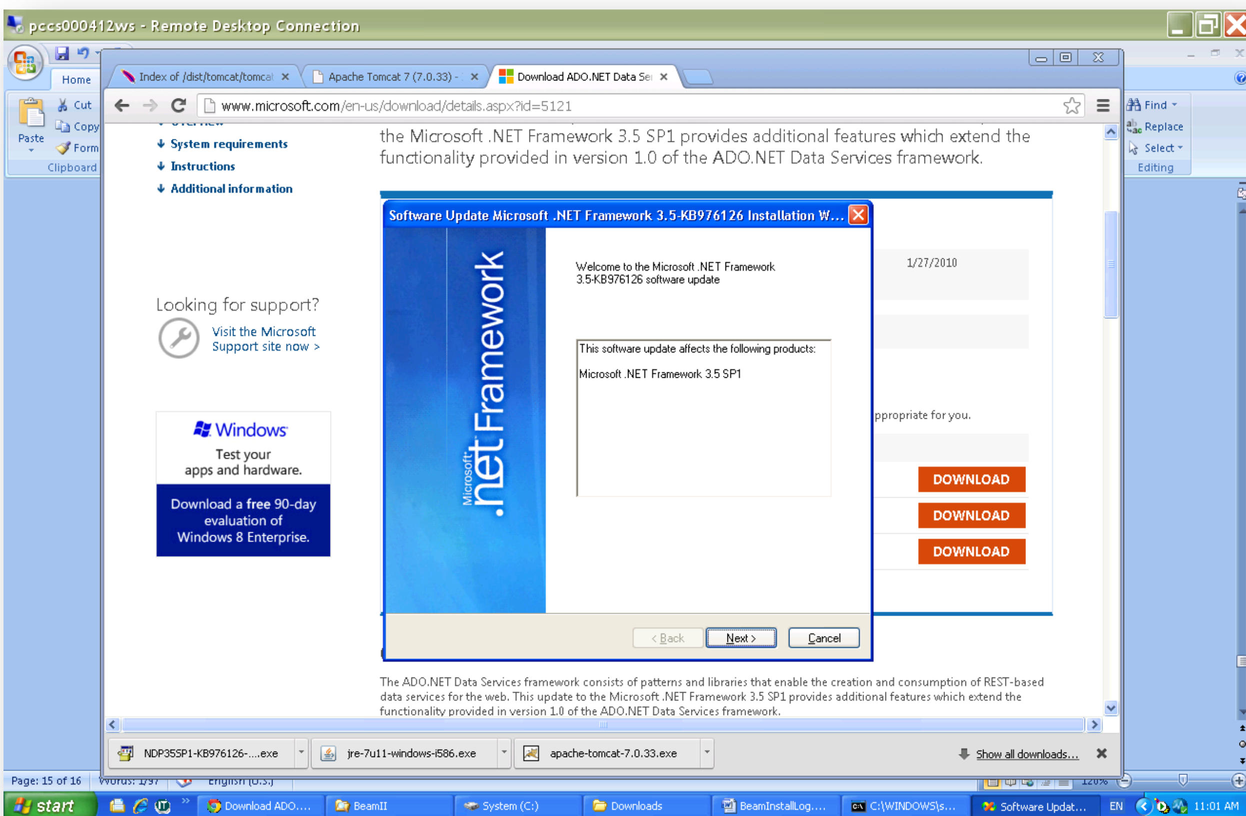
Need to install the following updates on top of .NET3.5 Framework

- ADO.NET Data Services Update for .NET Framework 3.5 SP1 for Windows 2000, Windows Server 2003, Windows XP, Windows Vista and Windows Server 2008

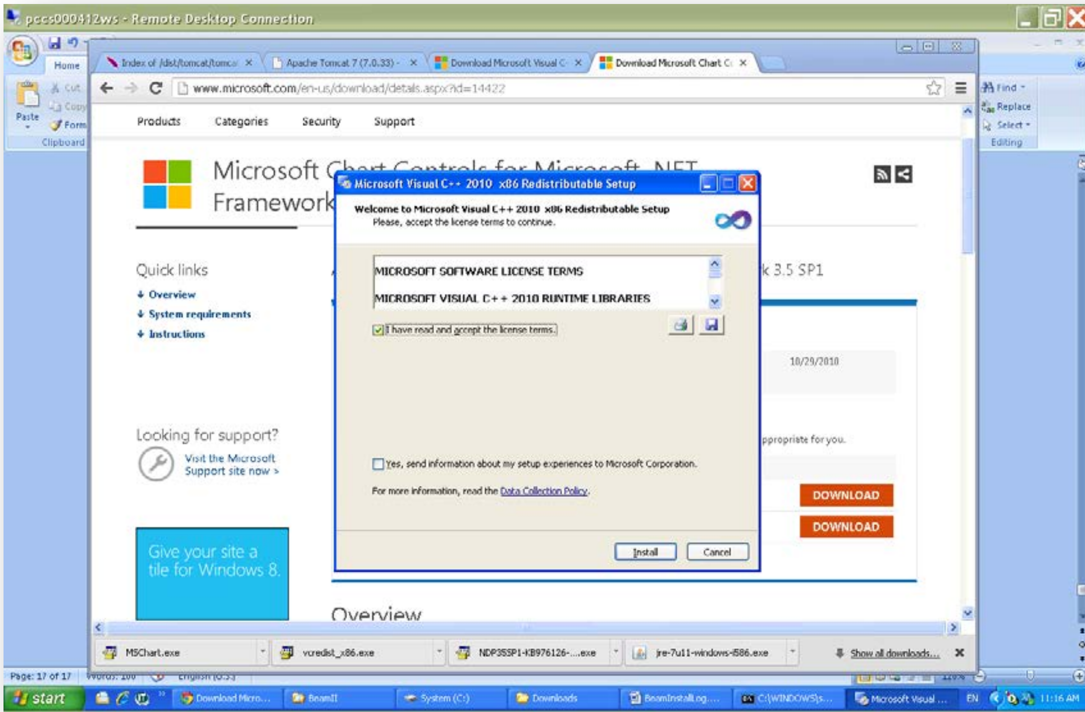
  http://www.microsoft.com/downloads/en/details.aspx?displaylang=en&FamilyID=4b710b89-8576-46cf-a4bf-331a9306d555
- Microsoft Visual C++ 2010 Redistributable Package (x86)

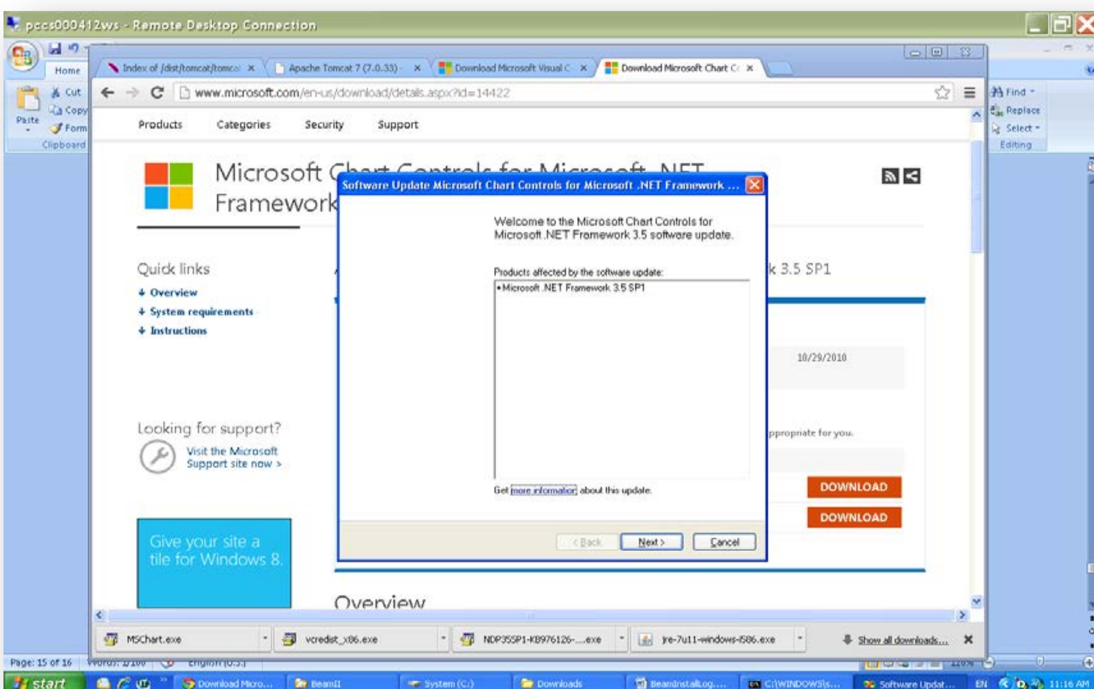
  http://www.microsoft.com/downloads/en/details.aspx?FamilyID=a7b7a05e-6de6-4d3a-a423-37bf0912db84
- Microsoft Chart Controls for Microsoft .NET Framework 3.5

  http://www.microsoft.com/downloads/en/details.aspx?FamilyID=130f7986-bf49-4fe5-9ca8-910ae6ea442c

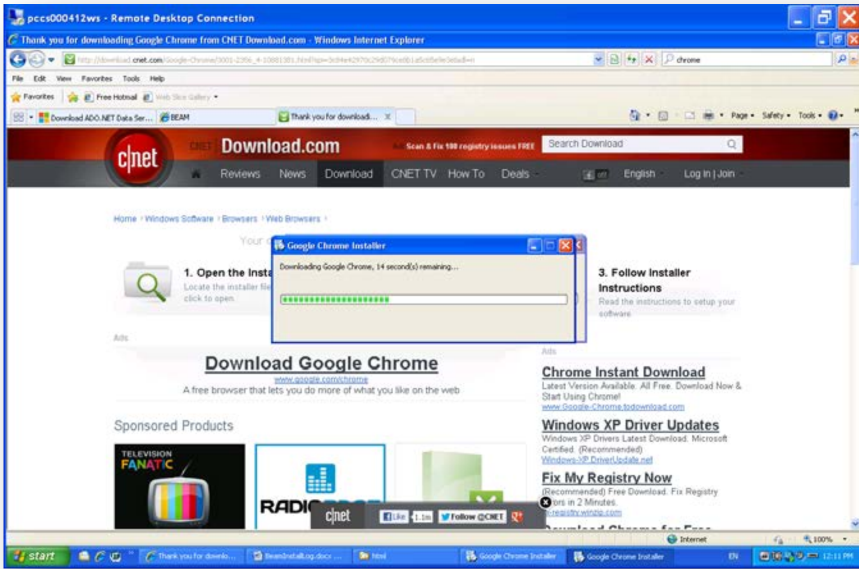


Only install vcredist_x86.exe


pccs000412ws - Remote Desktop Connection
www.microsoft.com/en-us/download/details.aspx?id=14422
Products
Categories
Security
Support
Microsoft Visual C++ 2010 x86 Redistributable Setup
Welcome to Microsoft Visual C++ 2010 x86 Redistributable Setup
Please, accept the license terms to continue.
MICROSOFT SOFTWARE LICENSE TERMS
MICROSOFT VISUAL C++ 2010 RUNTIME LIBRARIES
I have read and accept the license terms.
Yes, send information about my setup experiences to Microsoft Corporation.
For more information, read the Data Collection Policy.
Install
Cancel
Quick links
Overview
System requirements
Instructions
Looking for support?
Visit the Microsoft Support site now >
Give your site a tile for Windows 8.
Overview
DOWNLOAD
DOWNLOAD
MSChart.exe
vcredist_x86.exe
NDP35SP1-KB976126-....exe
jre-7u11-windows-i586.exe
Show all downloads...
start

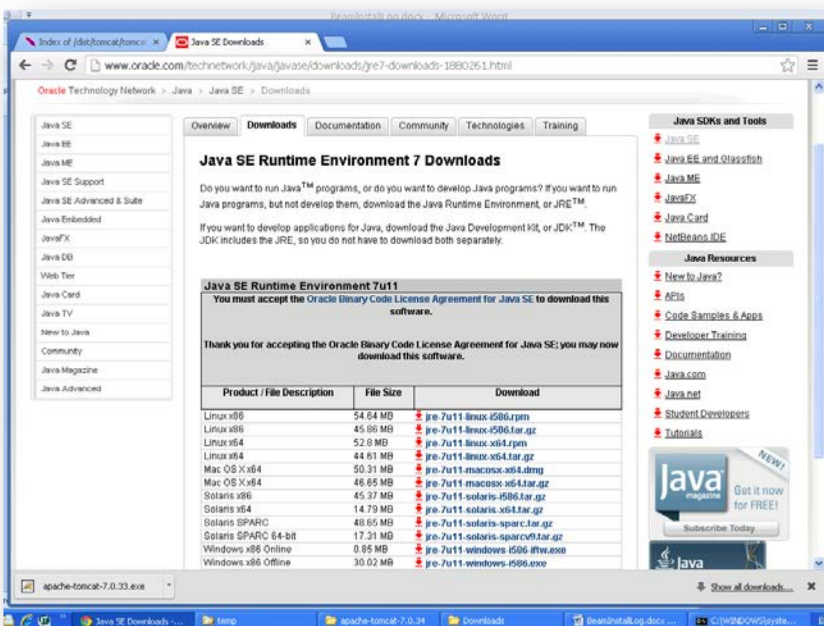

pccs000412ws - Remote Desktop Connection
www.microsoft.com/en-us/download/details.aspx?id=14422
Products
Categories
Security
Support
Software Update Microsoft Chart Controls for Microsoft .NET Framework ...
Welcome to the Microsoft Chart Controls for Microsoft .NET Framework 3.5 software update.
Products affected by the software update:
•Microsoft .NET Framework 3.5 SP1
Get more information about this update.
< Back
Next >
Cancel
Quick links
Overview
System requirements
Instructions
Looking for support?
Visit the Microsoft Support site now >
Give your site a tile for Windows 8.
Overview
DOWNLOAD
DOWNLOAD
MSChart.exe
vcredist_x86.exe
NDP35SP1-KB976126-....exe
jre-7u11-windows-i586.exe
Show all downloads...
start

Install Google Chrome
Download Chrome from CNET and run setup



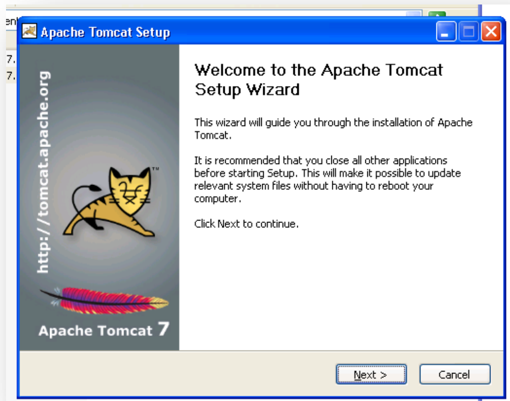
Install Java JRE 6.0 or above

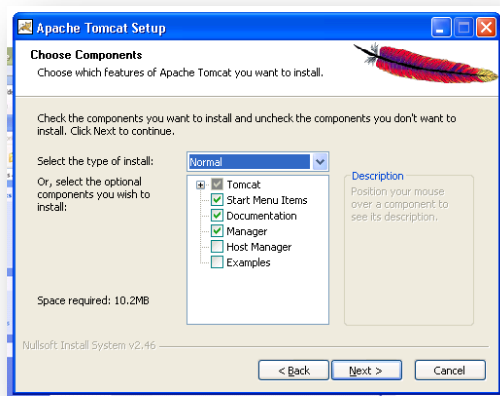
Download from http://www.oracle.com/technetwork/java/javase/downloads/index.html, choose “Windows x86 Offline”

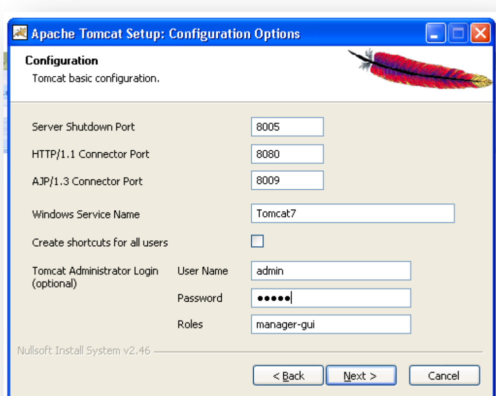


Install Apache Tomcat

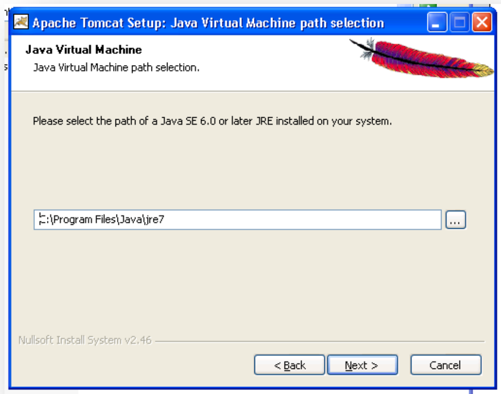
Download apache tomcat from http://archive.apache.org/dist/tomcat/tomcat-7/v7.0.33/bin/

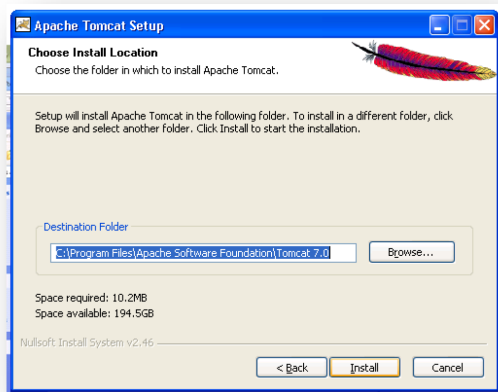


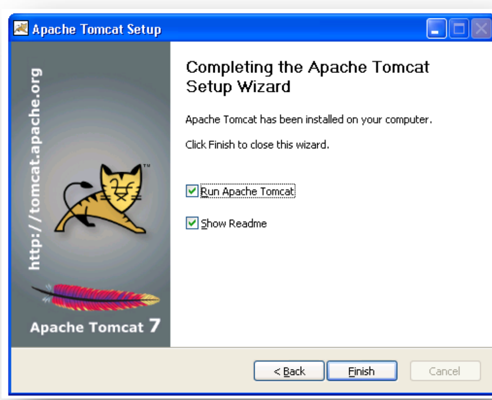




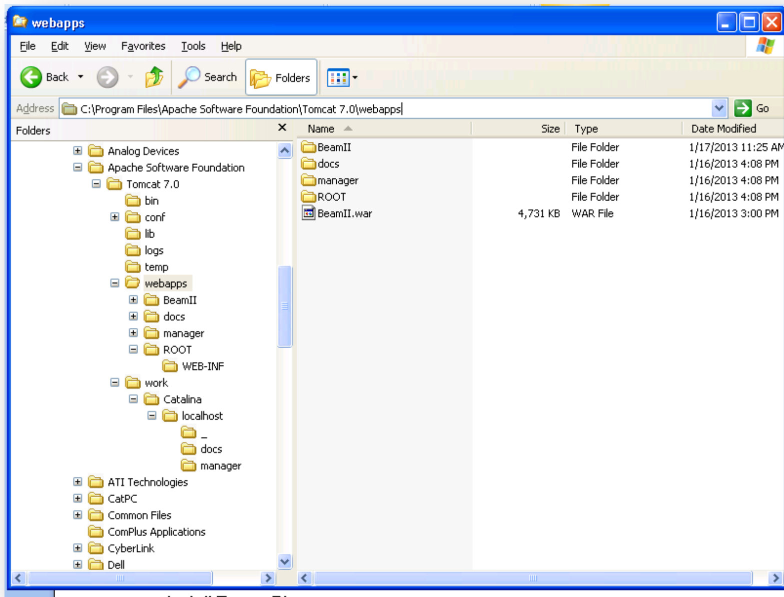
User Name: admin
Password: admin





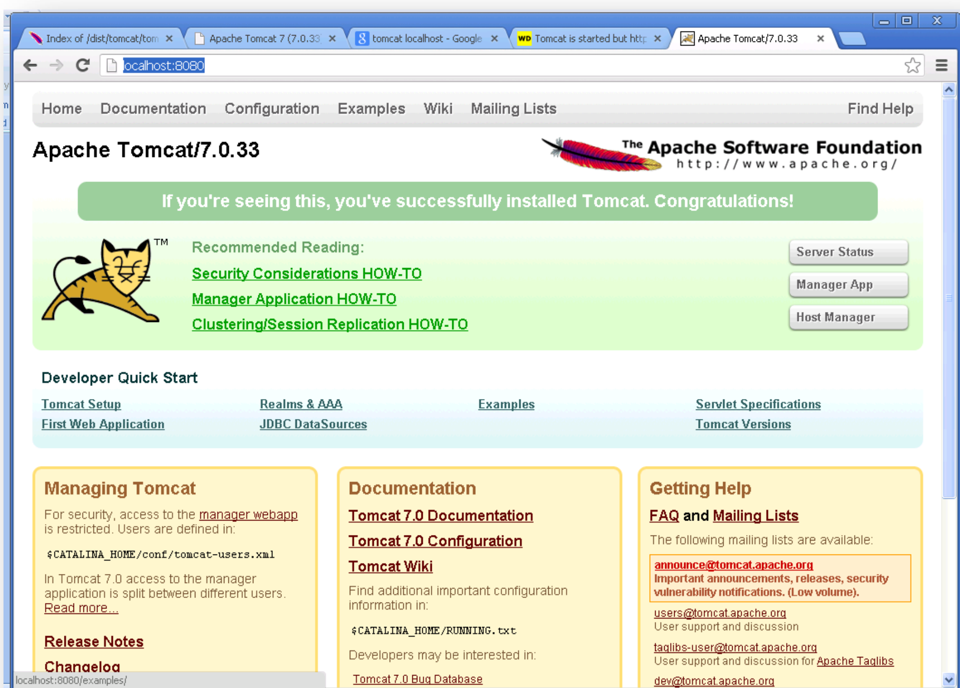


Setup BEAM Configuration Tool
Copy “BEAMIII.war” to C:\Program Files\Apache Software Foundation\Tomcat 7.0\webapps
A folder named BEAMIII is generated automatically



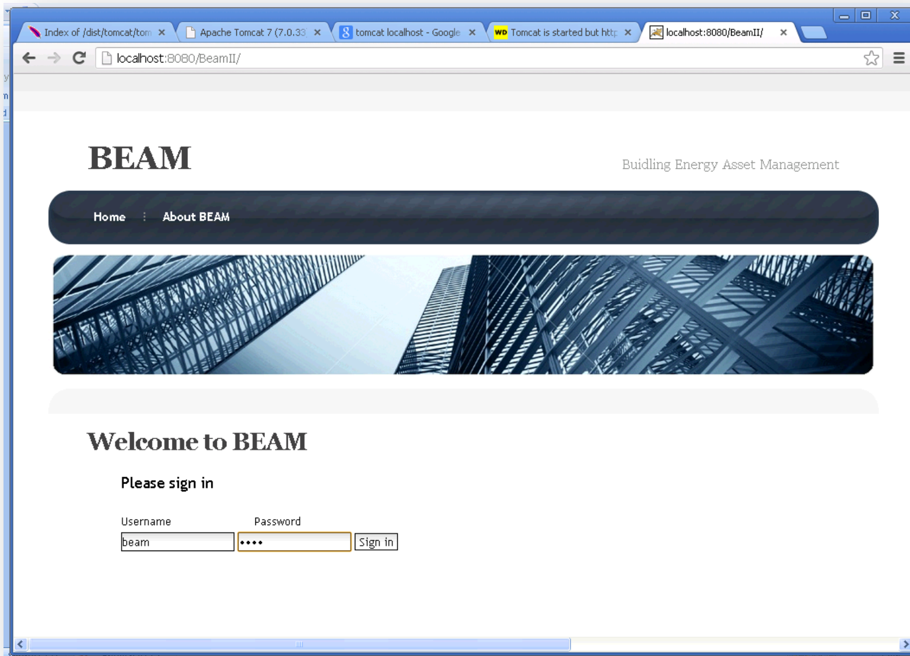
<u>Test BEAM Configuration Tool</u>

Startup Chrome browser and type in Localhost:8080 in the address bar. The browser windows should look like the screenshot below.



Startup BEAM Configuration Tool

Startup Chrome browser and type in URL http://localhost:8080/BeamIII/ (case sensitive)

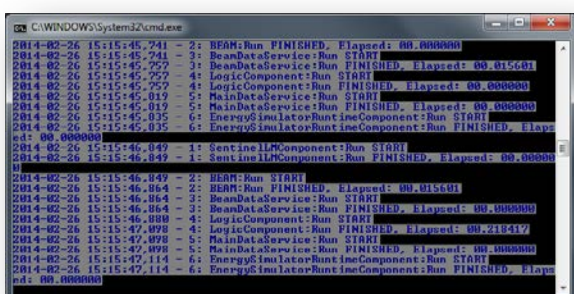


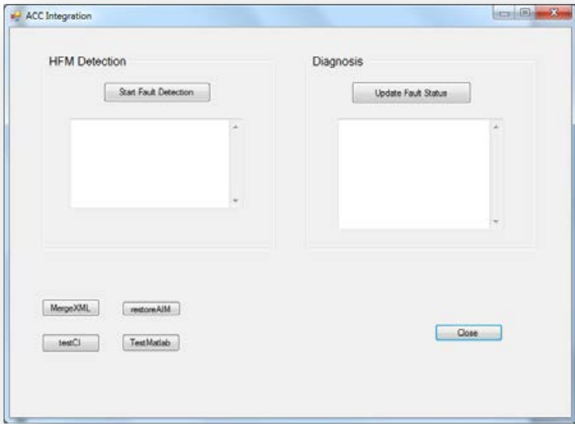
User Name: beam
Password: beam

Startup BEAM Runtime and Runtime HMI

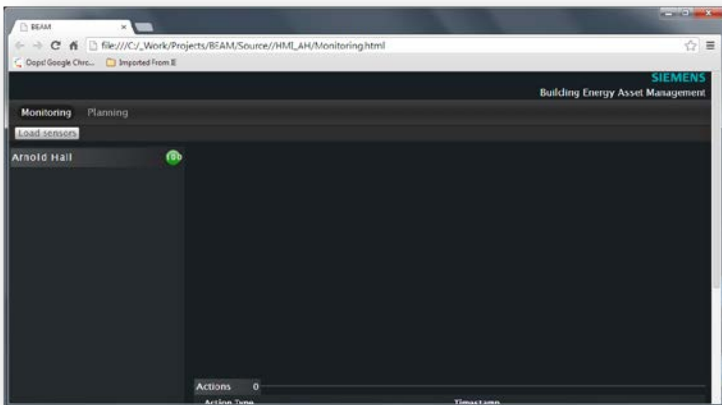
Start the beam runtime by starting the ArnoldHall_1.StartSEB.bat as administrator.

1) Right click on ArnoldHall_1.StartSEB.bat
2) Select "Run as Administrator" from the context menu
3) Two windows like shown below will show up

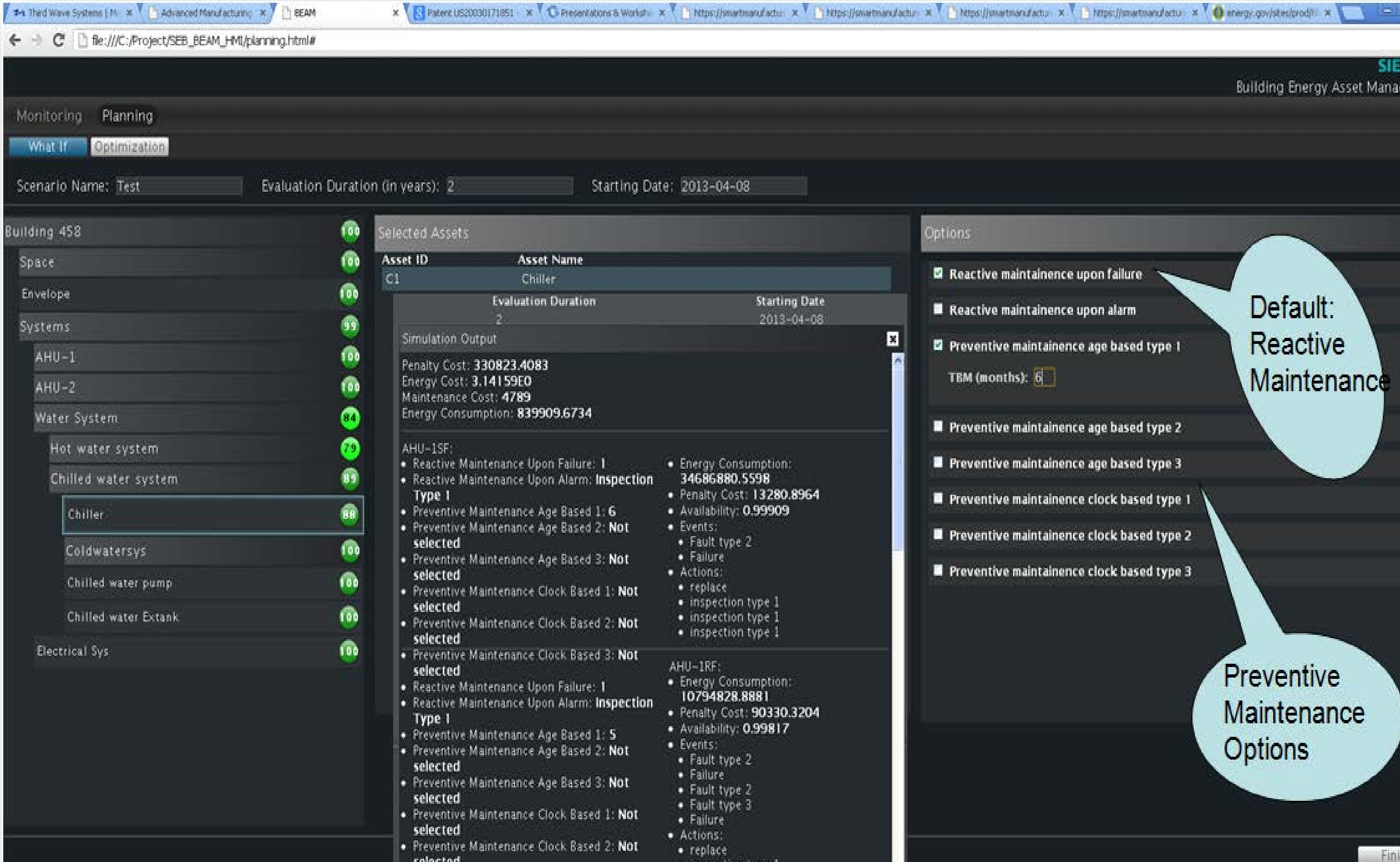




Now start the BEAM Runtime HMI by double clicking the ArnoldHall_2.StartBEAM.bat file. The Chrome browser window with the BEAM HMI should be visible like shown below



BEAM Condition Monitoring Main Screen



BEAM Condition Monitoring main Screen (suite)

BEAM Limitations

Due to the current BEAM architecture and data model design, there are three limitations Users should keep in mind during their stage of configuration:

Limitation One:

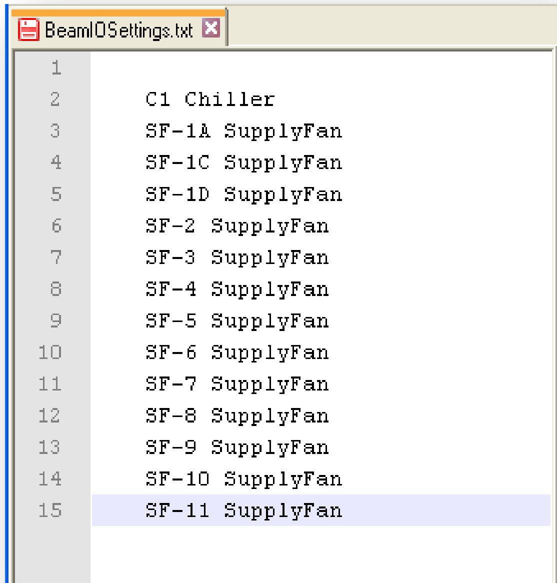
When specifying the season dates, the users should go to the asset model file “asset.xml” (located at \\BEAM_HOME\Resources\ArnoldHall\ ), here BEAM_HOME represents the path where all BEAM binaries located. It is where the users input their season dates (with the node x-path as “//Site/BEAM_Optimization/ Building_Considered/Seasnos”):

```xml
<BeamEngineMode>Optimization</BeamEngineMode>
<BEAM_Optimization Total_Budget="300000" Status="Ready">
  <Building_Considered Name="Arnold Hall" ID="ArnoldHall">
     <Seasons ID="Season" Name="Seasons">
      <Cooling StartDate="4-1" EndDate="10-15">
        <CoolingPeak StartDate="6-1" EndDate="8-30" />
      </Cooling>
      <Heating StartDate="10-16" EndDate="3-31">
        <HeatingPeak StartDate="12-1" EndDate="2-15" />
      </Heating>
    </Seasons>
    <BEAM_Analysis>
```

The BEAM Runtime automatically write these seasonal dates into the actual asset info model xml file “AssetInfoModel.xml” (located at \\BEAM_HOME\Resources\ ) in the same node path;

Limitation Two:

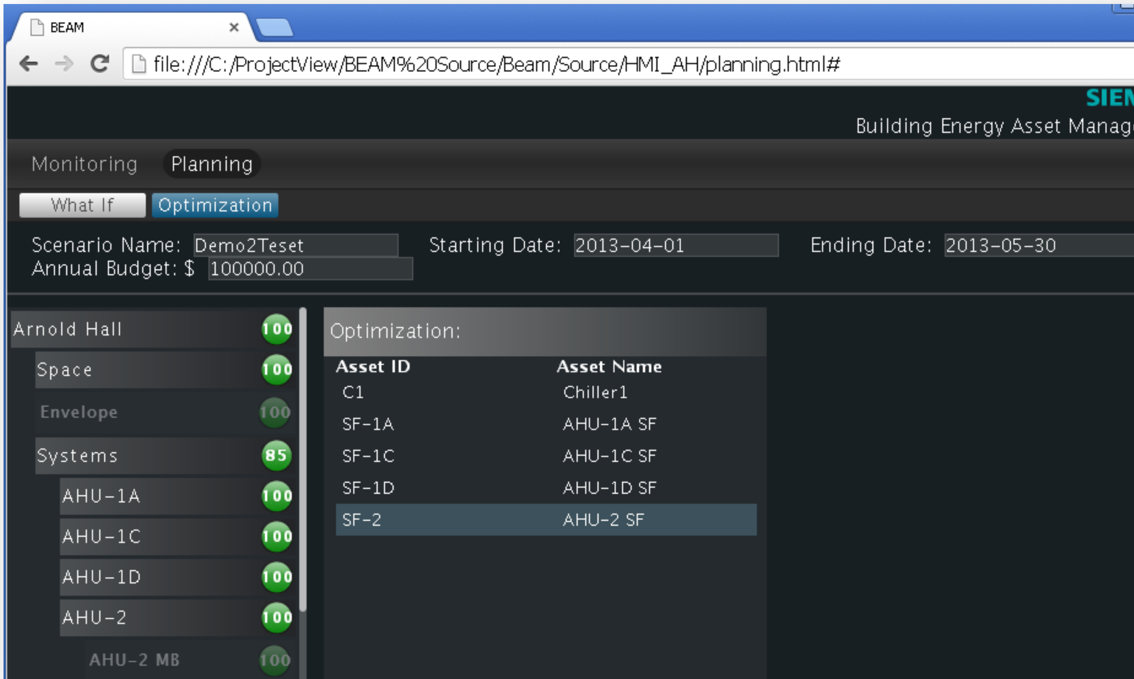
When selecting assets for BEAM optimization or what-if simulation, the order that users select each asset matters as the BEAM runtime read and write input and output data according to a Beam OS Settings configuration file (see the following).



```
BeamIOSettings.txt

C1 Chiller
SF-1A SupplyFan
SF-1C SupplyFan
SF-1D SupplyFan
SF-2 SupplyFan
SF-3 SupplyFan
SF-4 SupplyFan
SF-5 SupplyFan
SF-6 SupplyFan
SF-7 SupplyFan
SF-8 SupplyFan
SF-9 SupplyFan
SF-10 SupplyFan
SF-11 SupplyFan
```

There are fourteen assets are enabled to be involved in the simulation. For example, if users want to select the following five assets {'AHU-1A SF', 'AHU-1C SF', 'AHU-1D SF', 'AHU-2 SF', 'Chiller1'}, he needs to select the assets in the following order: 'Chiller1' → 'AHU-1A SF' → 'AHU-1C SF' → 'AHU-1D SF' → 'AHU-2 SF' (see below).



<u>Limitation Three:</u>
Beam Executable, which using Matlab compiler runtime and BCVTB simulation framework, requires that Java JRE 6.0 has to be installed and the installation path has to be added into the system environment PATH.

Appendix H: Whitepaper - Integration of Tools for Building Energy Asset

White Paper

Integration of Tools for Building Energy Asset Management (BEAM) with DoD BUILDER

Yan Lu and Zhen Song
Siemens Corporation, Corporate Technology
Mohsen Jafari and Peter Winslow
Rutgers University

July 2013

1. INTRODUCTION

The challenges of managing the complex systems that run the buildings within the military's real estate portfolio require innovative software tools. Poorly informed planning, policy, and operating decisions waste money and misallocate personnel, consume excessive amounts of energy and increase greenhouse gas emissions, shorten asset life, and impede mission accomplishment. Commanders and their subordinates at all levels of management need timely, practical, insightful, accurate, actionable information with which to maintain buildings efficiently and economically while accomplishing assigned missions.

DoD BUILDER ("BUILDER") is one such software tool developed by ERDC-CERL of the US Army Corps of Engineers and widely adopted across the Department of Defense. BUILDER, which is not specifically focused on "energy assets," is designed to inform decision-making by planners and operators of buildings at military installations. The approach taken by BUILDER is to extend the residual life of an asset and to increase the reliability of that asset.

BEAM (Building Energy Asset Management) is an innovative software technology developed collaboratively by Siemens Corporation, Corporate Technology and Rutgers University that applies modeling and simulation to the process of asset management to inform decisions about how best to maintain and invest in critical "energy assets" in a building so as to assure that the building meets its missions (or business objectives) while minimizing its overall lifecycle cost. BEAM was identified by ESTCP as a potential technology for DoD building asset management and is being demonstrated under ESTCP Project EW-201262.

Both DoD BUILDER and BEAM provide software tools for assessing the condition of building assets and for managing their maintenance. BEAM, furthermore, introduces innovations including:
[1] integrating asset management with runtime automated condition monitoring; [2] introducing asset business value into the asset operation and maintenance policy decision-making process that enhances accomplishment of critical missions; and [3] embedding modeling and simulation in the asset management process to provide integrated quantitative assessments of energy usage, energy costs, maintenance costs, and opportunity costs resulting from asset degradation or failure. ESTCP has assigned Project EW-201262 the task of analyzing these two technologies to determine whether they are inherently compatible or conflicting and if their simultaneous use would be duplicative or redundant. ESTCP has further assigned EW-201262 the task of investigating whether and how the two technologies may be beneficially integrated.

Through the experience of demonstrating BEAM for Project EW-201262 and the study of DoD BUILDER in consultation with ERDC-CERL, the project team has developed an in-depth understanding of both software systems. While BEAM and BUILDER embrace the same conceptual principles and share engineering mechanisms, the software tools they provide are quite different. Because each technology has different strengths and weaknesses that are mutually complimentary, the project team believes that integration of BEAM and BUILDER to combine their separate and conjoined capabilities could best improve DoD asset management practices. An integrated tool set will help management to maintain existing critical assets and to plan investment in new critical assets more effectively, while identifying significant potential opportunities for energy consumption and cost reduction.

This whitepaper summarizes the results from our assessment of both software systems and describes our proposed solution for integrating them.

2. TECHNOLOGY Comparison - BEAM vs. BUILDER

2.1 DoD BUILDER

DoD BUILDER is the state-of-the-art asset management system for DoD properties. The result of decades of research and development based on various patented technologies - including [1] Building Exterior Condition Index, [2] Knowledge-based Condition Survey Inspection methodology, [3] Functionality Index for asset management, and [4] Condition Lifecycle mathematical model – BUILDER uses quantitative measurement to provide software tools for systematic, efficient, and thorough asset management.

2.1.1 BUILDER Approach and Work Flow

The workflow of typical DoD use cases are described in the report "Engineered Management Systems in War, An In-Theater Application for Builder" [See Reference 7], where army field engineers inspected living facilities in Kuwait. The BUILDER system includes two components, the server side and the client side. In this document, we refer to the service side software as "BUILDER" and the client software as "BuilderRED," following the Army terminology.

Under standard cases, field engineers downloaded asset information from BUILDER to BuilderRED in their office. To accomplish the download, they connected a tablet computer that was hosting BuilderRED to the network, logged into the BUILDER web portal [See Reference 8], and downloaded asset information. Once the download was completed, the BuilderRED file contained action items for field inspections. The engineers then took the tablet computer to the field and inspected assets in accordance with BuilderRED suggestions. The asset conditions in BuilderRED are classified by category with text instructions on how to rate asset conditions based on visual inspection observations. The building level inventory screen is shown in Figure 1. For example, if cracks are found on a wall, in accordance with text descriptions provided by BuilderRED, engineers assign an appropriate Condition Scale number for the wall. Missing assets are also recorded using the software. All of this information is uploaded to BUILDER once the engineer returns to the office and connects the tablet to the office network. The BUILDER server software system updates the Site Condition Index (CI) values recursively, i.e., the Site CI is calculated based on the asset Condition Scale. The site CI displays the average CI of the buildings in the site, weighted by replacement cost. This metric provides an overall sense of the condition of the site as viewed in its entirety [See Reference 7]. Based on the manually updated CI scores, facility managers then use BUILDER to plan for asset maintenance using a Triage Score that factors in the importance of the missions for those assets. The details will be given next.

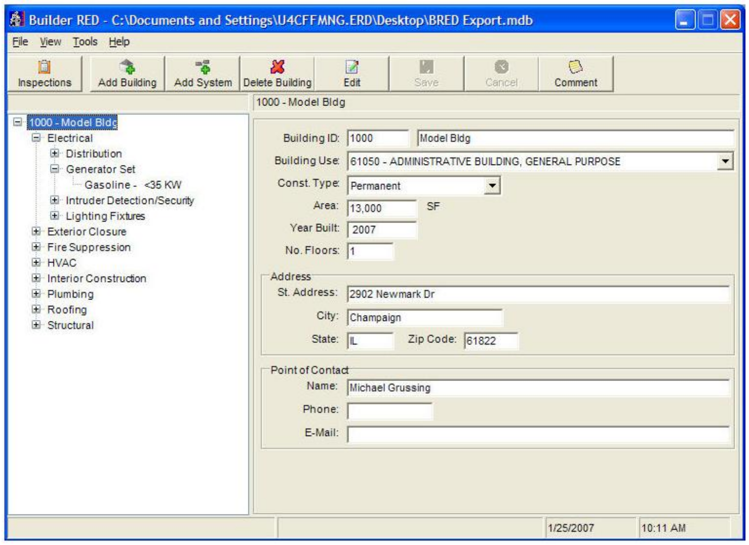


Figure 1 BUILDER RED building level inventory.

2.1.2 BUILDER Asset Condition Metric System

BUILDER introduced a metric system to quantitatively measure many asset management factors, including the aforementioned Condition Index (CI) and also other concepts, including Functionality Index (FI), Performance Index (PI), and Site Facility Condition Index (FCI). Most of these concepts are described in patents with numerous embodiments. To illustrate the concept, we briefly review this system of metrics and give basic examples for presentation purposes. Detailed design considerations and advanced use cases of these metrics are beyond the scope of this report.

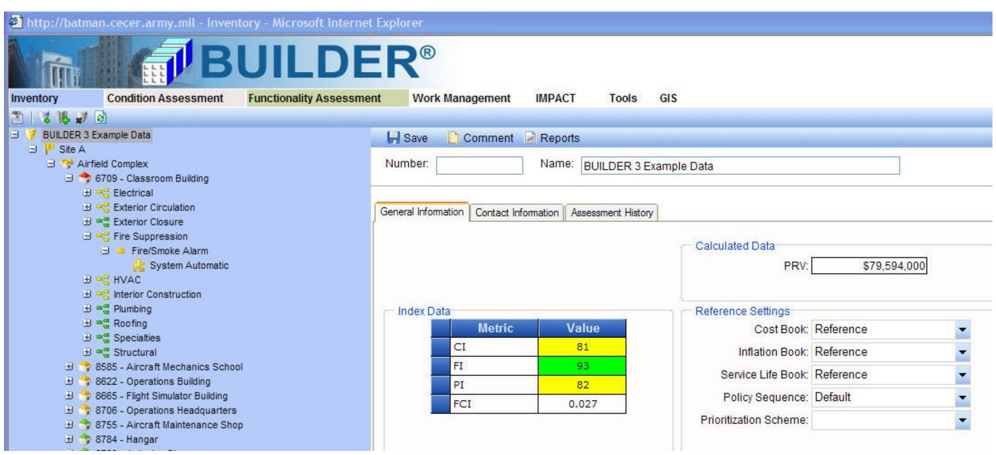


Figure 2 BUILDER organization data [9].

Table 1 shows the definition of CI in BUILDER from reference [See Reference 7], where the "Condition Scale" is the aforementioned CI. The condition descriptions are tailored especially for building system maintenance. More detailed assessment methodology is described in a standalone 161-page manual [See Reference 10], which contains a 100-page description of how to rate asset conditions for 22 different types of distresses based on visual inspections.

The exact input is based on experience and personal judgment. The system features an hierarchical CI system, starting from Building Component CI (BCCI), to System CI (SCI), to Building CI (BCI), to Complex CI, to Site CI, ending in the Group CI. From each lower level to the next higher level, CI values are weighted averages. Part of the hierarchical CI system is shown in Figure 3.

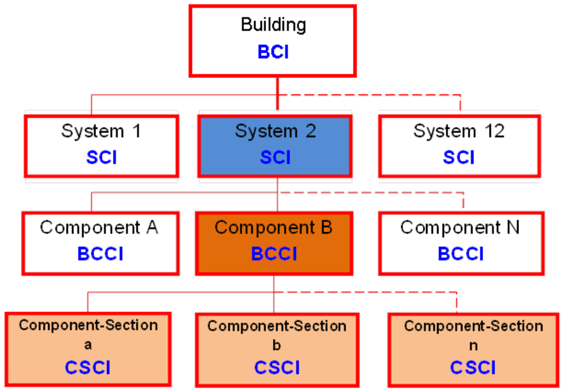


Figure 3 Hierarchical condition index system for BUILDER [10].

Table 1 BUILDER CI Scale Table

Condition Category	Condition Scale	Condition Description		
		Amount of Distress	Functionality	Type of M&R
Excellent	86 - 100	Minimal deterioration	Not impaired	Preventative or minor maintenance, or minor repair
Very Good	71 - 85	Minor deterioration	Slightly impaired	Preventative or minor maintenance, or minor repair
Good	56 - 70	Moderate deterioration	Somewhat impaired	Moderate maintenance or minor repair
Fair	41 - 55	Significant deterioration	Seriously impaired	Significant maintenance or moderate repair
Poor	26 - 40	Severe deterioration over small portion	Critically impaired	Major repair
Very Poor	11 - 25	Severe deterioration over moderate portion	Barely Exists	Major repair but less than total restoration
Failed	0 - 10	Severe deterioration over large amount	Lost	Total restoration

Similarly, Functionality Index (FI) can be quantified using Table 2. The organization FI is defined as the average FIs of the buildings in the organization, weighted by replacement costs. This metric provides an overall sense of the functionality of the organization as a whole.

Table 2 BUILDER FI Rating Table

FI	DESCRIPTION
100	No functionality problems exist in building.
86–99	Building, as a whole, is only slightly functionally impaired.
71–85	Building, as a whole, is functionally impaired but only to a minor degree.
56–70	Building, as a whole, is functionally impaired to a moderate degree.
41–55	Building, as a whole, is functionally impaired to a significant degree.
26–40	Building, as a whole, is functionally impaired to an extensive degree.
11–25	Building, as a whole, is barely able to serve its intended or proposed use.
0–10	Building is totally unable to serve its intended or proposed use.

Organization Performance Index (PI) displays the average PI of the buildings in the organization, weighted by replacement costs. This metric provides an overall sense of the performance of the organization as a whole [See Reference 9]. Building Performance Index (BPI) is a building-level metric, which measures the overall performance of buildings. It is a weighted combination of the Building Condition Index and the Building level Functional Index. The Site Facility Condition Index (FCI) represents the total maintenance and repair costs for the site, normalized by the total site present replacement values [See Reference 9]. This index represents the overall deferred repair work.

2.1.3 BUILDER Asset Management

With building inventory, condition assessment, and functionality data in place, a facility manager can begin to manage work in the building using BUILDER's powerful tools. Figure 4 is a dialog window in BUILDER to show all historical indices of a classroom building. Work item history is tracked in the format shown in Figure 5. For each expected repair, data for the fiscal year, budget, status, and return of investment (ROI) are stored in a database.

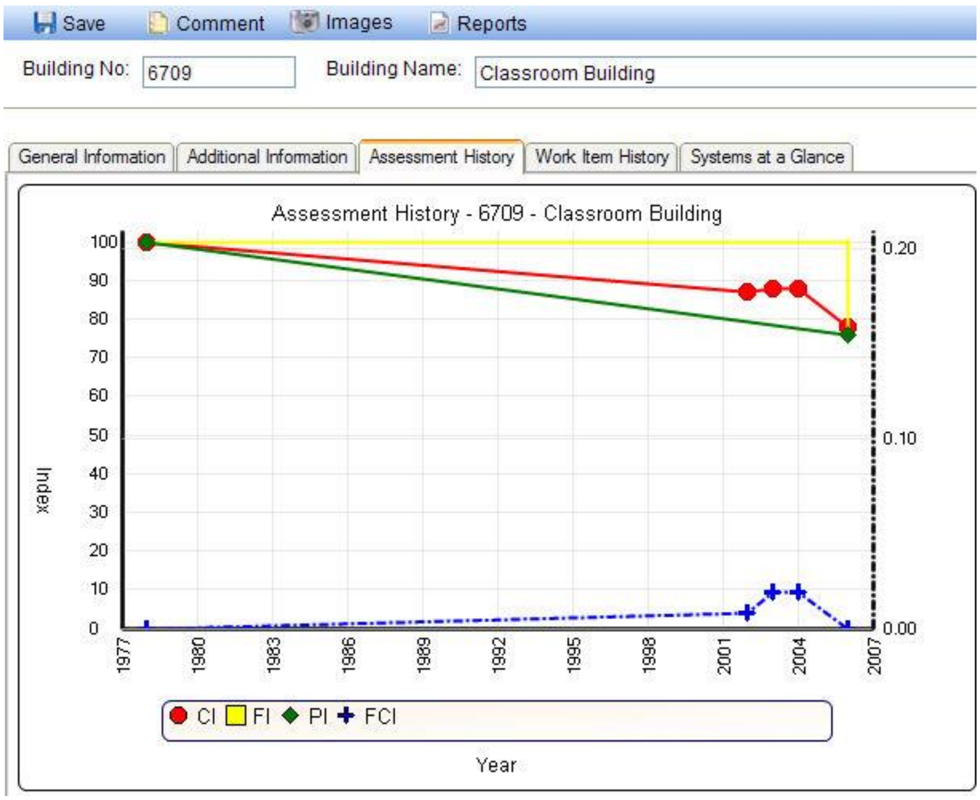
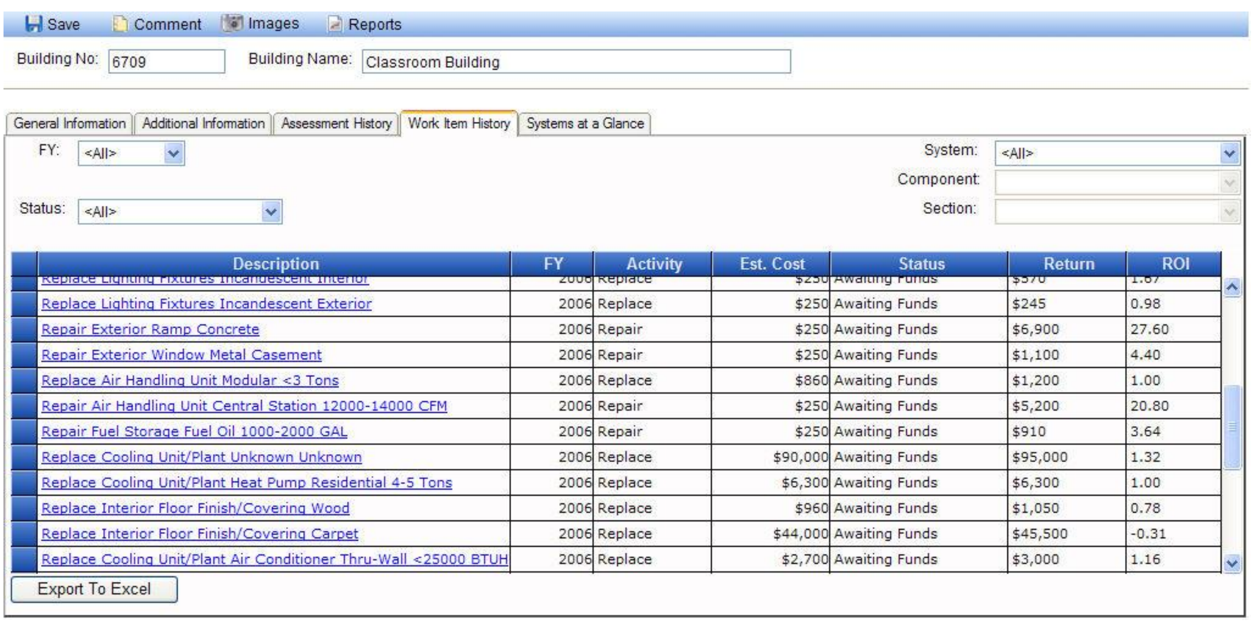


Figure 4 BUILDER assessment history.



Description	FY	Activity	Est. Cost	Status	Return	ROI
Replace Lighting Fixtures Incandescent Exterior	2006	Replace	$250	Awaiting Funds	$245	0.98
Repair Exterior Ramp Concrete	2006	Repair	$250	Awaiting Funds	$6,900	27.60
Repair Exterior Window Metal Casement	2006	Repair	$250	Awaiting Funds	$1,100	4.40
Replace Air Handling Unit Modular <3 Tons	2006	Replace	$860	Awaiting Funds	$1,200	1.00
Repair Air Handling Unit Central Station 12000-14000 CFM	2006	Repair	$250	Awaiting Funds	$5,200	20.80
Repair Fuel Storage Fuel Oil 1000-2000 GAL	2006	Repair	$250	Awaiting Funds	$910	3.64
Replace Cooling Unit/Plant Unknown Unknown	2006	Replace	$90,000	Awaiting Funds	$95,000	1.32
Replace Cooling Unit/Plant Heat Pump Residential 4-5 Tons	2006	Replace	$6,300	Awaiting Funds	$6,300	1.00
Replace Interior Floor Finish/Covering Wood	2006	Replace	$960	Awaiting Funds	$1,050	0.78
Replace Interior Floor Finish/Covering Carpet	2006	Replace	$44,000	Awaiting Funds	$45,500	-0.31
Replace Cooling Unit/Plant Air Conditioner Thru-Wall <25000 BTUH	2006	Replace	$2,700	Awaiting Funds	$3,000	1.16

Figure 5 BUILDER work item history dialog.

The IMPACT simulation tool embedded in BUILDER is designed to simulate performance and condition degradation. One simulation scenario is configured in Figure 6, where different maintenance strategies are assumed according to different CI zones. In Zone 1, where the CI value is the highest, preventative maintenance is adopted. The exact inspection interval and maximum number of inspections are specified in a dialog as shown Figure 6. In Zone 2, where

CI is less than in Zone 1, a corrective maintenance strategy is assumed. Based on the simulation configuration from the users, IMPACT simulates the asset's long term degradation conditions and budget usage for reference by the facility manager. For example, a facility manager can specify the knowledge-based maintenance strategies under different scenarios. The IMPACT software can simulate time periods of from 1 to 10 years and generate reports on expected degradation or on work plans, as shown in

Figure **8**. The report covers expected future CI, FCI, FI, PI performances, maintenance work plan, location budgets organized in different time frames, etc. This message gives a holistic overview on the impacts of a specific maintenance strategy.

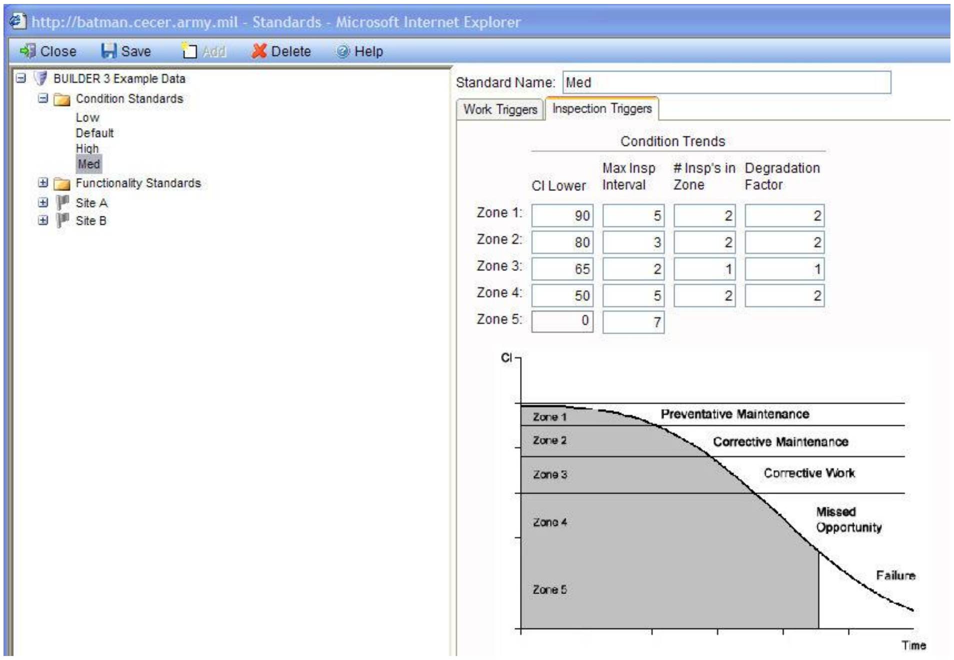


Figure 6 Knowledge based inspection schedule tool.

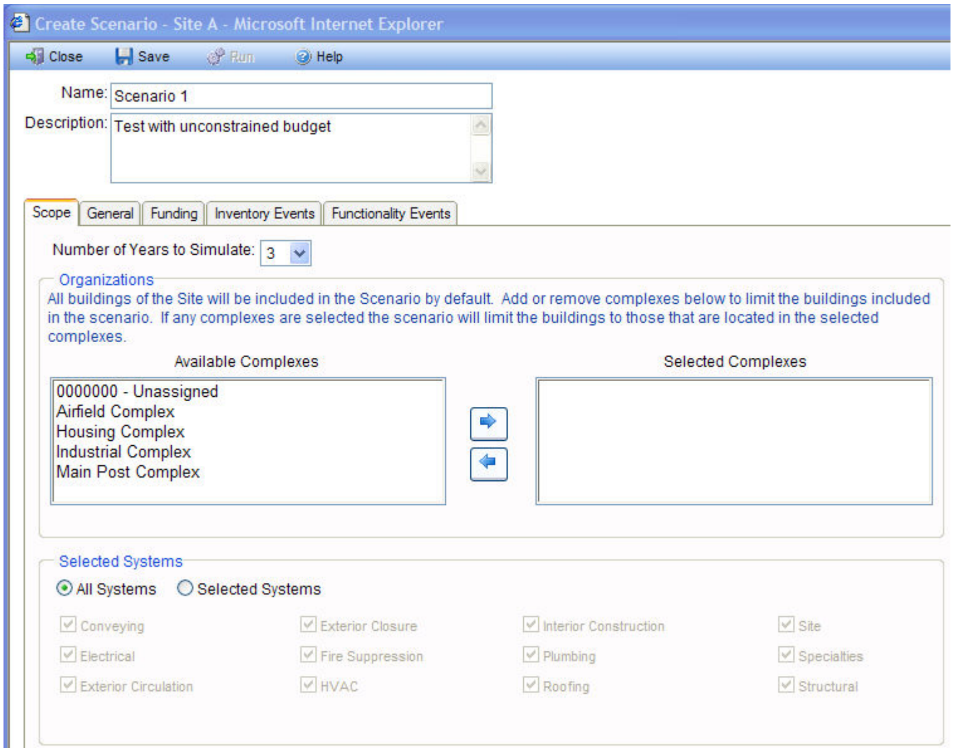


Figure 7 IMPACT scenario inputs.

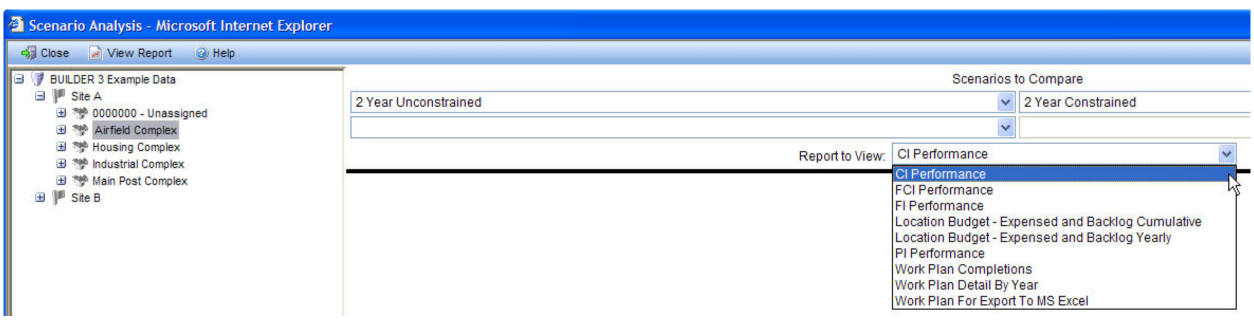


Figure 8 IMPACT scenario analysis outputs.

2.2 BEAM

BEAM is a suite of computer software tools which integrate innovative condition monitoring and asset management technologies and focus on how best to maintain and invest in "critical energy assets" in a building so as to assure that the building meets its missions (which in nonmilitary contexts are often referred to as "business objectives") while minimizing lifecycle costs. Figure 9 shows the schematic of BEAM framework.

In the BEAM framework, each building is conceived as being assigned "business objectives/missions" that its occupants are tasked to accomplish, for example, fire protection, air operations, admin support, morale welfare, recreation, education & training etc.. The "energy assets" - assets that produce, transfer, and/or use energy to support the activities associated with mission accomplishment at that building – possess what are considered "business values" that can be measured in relationship to their significance for mission accomplishment. Within the BEAM framework, the **business value** of each building energy asset plays key roles in the asset management process for prioritizing asset management investment and maintenance workflow. Meanwhile, the conditions of building energy assets are continuously monitored in BEAM - thereby enabling asset management decisions, whether preventive or predictive, to always be made based on the evaluation of current equipment and device conditions including fault and energy performance. For example, the BEAM tools can be connected to building automation systems and thereby incorporate run-time asset condition monitoring into asset planning. Moreover, BEAM asset planning optimization considers not only asset investment and maintenance cost, but also the building **operation cost and the potential penalty cost** projected to result from a loss of asset function. These unique features of BEAM support facility managers at building, military base, and regional command levels to make better decisions for optimizing energy asset operations and investments.

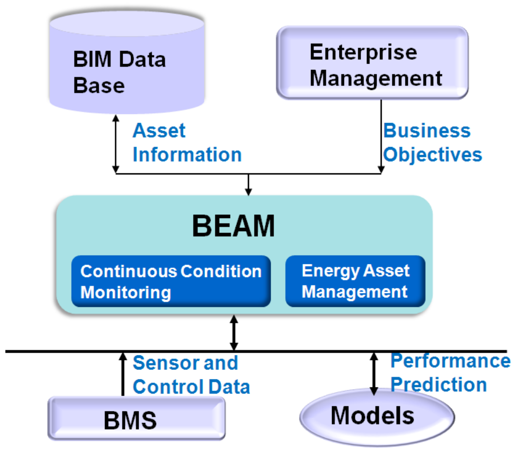


Figure 9 BEAM system architecture.

2.2.1 BEAM Approach:

BEAM technology uses a 5-step model as shown in Figure 10. The concept originates from Enterprise Asset Management (EAM) (Holland et al, 2005; Icon Group International, Inc. Staff, 2009), which has been used successfully by different sectors of the economy (e.g., Power grid, transit systems, and aerospace). The 5-step model applied to building energy asset management can be outlined as a 3-phase workflow, including Configuration, Planning and Execution phases. During the Configuration phase, the business values of energy assets are defined based on the mapping of building mission to energy assets through functional zones. The typical cycle for BEAM Configuration is in months, years, or whenever building mission/space purpose is changed. During Planning phase, the business values of building assets are used in simulations to evaluate building operation cost and failure risks from alternative O&M policies and to generate optimal strategies. The processes and the algorithms supporting BEAM configuration and BEAM planning phases are well developed by scholars and practitioners from both academia and industry. During Execution phase, BEAM runtime software is applied for continuous asset condition monitoring. Faults are detected and alarms on asset condition changes are generated and displayed for facility team to take actions. The continuous condition monitoring technology was developed by Siemens Corporate Technology.

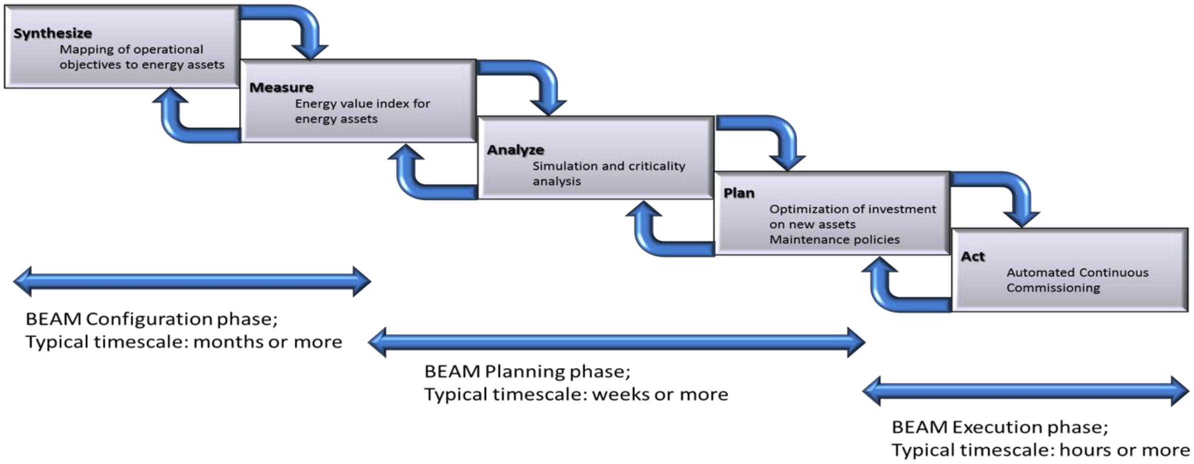


Figure 10. BEAM workflow

2.2.2 BVM Models:

The Building Energy Value Models (BVM) defined during the BEAM configuration phase map the "Missions" or "Business Objectives" identified for a building to the building energy assets available and critical for the fulfillment of those objectives. Using a combination of quantitative and qualitative techniques, "Business Value Models" identify the *Ordinal (criticality)* or *Monetary business value scores* of energy assets (*BVM-I*, *BVM-II* and *BVM-III*).

BVM-I measures criticality in ordinal terms [using a 0,1 matrix]; BVM-II measures criticality in dollar ($) terms; BVM-III measures criticality within a seasonal context in dollar ($) terms. More specifically,

- BVM-I derives ordinal criticality scores ($\in [0,1]$) for assets by mapping a building's Missions/Business Objectives to its Assets using a combination of *Analytic Hierarchy Process (AHP)* and *Failure Mode and Effects Analysis (FMEA).* Building "Missions" are mapped to systems of assets in the building, and their criticality is evaluated through AHP. FMEA is used to derive risks or criticality of assets to their corresponding asset systems. The two models are linked to derive criticality scores for building energy assets.
- BVM-II yields monetary business value scores for assets, which is applicable to most office buildings and commercial facilities. Such business values are defined by economic loss due to failure or degradation of building assets. In BVM-II, this economic loss is estimated using the aggregated value of the building employee's productivity loss due to unavailability of an asset. (Pay structure within the military - enlisted and officer - is comparable to civilian pay scales - labor and management; so the same principles for using compensation as a proxy for productivity apply.) Common indices such as *Predicted Mean Vote (PMV)* and it's relation with employee's productivity through regression analysis is utilized in BVM-II. The concept of PMV and its relation to productivity has been extensively used in practice.

- BVM-III extends BVM-II by introducing a function for seasonality, also measured in monetary terms. This model also extends BVM-II to be compatible for buildings with a wider range of "Business Objectives" and to include calculations for nontangible and difficult-to-quantify consequences of asset failure, thereby providing more sophisticated consideration of their contribution to the business value of building assets.

Note that BVM-I can be used for any building. It is Ordinal in nature and, therefore, independent of monetary considerations. In contrast, BVM-II&III use a monetary metric. However, dollar values are primarily a means for measurement; although related to monetary considerations in the real world – and usable for financial purposes – they are fundamentally measurement tools for purposes of comparative ranking and analysis. The monetary business models provide a better way to optimize asset maintenance policy considering both operation/repair cost and the penalty cost from asset failures.

BVM can be applied whether or not a building is "commercially oriented" or if it is occupied or unoccupied by people. Valuation can be derived in a variety of ways. For example, the value of dormitory space can be compared to market rents for comparable housing; the value of dining facilities can be valued based on meals served (in comparison to a comparable restaurant); fitness centers can be compared to membership fees in a commercial gym. Maintenance of environmental conditions for equipment or critical processes can be subject to similar valuation methodologies.

2.2.3 Continuous Condition Monitoring:

The Continuous Condition Monitoring (CM) module of BEAM is a function to check the status of systems and assets required for the building's operation continuously. The status of each asset and system is quantified in terms of an index called "Condition Index." Condition Index has a value between 0 and 100, with 0 corresponding to the worst condition and 100 indicating perfect condition. To calculate an asset's Condition Index continuously, our CM module includes three major functions:

- Automated fault detection and diagnosis (AFDD): We use runtime data from building automation systems to determine faulty HVAC parts and equipment based on a Heat Flow Model (HFM). During the fault detection phase, measured sensor and control values are used to perform estimations based on the physical properties of the system. Discrepancies of estimated and measured values are collected as a detection failure vector. Diagnosis seeks to find the most probable cause for the observed failures. In HVAC systems, the failures and faults form an "m-to-n" (matrix) relation. Our diagnosis is performed with an associative network to map the relations among failures and faults using the inherent fault simulation capabilities of the HFM nodes at runtime. The automatic fault detection generates Function Index of building asset.
- Automatic energy asset performance estimation: We use runtime data from the building automation systems to determine the energy performance of those energy conversion devices in a building, including its chiller, fans, boiler, and other significant system components that are monitored. The condition index of these equipment is calculated as the ratio between the Expected Power Consumption and Actual Power Consumption:

$$CI = \frac{Expected\ Power\ Consumption}{Actual\ Power\ Consumption}$$

Their performance degradation can be captured by assessment of a drop in efficiency or an increase in power consumption for a particular working condition.

- Condition from manual inspection: Manual condition monitoring is designed to address conditions of those components for which sensor data is not available. Manual condition monitoring may be accomplished through simple inspection or through detailed inspection and distress analysis. The frequency and procedures for inspections are matters for policy decision, presumably determined through reference to manufacturer recommendations and established industry best practices. Similar to automatic condition monitoring, the output from manual condition monitoring is an asset level Condition Index which is consistent to BUILDER's definition.

2.2.4 BEAM Engine

The BEAM Engine is an optimization software program, designed to explore the implications of a variety of asset maintenance policies and to identify a policy that yields minimal Total Building Cost. Such cost minimization combines three main cost elements: (i) asset energy cost, (ii) building value loss due to asset failures (Asset Penalty Cost), and (iii) maintenance cost. Each maintenance action has a fixed cost term (based on such factors as materials cost) and a variable cost term (dependent on time duration and hourly labor cost required to perform the maintenance action). Asset Penalty Cost is defined as economic loss due to failure of an asset. This cost can be calculated using BVM. Finally, asset energy cost includes the fixed and variable costs of consuming or generating energy (e.g., electric energy and natural gas). The BEAM engine is integrated with a customized building energy simulation model, which takes into account such important factors as climate, occupancy, system reliability, degradation and maintenance to identify the maintenance policies that are optimal over a planning horizon and within budget and financial constraints.

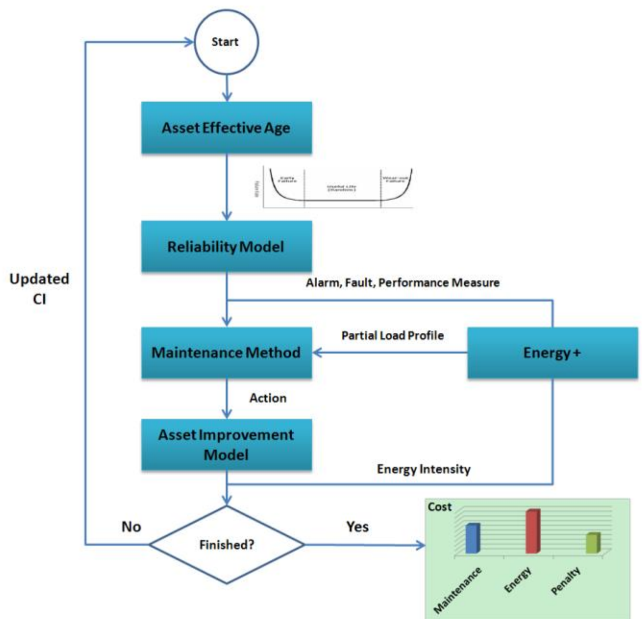


Figure 11 BEAM Engine

The probability of failure and degraded energy performance of an asset depends not only on the time elapsed since the asset's installation (actual age) but also on changes resulting from the cumulative load on the asset as well as the maintenance policies employed (Effective Age). Asset effective age is a function of asset condition index generated by BEAM-CCM. The Effective Age of assets is input to the BEAM Engine at the beginning of an optimization period. Using its Asset Reliability Model, the BEAM Engine then calculates the failure probability and energy performance efficiency of the assets as a function of Effective Age. After that both values are plugged into a building energy simulation to calculate building energy consumption. The BEAM Engine and Building Energy Simulation Model run in parallel, and communicate using a co-simulation platform. The Asset's Partial Load Profile is computed by the Building Energy Simulation Model and is input to the BEAM Engine's "Asset Efficiency Degradation" function, "Asset Reliability Model", and "Maintenance Optimization" model. The energy transfer or conversion efficiencies of assets are calculated based on their Partial Load Profile. Random failure events, characterized by asset availabilities, are also generated based on probability distributions. Asset performance and efficiency measures and availability indicators are then "injected" back to the Building Energy Simulation Model. Using the aforementioned inputs, the BEAM Engine identifies a maintenance policy that yields minimal asset energy cost, asset penalty, and maintenance cost. The BEAM Engine then updates the asset's Effective Age and CI according to the Improvement factor ($(IF \in [0,1])$) of the type of maintenance policy identified.

2.2.5 BEAM Tools

Tools for BEAM include software that can enable the 5-step workflow for BEAM configuration, planning, and execution with a focus on the energy asset systems within a building, including HVAC systems, lighting, building envelopes, etc. There are two main modules: BEAM Configuration and BEAM Runtime, as shown in Figure 12.

BEAM Configuration maps the "Missions" assigned to a building to the building's assets based on Business Value Models: *BVM-I*, *BVM-II* or *BVM-III*. The configuration tools are also used to generate models for automatic HVAC FDD, energy performance monitoring, and building energy simulation (Energy Plus). In addition, the building information and asset information gathered through the BEAM Configuration tool will generate a comprehensive xml-based database for BEAM Runtime to use, called Asset Information Model.

After configuration, building management personnel can use the BEAM Runtime software to browse building asset conditions in real time or for planning purposes. Building asset condition can be updated continuously if control and sensor data is imported to the software frequently (Figure 13). Device faults or energy performance degradations exceeding user-defined thresholds will trigger alarms. BEAM Runtime also provides asset-planning tools for projecting "what-if" scenarios to evaluate O&M policies or for synthesizing the best O&M policy for energy conversion devices such as chillers, fans, pumps, and boilers (Figure 14).

BEAM Runtime software can run in either *"Stand Alone"* or "*Integrated*" mode, differentiated by the connection types between BAS and BEAM Runtime software. For operation in the "Stand Alone" mode, the software doesn't need to be installed on the industry control network and communicate with BAS through BACNet. Instead, a user can upload BAS trend data daily, weekly or bi-weekly to assess asset condition at his own convenience. In this Way, BEAM technology presents lower security concerns to the control network. Running in an *"Integrated"* mode, BEAM will be integrated with the BAS system through the BACNet protocol; hence the continuous condition monitoring is fully automatic and there is no need for a user to upload data during operation. In addition, BEAM can detect and respond to faults more promptly in the "Integrated" mode.

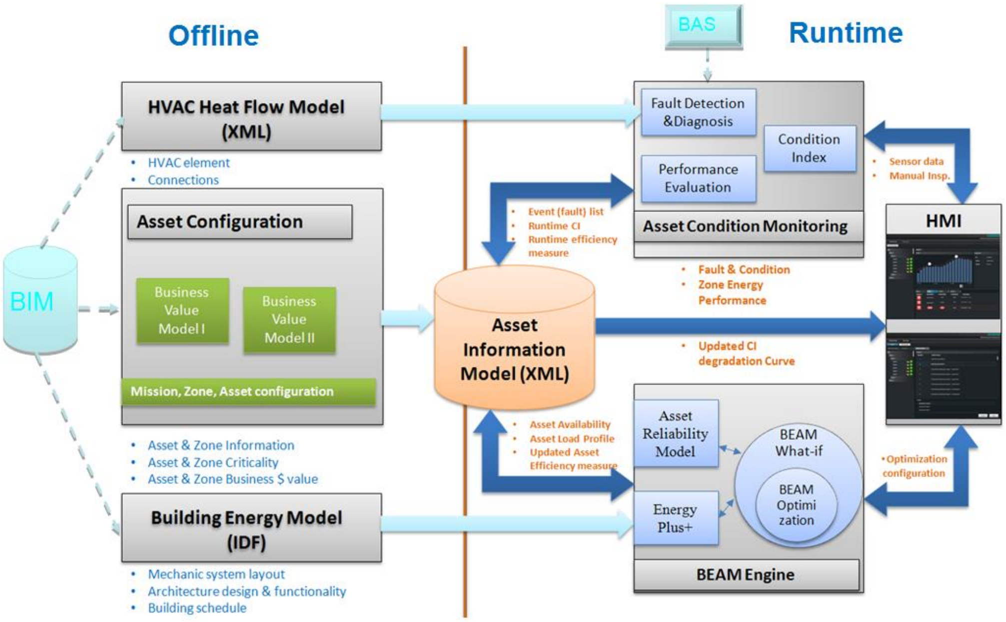


Figure 12 BEAM software overall architecture

Figure 13 Asset condition monitoring.

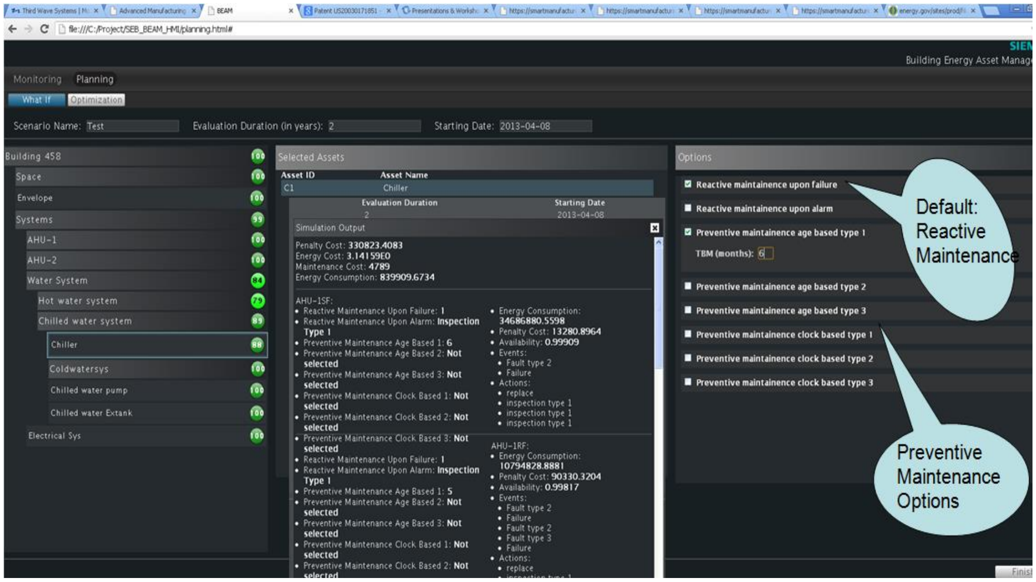


Figure 14 User interfaces of BEAM Runtime Software

2.3 Comparison-advantage and limitations of both technology

BUILDER and BEAM conceive the problems of managing the assets of a building in similar ways, and they embrace the same principles:

- Lifecycle tools for Management of Assets
- Weibull distribution for modeling risk of component failure
- Decisions for capital budgeting and operations budgeting

Both technologies are specifically concerned with Operations and Maintenance (“O&M”) strategies, planning, policy, and activities.

2.3.1 BUILDER Pros and Cons

<u>Matured methodology:</u> BUILDER has been adopted in DoD facilities for years. It is used to manage hundreds of buildings and to assist in maintenance budget planning.

<u>Simplicity</u>: BUILDER is a fully manual, low engineering cost, knowledge-based methodology for asset management. This methodology requires relatively simple numerical calculations, which make the technology easy to implement in different buildings.

<u>Low effort:</u> Rooted in simplicity, BUILDER does not require field engineers to collect much information for a building; therefore the engineering effort is low. According to Lance Marrano, the developer of BUILDER, the costs of inspection for BUILDER is around $0.1~$0.3 per square foot.

<u>Less advanced features</u>**:** Without advanced calculations, BUILDER is not designed to address long-term cost factors when energy consumption is within its scope.

2.3.2 BEAM pros and Cons

Performance Advantages: The BEAM technology is innovative and has not been demonstrated previously. The integration of continuous condition monitoring with asset management based on asset reliability and building energy modeling is a new idea which can provide facility planners and managers with tools to optimize both asset maintenance and energy cost over short-term and long-term time horizons and to perform "what-if" analysis in response to significant unexpected events. In addition, asset planning that is driven by business value can optimize organizational performance and secure critical missions.

Cost Advantages: BEAM is a software-based solution. The acquisition cost, including licensing and software installation as well as user training is expected to be low. Major costs are currently required for implementation, because the technology requires significant engineering effort during the configuration phase, including generation of the building asset information model, reliability model, and building energy model. However, after commissioning, no maintenance is needed for BEAM. Since the software is designed with an interface to the existing building automation system and supports continuous commissioning, there is no need for manual data collection for purposes of asset condition assessment. The return of investment is expected to be within 5 years, if the building already has a BAS system.

Performance Limitations: The BEAM tool requires supporting data on asset reliability, performance, and operating schedules. The problem of data availability is non-existent for new buildings. For older buildings that keep no asset information archiving and maintenance logs, the lack of data for asset reliability modeling may significantly hinder the applicability of BEAM, unless data on similar assets is obtained from the literature. A scaled down version of BEAM for older buildings may be possible for purposes of generic planning for buildings of standardized construction types, such as Quonset huts or barracks.

BEAM technology performs planning and optimization on the basis of building simulations. The existing simulation technology (e.g., EnergyPlus) requires extensive computational time, especially when the building modeling includes sufficient details, and runs are made for several years (i.e., 4 or 5 years). A typical BEAM optimization may then take several hours of computer time to complete. While running offline, the BEAM execution time may pose limitations, if decisions are expected immediately or within a short time interval. Although the BEAM system is complex, its HMI is being designed such that a casual user can quickly and intuitively obtain actionable information, while a power user can access more sophisticated capabilities.

Cost Limitations: A potential barrier to acceptance of BEAM technology is the time and expense required to generate all the models required by BEAM Runtime software. For example, the project team estimates that between one to three months would be required to build an EnergyPlus model for most buildings, depending on the building type, the size and complexity of the building, and the experience of the engineers who create the model. However, considering the potential for integrating BEAM and BUILDER, interoperability between BEAM and BUILDER could reduce BEAM engineering cost substantially. Furthermore, generation of building information models and EnergyPlus models as a routine aspect of building design by the

US Army Corps of Engineers and other architectural planners within the near future is a distinct possibility.

Social Acceptance: Our military partners have been enthusiastic about the concept of BEAM, and they have been receptive to the prospective opportunity to become early adopters of the BEAM technology. However, they also advised the project team that the advanced concept in BEAM could be overwhelming to some civil engineering teams. We envision that well designed training is necessary for final technology transfer. And, parallel dissemination activities are planned to educate military and civilian users and to promote the acceptance of BEAM technology.

2.3.3 Comparison results

BUILDER determines its CI through a process of periodic expert inspections, procedures that are inherently subjective. BEAM regards periodic inspections as part of a maintenance strategy. ACC determines CI for BEAM through computerized monitoring and analysis of sensor and control data as well as values projected by BEAM algorithms, a methodology that is objective in application.

A comparison of BEAM and BUILDER features is provided below:

Features	BEAM	BUILDER
Considers Mission	BVM (I, II, & III) Assesses business penalty cost	Considered in a non-quantitative way
Uses Building Automation Sensors/Controls	Automatic Condition Monitoring Condition reporting in real time	N/A
Simulation	Quantified analysis based on models and simulations	Functional Assessments
Condition Index	CI based on both manual inspection and automatic detection, depends on assets.	CI based on manual inspection
Planning Objectives	Multi-Objectives: Setting maintenance policies; minimizing energy consumption; optimizing lifecycle cost-effective performance; computing penalty cost of impact on mission from loss of asset function	Prioritizing maintenance work; allocating maintenance budgets
Engineering Effort	Significant upfront investment in EnergyPlus and other modeling	Moderate investment in developing Inventory
Acceptance	Unknown	In use by DoD

3. Integration of BEAM with Builder

An integration of the BEAM and BUILDER technologies should be designed to have the following features:

- a means of communications between BUILDER and BEAM
  - For a tight integration, BUILDER shall offer an Application Programming Interface ("API") for BEAM to access its data and operations.
  - For the loose coupling scenario, BEAM will read the data exported from BUILDER and write back updated messages.
- a consistent Condition Index definition between BEAM and BUILDER.
- a unified workflow and template to establish default values for similar buildings of the same type.

There are two potential solutions to integrate BEAM tools with BUILDER through either loose coupling or tight integration.

3.1 Tight Coupling

The goal of tight coupling is to seamlessly merge the two software system into one, so that users do not feel they are actually using two separate applications together. This solution will offer the best user experiences but requires higher development efforts than the loose coupling scenario.

A tightly coupled BUILDER/BEAM system will follow the workflow of the BUILDER system, for the most part, whereby BEAM becomes a natural extension of the BUILDER system. The integrated system offers the following new features: 1) Automatic data collection from building automation systems (BASs); 2) Automatic condition monitoring, including fault detection and diagnostics (FDD), CI updates, etc.; 3) HVAC equipment energy performance monitoring; 4) Building envelop energy intensity monitoring; 5) Advanced data visualization and 6) value driven asset planning/maintenance policy analysis and optimizations.

The workflow of the integrated system is as follows: Field engineers collect information using BUILDER RED and mobile devices. The data is then uploaded into the BUILDER server and accessible by BEAM system. The field engineers also establish connections between BEAM and the BAS so that BEAM can monitor the building conditions on real-time. The BEAM user interface provides a complete visualization solution on sensor data and processed metrics, including the CI, EP, and EI values calculated by BEAM, also CI and Triage, calculated by BUILDER. Facility managers will be able to manage both systems from the BEAM web-based user interface. When a fault is detected, FM will be notified for in-depth analysis, such as maintenance policy optimization or what-if simulations using BEAM. The metrics from BUILDER is also accessible. After analysis, the results can be printed from BEAM.

The system architecture is shown in Figure 15, where we highlight the internal structure of the BEAM system. BEAM will be able to access both the data and calculation functions within BUILDER. During the engineering phase, BEAM acquires building information from the BUILDER database, in order to minimize the effort and maximize the utilization of existing data.

After fault detected, BEAM will update CI values in BUILDER database and trigger related analysis functions.

Without disturbing the existing BUILDER workflow, engineers can continue to use BUILDER RED to upload building information collected from the field. Meanwhile, BEAM establishes an extra communication chancel, i.e., automatic sensor data collection from BAS to the BEAM runtime engine via BACnet protocol. This is a significant enhancement to BUILDER, which uses a manual system. The sensor data are processed by the Condition Monitoring component in BEAM for run time fault diagnostic and detection for CI updates, which will be feed into the BUILDER database via the BUIDLER API. The Optimizer component inside BEAM can conduct "what-if" simulations and Optimizations based on user inputs. The simulation and optimization results can be shared with BUILDER via the API.

The communication between BUILDER and BEAM can be implemented in HTTP-based web services, such as RESTful services or SOAP services. BUILDER would need to expose an API for BEAM, which can access the engineering information of existing buildings. Based on information from the BAS, BEAM runtime detects component faults and calculates the CI degradation for each applicable item of HVAC equipment, based on FDD algorithms already developed by Siemens during the DoD ESTCP BEAM project (EW-201262). Please notice that Siemens's algorithm was designed to match the manual inspection guideline provided by BUILDER for those assets not instrumented and continuously monitored. Therefore, CIs obtained from BEAM can be used interchangeably with the CIs obtained from manual inspection using Builder RED.

To embrace the age of mobile computation, BEAM UI is built on the latest web technologies. The BEAM UI is an interactive functional dashboard and configuration tool based on HTML5 and Javascript technologies. Via the UI, facility managers can monitor the condition of individual assets within a building and optimize their maintenance policies using different solution methodologies provided in the optimizer. For example, if a fault is detected, a facility manager can simulate the impacts of that fault in terms of energy or business value. The result is displayed visually on the dashboard.

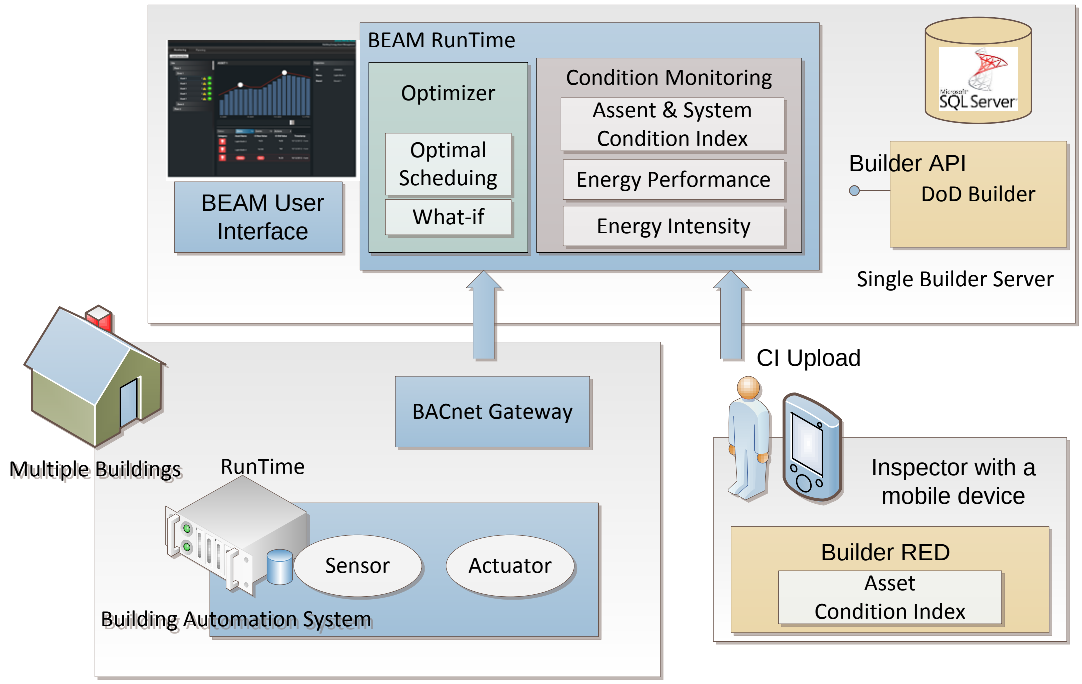


Figure 15 System architecture of tightly coupled Builder-BEAM system.

3.2 Loose Coupling

In the loose coupling scenario, facility managers need to operate BUILDER and BEAM as individual software and must manually transfer the data between the two applications. One advantage of this solution is that it requires less development efforts, at moderate sacrifice for the user experience.

The system diagram is shown in **Figure** 16, where BUILDER and BEAM interchange information via files on the same hard drive. In this scenario, users first collect building and asset information via the traditional BUILDER and Builder RED tool chain. The data are stored inside a Microsoft SQL server database and can be exported following the Microsoft Access format. Users than start the BEAM application and import the Access file into the BEAM system, more specifically an XML-based Asset Information Model database. This version of the BEAM engine is still featured with run time FDD, optimization and simulation, etc. The outputs of the BEAM engine are not automatically merged back to the BUILDER database. Instead, BEAM exports output into files and import into BUILDER. Notice that this import feature does not exist in BUILDER today. The BEAM and BUILDER teams can specify a common format for the data exchange purpose. Candidate formats include Excel, CSV, Access, XML, but not limited to these options.

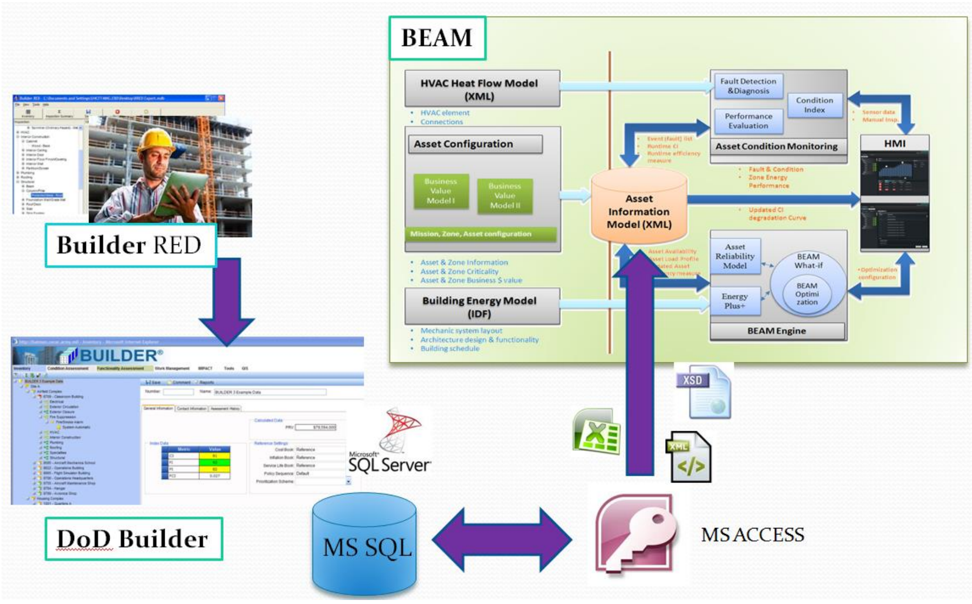


Figure 16 System architecture of loosely coupled BUILDER-BEAM system.

3.3 Additional Efforts needed for BEAM and Builder integration

1) API: An Application Programming Interface ("API") has not yet been developed for BUILDER. Development of an API would facilitate the integration of BUILDER with other software programs such as BEAM. In the absence of or preliminary to the availability of a BUILDER API, data sets in compatible format can be passed between the software programs, but an API is a superior solution.

2) Database: BEAM and BUILDER both use a unified database that describes the specifications for the (energy) assets of the building (its "Inventory") as well as data pertaining to the condition and function of those assets over time and in simulations. Protocols for sharing such information can avoid duplication of effort. Furthermore, automation of some data accumulation is possible.

3) CI: Both BEAM and BUILDER are driven by reference to a "Condition Index" metric that assesses the current and predicted future state of an Energy Asset. These two Condition Indexes are derived by using different methodologies, but they refer to the same assets and the status of those assets. A goal of the project is to coordinate these two Indexes so that they can be used interchangeably, or can exchange information, or can be synthesized so that only a single Index is required for all purposes.
   - The Siemens CI used for BEAM is calculated by an algorithm based on asset Energy Performance and Fault as detected by ACC.
   - The CERL CI used for BUILDER is based on a rating of components derived from inspection for the "Type" of negative condition, its "Severity," and its "Density."

4) In addition, standard works flows and templates are required for the integration of both technologies. A common template for BUILDER and BEAM for different types of

buildings can establish default values for initial configuration. As a result, the technologies can be extended more rapidly to multiple buildings and analysis of building cluster configurations.

4. Conclusion

The proposed integrated suite of tools will empower DoD strategic planners, capital budgeters, facilities managers, logistical tacticians, and base commanders with the combined strength from BEAM and BUILDER tools. The DoD will benefit generally from better decisions and better operations. Specifically, the DoD is expected to benefit from reduced energy expenditures, more efficient use of energy resources, more resilient building infrastructure relative to its energy assets, and better management of its built environment. Although the total dollar value of these benefits cannot be quantified at this time, when the models are run for scenarios provided by the DoD for testing purposes, the demonstration project will itself deliver analyses of typical savings to be derived.

Key Performance Indicators (“KPI”) vary for different kinds of Energy Assets. Although their cumulative impacts cannot yet be determined, the range of annual benefit for specific contributions of the BEAM technology is known. For example, the savings per rooftop cooling unit (“RTU”) from the fault detection and diagnostics (“FDD”) functionality of BEAM can be between $700 and $2,000.

BUILDER is already in deployment at DoD facilities. Integration of BUILDER with BEAM will enhance its value to DoD users. Conversely, integration will assist adoption of BEAM tools as a valuable extension of BUILDER. When BEAM is commercialized, the BUILDER installed base will provide a distribution channel for the BEAM software products and supporting services.

BEAM software and associated tools will be manufactured and packaged by Siemens Building Technology (“SBT”) in Buffalo Grove, IL. Training, engineering support, customer help, and other associated services will also be provided by the SBT division.

Since the identical human/machine interface (“HMI”) and software tools can be used by all levels of management, BEAM will be marketed to base commanders, Directorates of Public Works (“DPW”), facilities managers, and others concerned with the efficient management of buildings. The deployment strategy will be to train one BEAM facilitator within the DPW and, initially, one “power user” who is the facility manager of the first building on the installation to be configured with a BEAM model. The base commander can then use that cadre, with SBT support, to extend the technology implementation to other buildings at the installation.

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