FINAL REPORT

Model-Driven Energy Intelligence

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14. ABSTRACT
This is the final report for Model Driven Energy Intelligence, ESTCP Energy and Water program 201263. This pilot program, at Fort Jackson, SC, illustrates the benefits of creating a retrofit building information model (BIM) for operations in legacy facilities. Five legacy buildings at Fort Jackson were modeled in 3D using a tool Honeywell has developed to create a medium-fidelity BIM from 2D CAD. We demonstrated that it is cost effective to generate this retrofit model using our methods, and that it may be used to deliver additional insight to support better energy and operation management. Model-Driven Energy Intelligence is the combined benefit of using the BIM to more automatically unite information about the physical facility with information about the behavior of the comfort and energy systems, and present that integrated view in a more intuitive manner. The report includes an overview of the costs of generating a BIM using the Honeywell BIMBuilder, and an estimate of the potential impact on energy performance at Fort Jackson.

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ACRONYMS

ACS	Automation and Control Solutions
A/E/C	Architecture/Engineering/Construction
AEWRS	Army Energy Water Reporting System
AHU	Air Handling Unit
API	Application Programming Interface
BAS	Building Automation System
BIM	Building Information Model
BLCC	Building Life Cycle Cost
BMS	Building Management System
BOS	Building Optimization Suite
CAD	Computer Aided Design
CDD	Cooling Degree Days
CERL	Construction Engineering Research Laboratory
CL	Confidentiality Level
COBie	Construction Operations Building Information Exchange
CWAN	Contractor Wide-Area Network
COTS	commercial-off-the-shelf
DCS	Digital Control System
DDC	Direct Digital Control
DIACAP	Department of Defense Information Assurance Certification and Accreditation Process
DoD	Department of Defense
DoDD	Department of Defense Directive
DoDI	Department of Defense Issuance
DPTMS	Director/Directorate of Plans, Training, Mobilization and Security
DPW	Department of Public Works
DWG	Vector-based graphics file. A file name extension shown as .dwg
EBI	Enterprise Buildings Integrator
ECB	Energy and Construction Bulletin
EEW	Enterprise Energy Warehouse
ELIE	Equipment Layout Information Exchange
EM	Energy Manager
EMS	Energy Management System
EO	Executive Order
ERDC	Engineering Research and Development Center
ESTCP	Environmental Security Technology Certification Program
FIPS	Federal Information Processing Standard
FM	Facility Manager
GFEBS	General Fund Enterprise Business System
HDD	Heating Degree Days
HEM	Honeywell Energy Manager

HQUSACE	Headquarters, U.S. Army Corps of Engineers
HVAC	Heating, Ventilation, and Air Conditioning
IA	Information Assurance
IFC	Industry Foundation Classes
IR	Infrared
ISO	International Standardization Organization
LOD	Level of Detail
MAC	Mission Assurance Category
MCA	Military Construction, Army
MDEI	Model-Driven Energy Intelligence
MEP	Mechanical, Electrical and Plumbing
MT	Military Transformation
NEC	Network Enterprise Center
NIST	National Institute of Standards and Technology
NBIM-US	National BIM Standard for United States
O&M	Operations and Maintenance
ODBC	Open Database Connectivity
PI	Principal Investigator
POC	Point of Contact
ROI	Return on Investment
RPI	Real Property Inventory
RPLANS	Real Property Planning and Analysis System
RTU	roof top units
SCID	Sensitive Compartmented Information Facility
SNAC	Systems Network and Attack Center
SRM	Sustainment, Restoration and Modernization
SSIS	SQL Server Integration Services
STIG	Secure Technical Information Guide
TRL	Technology Readiness Level
UFC	Unified Facilities Criteria
UFGS	Unified Facilities Guide Specifications
UI	User Interface
UMCS	Utility Monitoring and Control System
USACE	US Army Corps of Engineers
VAV	Variable Air Volume

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EXECUTIVE SUMMARY

Building information models (BIM) offer a multi-dimensional information structure and visualization tool for design, construction, and operations. Use of this technology has produced significant savings through improved communication, particularly in the design and construction phases. The DoD has committed to applying BIM information standards and technologies for new construction and major retrofits.

According to ERDC-CERL analysis, since 2008, roughly 3.5% of Army facilities have met the new documentation requirements through replacement or remodel (retrofit); a rate of roughly 11% per decade. This statistic suggests that it could take approximately 100 years for the DoD to bring its total stock of operating facilities up to a modern information standard. One report estimates that 75% of the potential benefit of BIM savings will occur over the 50-75 years that the typical building is in service (McGraw Hill, 2009). Thus, while BIM is revolutionizing the construction process, the DoD is missing a large opportunity to reduce the total cost of ownership on their existing facilities.

DoD facilities built before the introduction of BIM can't readily take advantage of new tools designed to leverage this investment in data management for longer-term savings in operations.

The converse is also true—the relatively slow growth of a large body of facilities primed to exploit tools that leverage BIM for operations will limit the commercial success of such tools and slow the growth of these tools in the market. This will further impede the development and application of BIM-enabled technologies for operations.

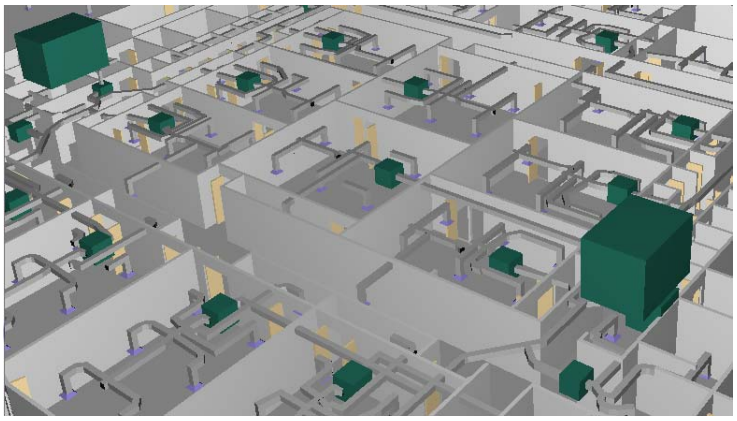


Figure 1. Portion of a Generated Model for Building 11000

To accelerate BIM-based tool development and deployment for operation, the lowest-common-denominator documentation standard for legacy (pre-BIM) facilities must rise. Enabling this elevation requires a cost-effective means to create a BIM-consistent model of an existing facility. Then, we can begin to develop tools to reap the benefits of BIM in operations for a wider body of facilities—not just the fraction constructed or remodeled in the last few years. These retrofit models do not need to achieve the same fidelity of detail that is required for construction; models need only include elements required for specific operations goals.

A BIM is an information standard that opens up the opportunity to improve building management and energy management practices, both on individual buildings and across large populations of buildings. This demonstration set out to test three related hypotheses about the application of BIM to legacy facilities:

- Honeywell's BIM Builder can be applied to legacy facilities that have CAD (computer aided design) documentation available. The tool can extract a medium-fidelity BIM semi-automatically, with reasonable investment of time and resources.
- Semi-automated context discovery can reduce the manual effort that is typically required to link data from real-time operations (e.g., building management solutions) to this standardized and structured view of the building and assets.
- Improved context for energy and operations management will facilitate better understanding of why buildings and assets are expending more energy than required and support more effective resolution.

BIM Builder for Legacy Facilities

While BIM is not strictly necessary for advanced building operations, it vastly reduces the cost to gather and validate the information required to configure advanced solutions. The prevailing method of 3D building modeling for design and construction is supported by tools suites offered by companies such as Autodesk, Inc. and Bentley Systems, Inc.

To address legacy facilities, Honeywell has developed a tool called BIM Builder, that imports CAD (two-dimensional vector graphics), and allows a user to selectively choose elements from those CAD drawings to generate a medium-fidelity three-dimensional (3D) model of the facility, spaces, and related equipment, semi-automatically. BIM Builder and the resulting models are not meant to compete with tools such as Autodesk for new construction, but to address an unmet need for operations.

In our trials, BIM Builder provided the best performance advantage over the prevailing method when modeling larger buildings because of the economies of scale provided by bulk extraction of like objects from the CAD sources. As the building gets larger, the efficiency of modeling (sq feet modeled per hour) increases.

Figure 2 shows that the time required to model a facility in BIM Builder is not a function of the size of the facility. One of the largest sites, Building 11000, took the least time to model with this method. By contrast, the Revit process for placing objects is likely to result in a performance curve that is a function of building size and complexity.

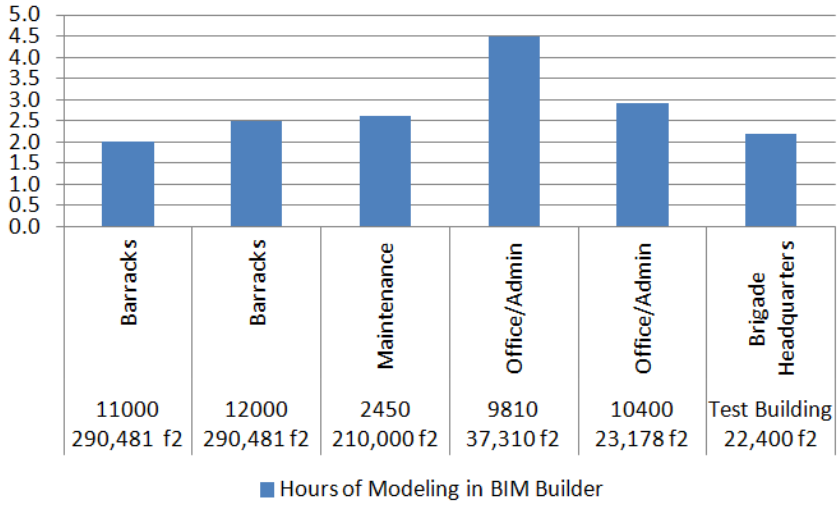


Figure 2: Modeling Time per Building by BIM Builder Expert

A controlled workshop conducted at the US Army Corps of Engineers' (USACE) Engineer Research Development Center (ERDC) - Construction Engineering Research Laboratory (CERL) demonstrated that the BIM Builder requires specific usability improvements to more seamlessly support the workflow and address user needs. It also showed that it is likely

that, given those improvements and minimal training, it can be used effectively by users at a variety of skill levels. Table 1 summarizes our testing methods and results.

Table 1: Test Methods and BIM Generation Results

Test Methodology	Conditions	BIM Generation Results
Development of BIM models for Fort Jackson pilot.	One experienced Honeywell user of BIM Builder	Significant performance differences in small vs. large facilities. Average of 8.8K sq ft modeled per hour in facilities under 45K sq feet. More than 130K sq ft/hour modeled for facilities over 100K sq feet.
Revit baseline	Experienced *(but not expert*) users of Revit Suite	22.4K Sq Ft Completion in 2.4 hours, 10.1K Sq ft per hour
Controlled Workshop at CERL using Brigade Headquarters	Five novice tool users in time-limited exercises	Average of 80% correct completion of 22.4K Sq Ft in two controlled exercises with novice users, conducted over approximately 6 working hours.

Our exercises in this pilot have led us to the following conclusions:

- It is possible to produce a medium-fidelity BIM in a few hours for an existing facility, leveraging existing information resources.
- Modeling efficiency in BIM Builder increases with building size.

Our goal was to show that we could drive the variable costs (labor) of producing a BIM to $1.00/ 100 sq ft. Our results indicate that we can achieve $.50/100 sq ft on average and that, as building size grows, this cost goes down. Our experience shows that in the hands of a trained user, BIM Builder has the potential to generate a BIM for an arbitrarily large facility in a relatively fixed amount of time (2-4 hours on average).

Semi-automated Context Discovery

Most building management systems produce a vast amount of information about the performance of buildings and equipment, including sensor data, equipment status, and scheduling. However, that data can be difficult to access for analytics due in part to the lack of supporting context, such as the proper name of the asset or the part of the building it affects. Quickly and cost-effectively finding and contextualizing those data points that are valuable, has been a limiting factor to developing analytics tools that can deliver new value from data generated through digital control and monitoring of equipment.

The buildings in this study included digital control devices or systems from multiple vendors, which were installed in different eras of HVAC practice and managed by different service organizations over time. Point names, the labels assigned to exposed data from a control system, are generally inconsistent sets of abbreviated concepts—human readable, but not generally machine parseable. The ways in which the same fundamental pieces of information were encoded in the data naming conventions vary widely, even within the same facility. Figure 3 provides an example of this problem.

Past experience in categorizing data with manual methods is highly variable, ranging from 8-80 hours spent to correctly identify and select the right data for logging and analysis.

Honeywell has developed an AutoContext tool to semi-automatically classify and map data from a DCS to common categories and to identify assets (equipment). This tool significantly reduces the manual effort of contextualizing raw telemetry from an existing system by as much as 80% and addresses the scalability problem posed by largely manual solutions.

Table 2: Data Labels from Disparate Systems Describing Supply Air Fan Status.

PointName
AHU_LN01Spyder2:nvoFanStatus
AHU10_LN01Spyder2:nvoSF_SS
C27_AHUF1AHU:nvoAHU_VFD_STS.state
AHU-H-1 FAN STS
AHU-H-2 SF STS
9810_AH3_SaFanSt
9810_AH4_SaFan
2450_CTL2RTU1:nvo2450_RTU1SaFan.state

Table 3 shows positive results for correctly classifying point data and identifying named equipment utilizing this method. Variability in the results stem from variability in the underlying naming convention used in the original system for each facility. Naming patterns that reduce many of the key concepts to single characters (e.g., T for Temp or F for Fahrenheit) require additional manual processing, either in tuning the processing input parameters, or in post-processing the results.

The results of this automation can be readily post-processed by a human user to validate the mapped points, and classify the remaining points of interest. Using this tool and methodology, we were able to manually complete the mapping of the desired points for building 12000 in 2 hours. This exceeded our performance goal of mapping 500 points in 4 hours, as stated in the performance objectives.

Table 3: Summary of AutoContext Processing Results

Building	2450	9810	10400	11000	12000	Total
Total Points	542	243	650	252	861	2296
Configured Points for logging+	262	91	84	252	847	1536
Auto-Context Correct Point Roles	205	77	23	51	653	1009
% Correct Role Classification	78.24%	84.62%	27%	20.24%	77.10%	
% Correct Equipment Classification	92.75%	91.21%	88.10%	10.32%	94.21%	
Time to Generate Point Roles (sec) ^	25	14	26	14	40	
+ Number of points that are mapped and available through the Building Control System, and utilized in this pilot						
^ Total Points list used in Auto-Context application						

Model-Driven Energy Intelligence (MDEI)

A critical element to deliver the value of BIM to operations is to make this integrated physical and control information readily available to an energy manager or building operator.

The MDEI User Interface (UI) provides the navigation environment that allows anyone to access relevant BIM and Energy information to explore unusual spikes in energy use and discover root causes of energy waste. By providing a means to put information about energy performance in context with the building structure and HVAC design, root causes for anomalous behavior can be more easily understood. Combined visualizations reveal the behavior of specific systems or subsystems that are affecting energy use in the facility. Figure 3 shows a composite view of a facility and a subset of the trended data from the control system.

Figure 3: MDEI View of One Facility with Subset of Trended Data for Dec. 18-28, 2013

In Figure 3, we quickly get an impression of the overall behavior of the MDEI system relative to space temperatures (light green lines), and chilled water demand for cooling (darker green line). We can see how the building responds to changes in outside air temperature (grey line), and that it is operating continuously to the same set points. We can also see which terminal units receive air from this system (lower left).

Detailed review of energy performance and the associated equipment behavior has led us to the conclusions shown in Table 4 about the energy savings potential on the subject facilities.

Table 4: Estimated Savings Potential

	Simultaneous heating and cooling	Continuous Operation	Incomplete Shutdown
Building Number	10400	2450	9810
Issues	Terminal unit behavior, including reheat and overall system operation	RTU behavior, and Gas Use for heating in vehicle bays	Scheduling anomalies
Solutions	• Improved scheduling • Retrofit improvements to air delivery to principal working space	• Improved scheduling. • Additional automa-tion on vehicle bay IR units.	• Improved scheduling
Potential Savings	18-25%	15-25%	15%
Annual Savings (kWh)	340,255	341,616	175,121
Annual Savings (MBTU)	1161	1165	597

Feedback from the energy manager at Fort Jackson was positive; however, the circumstances of the deployment environment made it inconvenient for the energy manager to regularly access the data and integrate the tool in his normal workflow. These difficulties stem largely from the isolation of control systems on dedicated networks, and the difficulty of information integration across network boundaries.

Conclusion

BIM receives a great deal of attention for new construction, but the real asset management problem is the 96.5% of existing managed facilities, many of which will be managed for another 50 years.

The value of a BIM can only be realized when the data about the building is kept current with existing conditions. It is not until the data becomes visible that it becomes maintainable. The only way to maintain the quality and value of such data is through regular use. One of the principal benefits of making BIM accessible in operations is making the BIM a living document, delivering value to operations long after the building is commissioned.

1.0 INTRODUCTION

The Building Information Model (BIM) is transforming the building industry, supporting collaboration across stakeholders via a standards-based infrastructure to share information and orchestrate design and construction. BIM-enabled advancements are precipitating change in the long-term management of buildings, including daily operations. The potential value of BIM-enabled savings in operations may be much as 15% of the life-cycle cost of the building (Watson, 2009).

BIM-driven identification and classification enables normalized access to more standardized and actionable information about asset-level energy expenditures, including the vast amount of data measured by building automation systems and other, presently isolated, information sources (see Table 5). The improved accessibility of better metrics will enable more efficient control across the DoD portfolio, helping to achieve the aggressive energy reduction goals. Simultaneously, it reduces the burden involved in the analysis and reporting required for monitoring and tracking these metrics to achieve the desired goals.

Table 5. Isolated data sources addressing facilities and assets

Source	Access
CAD/Blue prints	Print outs
Control system	Console
Maintenance records	General Fund Enterprise Business System (GFEBS) or other
Capital conditions	BUILDER and other tools in the Sustainability Management Suite

However, the majority of structures the DoD will need to manage over the next 50 years were designed with conventional 2D CAD or paper draftsmanship and lack the relational reference model that enables dramatic productivity gains over the building life cycle.

This pilot was designed to demonstrate an innovative and cost-effective method to generate a BIM-compliant contextual model, appropriate to a significant portion of the *existing structures* in the DoD portfolio (see Section 6.6). This medium-fidelity BIM, which focuses on the location and identity of assets for operations, rather than the precision and detail required for construction, provides a spatially-aware information structure to gather and more effectively utilize information about HVAC assets and their associated operating costs.

We estimated that this technology will reduce the effort to develop a BIM up to 80% over prevailing BIM modeling methods, for a significant number of DoD facilities, enabling wider deployment and use of BIM across the DoD building portfolio. The resulting BIM models may then serve a vital role in information integration and visualization.

Information interoperability is a significant benefit of standards-based digital representation of building information. We provide a gap analysis of interoperability of the information from our BIM-based tools with other tools, including:

- simuwatt® Energy Audit, being piloted on the ETSCP Program, Electronic Auditing Tool with Geometry Capture [EW-201260] (See Section 6.8)

- The BUILDER Sustainment Management System (SMS) developed for capital management by the Army, and being adopted by DoD (See Section 6.1 and Appendix J).
- The Construction Operations Building information exchange (COBie) (See Appendix F.)

The hypothesis that Honeywell has pursued in this study is that providing an integrated view of the arrangement of equipment and spaces, and the relationship between energy use and equipment behavior can lead to better insights and more effective and timely energy management interventions. By using the physical information model provided by BIM, and attaching the operational information provided by the control system, we provide an energy manager and other interested stakeholders with a ready source of rich information about how and why a building performs as it does.

1.1 BACKGROUND

The typical facility management operation is hard pressed to stay on top of day-to-day issues. Direct digital control systems (DDC) or Utility Monitoring and Control Systems (UMCS) are installed to execute and monitor the functioning of energy loads and comfort control systems in real time in some facilities. Complications stem from the proliferation of individual tools, a variety of vendor products, and specialized applications for energy management within and across DoD installations. The DoD has "pockets of excellence" and silos of data in energy management that do not scale easily across the DoD portfolio. A proliferation of individual tools and concerns may lead to uncoordinated efforts and ineffective asset management—negatively affecting overall energy costs.

Energy Awareness

This picture is starting to change with the introduction of the US Army Corps of Engineers, Meter Data Management System (MDMS). This system is designed to centrally collect whole-building energy and water meter data in the Energy Center at Huntsville, Alabama, for standardized enterprise energy analytics. This is an enormous step in the right direction, which will help the Army to understand energy use within and across installations, and track down unexpected spikes in use. However, this is only the beginning, and it will take some time for the Army to roll this program out systematically to all installations.

In the meantime, many installations have a mixed bag of energy reporting solutions. At Fort Jackson, there are 500 buildings, and 125 of these are reported to have DDC or UCMS systems. There are 249 utility meters installed on buildings; 138 of these are configured to be automatically recorded by an energy management system. However, unless the meter is needed for tenant billing, meters may no longer be reporting correctly, and data quality is questionable. Roughly 1/3 of those that were connected at some time are no longer reporting. Without regular monitoring, data connections get dropped, data gets corrupted, and value is lost. See section 5.6 for further elaboration regarding metering issues.

Asset Awareness

The first and most difficult problem in managing a portfolio of assets is to know what you have. BIM models are generated only on new building projects, or significant retrofit programs. The Whole Building Design Guide provides guidance for mining this data for later value in operations through a set of information exchange tools, such as COBie. The balance of the DoD portfolio lacking such models cannot cost-effectively reap the benefit of information exchange,

information access, and information integration, particularly with respect to spatial and operational relationships of elements within these facilities.

The US Army Corps of Engineers have developed BUILDER to help to address this gap and track the condition assessment of major assets. However, populating this data for BUILDER is still a largely manual process, and there are limits to how much data can reasonably be collected and kept up-to-date by these means.

BUILDER is part of the Sustainment Management System (SMS), a suite of web-based software applications developed by ERDC's (Engineering Research and Development Center) Construction Engineering Research Laboratory (CERL) to help facility engineers, technicians, and managers decide when, where, and how to best maintain the built environment. The SMS modules include BUILDER™ and ROOFER™ for assessing building conditions, PAVER™ for pavements, and RAILER™ for railroad infrastructure. The DoD issued a memorandum requiring the use of this Sustainment Management System across all branches in September, 2013.

[To clarify, BIM Builder is a tool developed by Honeywell that has no relationship to BUILDER or SMS, developed by the DoD. They are not related in any way, and the names are simply coincidental.]

Operational Awareness

Some of the richest and most relevant information about the operating health of existing facilities is largely locked within legacy DDC or UMCS solutions. In general practice, data produced during real-time operations (telemetry) is coherent only within the context of the original application. That is, a knowledgeable engineer can interpret the information value of a specific piece of telemetry (sensor data or system commands) by looking at a system display that provides *visual context* that a specific value in the system represents (for example) the current SupplyAirTemperature of a specific Air Handling Unit. However, the vast majority of legacy systems do not encode this information in a manner that can be exported for use by other systems.

BIM as a Mechanism to Drive Cross-functional Awareness

BIM provides a partial answer to this information integration problem for new construction, as the BIM mechanical model, combined with the architectural model, delivers a significant part of the missing context for the control telemetry, and the spatial context in which services are delivered. However, only about 3.5% of the Army facilities under active management have BIM models (see Section 6.4 for detailed analysis), and none that we know of use them for operations today. Furthermore, BIM on its own does not address the lack of standards in the vocabulary of building control.

To use tools and methods for design and construction to produce a BIM for existing structures in the DoD portfolio is likely not cost-effective. Typically, a BIM is developed by a designer skilled in the use of a BIM/modeling tool such as the Autodesk or Bentley suites of modeling tools. These tools are designed to support the construction process and provide exacting and detailed models. Traditional methods for retrospective BIM creation start with as-built 2D floor plans and other reference material. These are used by the BIM developer as “underlays” within Revit, and are traced by the draftsman. (This process is illustrated in Section 6.5.) Specifications and schedules for mechanical and other systems help the BIM developer to correctly identify and locate components within the facility spaces. This is a highly manual process. (Brucker, 2009)

Models can also be generated through laser scanning of structures; however, these visual scanning methods do not deliver the required resolution of meta-data about the assets represented in the resulting model. Laser scanning provides the geometry, but further processing is required to identify the assets of interest, many of which may be behind walls and not visible to scanners.

The persistence of this vast information maturity gap, from nearly undocumented facilities to fully populated BIMs, will have a long-term impact on the development and availability of tools designed to leverage the full power of BIM for operations. If there is only a limited market of facilities with BIM, then fewer developers and vendors will be able to find a market for tools that target this data to deliver value for operations and other building lifecycle concerns.

To address this information availability gap, Honeywell has focused on the most prevalent sources of electronic information about legacy facilities, such as as-built CAD drawings that contain much of the spatial, operational, and semantic information about specific assets depicted in the drawings, including HVAC equipment and other distribution networks. It is our belief that these sources of data may be utilized to partially automate the generation of information models with sufficient detail to support a variety of facility operations tasks. This program set out to demonstrate the feasibility and cost-effectiveness of creating a retrofit BIM for operations from CAD sources, and then to demonstrate how to utilize this data to drive improved energy awareness for facility management.

Potential Benefits

- **Fast BIM deployment**: BIM auto-generation technology will enable the DoD to use BIM in practice across the portfolio of existing sites with CAD source files. Life-cycle costs for BIM management are expected be lower due to fewer disparate tools and technologies required to generate models and the fact that BIM generation is partially automated. Further, when more applications can take advantage of a common model of the facility, the information management burden across these silos can be reduced.
- **Advanced analytics application**: Although significant energy savings can be obtained site by site without BIM, standardization to BIM semantics enables faster propagation of effective strategies from site to site and more comprehensive management across a portfolio. Standardization also allows for scalable design and easier integration of new sites into a DoD-level information architecture.
- **Effective energy-saving strategies:** With information from automation systems effectively connected to the context provided by BIM, identification and application of energy-saving strategies is more efficient and effective.

1.2 OBJECTIVE OF THE DEMONSTRATION

The objective for this program was to demonstrate that a retro-fit BIM can be produced cost-effectively, and that this standardized information model of the building and its assets can provide essential context for data collected from control systems. This missing context allows the information produced by real-time sensors to be used more widely and effectively for energy and asset management. Further, by providing this context in an integrated visualization, energy managers and facility managers can better understand the causes and effects of equipment performance issues.

Figure 4 provides an overview of the demonstrated MDEI solution.

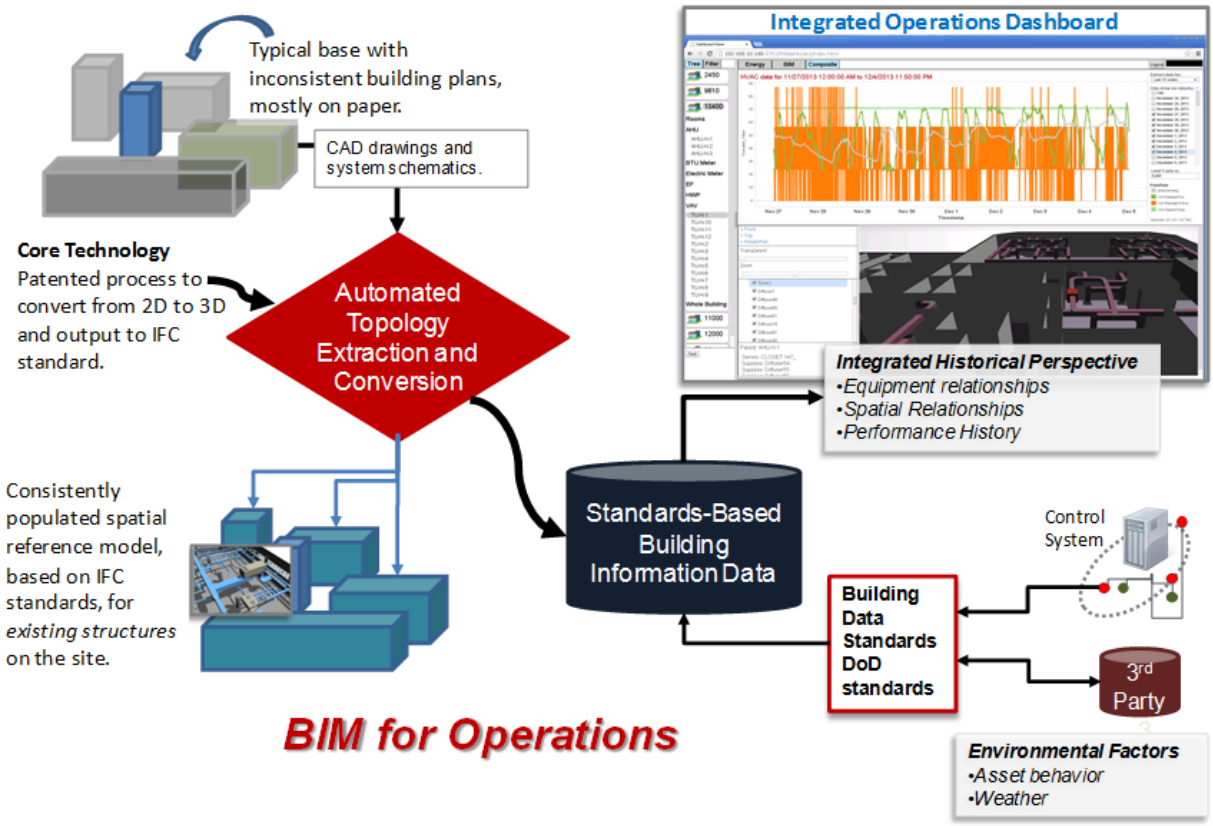


Figure 4: Conceptual Overview of Model-Driven Energy Intelligence

The program was designed to implement the following steps in information integration and presentation, to improve facility operations.

- **Partially automate the generation of a BIM suitable for operations in a legacy building, by incorporating and transforming CAD data from a 2D drawing to an IFC standard model.**
  Goal: Reduce the development cost of a BIM for operations by 80%.
  Result: We demonstrated that our tools are highly effective when sufficient CAD data is available. Applied to buildings of sufficient size and complexity in this pilot (>45K ft^2), our scalable approach exceeded the 80% cost reduction goal for BIM development. For smaller or less complex structures, our solution is comparable to prevailing BIM development techniques. The detailed findings are presented in Section 6.5 and in Appendixes G and H.
- **Partially automate the correlation of data from legacy sources (e.g., control systems) to assets identified within the BIM.**
  Goal: Reduce the level-of-effort to map data from legacy systems by 50% or more.
  Result: We demonstrated automation that vastly reduces the manual effort for typical systems (those with some human-readable descriptions on exposed variables) and results in an average point identification success rate of 57.44%, and an average equipment identification success rate of 75.21%. This reduces the manual effort to identify interesting telemetry to manageable levels. See Section 6.6 for a detailed discussion.
- **Demonstrate the additional value that information fusion can bring to energy decision-makers through visualizations that provide rich context within an information model that is aligned to BIM concepts.**

Goal: Increase the productivity of decision makers by at least 10%, as measured by number of buildings served or opportunities identified.
Result: The study highlights specific benefits of data integration, but it was not possible to gather statistically-relevant data about the effect on energy manager productivity in this study.

1.3 REGULATORY DRIVERS

The technology demonstrated in the project addresses these regulatory drivers:

EO 13327: Section 3.b.ii.

This section prioritizes actions for improving the operations and financial management of the agency's real property inventory.

Technology Solution: Adhering to BIM standards helps meet this driver, and the technology to be demonstrated offers an improvement over traditional, fully manual, and error-prone survey collection methods.

EO 13423: Section 2.

This section is designed to help (a) improve energy efficiency and reduce greenhouse gas emissions of the agency, through reduction of energy intensity by (i) 3 percent annually through the end of fiscal year 2015, or (ii) 30 percent by the end of fiscal year 2015, relative to the baseline of the agency's energy use in fiscal year 2003.

Technology Solution: Using BIM-enabled technologies (1) eases the implementation and usage of an energy management system; (2) quickly identifies environmental compliance for energy consumption; (3) provides detailed performance evaluations through improved data integration; and (4) allows managers to easily create award programs based on performance by supporting more detailed information about performance at specific functional levels/locations.

EO 13514: Sections 2.a.i, 2.g, 8.e and 8.f

This executive order for Federal leadership in environmental, energy, and economic performance requires that all new Federal buildings achieve zero-net-energy by 2030.

Technology Solution: The key point of this driver is reduction of energy consumption. The demonstration provides clear direction for reducing energy consumption, including the fundamental data structures to support metering or virtual metering of specific energy loads, and relationships between load-contributing assets, leading to more actionable information about energy consumption.

Detailed information about energy demand on the base allows for more effective use of local and renewable energy sources, providing for better energy security and mission readiness in a net-zero environment.

Federal Leadership in High Performance and Sustainable Buildings Memorandum of Understanding: Section I, II and IV.

Technology Solution: By adhering to BIM-based standards, the principles of building commissioning (I) can be followed. Optimizing energy performance (II) is available through the demonstrated technology's visualizations of energy data. Finally, by having detailed building energy system device data, specific aspects of indoor environmental quality (IV) can be tightly controlled.

ASHRAE 189.1

Standard 189.1 offers overall reduction in energy costs over earlier standards through the addition of renewable energy, peak load reduction and other improvements.

ASA-IEE Net Zero Directives

The Net Zero approach consists of five interrelated steps: reduction, re-purpose, recycling and composting, energy recovery and disposal. A Net Zero Energy installation produces as much energy on site as it uses, over the course of a year. Solutions to reduced and maintain a lower load overall are critical to the success of Net Zero strategies.

Energy Independence and Security Act (EISA), Public Law 110-140 (2007)

The Energy Independence and Security Act of 2007 (EISA) reinforces the energy reduction goals for federal agencies put forth in Executive Order 13423, as well as introduces more aggressive requirements. The three key provisions enacted are the Corporate Average Fuel Economy Standards, the Renewable Fuel Standard, and the appliance/lighting efficiency standards.

Technology Solution: This demonstration directly supports the efforts of local energy managers to better understand and control appliance/lighting efficiency at DoD installations.

1.3.1 Other Resources for Guidance from DoD Regarding Sustainable Buildings

Whole Building Design Guide

This program made use of resources compiled by the Whole Building Design Guide (WBDG), particularly with respect to the identification of information specific to HVAC, as defined by BIM standards and by Construction Operations Building Information Exchange (COBie). The goal of this program is to show how these guidelines can be applied or extended to address data relevant to operations, and to ensure that the data produced on this program is interoperable with data produced through other channels, by ensuring adherence to appropriate standards.

2.0 TECHNOLOGY DESCRIPTION

This section describes the technologies underlying the piloted solutions.

2.1 TECHNOLOGY OVERVIEW

The Model-Driven Enery Intelligence (MDEI) pilot made use of Honeywell-developed tools for generating building models and integrating data and contextual information into the model. The following paragraphs describe the BIM Builder, the Auto-Context semi-automatic context discovery system, and the MDEI user interface (UI) used to present the data and context.

BIM Builder

Honeywell developed an innovative system, BIM Builder, to generate a medium-fidelity BIM from legacy documents and information gathered about a facility. The generated BIM adheres to Industry Foundation Classes (IFC) standards of description but is focused on identifying a specific subset of data for operations, rather than a detailed and precise plan for construction.

Figure 5 illustrates the BIM Builder approach, which largely automates the population of the basic geometry and the recognition of significant concepts, such as those identified by COBie and other standard data sets; it combines those data into a unified building context—without the need for draftsmen or countless hours of manual data entry and manual validation.

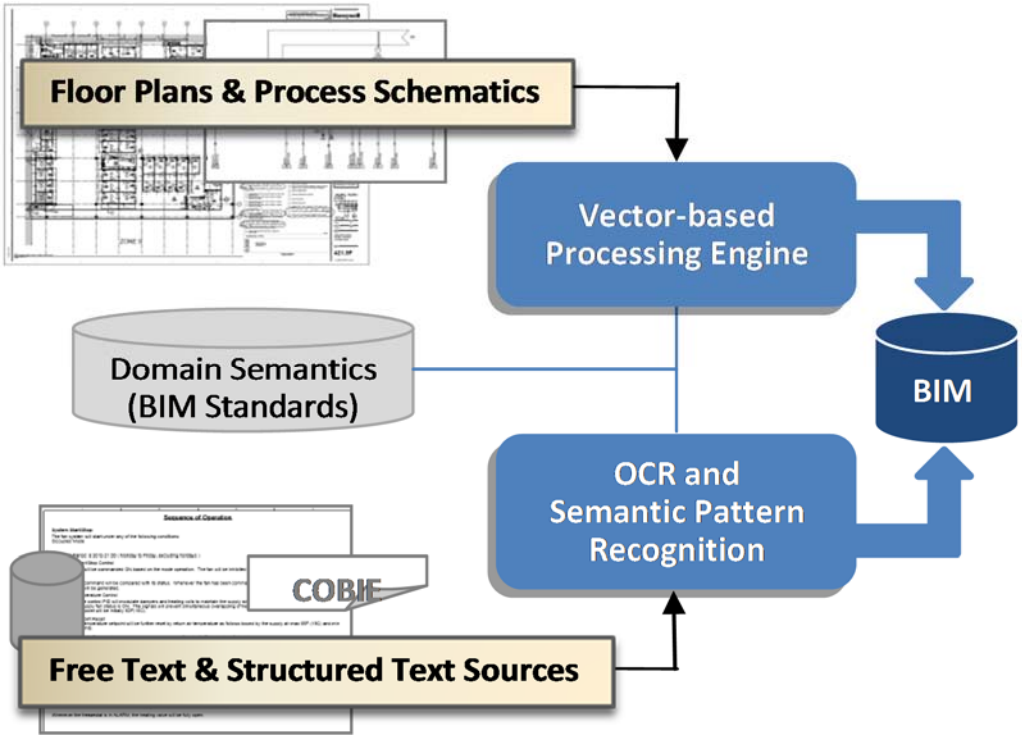


Figure 5: Identification and Extraction of Building Context into BIM

Honeywell invested in technology to extract 2D geometry and match elements to the domain semantics provided by the IFC, and then convert them from 2D to 3D geometry. This innovation is significant, because most 2D geometry sources describe only a set of vectors that have no semantic description and have neither type nor identity. Figure 6 illustrates this process.

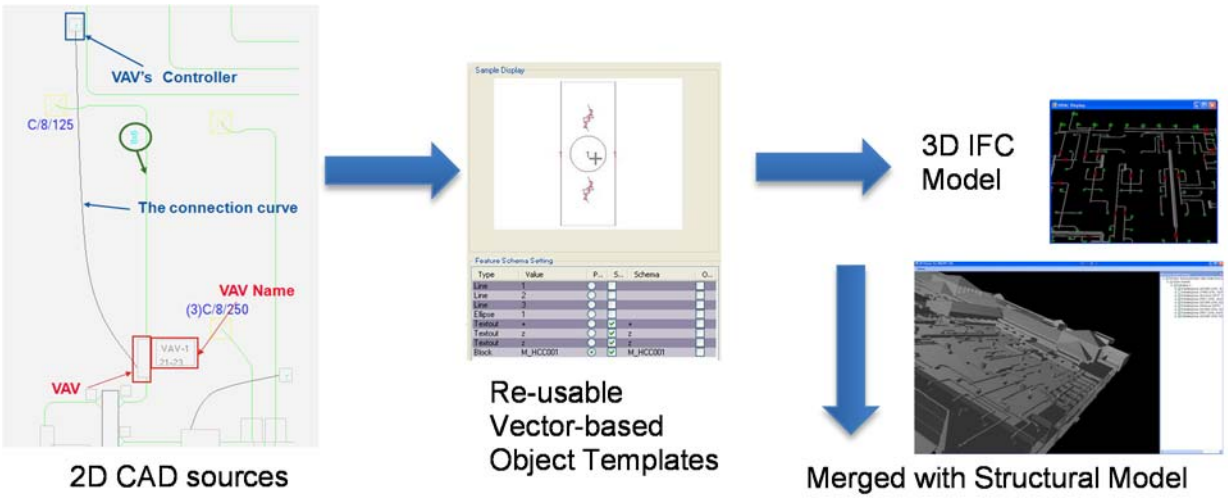


Figure 6: Process Overview for the Partially-automated Development of BIM from CAD

Further context and network structure can be extracted through semantic matching from other text and electronic sources of information about the site, including the control system. By employing data fusion techniques we can improve both the accuracy and content of the automatically-generated BIM. Details of this process are described in Appendix B.

The generated BIM (Figure 7) can be IFC and COBie compliant, thus making the data content of the model available to any system using these standards (e.g., AutoCAD, Revit, BIMserver, and other commercial and open-source tools).

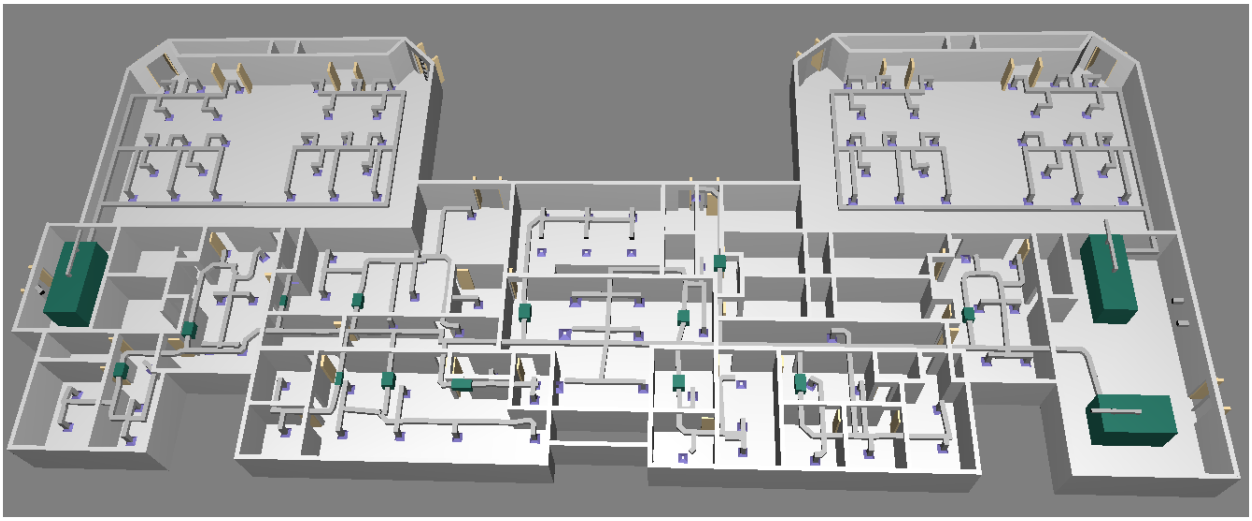


Figure 7: Generated BIM for Fort Jackson facility

Automatic Context Discovery for Control Information Integration

Data available from building controls can provide very specific insight into how building systems are behaving and what impact the behavior of individual assets may be having on occupant comfort or energy use. Unfortunately, this data can be hard to access for regular and repeated evaluation by an energy manager.

Honeywell developed the Auto-Context application to leverage patented algorithms and techniques, to classify and map DCS points to common categories and to identified assets (equipment) using a partially-automated process which leverages semantic standards.

The application accepts a list of point names (exposed variables) from a BMS installation, and processes these into a structure that allows patterns in the naming convention to emerge. Algorithms identify and map the unique tokens in the local naming convention, according to domain rules. The results are queried against a standard set of system aspects to find the best matching description of the point and its role. To improve the confidence of matching tokens to concepts, the algorithm allows for the user to provide a 'Lexicon,' which is a simple relational table of common terms found in the domain to which the points belong, e.g. "AHU" means "air handling unit." This approach is flexible, both to the subject or domain of the system (e.g., security vs. HVAC) as well as to the language used in the system configuration (e.g., English vs. Spanish, or vendor-specific or region-specific conventions). It is robust to most control system types, so long as some human readable description or name is present for processing.

As part of the tokenization process, each point is mapped to the most likely named entity (e.g., AHU-1), and that entity is identified by type. Tokenization supports mapping to entities (equipment) identified through the BIM Builder process, enabling the necessary link between DCS point data (telemetry) and structured BIM data. The result is a scalable solution that reduces the manual effort of contextualizing the raw telemetry from an existing system.

MDEI User Interface

Information about structure can lead to further insights about how systems interact with each other, either through the arrangement of spaces, orientation and solar gain, or other concerns. Typically, the facility manager or energy manager must use a vendor-specific console to access trend data, but such consoles are typically designed to support local, near-term trouble-shooting, rather than the discovery of long-term patterns of operation.

Facility managers can also turn to CAD drawings, their own recall of a facility, or in modern buildings, they may have access to a complete BIM. Especially with large campuses, it is difficult to retain working knowledge of the layout of every building subsystem or know which systems affect comfort in a specific location.

While these sources of data have been available to energy managers for some time, they can rarely be referenced simultaneously for a complete picture of building operations or for easy, regular viewing. While energy managers may take the trouble to collect data from these sources from time-to-time for a specific snap-shot analysis of operations, it is not typical for an energy manager to have on-demand access to integrated information.

By using the physical information model provided in the BIM and attaching the operational information provided by the control system (through the Auto-Context context discovery process), we can provide rich information about how and why a building performs as it does. The MDEI UI provides the navigation environment that the energy analysts and energy manager utilized to access BIM and energy information, as shown in Figure 8.

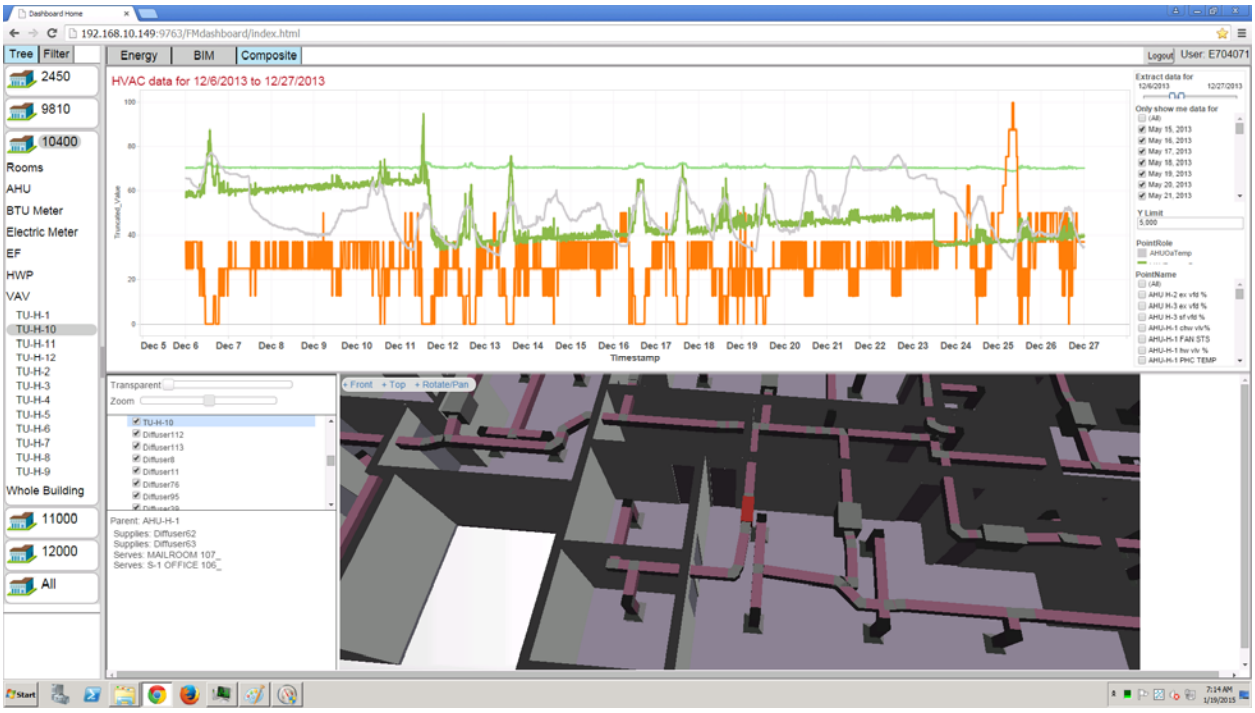


Figure 8: Integrated view of BIM and UMCS Data in the MDEI UI

The entire interface was constructed as a web service, built using HTML, CSS and JavaScript™, and therefore the client (user) only requires a web browser to access it. However, during this pilot project, only Firefox® and Chrome browsers successfully display the 3D BIM, as they natively support WebGL™ technology. The user interface (UI) environment is detailed in Appendix C.

The interface is completely web-enabled, served through an Apache™ Tomcat™ web server, with basic page elements written in HTML and supported by JavaScript libraries. The textual navigation menu on the left is basic HTML list-elements, the top half of the view is generated by Tableau® through its JavaScript API, and the bottom half is BIMSurfer views of the building .json data files.

Data-driven navigation in the MDEI UI is dynamically constructed based on the spaces and assets identified by the BIM; therefore, the UI does not need to be rebuilt when additional buildings or assets are added to the ecosystem.

Building navigation is accomplished through either the data-driven menu or the 3D BIM model. Appendix H discusses the process of generating, displaying and navigating these 3D models through the web interface.

2.2 TECHNOLOGY DEVELOPMENT

The BIM Builder tool is the result of several years of investment by Honeywell. No DoD funds were used in the development of this tool. However, as we encountered issues with the CAD files we received for Fort Jackson, Honeywell funds were used to improve BIM Builder to address the requirements that were made evident in the DoD CAD sources.

Processes and algorithms for automated context discovery were developed by Honeywell prior to the pilot, and exercised on data from the Fort Jackson facilities. No program funds were spent on the development of this approach.

Prior to deployment, Honeywell configured a pilot-specific web environment for navigation of the data made available to the energy manager. The details of this pilot dashboard (Figure 8) for Model-Driven Energy Intelligence are provided in Section 5 and Appendix C. The architecture of this web-based application is fully explained, and the provided visualizations are also described. For the most part, the team used commercial, off-the-shelf (COTS) tools to construct this dashboard, providing the final linking mechanism between sources of data to be integrated for the energy manager.

2.3 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

Process Requirement: Generating a medium-fidelity BIM suitable for energy and asset management for operations, for legacy facilities.

- Most typical current practice: Someone familiar with commercial 3D BIM modeling tools can use legacy CAD drawings as an underlay to place objects in a new 3D model. These objects must also be manually identified/labeled.
- MDEI Approach: We semi-automatically extract the necessary contextual information about spaces and equipment from 2D CAD using BIM Builder, including the names or labels embedded in the CAD source, and express this information using BIM standard representation (IFC).
- Advantages:
  - The BIMBuilder tool and methodology reduces the cost to model very large facilities due to economies built into the automation. Modeling efficiency improves as the size of the building to be modeled increases.
  - Using a common description for the Building makes this data more widely available for multiple purposes.
- Limitations:
  - On buildings under 45K sq ft, the BIMBuilder method may be equal in processing costs to using the typical current practice of placing objects using commercial 3D tools.
  - The effectiveness of BIM Builder can be affected by the quality and validity of the CAD sources that are available. For buildings with no CAD in .dwg (digital) format, this process can't be applied.

See Section 6.1, Appendix F, and Appendix G for a deeper discussion of the related technologies and pilot activities and findings.

Process Requirement: Identifying and mapping data about equipment behavior and performance from legacy DCS systems and associating that data with named assets and spaces.

- Most typical current practice: Someone familiar with the building and the energy management problem must manually comb through the available data sources, and document the relationships between each data point and the related equipment and/or spatial assets that describe its context.

- MDEI Approach: We semi-automatically extract the necessary contextual information about spaces and equipment from the naming conventions used by the DCS system at the site. AutoContext assists the user in quickly associating this data to the right assets as identified in the BIM.
- Advantages:
  - Using AutoContext we can significantly reduce the manual effort of sifting through large numbers of possible variables exposed by control systems to quickly identify and link the useful data for energy and asset management.
  - The process is not dependent upon having a BIM, so it can be used in any case that entails classifying large quantities of DCS data that is not well described.
- Limitations:
  - Some DCS systems are deployed with naming conventions that cannot easily be addressed by automation, such as those that use numbers as identifiers, or those that make heavy use of single characters in the naming convention

See Section 6.4 for further discussion of these issues.

Process Requirement: Identifying the root cause of unusual energy use in a facility.

- Most typical current practice: Someone familiar with the building and the energy management problem must review data from several sources and several systems to collect the information necessary to troubleshoot. Usually, this process starts with whole building energy and then progresses to investigation of how the DCS is programmed to manage comfort and energy. Sometimes it requires looking at CAD drawing of the building or visiting the building to obtain enough information to understand underlying causes.
- MDEI Approach: We bring together all the information sources that an energy manager can use to troubleshoot causes of energy waste or other operating problems in a building, into a single, browseable interface for easier remote investigation.
- Advantages:
  - By using BIM as a means to integrate, navigate and understand the relationships between the equipment and spaces, it is possible for the energy manager to easily connect performance issues with specific behaviors occurring in the facility, and to immediately see the unique aspects of the building systems and functions that might be hard to discern otherwise
  - The data from all these sources is unified by using the physical model to aid understanding, and mask the vendor-specific implementation differences that can make investigations more difficult.
- Limitations:
  - The solution can only deliver value when it becomes an integral part of the energy management process.
  - Network issues, information management requirements, and isolated legacy control infrastructures are significant barriers to integrating data into a single environment, .

- Appropriate 3D navigation interactions still need to be addressed for casual users of 3D models. The the default behaviors of the available COTS tools employed in this pilot are not optimal for our use cases.

These issues are discussed further in Sections 5, 6.2, 6.3, and Appendix J.

3.0 PERFORMANCE OBJECTIVES

Table 6 and Table 7 present the qualitative and quantitative performance objectives along with the performance metric and the success criteria for each of the identified objectives. In every case, more detailed results are provided in Section 5 (data collection and metrics) and Section 6 (detailed performance results).

Table 6: Quantitative Performance Objectives

PO1: Produce a functional BIM for operations through a semi-automated generation process.			
Metric	**Data Requirements**	**Success Criteria**	**Results**
Level-of-detail (LOD)	Assessment against LOD requirements for energy management use cases. 2D CAD floor plans and MEP.	BIM supports the data required for specified energy management use cases. These use cases are described in Section 6.1	The expected LOD goal was met. However, the evaluation conducted by the ERDC-CERL team revealed some required improvements to IFC export to support data integration using IFC and COBie. See Section 6.1 and Appendix F.
PO2: Asset-level energy intelligence impacts energy use in managed buildings.			
Metric	**Data Requirements**	**Success Criteria**	**Results**
Meter data (BTU/ft2, or kWh/ft2)	Asset and system performance data; meter data at building/asset level. Duration of each abnormal energy use event. Re-occurrence of abnormal energy use events. Track use of tool, and logged identification of issues.	Reductions in energy use by 10-20% from existing baseline use, due to faster and improved responses to abnormal energy use patterns.*	We estimate that it is possible to achieve 15% or better energy intensity reductions based on observed behaviors described in Section 6.2, however, no substantial remediation was taken as a direct result of our recommendations during this program. Therefore, the savings can't be substantiated by experience on this pilot.
PO6: Partially automated identification and standardized classification of control points.			
Metric	**Data Requirements**	**Success Criteria**	**Results**
Time required to correctly classify 500 points relevant to advanced analytics	Control system points with typical inconsistency in naming such as the use of capital/lower case, the use of spaces or special characters as concept delimiters, and inconsistent concept abbreviations. E.g. Bldg1_AHU3_RetTemp and B1_AH4RATmp have the same classification but are inconsistently identified.	Enable correct identification and classification of pertinent telemetry from one or more buildings within 4 hours.	We demonstrated that AutoContext can be used on systems with wide variation in naming conventions to significantly reduce the manual effort required to identify and map points for use in energy management. We met the goal of showing that we can map 500 points of interest in less than 4 hours, and expect that this approach can be improved upon.
* Since Honeywell can't control whether energy savings measures are actually implemented, we separate the identification of actionable energy savings practices from implemented energy savings practices.			

Table 7: Qualitative Performance Objectives

PO3: Improve energy manager visibility into building performance data.			
Metric	**Data Requirements**	**Success Criteria**	**Results**
Percent of pilot buildings reviewed per month using BIM and energy data	Quarterly user interview to assess frequency of viewing and value of information. Note resulting actions.	Building energy usage reviewed monthly using BIM and performance data; information perceived as useful.	The energy manager did not regularly review the buildings. The reasons for this are discussed in Section 6.3.
PO4: Transferability of conservation measures to other like assets.			
Metric	**Data Requirements**	**Success Criteria**	**Results**
# of assets that are candidates to benefit from monitoring for a specific operating anomaly	DPW Response regarding the benefits and feasibility to implement the monitoring methods for other buildings at the installation. Catalog asset inventory to assess transferability of energy measures to other similar assets across DoD.	In at least 50% of cases, a monitoring approach can be applied to at least 50% of similar monitored assets in DoD Facilities. The team concluded that roughly 69K DoD facilities of the 176K total that require conditioning could benefit from monitoring for the noted ECMs.	According to the analysis conducted by ERDC-CERL on DoD active inventory, approximately 40K existing facilities, or those expected to be constructed in the next few years, are likely candidates for the demonstrated approach. These are buildings of sufficient size, that are likely to have CAD or BIM, and digital control, and benefit from the ECMs applied in this pilot. This is slightly more than half of the potential candidates for monitoring.
PO5: Efficiency of the BIM tools for effective site survey and Medium-fidelity BIM generation.			
Metric	**Data Requirements**	**Success Criteria**	**Results**
Square feet of buildings per hour of BIM developer time	Productivity data: Tracking in the BIM tool to monitor rate of completion. Self-reporting by users. Survey and observe users.	An experienced user produces the BIM at ~20% the typical cost of a BIM produced by traditional means (Brucker, 2009).	Our goal was to show that we could drive the variable costs (labor) of producing a BIM to $1.00 / 100 sq ft. Our results indicate that on average, we can achieve $.50/100 sq ft, and that as building size grows, this cost goes down.
PO7: Conduct gap analysis of the content and quality of data represented in the generated BIM with respect to BUILDER database			
Metric	**Data Requirements**	**Success Criteria**	**Results**
Level-of-detail and consistency of data with BUILDER data requirements	Generated BIM BUILDER data definitions or templates for data collection.	Demonstrate that the generated BIM data is an appropriately defined subset of the data required for BUILDER objectives and can be used to populate BUILDER data fields.	The investigation conducted by ERDC-CERL revealed shortcomings in the export format of the information collected in BIMBuilder. Honeywell estimates that these issues can be remediated at low cost to support direct compatibility.

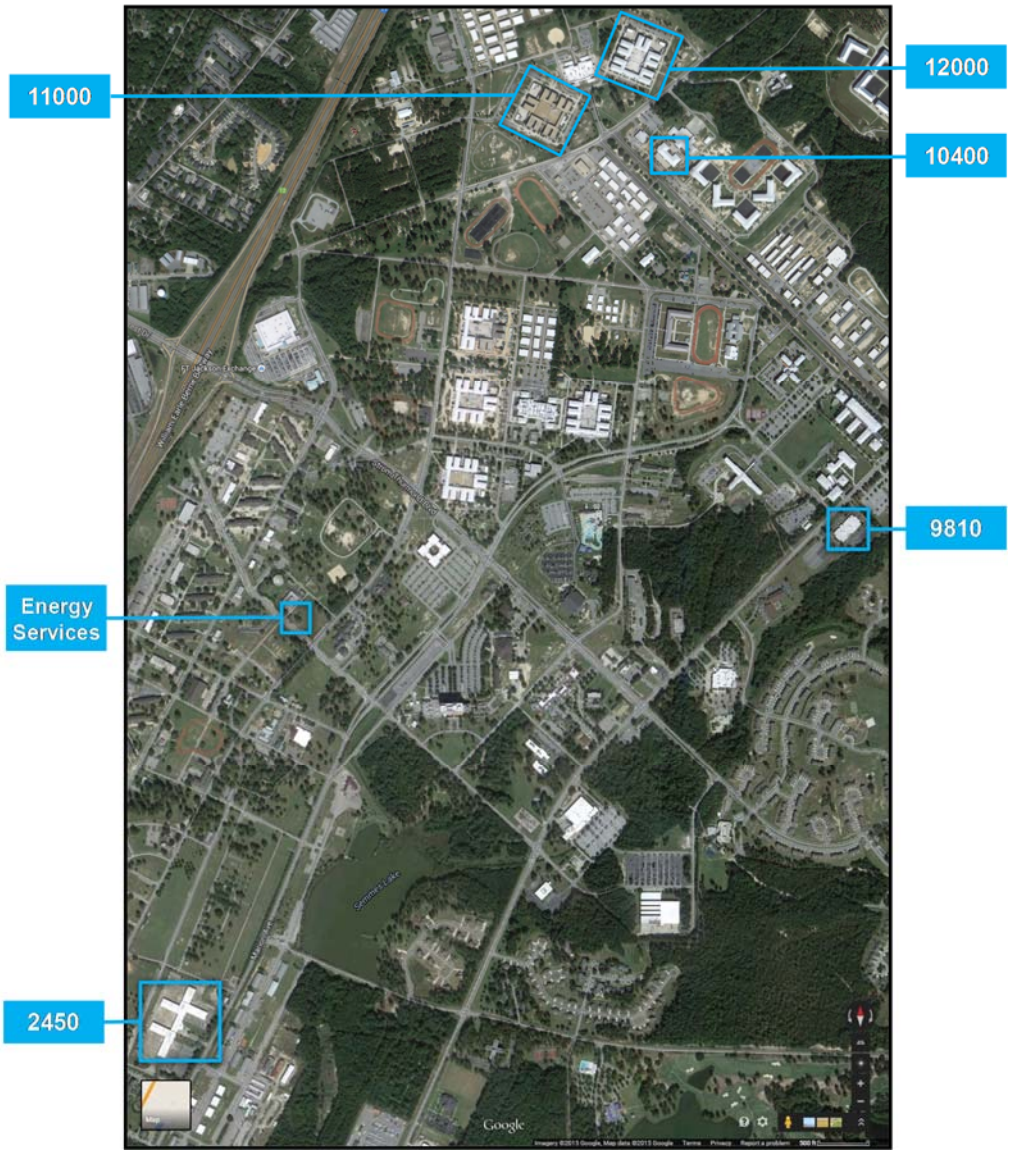
4.0 FACILITY/SITE DESCRIPTION

This section describes the selected demonstration site at Fort Jackson near Columbia, South Carolina.

4.1 FACILITY/SITE LOCATION AND OPERATIONS

Fort Jackson is a large post near Columbia, South Carolina, with a primary mission of training. There are more than 1000 buildings within the developed regions of the Fort. Keeping buildings running consistently is particularly challenging because a large part of the population is transient.

The view of Fort Jackson in Figure 9 highlights the buildings used in the MDEI demonstration.



Imagery ©2015 Google. Map data ©2015 Google.

Figure 9: Layout of Fort Jackson

The commander of the DPW is Col. Tom Robertson, and our principal point of contact for the project was the Energy Manager, Matt Gibbs (civilian). In addition to command support, we were supported on-site by Honeywell staff under contract for energy services at Ft. Jackson.

Figure 10 illustrates the energy conservation challenge at Fort Jackson. While Fort Jackson energy trends are improving, the installation is failing to meet the projected goals. From 2007 to 2009, the site's total energy consumption (MBTU/KSF) consistently increased year-after-year, exceeding baseline levels set back in 2003. The red line indicates the Energy Usage Goals mandate, a steady decrease in energy demand of 3% year-over-year, or 30% by 2015.

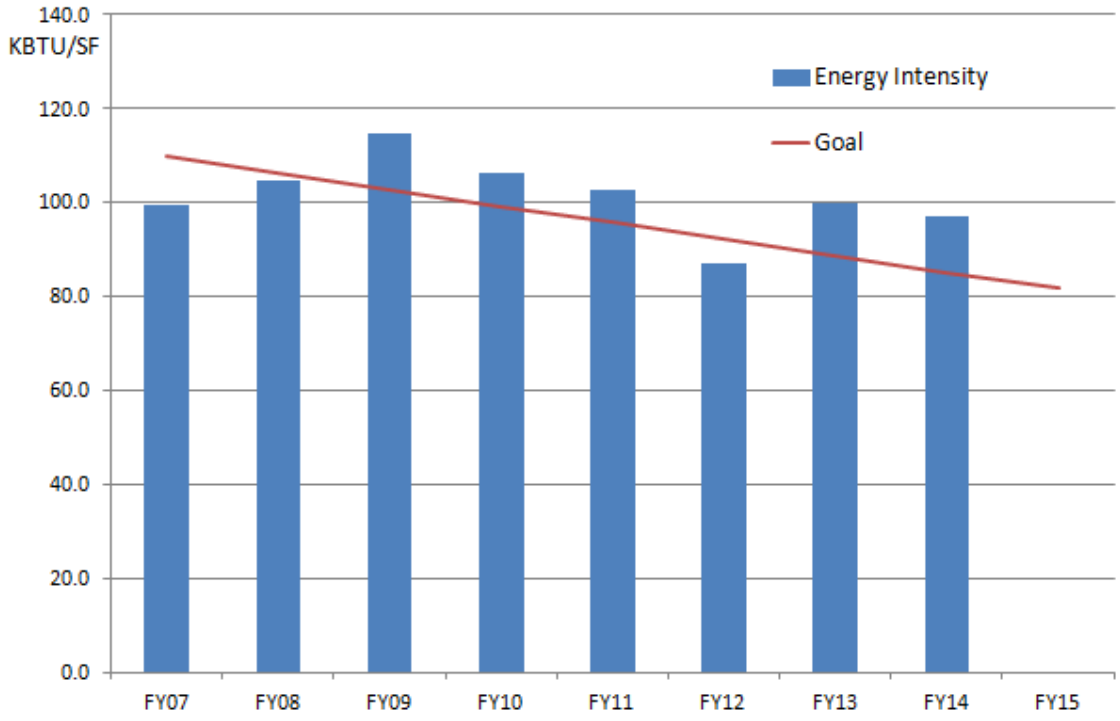


Figure 10: Fort Jackson Energy Use Trend

Figure 11, which is based on 2011 consumption, shows how the annual energy consumption is distributed across several structural categories, based on sub-metering at the site. The consumption in the energy plant is for producing chilled water and pumping energy (hot and cold) to all the facilities they serve. For barracks and administrative buildings, the power consumed is from plug load, pumping, fan energy, and lights. The "All Other" category includes all buildings without meters; all the DPW facilities, Post HQ, DOL, ranges, and many small classrooms and facilities. Reimbursable is the hospital and family housing and includes the PX, commissary, the banks on post, and other enterprises that are billed for their utility use.

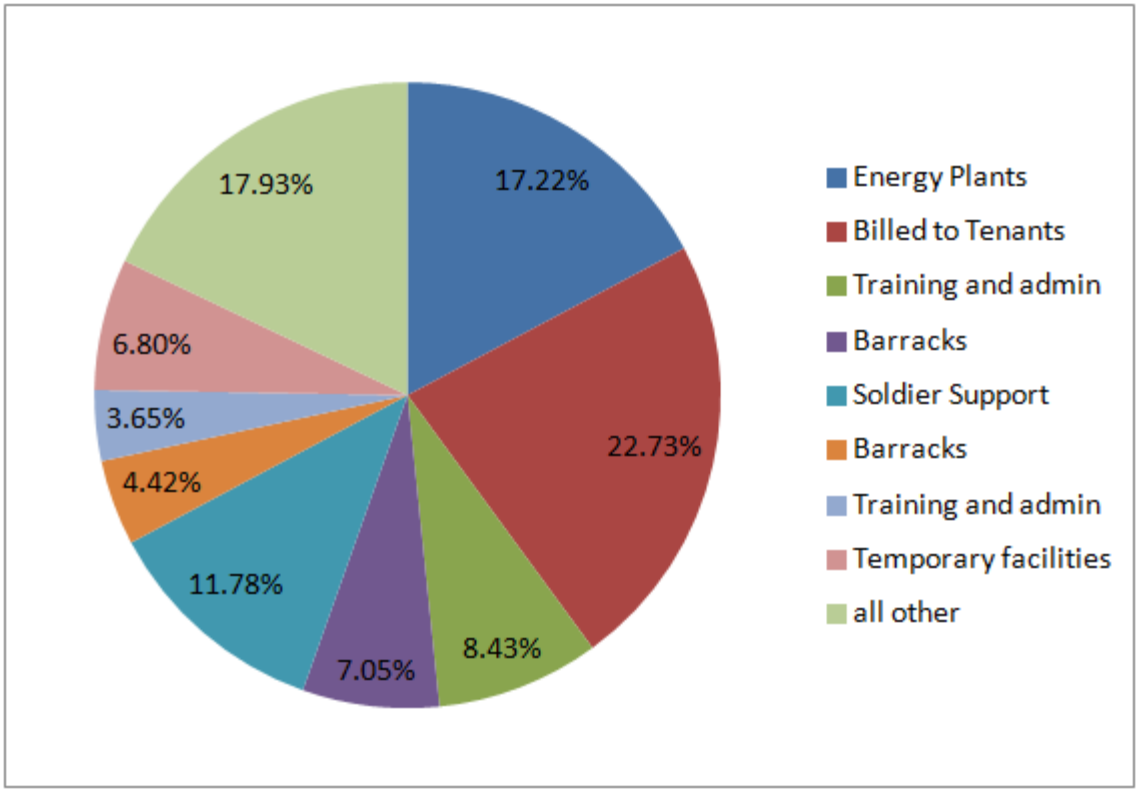


Figure 11: 2011 KWH Distribution for Fort Jackson

In cooperation with the Fort Jackson Energy Manager, the team selected five buildings on the Fort that could support demonstration objectives, and were interesting for the purposes of this pilot. Table 8 summarizes the facility selection criteria. The buildings selected for this demonstration are listed in Table 9.

Table 8: Building Selection Criteria

Instrument Criteria	Facilities are already instrumented with DCS-based control and monitoring solutions and energy metering.
Energy Data	Utility use and related historical energy interval data are readily available at the whole building level
BIM	Access to CAD files for the facility/structure, or a structure built from the same fundamental design.
Representativeness	The selection of facilities included buildings of different types, uses, and complexity to illustrate that the techniques we apply are not limited to a single type of facility.
Other Selection Criteria	Other criteria include: ready-access to the facility, access to the control system data from the building.

Table 9: Selected Buildings at Fort Jackson

Building Number	Building Usage Category	Building Automation System	Estimated Area Sq/ft	CHW Source	HW Source
11000	Barracks	Honeywell	290,481	Plant 2/ Zone 2	Plant 2/Zone 2
12000	Barracks	LonWorks	290,481	Plant 2/ Zone 2	Plant 2/Zone 2
10400	Office/Admin	iNet™/TAC	23,178	Plant 4	Plant 4
2450	Maintenance	Honeywell	125,000	AC Units	Stand-alone
9810	Office/Admin	Honeywell	37,310	Stand-alone	Stand-alone

These five buildings provided a good cross-section of the various types of facilities on the Fort. One reason Building 10400 was selected for this project was to demonstrate that our practices and solutions generated during the pilot have the ability to work with other manufacturer's automation systems. Buildings 9810 and 2450 provided a case for understanding energy data for a facility which is not served by a central plant. Finally, buildings 11000 and 12000 would enable research capabilities for like-structures.

During development of the demonstration plan for this project, the DPW Energy Manager (EM) was consulted on various aspects of the five selected buildings, as well as his day-to-day job requirements and miscellaneous activities. The EM was genuinely concerned about energy usage across the Fort, and was working on re-instituting building-level energy managers, as well as providing a training program for these personnel. Ultimately, the EM had to coordinate directly with the Building Commander for each building, and was not able to institute his program during the course of the pilot program. We coordinated with the Building Commander or his/her point-of-contact (POC), when we required information or access to the building. All five POCs mentioned that their role as the building's energy manager was an 'additional duty', and not their primary function. Generally, these building energy managers do not understand the operation of HVAC systems, and energy conservation tends to be prioritized very low on their list of operational objectives.

4.2 FACILITY/SITE CONDITIONS

There were two major issues encountered at the site during the pilot project. Beginning around March 1, 2014, the DPW contracted another vendor to remove and replace all air handling units and one boiler at building 9810. This is evidenced in the data quality figures (reported in Section 5.6) and resulted in significant drops in the collection of point data from 9810.

Another significant data collection issue was identified with buildings 11000 and 12000. Several aspects with the commissioning of these buildings were not completed. The gas and electric meters were never fully commissioned in 12000 and data transmission from some field control devices (certain HVAC equipment) was never established in 11000. We worked with the DPW and the responsible parties to get these systems online, but were not entirely successful. Due to this very incomplete energy data, we are unable to provide energy analyses for these facilities. This situation was reported to the ESTCP program management office in June, 2014. By mutual agreement, we adjusted the demonstration expectations to address the missing data.

Table 10 summarizes the last status of utility metering as of 1 September 2014.

Table 10: Meter Data Availability at Pilot Facilities

Building	Gas Meter	Electric Meter	BTU Meter	CHW Data	HW Data
2450	Good	Good	n/a	n/a	n/a
9810	Stopped reporting	Good	n/a	n/a	n/a
10400	n/a	Good	Good	Temps only	Pump Status & Temps
11000	Bad Data: All values are 0	Good	Good	Pump Status & Temps	Pump Status & Temps
12000	Not Available	Not Connected	Good	Pump Status & Temps	Pump Status & Temps

Our experience on this pilot reflects the general status of the metering infrastructure at Fort Jackson, described in Table 11. Local site staff report that roughly 1/3 of the installed meters noted below are no longer reporting because of the lack of maintenance of these systems.

Table 11: General Condition of Metering Services at Fort Jackson

Meter Type	**Number of Meters**	**Percentage "Advanced"**	**Data Collection**		
			Manual Readings	**LAN Connected**	**EMCS Connected**
Electric	185	63%	68	117	117
Gas	42	50%	21	21	21
Water	22	0%	22	0	0
TOTALS	249	n/a	111	138	138

5.0 TEST DESIGN

The vast majority of DoD buildings are difficult to manage due to a lack of order in collecting and managing information about them. The current DoD emphasis is to upgrade existing buildings rather than building new ones. Creating a BIM with current tools to aid collection and management of information can be expensive. This demonstration was intended to show a practical way to create and manage BIM for legacy building management at a reduced cost.

A great deal of building/equipment behavior information could be made available that would improve energy management for legacy structures with DCS systems. However, this data is not collected and organized in a way that facilitates effective decision making for long-term energy management and related capital decisions. This demonstration showed how BIM-driven energy data can be made more available and visual to enable effective energy management.

Two overarching questions embody the goals of the test design:

Q1: Does the BIM Builder tool reduce the cost of generating a useful medium-quality BIM as compared with traditional means?

Q2: Does providing BIM-driven visualizations deliver the context for energy usage and consumption needed to drive action to reduce energy waste?

5.1 CONCEPTUAL TEST DESIGN

The test design was structured around the two research questions presented above. Each performance objective is directly related to at least one of the questions.

Q1: Does the BIM Builder tool reduce the cost of generating a useful medium-quality BIM as compared with traditional means?

Hypothesis

The BIM Builder will produce a medium-quality BIM at approximately 20% of the typical cost (Brucker, 2009) of delivering a retrofit BIM with a comparable level of fidelity. We further expected that BIM Builder would produce a medium-quality BIM more quickly and more accurately than other techniques. The reduced cost of generating a BIM should lead to sufficient ROI to enable the DoD to use BIM in the effective management of both old and new structures and related assets

Related Performance Objectives:

PO1: Produce a functional, medium-fidelity BIM for asset management

PO5: Efficiency of the BIM tools for medium-fidelity BIM generation

PO6: Partially automated identification and standardized classification of control points

PO7: Transferability of data from the BIM to the BUILDER SMS program for asset assessment

Test Design

Conceptual testing was designed to show that the tools being piloted support the generation of a BIM that:

- Can be generated at a low cost, with sufficient detail and accuracy to support energy management use cases.
- Is consistent with BIM standards and can be exchanged with other tools that use BIM standards.
- Delivers information that can be readily utilized for DoD asset management.

Test Phases

Phase I: BIM generation: The outcome of this task was the collection of all necessary data, requirements, and artifacts, including CAD source files, in order to construct the BIM, initial models for the site, and statistics related to the time/cost for BIM generation.

Phase II: BIM validation: The outcome of this step was a validated functional BIM for operational use for each of the pilot facilities, with all gaps assessed and addressed.

Phase III: Enhance BIM with building automation references: The outcome of this task was a fully representative, BIM-consistent model of the data to be used for analysis and visualization.

Phase IV: Assessment of efficiency of the Honeywell BIM Builder tool with representative DoD employees: The BIM Builder tool was exercised in a controlled setting with ERDC-CERL participants. The findings of this exercise are described in Section 6.5.

Phase V: Assessment of transferability of BIM data to BUILDER SMS: The outcome of this task is an evaluation by ERDC-CERL of the means by which BIM data may be used to populate required BUILDER data. Details of this evaluation are provided in Section 6.7 and Appendix I.

Phase VI: Collaboration with ESTCP 201260: The teams examined the potential of integrating these complementary solutions to improve the ability to generate spatial reference models for buildings of any age—with or without existing documentation of the architecture and assets. Results of this phase are documented in Section 6.8.

Dependent Variables

Time expended to produce a BIM (with a specified degree of detail), measured in square feet per hour.

Independent Variables

Tool or method used to create BIM: In this study, we compared the projected cost of creating a medium-fidelity BIM using two different methods: (1) Honeywell BIM Builder tool and (2) Autodesk Revit. We compared our results with the results from earlier studies, as measured by Brucker, et al (Brucker, 2009). This comparison is detailed in Section 6.5.

Controlled Variables

User competency: The skill of the user is a variable that we controlled by training novice test users to a consistent level of competency with the tool prior to the trial. (Note: this program did not propose to test how long it takes a user to achieve full competency.) See Section 6.5 for a more detailed description of subject user competency.

Complexity of the site to be modeled: This variable was controlled by enlisting ERDC-CERL to select a sample building of suitable CAD complexity to offer reasonable challenges to test the tool and users, and reasonably representative of the type of facilities that the DoD needs to manage.

Table 12 describes level of detail (LOD) and provides examples related to this pilot. LOD descriptions identify content requirements and authorized uses for model elements at progressively detailed levels of completeness. These definitions are provided in AIA Document E202-2008 (AIA, 2008).

Table 12: LOD Requirements and Examples

LOD	Environmental: Lighting, Energy Use, Air Movement Analysis and Simulation	Examples of data at each LOD required for this pilot
100	Strategy and performance criteria based on volumes and areas.	List of rooms and their area
200	Conceptual design based on geometry and assumed systems types.	Approximate location of rooms in appropriate relative size and physical relationship.
300	Approximate simulation based on specific building assemblies and engineered systems.	Relatively correct room dimensions. HVAC System design with device types, connection requirements, schedules of named elements, and relationship to physical spaces.
400	Precise simulation based on specific manufacturer and detailed system components	N/A
500	Commissioning and recording of measured performance	As built details. Validation of the correct physical spaces. Measured values from the control system.

Q2: Does providing BIM-driven visualizations provide enough context around energy usage and spend to drive action to reduce energy waste?

Hypothesis

Buildings equipped with BIM-driven visualizations of energy spend data will experience a reduction in energy waste by 10% in comparison to the energy spend before being equipped. Specifically, we hypothesized that the ability to associate contextual data about devices with their energy consumption will drive action to reduce energy waste within the respective buildings

Related Performance Objectives

PO2: Impact energy use at the site through improved insight into building-level energy use

PO3: Improve energy manager visibility into building performance data

PO4: Assess transferability of the conservation measures to other like assets

PO6: Partially-automated identification and standardized classification of control points

Building consumption was measured both *before* and *after* the implementation of Honeywell's BIM-driven visualizations of energy data.

Test Phases

Phase I: Research & Requirements: The team conducted interviews with the energy manager and other DPW staff, as well as individual building managers to assess their requirements and how to best engage these individuals during the pilot.

Phase II: Facility Energy Baselines (Pre-Test): Details of baseline analysis on collected energy data are provided in Section 5.2.

Phase III: Visualization Review: The Honeywell team reviewed the energy visualizations and analyses with the energy manager at Fort Jackson and other team members to collect feedback on the usefulness of the contextualized data and the validity of the observations.

Phase IV: Facility Energy Usage (Post-Test): Follow up conversations were conducted with the energy manager to assess the utility of the information and the impact on energy management activities.

Dependent Variables

Energy Meter Data: Meter data collected for each building included electrical as well as gas, chilled water, and hot water (for central heating/cooling) where those measures are applicable.

Equipment Run Time: Equipment run time was collected either directly or indirectly based on current DCS configurations and available data.

Pre-/Post- Tests: The dependent variables were measured before (pre-test) and after (post-test) the implementation of the visualizations.

Independent Variables

BIM-driven data visualization: The measured independent variable is the impact of providing the BIM context to further aid interpretation of energy data.

Controlled Variables

Building properties: Physical characteristics of the facilities, size, and configuration of treated spaces and related equipment.

5.2 BASELINE CHARACTERIZATION

Careful assessment of facilities at Fort Jackson led us to select five buildings for which it was expected that we could acquire the best historical data for benchmarking. In practice, we learned that most facilities at Fort Jackson had spotty data collection histories, despite assurances that metering was in place and that meter data had been collected. See Section 8 for a further discussion of these issues. Since this seemed to be true of most buildings at the installation that could otherwise qualify for this pilot, we determined that there would be no benefit to looking for alternative facilities at Fort Jackson, as similar issues would be encountered in every case. It was also determined that selecting facilities at an alternate site would significantly increase the cost of the study, and was not desirable.

This section describes the data that was available for baseline characterization in each facility, and the results of baseline analyses. It is important to note that since no new energy strategies

were being applied any of the facilities during the pilot period, some baseline characterizations include the entire body of collected data, normalized by Heating or Cooling Degree days.

Due to the difficulty in getting data for some of the facilities, as noted below, complete baselines and further energy analyses are provided for only three of the five pilot facilities. This was agreed upon in negotiation with the ESTCP program office.

Figure 12 provides a normalized view of the total intensity of energy use across the pilot facilities. Gas meter data is not available for building 9810, so its actual energy intensity is even higher with respect to the other two facilities.

Energy intensity for 2450 during the cooling season appears unusuallylow because only 45K sq ft of the 210K sq ft facility is cooled.

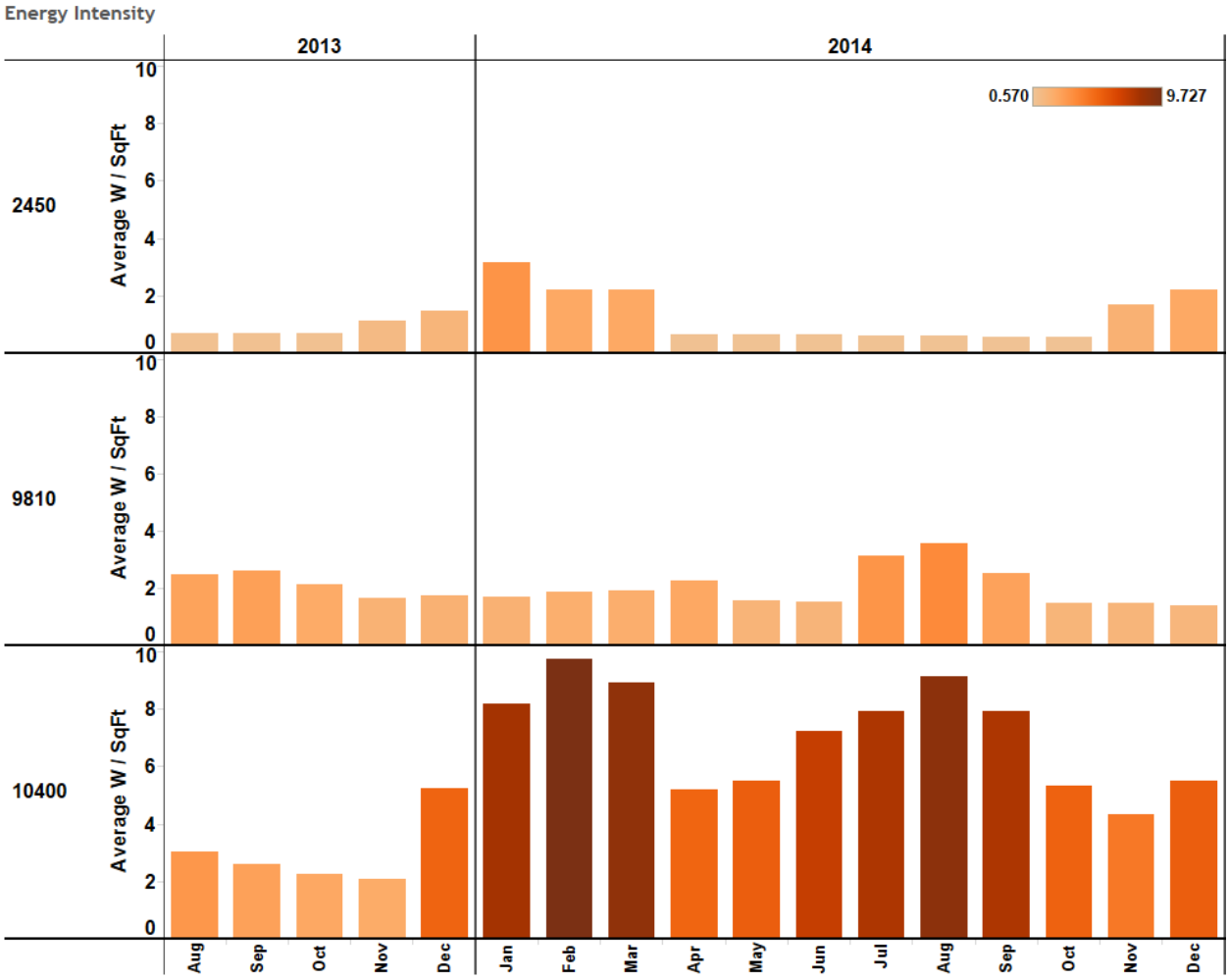


Figure 12: Total Energy Intensity in Average W/ sq ft

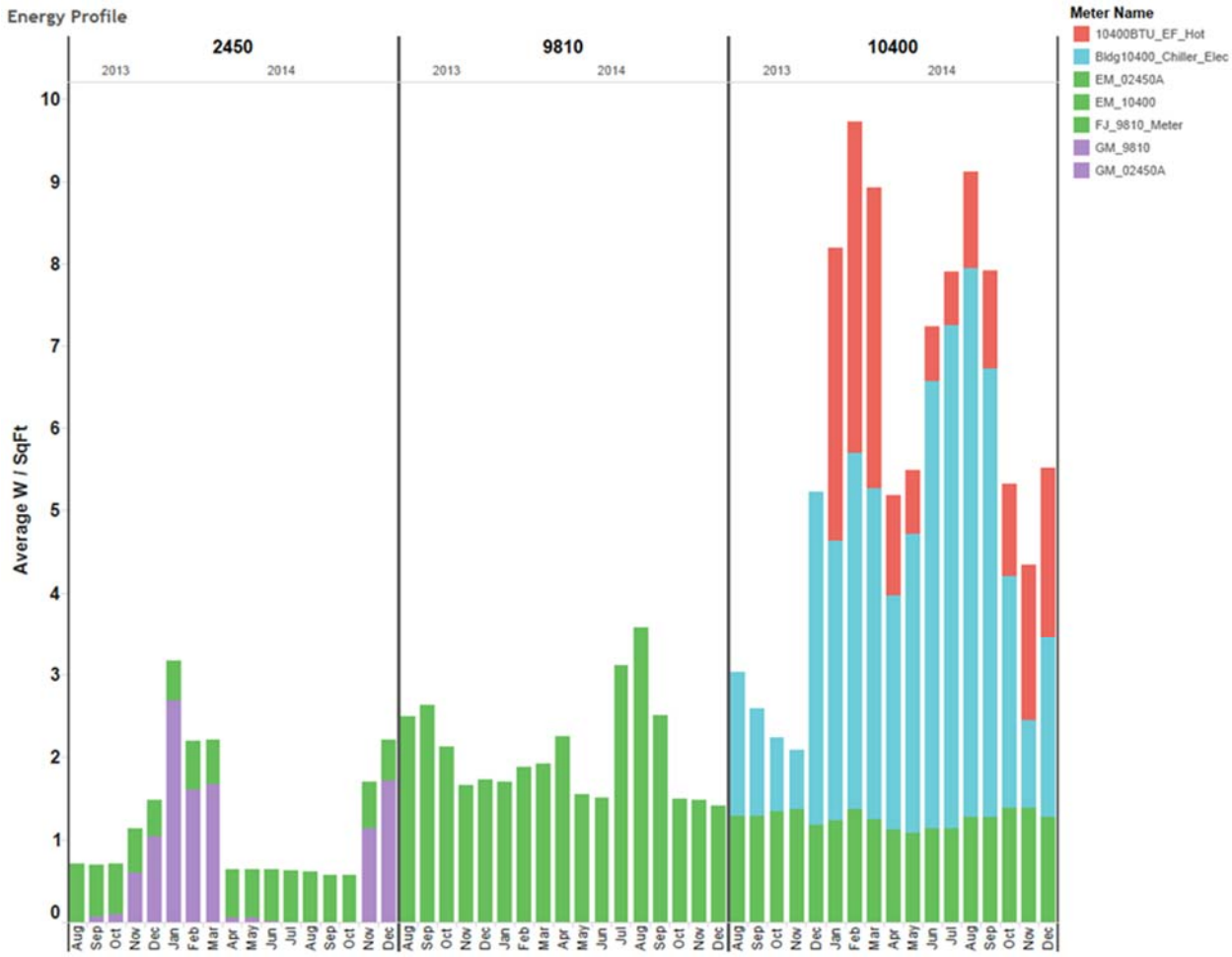


Figure 13: Energy Intensity by Constituent Energy Sources at Each Facility.

Figure 13 shows the same information, but exposes the different energy sources for each site. Here, the missing gas data for 9810 is noticable. 10400 is the only building in this set that uses HotWater and ChilledWater from centralized plants at Fort Jackson. The Hot Water meter at building 10400 did not start reporting until January of 2014.

Table 13: Annual Energy Intensity in Total kBTU/sq ft

Building Number	2450	9810	10400
Purpose	Vehicle Maintenance	Soldier Services	Barracks Administration
Energy Intensity	53.8	83.2	289.6

By comparison, the US Department of Energy 2011 Buildings Energy Data Book suggests that average Federal Building Energy Intensities in 2007 were 112.9 kBTU/sq ft, annually. While buildings 2450 and 9810 are performing considerably better than the Federal average, our analysis incidates that both sites are capable of significant energy reduction. The behaviors leading to high intensity in Building 10400 are explored in depth in Appendix J.

In thorough analysis of the historical energy use data for each facility, there was no satisfactory individualized base temperature made evident by the data for any of these three buildings. This is one indicator of the potential for energy savings in each of these facilities. In each case, separate baseline characterizations were applied to each energy source and cooling/heating seasonal behavior. For the purposes of comparison, we have used a consistent base temperature of 65 F in every case. For cooling load analysis, we excluded days where CDD < 5 or where HDD >= CDD/2. For Heating Load analysis, we excluded days where HDD < 5 or where CDD >= HDD/2. In all regressions, Holidays and other *explainable* outliers were also removed.

We are looking for consistent patterns in the behavior of the buildings that reflect differences in operation based on occupancy or use (sometimes reflected through equipment scheduling[1]), and whether buildings are falling back to minimum consumption levels during off hours. For that reason, we have classified the data by weekday and weekend to make any such patterns more evident.

5.2.1 2450 Vehicle Maintenance School Baseline Assessment

Building Name	2450 Vehicle Maintenance School
Building Use	Classrooms, offices, and 5 large vehicle maintenance wings with cold weather infrared heating apparatus and heavy duty exhaust fans.
Square Feet	120000 sq ft (minus unconditioned out-buildings) 45000 sq ft conditioned spaces 75000 sq ft vehicle bays with infrared heating (gas fired)
Construction	Cement block. Built in 1987. HVAC system refresh in 2011.
Type of Heating/ Cooling	3 Packaged Roof Top Units. No services from central plants.
Significant Loads	3 RTUs on office and classrooms. Infrared heating and ventilation in open vehicle bays, along with significant equipment loads, such as air compressors.
Data Quality	Some meter data was dropped at this facility due to a faulty radio connection, but several months of good data is available during critical heating and cooling periods, so a sound baseline analysis is possible.

Figure 14: Street View of Building 2450

[1] Scheduling is the method used to control HVAC operations to correspond to times when the building is occupied, adjusted to activities during occupancy, or times when the building is vacant or nearly vacant.

Figure 15: Satellite View of Building 2450
Imagery ©2015 Google. Map data ©2015 Google.

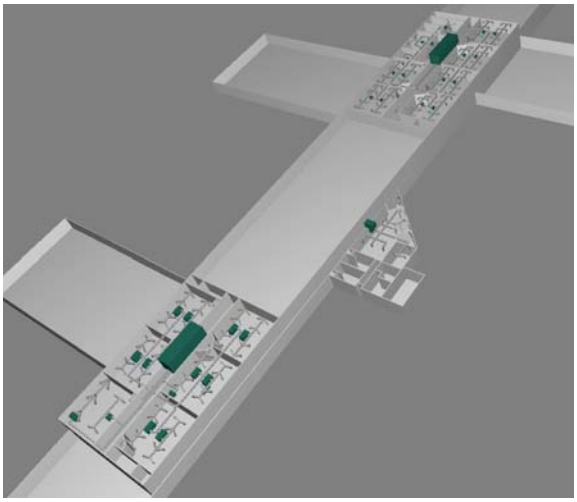


Figure 16: BIM Builder Visualization of the Model of 2450

Summary Baseline report for 2450

Very poor R^2 values across the baseline period assessment indicate much more variation in energy use than is ideal—this points to what appear to be many manual overrides to set points and ineffective scheduling. This building is equipped with local wall modules for comfort adjustment in classrooms and offices, so some volatility is expected during normal occupancy periods.

In 2450, individual offices and classrooms are served by variable air volume (VAV) terminal units, which receive treated air from one of the three roof top units (RTUs). Two of the RTUs are serving roughly 20,000 sq ft each across two floors, with no opportunity for propagation of cooled air between floors. The third RTU is much smaller and serves the front office area of the facility, which is roughly 4,000 sq ft. Only these systems are instrumented with controls that are centrally monitored.

Each of the five vehicle maintenance areas has 20 infrared heaters and eight vehicle exhaust fans that are generally used only in winter, and controlled manually. The five vehicle bays contain a total of 100 IR units and 40 exhaust units. The energy used by this equipment is captured in the metering data, but there are no monitored control elements to report how and when these devices are operated. Because we had no operational data on these devices, they were not included in the BIM model.

The energy baselines indicate that some scheduling is applied, but is not as effective as it should be. Large spikes in gas use and 24-hour activity suggests that IR units are not always shut down when the vehicle bays are not in use. Base loads drop well below the regression curve, suggesting that the building HVAC systems could be shut down much more effectively to achieve a better base load during non-occupied periods.

The following figures illustrate the days of good data used to produce the baseline analysis. The baseline analysis is shown in Figure 19 through Figure 21.

	2013	2014
Feb		1
Apr		12
May		24
Jun		30
Jul		31
Aug		31
Sep	25	
Oct	13	
Nov	1	
Dec	2	
Grand Total	**41**	**129**

Figure 17: Days of Electric Meter Data Employed for CDD and HDD Analysis

	2013	2014
Jan		26
Feb		24
Mar		23
Apr		6
Nov	7	
Dec	13	
Grand Total	**20**	**79**

Note: The gas meter at this site failed in April 2014 and gas data could not be reliably collected after that date.

Figure 18: Days of Gas Meter Data Employed for HDD Analysis

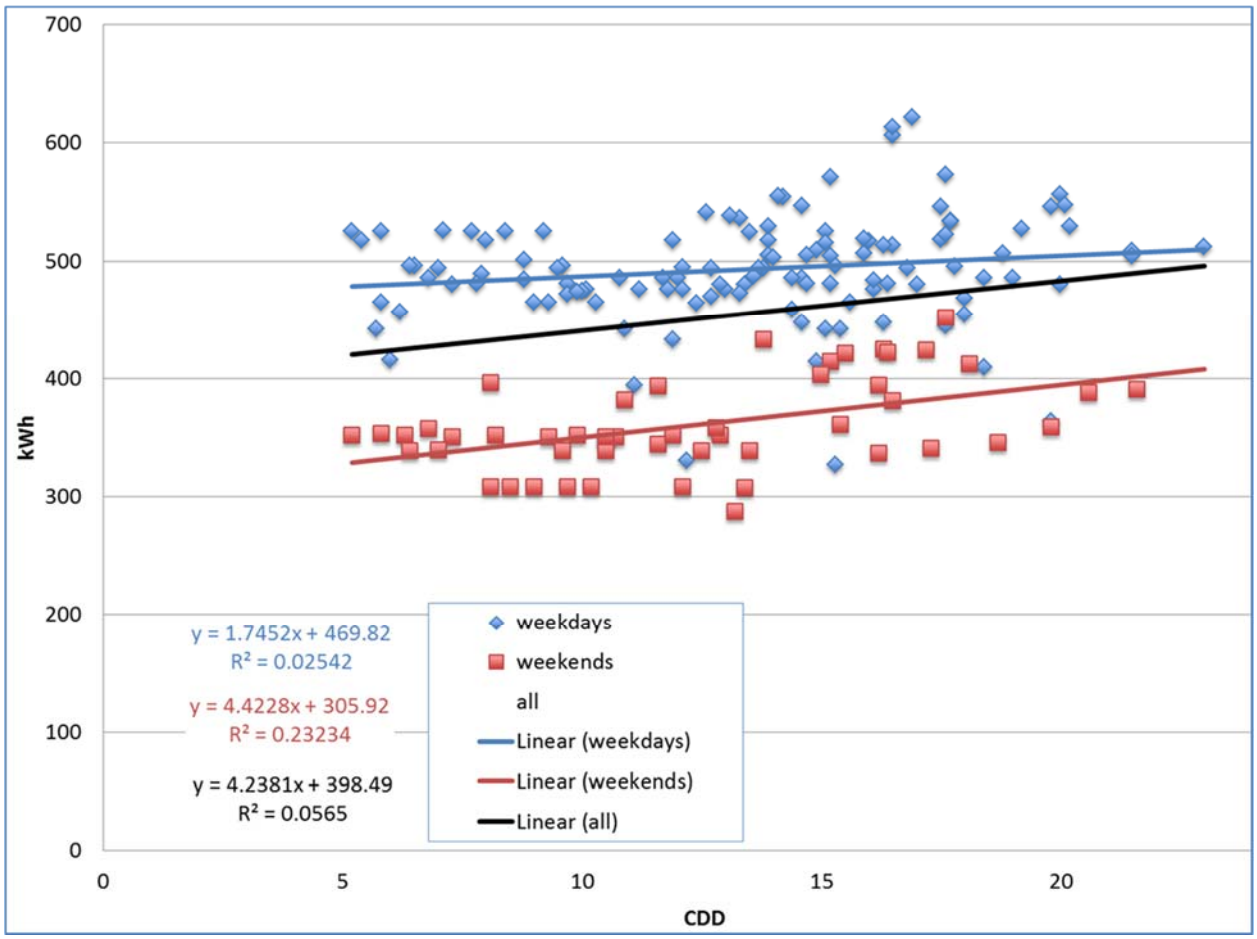


Figure 19: Electrical Use during Cooling Season for Building 2450

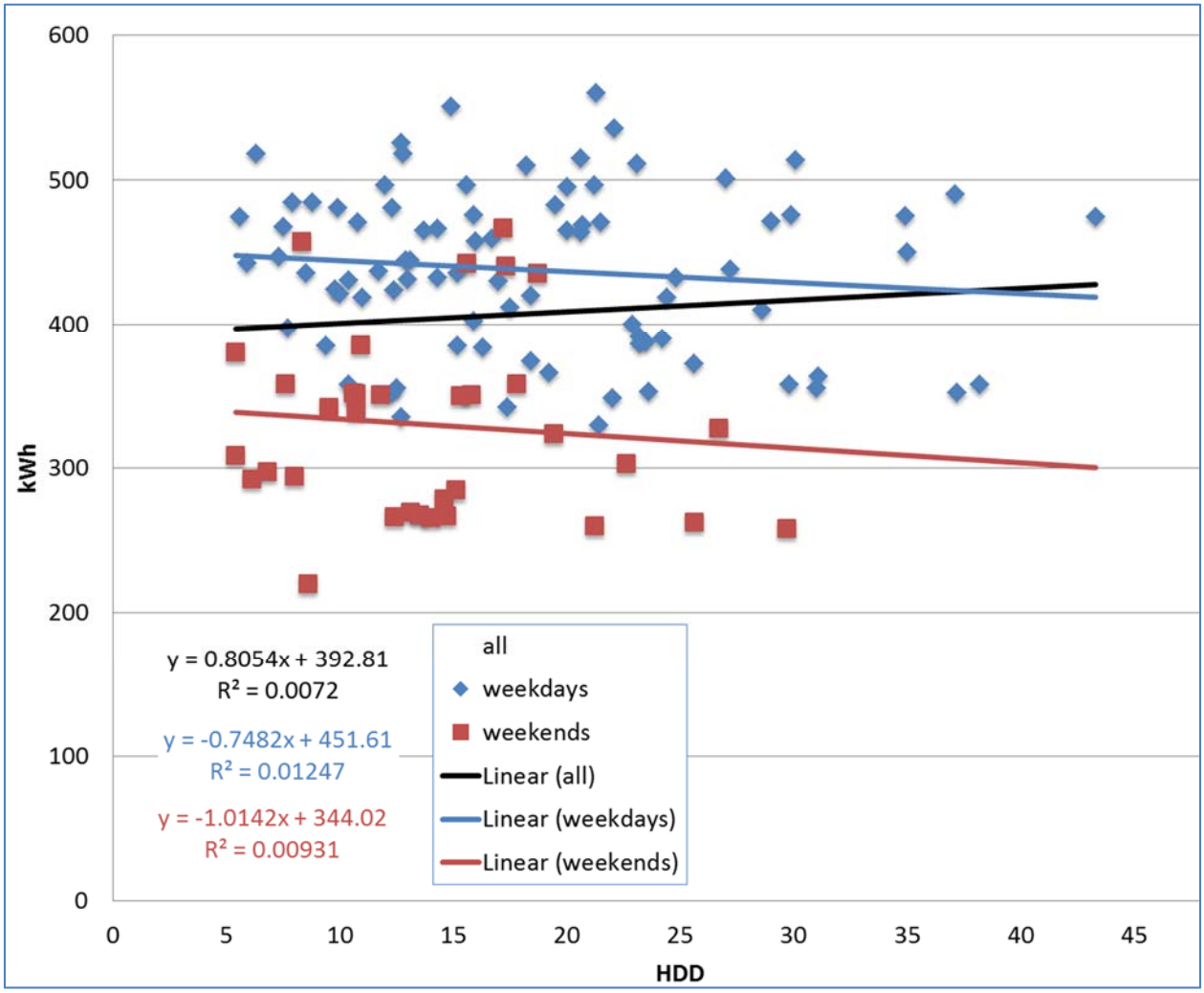


Figure 20: Electrical Use during Heating Season for Building 2450

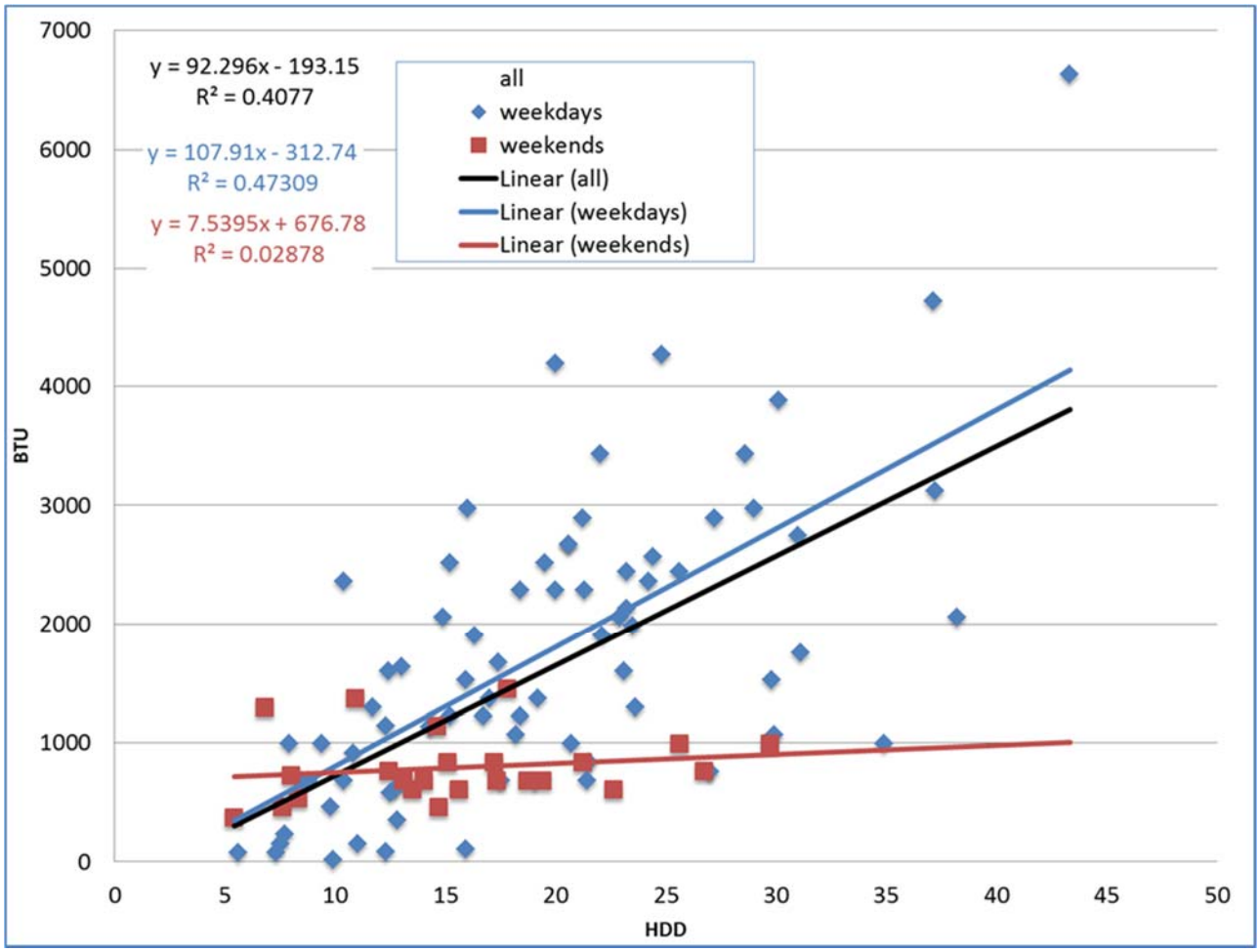


Figure 21: Gas Use during Heating Season for Building 2450

Notes:

The gas meter was offline from 9/1/13–11/13/13; fewer days were modeled in this regression than for the electrical meters.

Observations:

- Weekends show little temperature dependency, indicating that occupancy scheduling is being applied.
- Wide variance in usage—outliers are not removed because we have no consistent basis on which to exclude them. These outliers may be related to specific training activity during cold weather requiring higher use of the IR heaters.
- Very high usage days show constant gas consumption over 24 hours, suggesting that maintenance activities were being conducted 24x7, or that the IR units were not being shut down consistently when no longer needed.
- Area under the weekend regression line is only about 40% of that under the overall regression line. There is a clear opportunity to further improve the consistency of savings during off hours.

5.2.2 9810 Soldier Services Building

Building Name	9810 Soldier Services Building
Building Use	Multi-tenant. Mostly small offices, some partitioned spaces. Largely houses disability and chemical dependency services. No operating windows, so all ventilation air comes through air handling.
Square Feet	37,210 sq ft.
Construction	Cement block, split level design. Constructed in 1975.
Type of Heating/ Cooling	Standalone facility with local chiller and five zoned AHUs.
Significant Loads	Five air handlers and one chiller. Work undertaken in 2014 by a third party took some major HVAC systems off line for a significant time.
Sources of Energy Data	Electric meter. Gas meter was installed but stopped reporting. The DPW had no plan to repair it.

Imagery ©2015 Google. Map data ©2015 Google.

Figure 22: Aerial view of 9810

Figure 23: Street View of 9810

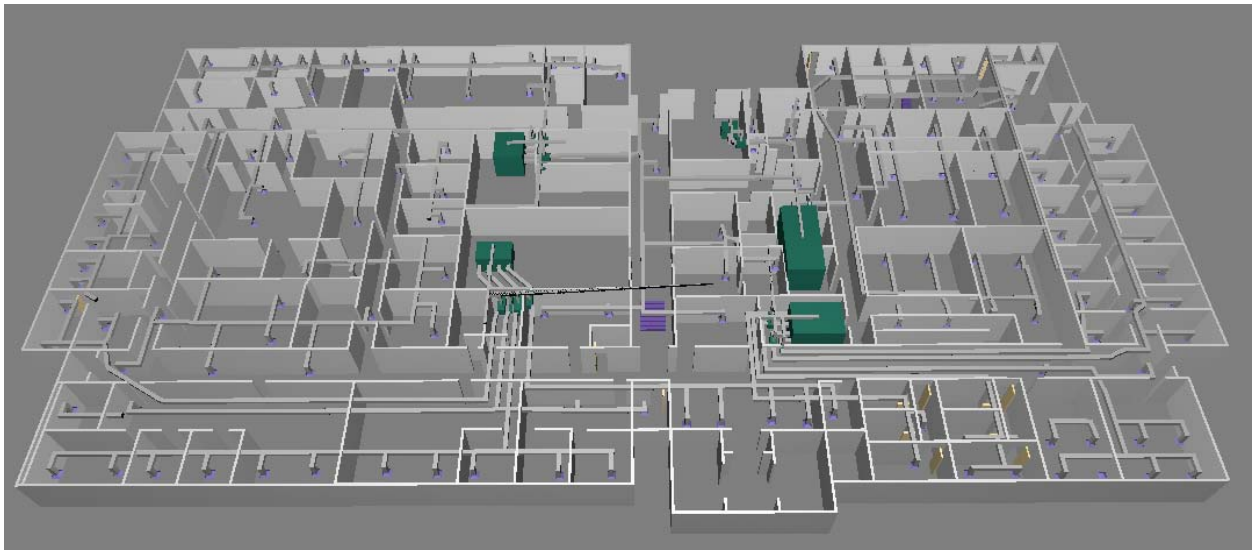


Figure 24: BIM Builder Visualization of the model for 9810

Summary Baseline Report for Building 9810

In 9810, individual offices and other spaces are served by zoned AHUs, with no terminal units to refine temperature control in specific areas. This reflects construction practices in that era; this is the oldest of the subject facilities, constructed in 1975.

Due to the lack of gas meter data, we could not provide a reasonable baseline heating load analysis. Therefore, only the cooling load analysis is included here (Figure 25). Furthermore, due to a conflicting project at the site, we are unable to use data from May 1 through September 1 2014, as operations and data transmission were both disrupted, and energy metering is not representative of normal operations during this time.

Energy profiles indicate that some scheduling is in place, because systems shut down in the evening, but restart and run all night long. Energy use shows a high degree of weather dependency, 24 hours per day, 7 days per week. However, the R^2 value of .63 indicates a wide variation in energy loads that would not be anticipated given this type of facility and operation.

It is possible that some of these service organizations offer support 24x7 to soldiers in need, but it is probably not the case that these services encompass the entire facility.

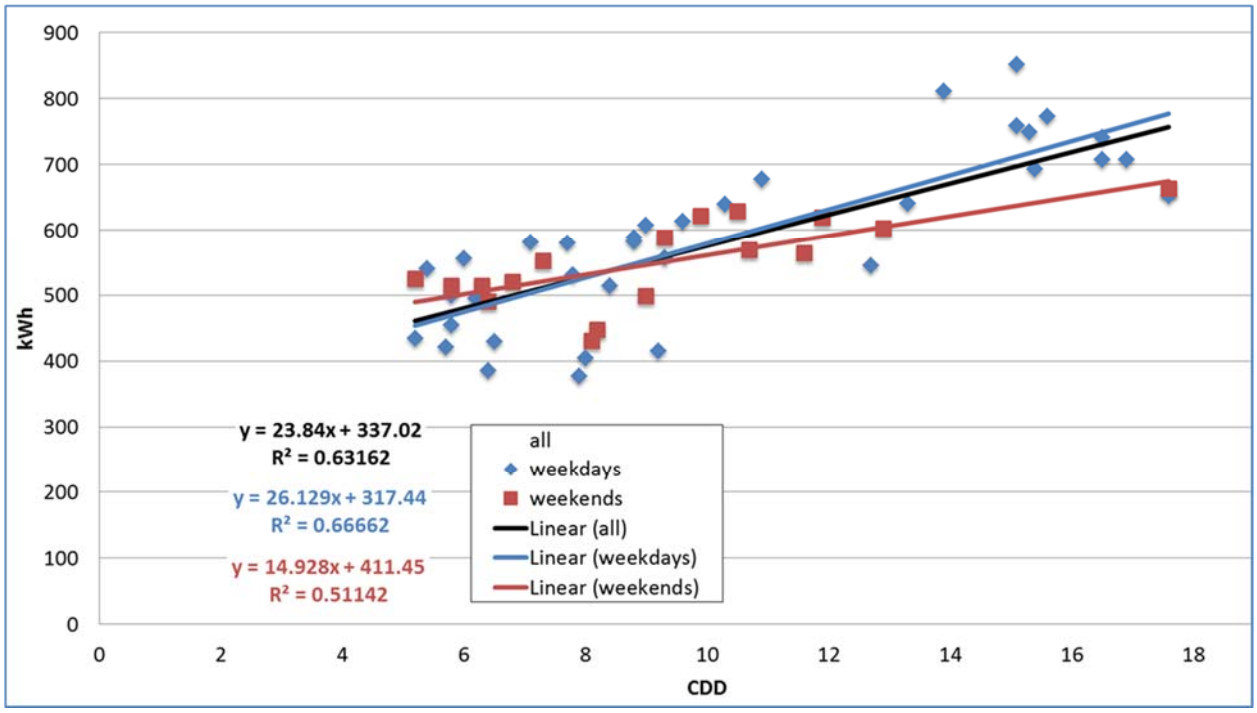


Figure 25: Cooling Load Analysis for Building 9810

5.2.3 10400 Barracks Administration Offices and Classrooms

Building Name	10400 Barracks
Building Use	Two large classrooms and assorted office spaces. Mixed open/cubicle design and traditional offices.
Square Feet	23,178 sq ft.
Construction	Single level. No operating windows, so all ventilation air comes through air handling. Built in 2005.
Type of Heating/ Cooling	Chilled water and hot water supplied by the central plant.
Significant Loads	Three air handlers. One air handler serves office operations. Each of the classrooms has its own dedicated air handling system.
Sources of Energy Data	Electric meter, BTU meter and gas meter.
Data quality	Some issues with meter data quality, which affect baseline calculations.

Imagery ©2015 Google. Map data ©2015 Google.

Figure 26: Aerial View of 10400 Barracks Administration

Figure 27. Street View of 10400 Building

Figure 28: BIMBuilder Visualization of 10400 Model

Summary Baseline Report for 10400

The energy patterns indicate that the entire building is operated to the same requirements 24x7, including class rooms, with no scheduling for occupancy or weekend operations. The flat slope in energy use in both CDD and HDD (Figure 29 and Figure 30), shows that there is significant electrical load in moving air through the facility 24x7, since both heating and cooling are provided by the central plants. But analysis of the heating and cooling demands on the central plant illustrate a high degree of simultaneous heating and cooling, and relatively high energy intensity for operations year-round.

The energy intensity of this facility is significantly higher than would be expected for a building of this age and design that has no direct heating or cooling load on site.

An in depth analysis of the energy behaviors at this facility is provided in Appendix J.

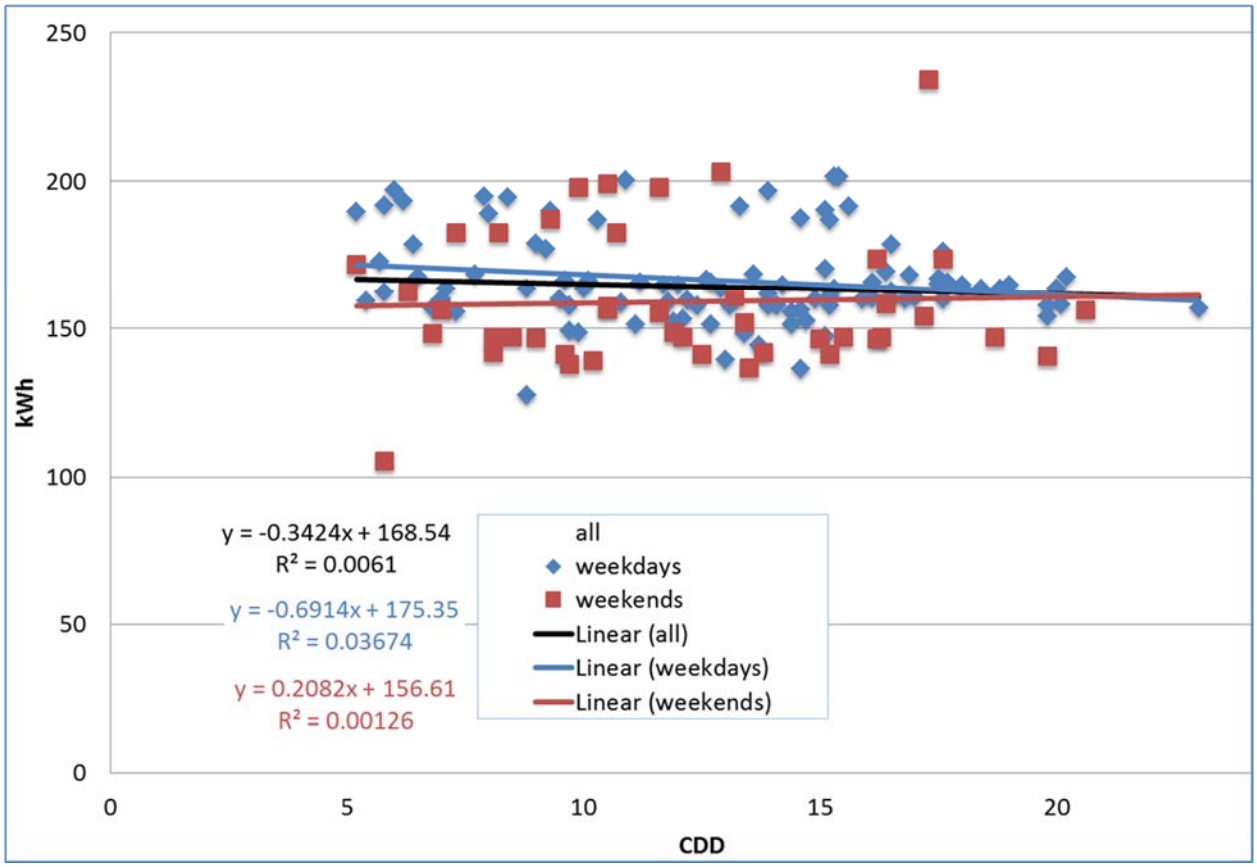


Figure 29: 10400 Electrical CDD Baseline Regression

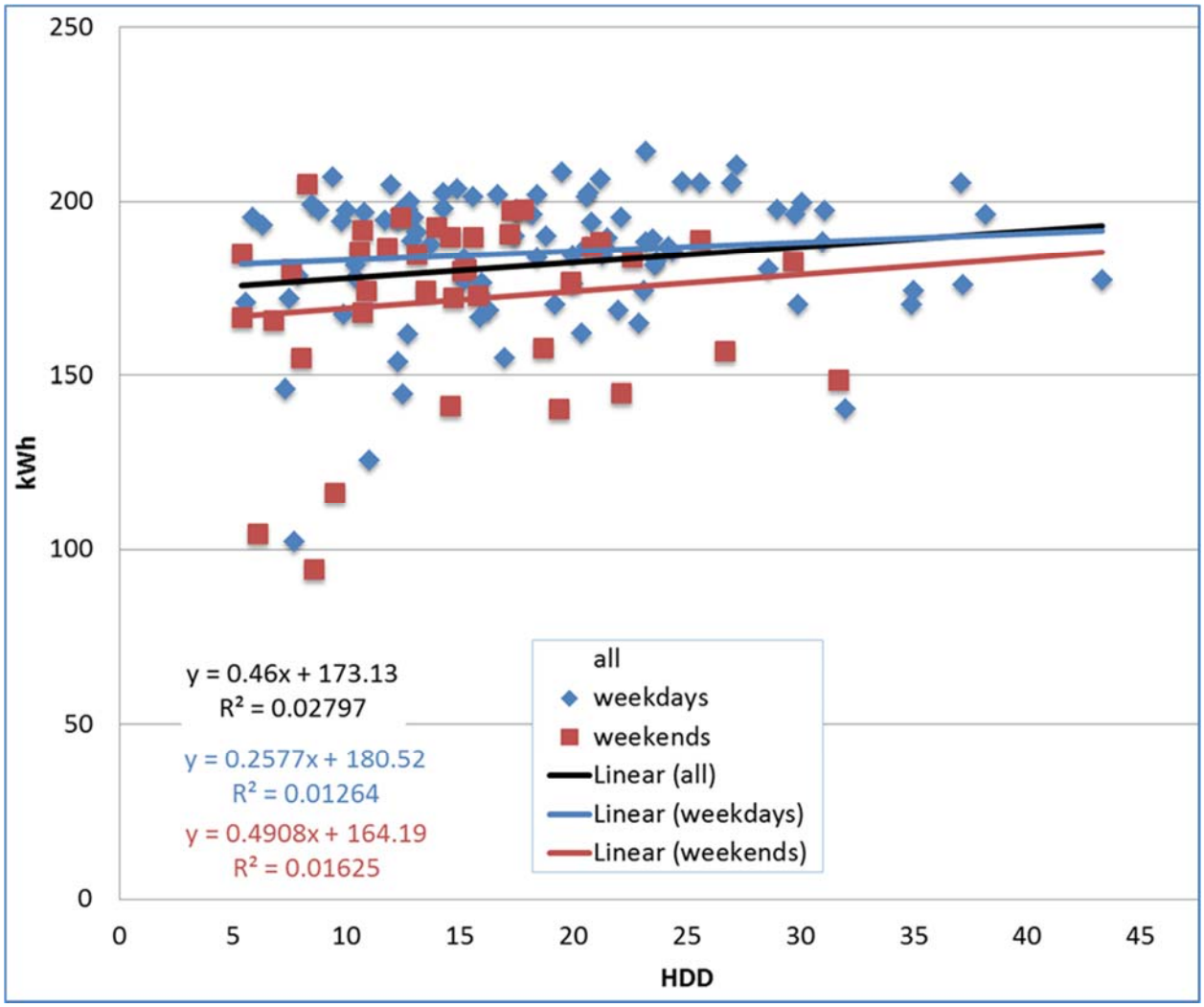


Figure 30: 10400 Electrical HDD Baseline Regression

Both electrical baselines show that the electrical load in this facility is nearly constant, regardless of season, or occupancy. This is largely due to the 24 x 7 operating patterns maintained for office areas as well as classroom facilities in this building.

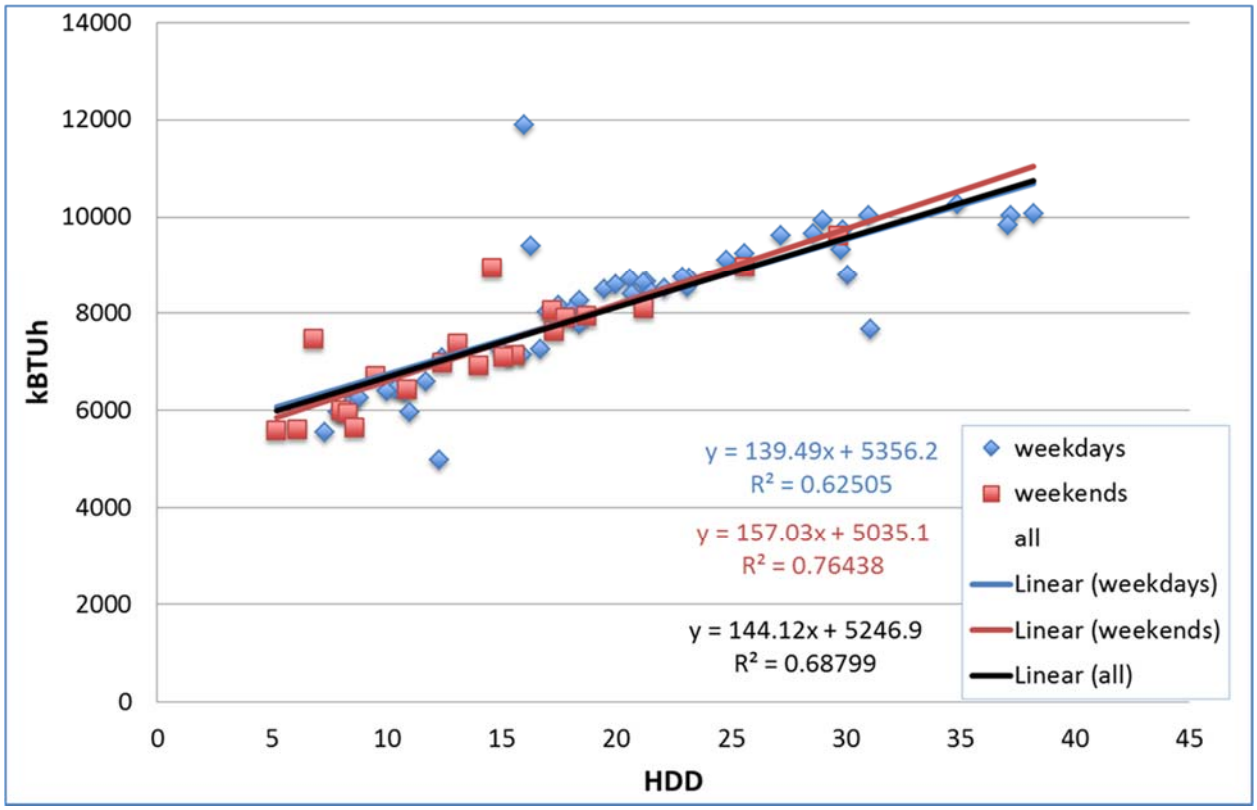


Figure 31: 10400 Central Hot Water (BTU) Baseline Regression

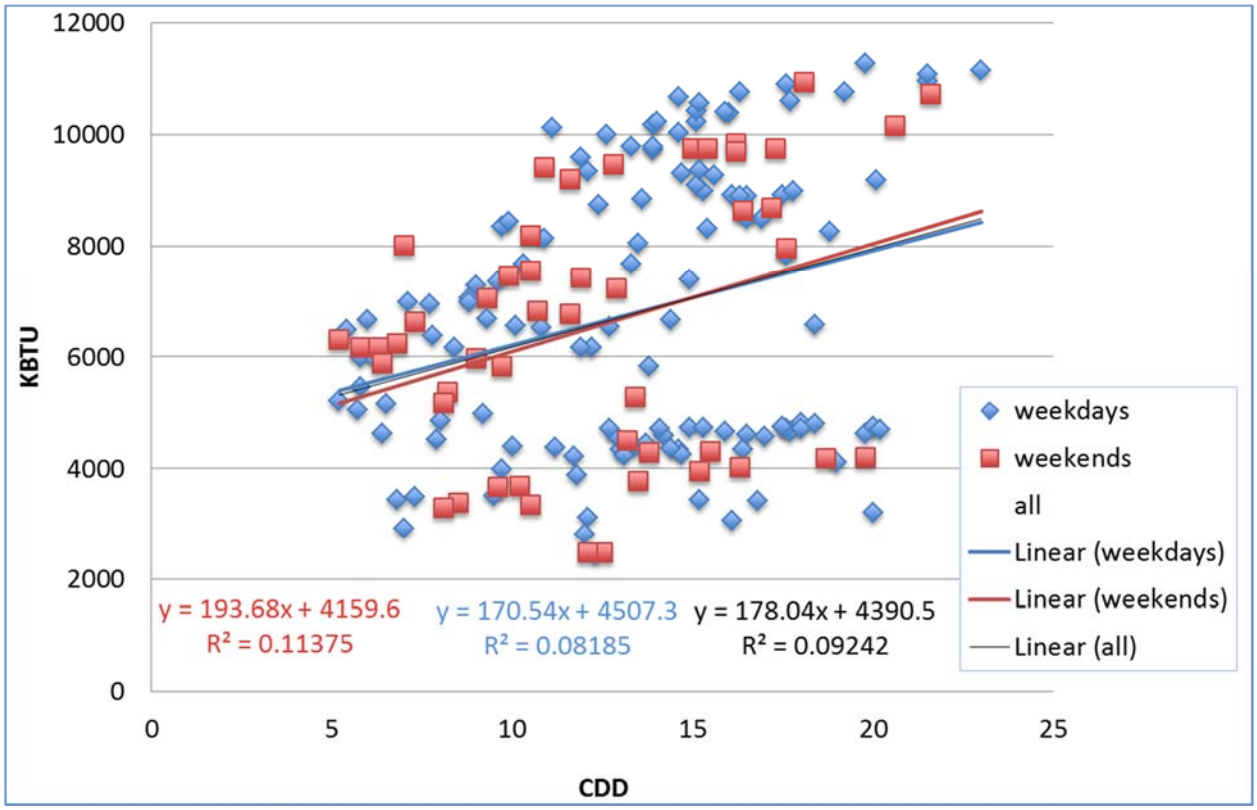
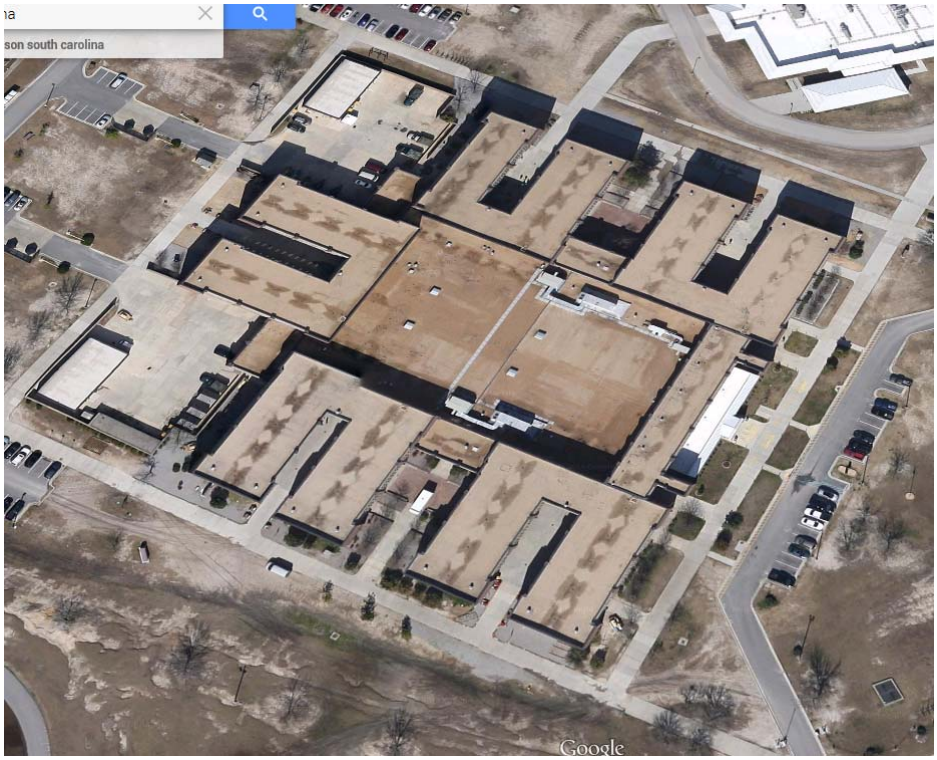


Figure 32: 10400 Central Chilled Water (BTU) Baseline Regression

The BTU regressions for hot water and chilled water consumption also illustrate that there is little difference between weekday and weekend operation, though there is considerable variability as indicated by the very low R2 values. This may be due in part to the high incidence of simultaneous heating and cooling observed. Furthermore, casual observations while visiting the site indicate that classroom occupants use the egress doors on the classrooms to moderate temperatures (classrooms are considered too cold), and that this uncontrolled introduction of outside air certainly has an influence as well during the cooling season.

5.2.4 11000 Barracks (Starship design)

Building Name	11000 Barracks
Building Use	A large, single-story, central space provides extensive classroom facilities and a small front office area for administrative personnel. Five, two-story, elevated, U-shaped barracks extensions provide office and living space for each Cadre housed in the barracks.
Square Feet	290,481 sq ft.
Construction	Cement and brick. Construction in 1987 with extensive remodel and retrofit in 2010-11.
Type of Heating/ Cooling	Chilled water and hot water supplied by the central plant.
Significant Loads	29 AHUs, pumping systems for central hot and chilled water
Data Quality	Very poor.



Imagery ©2015 Google. Map data ©2015 Google.

Figure 33: Aerial View of 11000

Figure 34: Street View of 11000

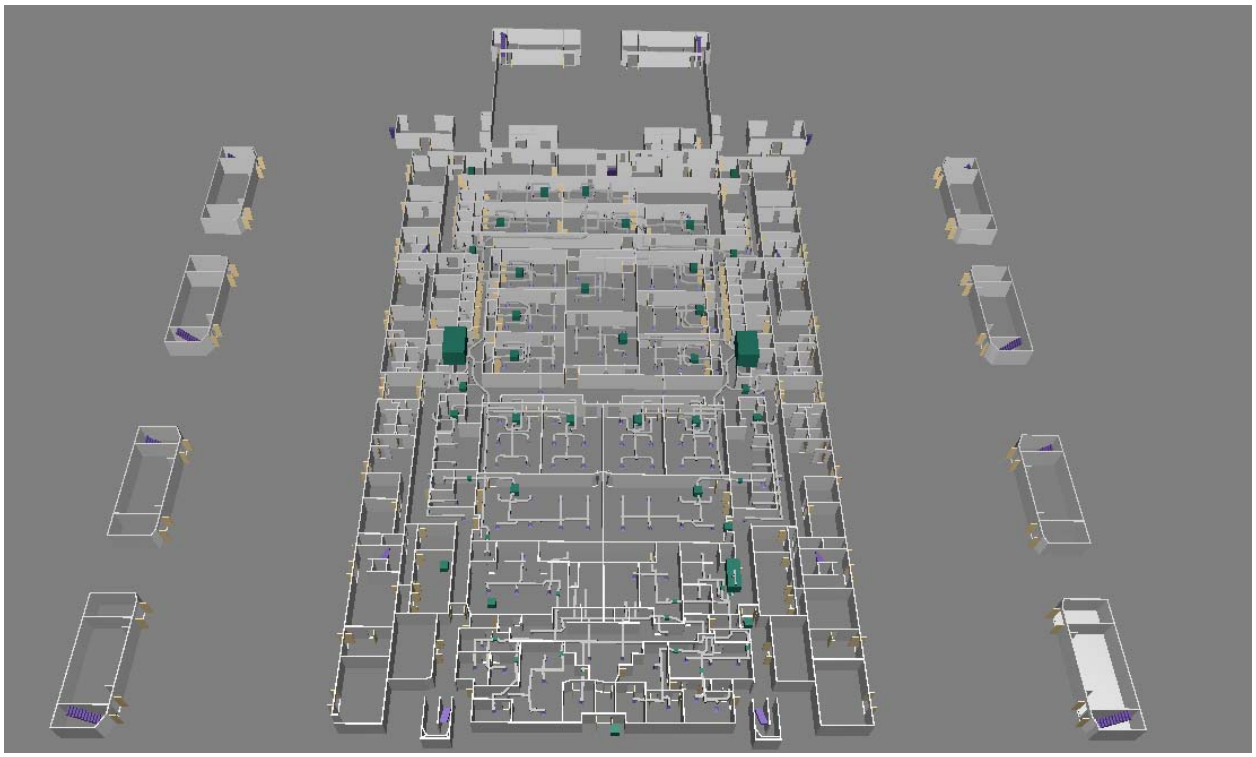


Figure 35: BIMBuilder Visualization for Bldg 11000 First Floor Offices and Classrooms

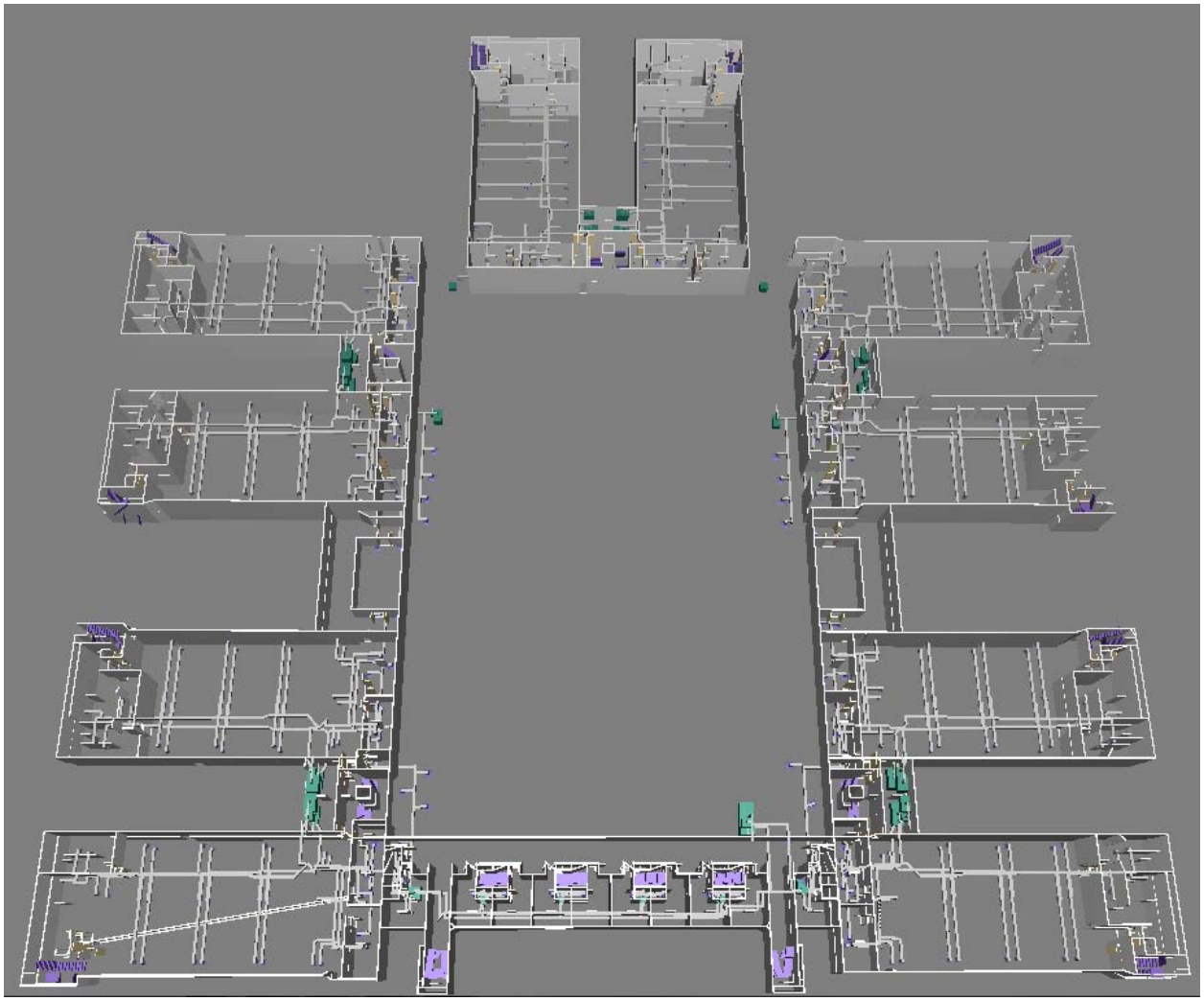


Figure 36: BIMBuilder Visualization for Bldg 11000 Second and Third floor Barracks

Summary Baseline report for 11000

Due to significant issues with data quality from 11000, no baseline measures can be provided. There were substantial data drops from electrical, gas, and BTU metering because of incomplete meter commissioning. Further missing data from unsupervised controllers on significant HVAC loads left no means to provide accurate baseline analysis.

It is useful to note here that 11000 and 12000 are contemporaries at Fort Jackson, built and remodeled in the same timeframe, yet they are substantially different in their spatial and HVAC configuration. This observation is an important footnote to expectations for any consistency across buildings of similar age and even similar design across the DoD. A short study of the variability of the starship design is provided in Section 6.5.

5.2.5 12000 Barracks (Starship design)

Building Name	12000 Barracks
Building Use	A large, single-story, central space provides extensive classroom facilities and a small front office area for administrative personnel. Five, two-story, elevated, U-shaped barracks extensions provide office and living space for each Cadre housed in the barracks. Construction in 1987 with extensive remodel and retrofit in 2011.
Square Feet	290,481 sq ft.
Construction	Cement and brick. Pitched metal roof and other variations from 11000. Constructed in 1987 with extensive remodel and retrofit in 2011.
Type of Heating/ Cooling	Chilled water and hot water supplied by the central plant.
Significant Loads	15 AHUs, pumping systems for central hot and chilled water
Data Quality	Very poor.

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Figure 37: Aerial View of 12000

Figure 38: Street View of 12000

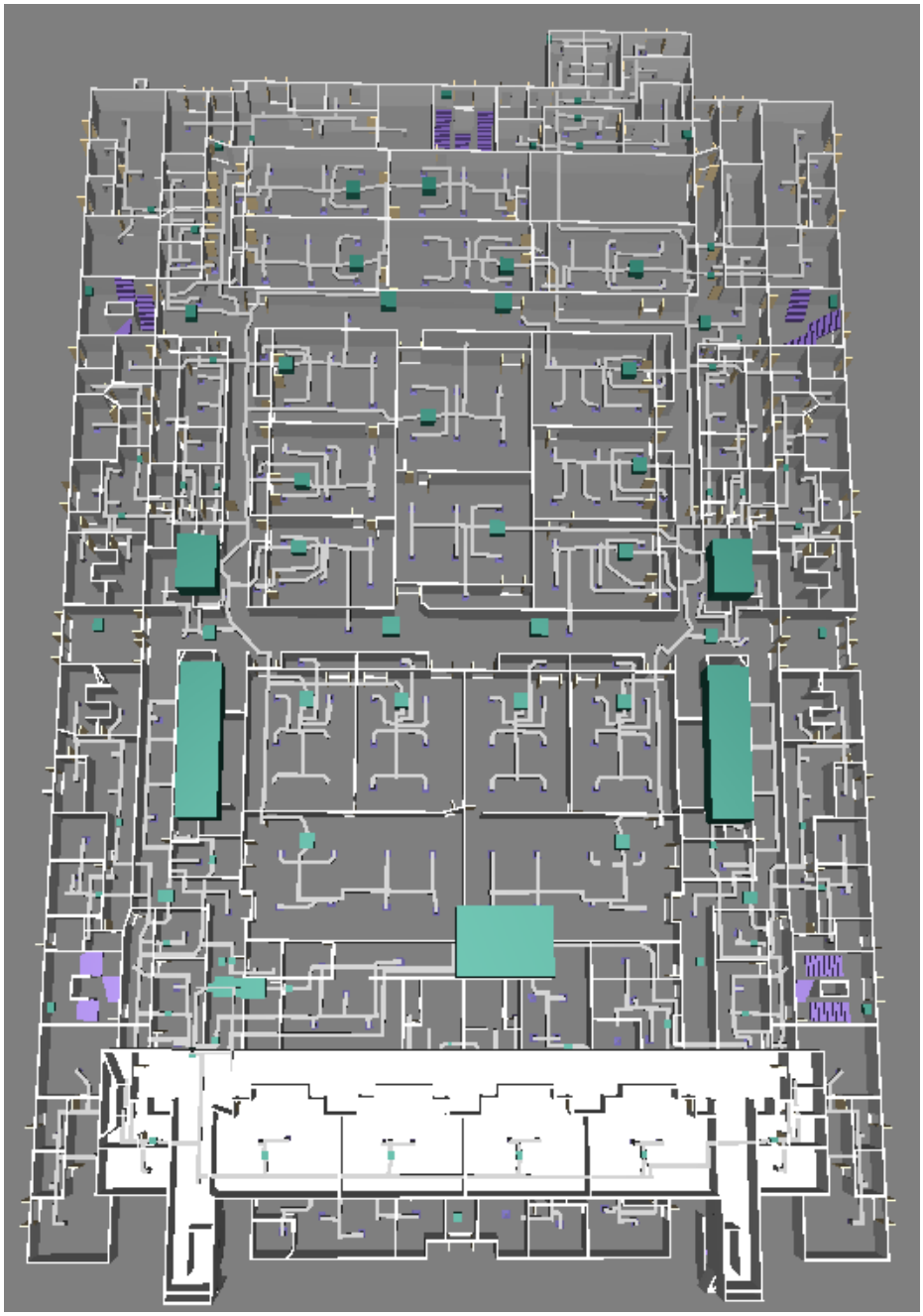


Figure 39: BIM Builder Visualization for Bldg 12000 First Floor.

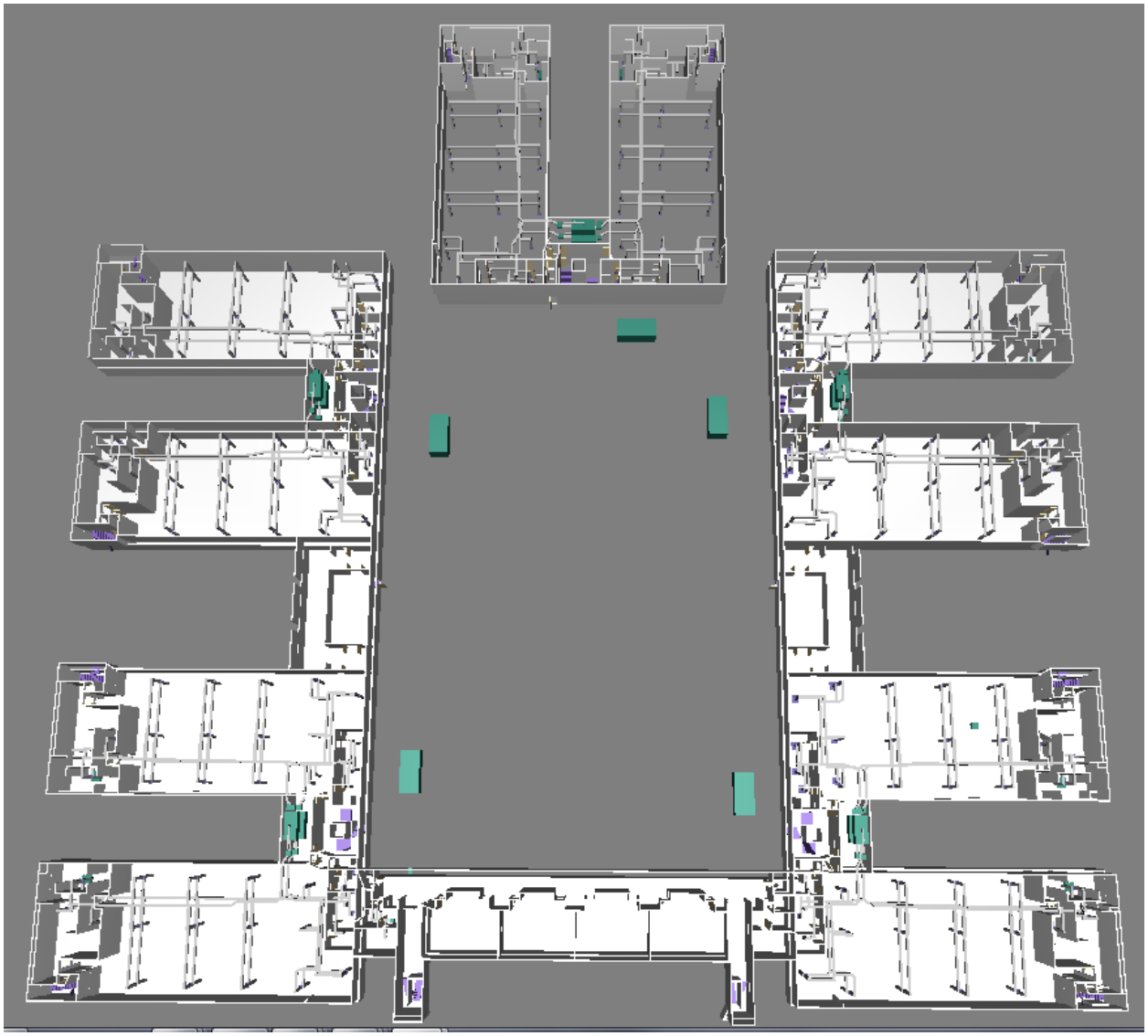


Figure 40: BIM Builder Visualization for Bldg 12000 Second and Third Floor

Summary Baseline report for 12000

Due to significant issues with data quality from 12000, no baseline measures can be provided. Substantial data drops occurred for both electrical, gas and BTU metering because the meters were incompletely commissioned. Further missing data from unsupervised controllers on significant HVAC loads left no means to provide accurate baseline analysis.

5.3 DESIGN AND LAYOUT OF TECHNOLOGY COMPONENTS

The following subsections provide an overview and summary of the technology and design of the MDEI supporting architecture. Some new components were added to the Ft. Jackson Energy Center infrastructure to support this project while also utilizing existing technology.

5.3.1 System Design

The principal technical components of the MDEI Server architecture include the following commercial products: Dell™ Server Hardware, Windows® Server 2008 Operating System, Microsoft® SQL Server 2008, Apache Tomcat web server and Tableau® Server. Each of these solutions has applicable Security Technical Implementation Guides (STIG), which can be applied to make them suitable for deployment in a secure DoD environment.

Additionally, Honeywell EBI and Honeywell Energy Manager (HEM) were used to facilitate the collection of DCS and meter data. These commercial solutions are already approved and employed at the site for similar purposes.

The final component is a standard Windows OS Desktop system, procured as part of this contract, and installed within one of the EM's workspaces. The system is connected to the Energy Center LAN using an existing wireless network, previously approved for remote access to the Fort Jackson Energy Center, for the purposes of access to the installed supervisory control systems. Figure 41 illustrates the system architecture.

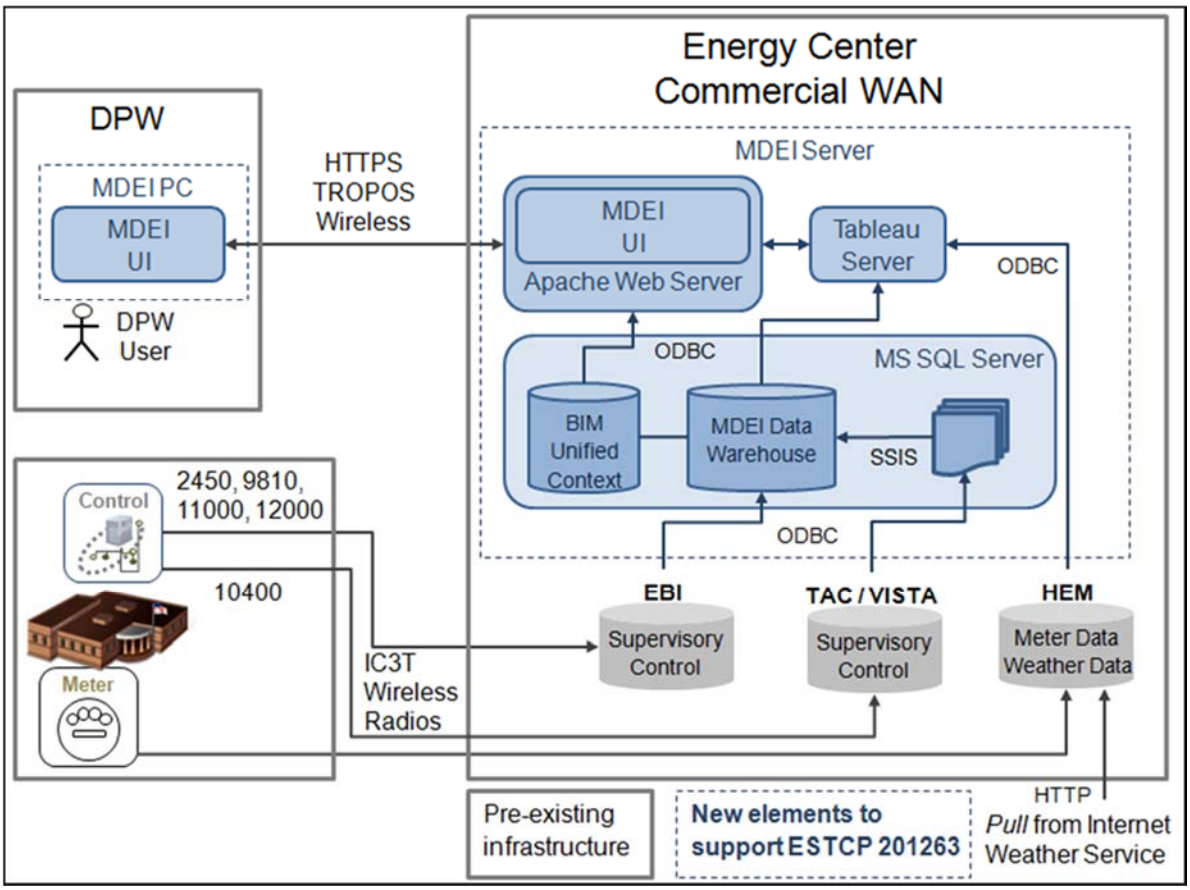


Figure 41: System Architecture and Communications

5.3.2 System Communications

The Honeywell Energy Center is positioned within two local networks that host the metering devices and some building automation solutions, as well as Honeywell Energy Manager and EBI. The local Energy Center network collects data from sites on the base using approved wireless networks that meet the DoD requirement for FIPS 140-2; The buildings selected for this project have control systems reporting across these local networks. Figure 42 is a diagram of the network.

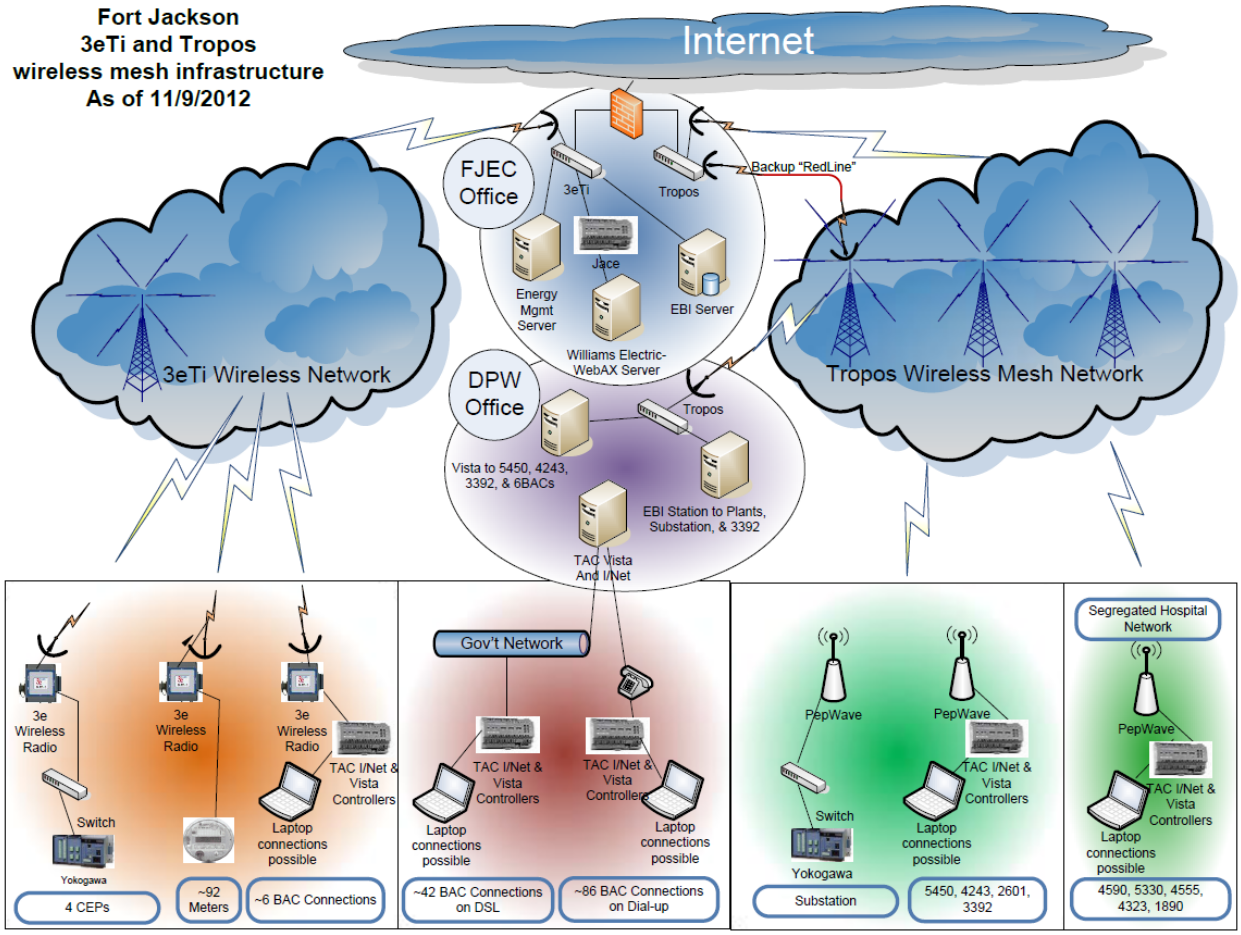


Figure 42: Network Infrastructure through Ft. Jackson Energy Center

5.3.3 System Components

MDEI UI: The MDEI User Interface (UI) provides the navigation environment that the energy analysts and energy manager utilized to access relevant BIM and energy information. The entire interface was constructed as a web service, built using HTML, CSS and JavaScript, and therefore the client (user) only requires a web browser to access it. However, as noted in the BIM subsection below, during the pilot project, only Firefox and Chrome browsers successfully display the 3D BIM, as they natively support WebGL technology, whereas the Internet Explorer® browser does not. A walkthrough of the UI is provided in Figure 43.

Figure 43: UI Generation for Composite View

Data-driven navigation is dynamically constructed based on the spaces and assets identified by the BIM. It supports the user in selecting the scope of interest. Because the menus are built dynamically using the underlying BIM data stored in a database, the UI does not need to be rebuilt when additional buildings are added to the ecosystem.

Navigation of the building(s) is available through either the data-driven menu, or by utilizing the 3D BIM model. Appendix C discusses the process of generating, displaying and navigating these 3D models through the web interface.

Tableau™ is employed to provide energy visualizations. Navigation via either the menu or 3D BIM view will dynamically update the energy visualizations. Tableau visualization development and deployment is discussed in more depth in Appendix C.

One disadvantage that most installation energy managers face is the disparity in how and where trend data is accessed and displayed across a variety of control systems. This creates artificial barriers by forcing the energy manager to access multiple systems and recall how to get to the appropriate screen. The MDEI UI supports uniform access to all the data collected about each of the facilities, regardless of which system produced that data.

The dashboard environment that was made available to the energy manager is detailed in Appendix C. Figure 43 illustrates the various elements that make up the UI infrastructure. The interface is completely web-enabled, served through an Apache Tomcat web server, with basic page elements written in HTML and supported by JavaScript libraries. The textual navigation menu on the left is basic HTML list-elements, the top half of the view is generated by Tableau through its JavaScript API, and the bottom half is BIMSurfer views of the building .json data files.

General navigation in a tree-style is provided on the left-hand side, which allows the expansion of each facility and equipment class on demand. Figure 43 shows the tree for building 10400 expanded. The 3D image also supports navigation by clicking on assets of interest.

In Figure 43, the user has selected the Composite tab, which shows the BIM view and the Energy view together in a tiled format. The user can select a different building element at any time using the menu or 3D BIM, and both views will update accordingly.

To the right of the trend graph is a selection pane supporting the end user to adjust the date range to be reviewed, and provides the legend for the points that are presented. This legend has been standardized to a set of predetermined, standardized point classifications, by system type. This facilitates standardization of display across units with different point name conventions. Further details are available at each point on the trend line through a pop-up context box, which includes the originating point name and the precise timestamp and value. Tableau natively supports extraction of data underlying the chart using a context (right-click) pop-up menu. However, if this solution were productized, other methods to extract tabular data for further analysis would likely be required.

BIM Unified Context: BIM data relevant to this demonstration is stored in a Microsoft SQL database and accessed via standard query/response techniques. The MDEI Data Warehouse (MDEI-DW) and BIM Unified Context data sources contain appropriate cross-referencing to identify and relate entities (e.g., assets and spaces). Historical time-series information is associated through the BIM to its relevant building context to enhance building and energy management tasks, analytics, and visualizations. See Section 6.6.1 for details on linking this data.

Honeywell's BIM Builder provides data output in the Industry Foundation Class (.ifc) format. These data files were sent to a local BIMserver (Open Source software available through bimserver.org) which provides the capability to transform the format of the data to JSON. Modifications were made to the BIMsurfer JavaScript libraries to enable object linking of BIM entities to the rest of the UI components, along with visual controls and highlighting. The JSON files for the buildings were stored in the web applications /resources folder. The directory is available through a normal windows file explorer, allowing easy updates of the building models to the web interface.

One requirement for viewing these 3D BIM models with BIMsurfer is a browser which supports the HTML5 Canvas and WebGL extension. During the development of the MDEI UI, HTML5 was not yet standardized (final version standardized October 2014), and a stable version of WebGL was not released until March 2013. Out of the three browsers tested: Internet Explorer (IE) 9, Firefox and Chrome, only Chrome provided complete support for the requirements, and could handle the large size of the JSON files for the building models. However, even Chrome intermittently failed to load the full building model for buildings 11000 and 12000. A decision was made to split those models into two files, one containing the BIM for the center office and classroom spaces, and the other for all 5 wings and floors of the barracks. This had the side-effect of not being able to fully navigate the entire building model in one view. Limitations such as this will be addressed as the applications become more prevalent; it is not a functional limitation of the technology.

Tableau Visualizations: Visualizations are created using the Tableau Desktop application, and then uploaded to Tableau server which allows for integration in the web-based UI. In this pilot project, dashboards for energy consumption and equipment behavior, ranging from the whole-building, down to individual asset levels, were generated. Figures in Appendix C demonstrate the various aspects of the MDEI UI and the distinct views generated through Tableau.

Tableau has two components, Desktop and Server, which are both installed on the MDEI Server. Tableau Server was configured in the Trusted Ticket Authentication mode, which allows user authentication to occur at the web application container level. Such authentication allows easy access configuration for various users and roles outside of Tableau and makes it possible for the web application to control various aspects of the UI based on who logs in.

Tableau Server has a web console that enables easy management of dashboards that have been uploaded, via a JavaScript API. The web application sends a filter request to the dashboard, with a payload that contains the point names and a date range, and then the visualization is constructed after extracting the specified data from the database.

The color scheme used to graph energy data for the building points are aligned to a set of common point roles. This means that all points of a particular type (for example, SupplyAirTemperature) will have the same color, which helps the user to quickly and easily identify what a graph line represents from one visualization to the next. See Appendix D for further details about this implementation.

Building Automation and Meter Data: Time-series data is supplied from existing UMCS and meters on site. Every day starting at 2:00am local time, SQL Server scripts and SQL Server integrations services (SSIS) packages are run to extract this data from the EBI and HEM production servers into the MDEI Data Warehouse. This was done to help separate data access demands for the purposes of this pilot project and not interrupt the production servers.

Weather Service Data: This data consists of 15 minute interval data (96 samples per day) for key characteristics of the ambient weather conditions at Fort Jackson. This data was supplied by an existing subscription service in the energy center.

5.3.4 System Integration

Information collected from control systems installed in buildings on the base is transmitted locally to the Fort Jackson energy center using the existing wireless networks, as per current site implementation.

Collected data from metering solutions, UMCS monitoring, and BIM data is integrated within an MDEI Data Warehouse (Microsoft SQL Server) installed on the MDEI Server (Dell PowerEdge R320 Server with Windows Server 2008 OS) located in the server room of the Energy Center. The path of information is one way, from existing systems that produce data to this common repository.

The Apache web server, Tableau Desktop and Tableau Server are also installed and running on the same Windows server. This server is fully contained inside the Energy Center WAN. See Figure 41 for a diagram of the system.

The DPW uses an approved wireless connection to the Energy Center to connect remote management clients. The MDEI interface was made available through this existing channel.

5.3.5 System Controls

The Dell server, which hosts all the above applications and associated data, has a single administrator account with password requirements per government and Honeywell policy. An onsite Honeywell employee within the Energy Center is the administrator for all applications resident on the server, and also has immediate physical access to the server. The Administrator manages user accounts, which were created for Honeywell team members on the contract and Ft.

Jackson personnel identified by the DPW. Separate accounts were established to access the FM Dashboard web application.

5.4 OPERATIONAL TESTING

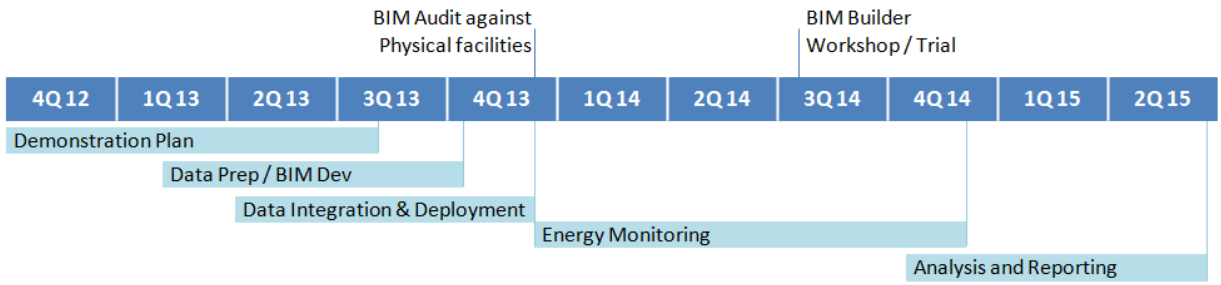


Figure 44: Timeline of Pilot Activities

5.5 SAMPLING PROTOCOL

The data communicated during the pilot installation period, and the data generated during the pilot execution period, consists of four main categories:

- Structural data:
  - CAD data (as provided by the site or USACE)
  - Generated BIM files, as produced by Honeywell applications
- Metering data: Building meter data, collected and warehoused at the Fort Jackson Energy Center.
- Building telemetry data: Point data from energy-related devices within the monitored buildings, collected and warehoused at the Fort Jackson Energy Center.
- Third-party Weather data, accessed through Honeywell HEM via existing site subscription.

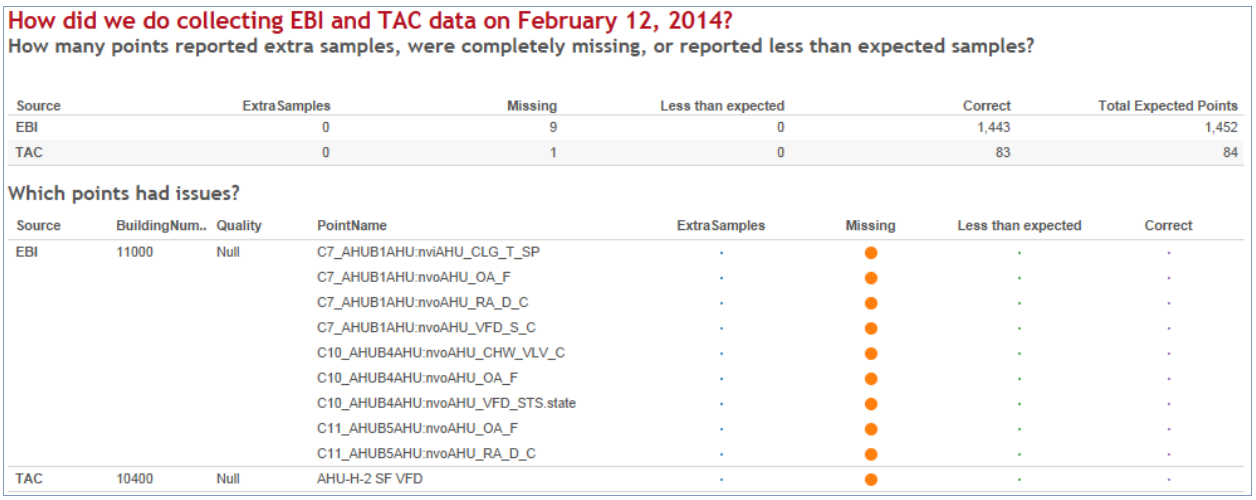
The following table outlines the processes or procedures followed to sample or generate the data.

Data Type Description & Quantity	**Meter, DCS and Weather Data:** Meter data was collected automatically at 15-minute intervals using previously installed equipment. Section 4 details data collection and quality issues regarding meter data. The resulting volume of data was approximately 500K time-stamped meter records. DCS Data from each building was collected automatically, at 6-minute intervals. These 6-minute data points are averaged values of the 1-minute interval point data for the last 6 minutes of data collection. The data includes more than 150M time stamped records. Weather data was available in 15 minute intervals (96 samples per day) through third-party subscription.

	BIM Data: BIM data is comprised of the following: CAD files, BIM Builder project files and output files (.ifc, COBie-style .xlsx documents), and transformed JSON data files. We say COBie-like documents because the format of the data is not exactly standardized as expected for COBie documents. See the table in Appendix F for details about these BIM-related products. CAD files and other schedules of known assets and asset properties were obtained from site support staff as well as external agencies. See Section 6.5 for a listing of sources.
Calibration	**BIM Data:** Macro level (accuracy in 10's sq. ft.), assessed during site survey to validate the as-generated BIM and augment with information not available through electronic sources. Typical BIM augmentation included adding room numbers, adding or removing walls and doors, identifying undocumented equipment. Sensor calibration was not part of this study, and no other computational models were applied that would require calibration.
Data Recording	**DCS, Meter Data and Weather data:** Real-time data collection from meters and UMCS solutions were fully automated and monitored by Honeywell staff at the Fort Jackson Energy Center. **BIM Data:** The majority of the BIM data was automatically generated from BIM Builder. Some other building-related data (renovation schedules, room / space utilization) was collected through surveys and interviews with the site Energy Manager, Building managers, and other facility support staff knowledgeable of the related assets and systems.
Data Storage and Backup	Data storage occurs within two databases—one for storing BIM-related data and the other for real-time telemetry from building energy devices. Both databases exist on the MDEI Server and are managed within MS SQL Server. A backup of the telemetry data was generated and stored on an external encrypted drive. Even if databases were lost on the MDEI Server, the telemetry data could be restored from the EBI Server.
Data Collection Diagram	See Figure 41 in Section 5.3 for details.
Survey Questionnaires	No formal surveys were conducted; informal interviews were conducted with the Energy Manager and building managers to get feedback about their engagement in energy management at Fort Jackson. See Appendix J.

5.6 SAMPLING RESULTS

At the outset of automated sampling, we routinely analyzed the collected data to confirm that all the expected data was received. Most of the analysis at the start of data sampling ensured that the data points represented the expected system behaviors and were not incorrectly identified during configuration. For example, supply/ return temperature and temperature-setpoint points all had values within an expected operating range, versus a 'status' (on/off) type point, which has a value of 0 or 1. We developed automated analysis processes later in the project to help reduce the manual effort required for monitoring data collection. Tableau dashboards were generated to summarize the number of samples collected for the past 24 hours, and then scheduled to be embedded in emails sent to registered users every morning at 5:00 a.m. local time. Figure 45 shows this data quality monitoring dashboard.



How did we do collecting EBI and TAC data on February 12, 2014?

How many points reported extra samples, were completely missing, or reported less than expected samples?

Source	ExtraSamples	Missing	Less than expected	Correct	Total Expected Points
EBI	0	9	0	1,443	1,452
TAC	0	1	0	83	84

Which points had issues?

Source	BuildingNum..	Quality	PointName	ExtraSamples	Missing	Less than expected	Correct
EBI	11000	Null	C7_AHUB1AHU:nviAHU_CLG_T_SP	·	●	·	·
			C7_AHUB1AHU:nvoAHU_OA_F	·	●	·	·
			C7_AHUB1AHU:nvoAHU_RA_D_C	·	●	·	·
			C7_AHUB1AHU:nvoAHU_VFD_S_C	·	●	·	·
			C10_AHUB4AHU:nvoAHU_CHW_VLV_C	·	●	·	·
			C10_AHUB4AHU:nvoAHU_OA_F	·	●	·	·
			C10_AHUB4AHU:nvoAHU_VFD_STS.state	·	●	·	·
			C11_AHUB5AHU:nvoAHU_OA_F	·	●	·	·
			C11_AHUB5AHU:nvoAHU_RA_D_C	·	●	·	·
TAC	10400	Null	AHU-H-2 SF VFD	·	●	·	·

Figure 45: Data Sampling Daily Result Dashboard with Missing Sample Details

During the pilot period, data sample quality was measured by verifying that the data point reported a value for the expected number of collection times in a day, e.g. for 6-minute data, 240 data values were collected. This verification was done mainly to ensure that data collection methods were not broken. Once data sampling quantitative quality stabilized, A closer examination followed on actual point data value quality measures. The trustworthiness of the collected data may be affected by the configuration of the underlying system, environmental impacts (sensors installed improperly), and sensor calibration issues, among other potential causes. For this pilot, data quality was managed through observation. In a scaled solution, data quality would be instrumented so that bad data would be identified automatically.

Table 14 shows quality of data from the five buildings over the course of the pilot project. The darker green shows where the best quality occurred. Yellow cells represent data of lesser quality. Gray cells show where no data was available. The value indicates the percentage of data collected as compared to expected sampling (typically, 96 samples/day at 15 min intervals).

Table 14: Percent of Expected Samples Collected for Each Source in Each Month during Pilot Demonstration

Building / Data Type	2013					2014									
	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
2450 BMS Data		99.71	99.70	100.00	96.55	99.96	99.95	99.60	99.89	99.92	100.00	97.77	96.06	96.17	4.80
2450 Electric Meter	94.89	15.76	0.00	1.18	85.15	99.73	99.93	99.70	46.91	0.00	63.58	100.00	75.91		
2450 Gas Meter	95.87	15.83	0.00	0.97	84.98	99.19	99.33	99.70	46.94	0.00	63.58	99.93	75.71		
9810 BMS Data		88.11	99.07	99.43	93.94	99.93	85.07	81.10	64.12	46.08	67.12	88.23	81.28	73.32	99.99
9810 Electric Meter	89.15	99.55	99.56	99.48	96.27	99.80	83.26	7.35	53.68	63.51	88.47	98.86	85.18		
9810 Gas Meter	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		
10400 BMS Data	98.08	63.10	99.99	100.00	96.53	99.59	100.00	96.88	92.52	99.68	98.81	91.18	86.06	98.81	28.69
10400 BTU Meter						99.68	100.00	96.91	92.24	100.00	100.00	89.35	100.00	99.96	99.69
10400 Electric Meter	98.57	97.97	99.43	99.34	95.56	96.94	99.63	97.86	93.80	50.49	50.00	50.00	50.25		
11000 BMS Data		34.82	52.14	52.13	50.42	52.16	52.26	51.08	49.59	52.26	52.20	52.10	52.26	52.26	52.26
11000 BTU Meter						99.68	100.00	96.91	92.39	100.00	100.00	99.60	100.00	100.00	100.00
11000 Electric Meter	12.74	0.00	0.00	30.89	94.86	98.72	98.07	92.90	95.28	99.80	99.86	99.16	98.69		
12000 BMS Data		33.39	64.41	82.64	79.55	82.55	82.75	79.90	76.41	82.65	81.39	80.24	80.39	79.98	80.55
12000 Electric Meter															
12000 BTU Meter						99.49	100.00	96.77	92.23	100.00	100.00	99.67	100.00	99.99	100.00

Table 15 highlights other identified problems with data collection during the course of the pilot program. These issues reflect the normal challenges that occur in any complex environment where many different vendors are engaged in multiple projects. These challenges can be amplified on a large installation or on any campus where the number of vendor relationships is likely to be significantly higher than the number of buildings and services to be managed.

Table 15: Data Collection Issues

Date Identified	Impacted Building(s)	Problem
8/28/2012	All	Fort Energy Manager states there are no building-level energy managers, he is working to re-instate them.
2/7/2013	All	Fort Energy Manager reports incorrect / incapable personnel identified to attend first meeting to establish building-level energy managers; building Commanders are asked to help.
6/12/2013	12000	Final attempts to read data from meter at building 12000 fail. Fort Energy Manager asked to assist with resolving meter connectivity and testing. Through July 2013 the EM works with the Army Corps of Engineers to connect the meter and test the reporting.
7/24/2013	11000 12000	Honeywell site Engineer reports electrical contractors are actively working on buildings 11000 and 12000, reports that the control systems were never properly completed, commissioned, tested, etc.
10/22/2013	2450 9810 11000	First round of data analysis finds missing point data for buildings 2450 and 9810, and bad meter data for 2450 and 11000. Additional data quality reports are put in place to assist in quickly evaluating whether data points were collected and values are 'Good' (per EBI specification).
10/25/2013	2450	Honeywell site engineer reports fixing a bad radio at 2450; meter data becomes available again.
11/13/2013	11000	Several AHU's at building 11000 have no data available that all other AHU's have. Honeywell site engineer must review previous contractors work and determine level of effort to make the required changes to bring these AHU's online.
11/26/2013	9810	All network communication to building 9810 fails. Weather conditions prevent restoring service to wireless network until following day.
11/26/2013	12000	Fort Energy Manager requests Army Corps of Engineers to address work not completed – connecting the electric meter to the transformer. Army Corps begins investigation into original contractor's responsibilities.
12/27 – 12/29/2013	All	Fort has planned power outage across entire fort; DPW shuts down EBI front-end on 12/27, and Honeywell Energy Center performs shutdown at start of 12/29 and brings systems back up on 12/30.
1/24/2014	11000 12000	Data analysis review shows 116 out of 252 points collected daily for building 11000 continue to report 'Bad', and 146 out of 847 points for building 12000. Many devices (AHUs) continue to be offline. Honeywell site engineer continues to work with DPW and other site contractors about connecting the offline equipment.
3/1/2014	9810	New contractor making modifications to building 9810, replacing all AHUs

Date Identified	Impacted Building(s)	Problem
		and a boiler. Data collection for 9810 suffers (see quality charts).
4/22/2014	2450	Electric meter is reported as failing since 14 April. Options to attempt to repair the meter and to completely replace it are reviewed.
6/12/2014	11000 12000	Data analysis continues to show bad data for all points identified on 1/24/2014.

6.0 PERFORMANCE ASSESSMENT

6.1 PO 1: FUNCTIONAL BIM

PO1: Produce a functional BIM for operations through a semi-automated generation process.

The principal measure of this analysis is the level of detail provided, and the coverage of data points expressly required by the operational use cases we had defined.

- A location for required fields within the model as evidenced by the tools.
- Ability to populate these data for the buildings in the study and have a reasonably accurate model of the facility with respect to current conditions.
- Assessment of the time required to populate a BIM by someone who has achieved competency with the tools; normalized for building size and complexity.

An overview of the BIM Builder software has been provided in Appendix B. The intent of this objective was to show that the BIM Builder software provided by Honeywell could produce output consistent with DoD expectations for information integration, and that the IFC output of BIM Builder would enable information re-use through the application of DoD tools for conversion into other formats, such as COBie.

The evaluation of BIM Builder's utility as a tool for knowledge extraction from CAD files consisted of three activities:

1. Generation of a BIM for each of the five facilities in the Fort Jackson Pilot, using "as-built" CAD
2. Physical audit to confirm and corrrect the accuracy of the generated BIM against the existing facilities at Fort Jackson.
3. Evaluation of the format and content of the resulting models by the team at CERL.

There are two related objectives, PO5, which discusses the efficiency of using the BIM Builder software to generate models, and PO7, which discusses the overlap and transferrability of this data to support BUILDER requiremments. All three of these performance objectives were substantially evaluated by the team at ERDC-CERL. The complete context of their overall evaluation is provided in Appendix F. Extracts of that report are provided to summize results for each objective.

To understand the results, it is necessary to be clear about the specific end-use goals for the resulting medium-fidelity BIM, and also, to describe the relevant data that it is possible to extract from CAD drawing for these purposes.

- Detect unusual HVAC consumption
  - Is equipment running when it shouldn't be?
  - Is the buiding adquately, or excessively ventilated?
  - Is the equipment meeting its goals for comfort at the space level?
- Detect unusual unoccupied consumption for a single building against the building type
  - Consumption for a time slice in day and night against expected occupancy schedule by building type

The resulting models met the LOD requirements as shown in Table 16 for the above use cases.

Table 16: LOD Requirements and Examples

LOD	Environmental: Lighting, Energy Use, Air Movement Analysis and Simulation	Examples of data at each LOD required for this pilot
100	Strategy and performance criteria based on volumes and areas.	List of rooms and their area
200	Conceptual design based on geometry and assumed systems types.	Approximate location of rooms in appropriate relative size and physical relationship.
300	Approximate simulation based on specific building assemblies and engineered systems.	Relatively correct room dimensions. HVAC System design with device types, connection requirements, schedules of named elements, and relationship to physical spaces.
400	Precise simulation based on specific manufacturer and detailed system components	N/A
500	Commissioning and recording of measured performance	As built details. Validation of the correct physical spaces. Measured values from the control system.

Results

BIMBuilder was used successfully to extract the necessary details from CAD and produce the BIM model in IFC, and the equipment and space relationships required for ease of navigation and data integration. The resulting models were deployed in the pilot.

Table 15 describes the CAD features extracted for each of the five facilities.

Table 17: CAD Features Extracted for Five Facilities

Building	Total Sq Ft	# HVAC Assets	# Spaces
2450	120000	353	119
9810	37310	358	113
10400	23178	135	49
11000	290481	807	469
12000	290481	974	512

Details related to the extraction process for each facility are detailed in Appendix I.

In wide-scale application, an individual familiar with the site would be able to validate the resulting model quickly, and visual verification would be required only by exception. For this pilot, the project team, including representatives from both Honeywell and ERDC-CERL, conducted a visual audit of the resulting models, touring each facility and verifying the accuracy of the spatial representation, and the correct identification of rooms and equipment in the model. The audit took between 2-3 hours per facility. It took roughly 30 minutes to make the

appropriate adjustments to the generated model for each facility, consisting mostly of corrections to room labels, and adding or removing walls or equipment per actual site conditions. In only one case was the CAD data significantly out-of-date with respect to modifications to the facility (9810).

An analysis by ERDC-CERL concluded that the output of BIMBuilder should be improved to ensure interoperability through the public standard mechanisms, with an emphasis on improving the encoding of building components in IFC. Honeywell plans to implement these improvements.

The full analysis of the content of the resulting output, and the aspects to be improved are detailed in Appendix F. Additional interoperability interests are discussed in Section 6.8.

6.2 PO 2: ENERGY INTELLIGENCE IMPACT ON ENERGY USE

Associated Performance Objectives	PO2: Asset-level energy intelligence impacts energy use in managed buildings
Performance Objective Analysis Overview	We collected meter data continuously at the building level for three of the pilot facilities. Two facilities were incompletely commissioned and insufficient meter data was available for detailed energy analysis. Individual building managers were interviewed, but given their low level of engagement in energy management, no repeated surveys were conducted.
Statistical Methodologies	Regression analysis
Graphical Methodologies	Time series and scatter plot visualizations
Industry Standards	We used whole facility data, Option C from the International Performance Measurement and Verification Protocol (IPMVP) to establish savings resulting from the increased information. Using weather and occupancy data as normalizing factors, we established a baseline model for each building using data collected before and during the demonstration. Based on an evaluation of equipment behavior at the site, we then estimated the impact of enacting reasonable energy conservation measures.

The hypothesis that Honeywell has pursued in this study is that providing an integrated view of the arrangement of equipment and spaces, and the relationship between energy use and equipment behavior can lead to better insights and more effective and timely energy management interventions. By using the physical information model provided by BIM, and attaching the operational information provided by the control system, we provide an energy manager and other interested stakeholders with a ready source of rich information about how and why a building performs as it does.

In the following example visualization from our MDEI UI, the Navigation Pane shows that Terminal Unit TU-H-1 has been selected in the left-most navigation pane. In the upper right the Energy Manager can specify the date range of interest. The bottom half of the screen provides the physical context, showing the location of this device in the building. To the left of the 3D visualization is a list display showing the number of diffusers being served (children), and the Air Handling Unit (AHU-H-1) that is providing treated air to this Terminal Unit.

Beneath the date range selection is a tool for fine-tuning the time period, and a legend for the points being displayed. This legend shows the points by their role in the system, rather than by their point name. This ensures that the charts for individual items with common data will always be the same.

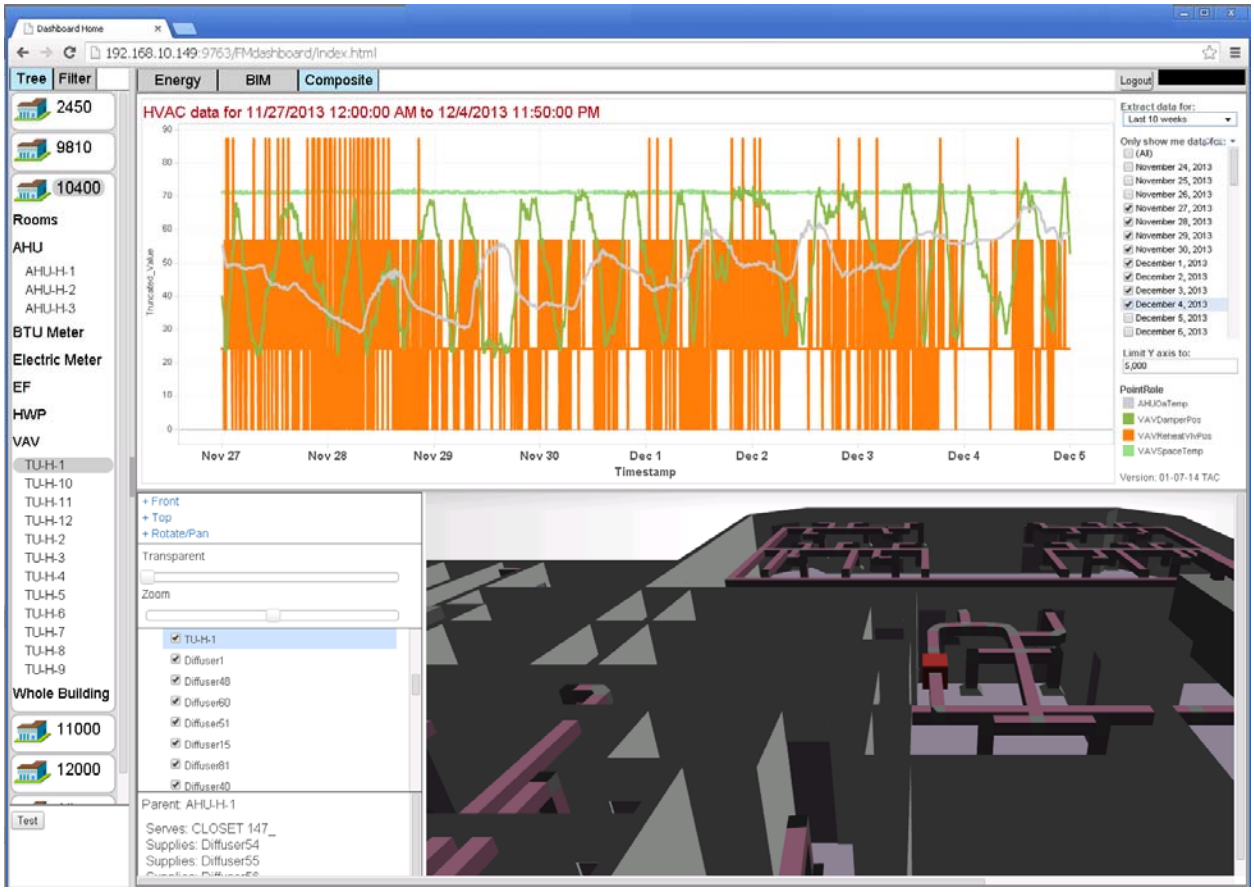


Figure 46: Example Integrated Display Showing Equipment Context and Behavior.

Energy Conservation Measures

The energy monitoring goals defined for this pilot demonstration were to identify occurrences of these common efficiency issues in building operation:

- HVAC equipment running when it shouldn't be;
  - for example, cooling when the building is unoccupied.
- Excessive consumption by HVAC equipment caused by the introduction of excessive or inadequate outside air.
  - For example, the OA damper being open 100% continuously
- Excessive HVAC consumption through a failure of the equipment to meet comfort goals;
  - for example, SupplyAir temperature(s) too high

- Unusual patterns of operation, such as high consumption during unoccupied hours when compared to buildings of the same type and occupancy schedule.

We concentrated on behaviors that can be discovered through analysis of existing systems at Fort Jackson. Therefore, we did not include lighting control in the study, as most of the lighting at Fort Jackson was not instrumented in a manner to provide the required data for analysis. The methods that we have applied to assess equipment behavior can easily be translated to include lighting as a monitored concern. Note that the energy metering includes all lighting and plug loads and HVAC components.

Results of Monitoring

As we anticipated, the collected trend data uncovered many instances of inefficient operation in the monitored facilities. This section of the document discusses how the collected data were used to direct attention to problem behaviors.

We have summarized three examples that were evidenced by the collected data. We have further detailed one of these, the example relating to Building 10400, in Appendix J.

Table 18: Summary of Energy Analysis Results

	Simultaneous heating and cooling	Continuous Operation	Incomplete Shutdown
Building Number	10400	2450	9810
Issues	Terminal unit behavior, including reheat and overall system operation	RTU behavior, and Gas Use for heating in vehicle bays	Scheduling anomalies
Solutions	• Improved scheduling • Retrofit improvements to air delivery to principal working space	• Improved scheduling. • Additional automa-tion on vehicle bay IR units.	• Improved scheduling
Potential Savings	18-25%	15-25%	15%
Annual Savings (kWh)	340,255	341,616	175,121
Annual Savings (MBTU)	1161	1165	597

Energy Intensity

The visualization shown in Figure 47 is available from the UI MDEI Energy Dashboard by selecting the “All” node. It provides a comparison of electrical energy usage demand between buildings, normalized for size (Average Watts per Square Foot).

We use average demand figures because they are more robust to dropped and missing interval data in an overall analysis of energy use. This approach avoids problems in analysis when utility quality billing data is not the primary source of data for analysis.

The time span begins at March 2013 (left-most bar) through October 2014 (right-most bar). Month by month, the EM can quickly see how the buildings compare.

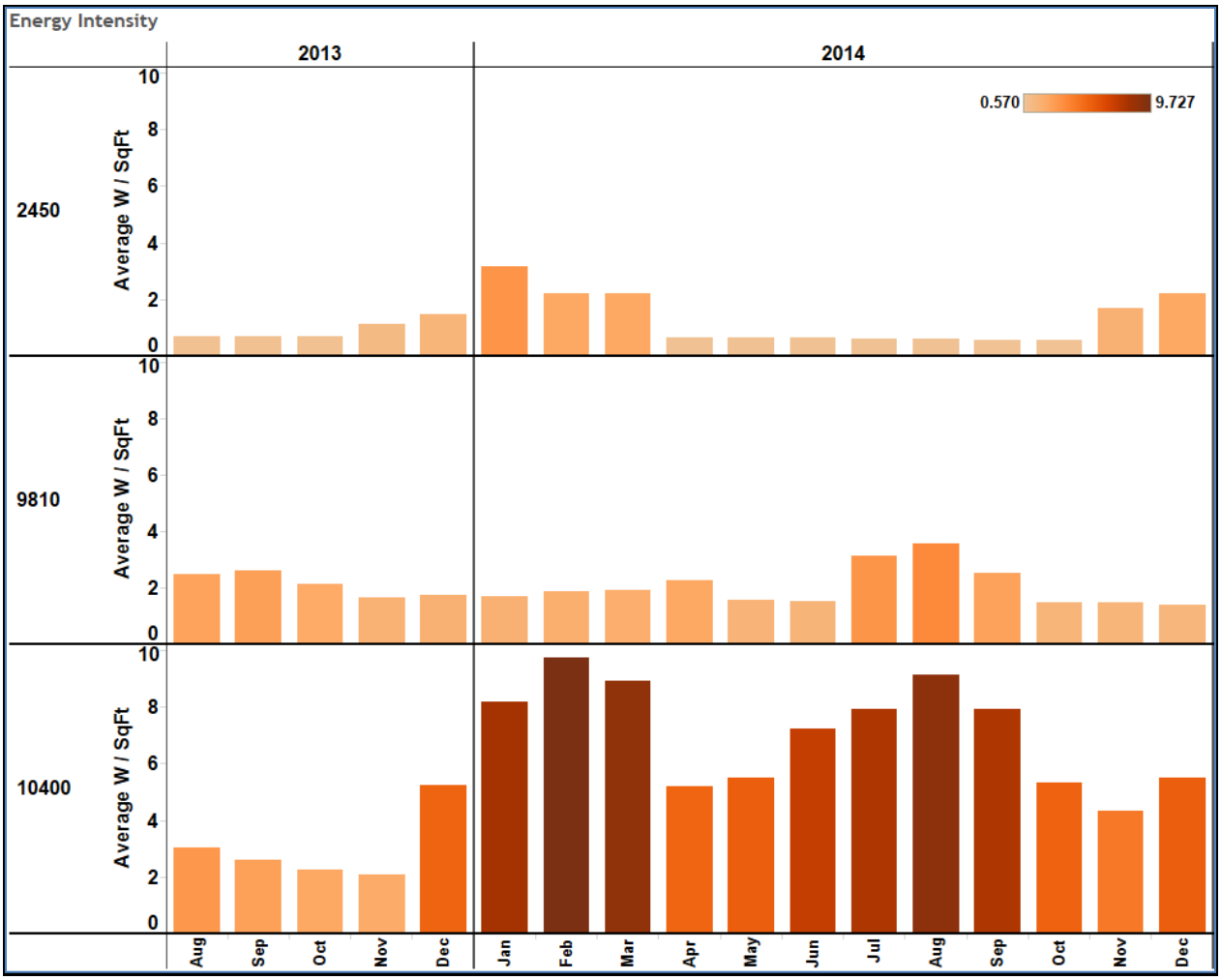


Figure 47: Energy Intensity Comparison using Average W/Sq Ft

Notes about the underlying data:

- Gas data was not available for 9810, so it is not reflected in energy intensity for that facility. 9810 has a local chiller and boiler.
- BTU data for central HotWater and ChilledWater are factored into the figures for 10400.
- Both gas meter data and electrical are included in for 2450, which has a local boiler.
  - The heating load in 2450 applies to the full 210K sq ft including vehicle bays.
  - In those months with low gas usage for 2450 (April-Oct), average cooling demand is 1.65 KW/sq ft when spread only across the 45K of cooled classroom and office space. This still results in an average intensity that is considerably lower than 9810 and 10400 during the warmest months of the year.

Estimated Savings Potential in Building 2450 – Vehicle Maintenance Training Facility:

Since no substantial changes were made to the operation of 2450 during the pilot period, we are estimating savings potential from the regression analysis, and our observation of days that represent best performance. Using the weekend electrical baseline as a reference, and assuming

a nominal 45-hour normal operating period during the week (based on interviews with the staff), a conservative estimate is overall reduction of 15% electrical consumption over current operating practices.

In this facility, gas consumption is a significant cost of winter operations, to heat the vehicle maintenance bays. Our analysis shows that the heaters often run all night, though the staff has not indicated that overnight operation is typical in this class room facility. Therefore, given the observed performance, we estimate a potential 25% savings from baseline gas use on heating days, if the IR heaters are operated only as needed.

Figure 48 illustrates the energy savings for CDD based on the regression analysis. We have observed that the building is capable of dropping back to these levels, and that a minimum reduction of 15% could be achieved during the cooling season, based on typical occupancy.

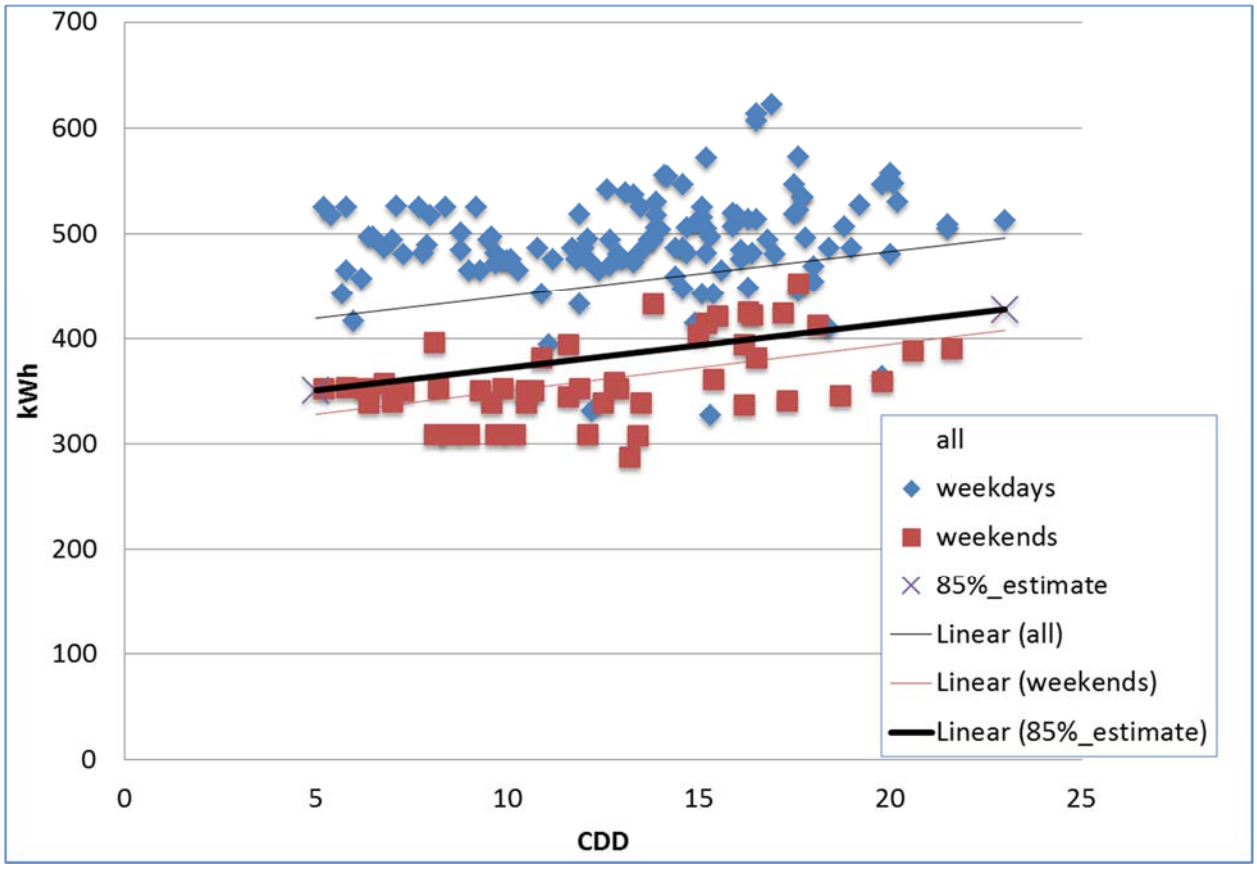


Figure 48: 2450 Estimated Savings Potential based on Electrical CDD Regression

Figure 49 and Figure 50 illustrate the energy savings for HDD based on Electrical and Gas HDD regressions.

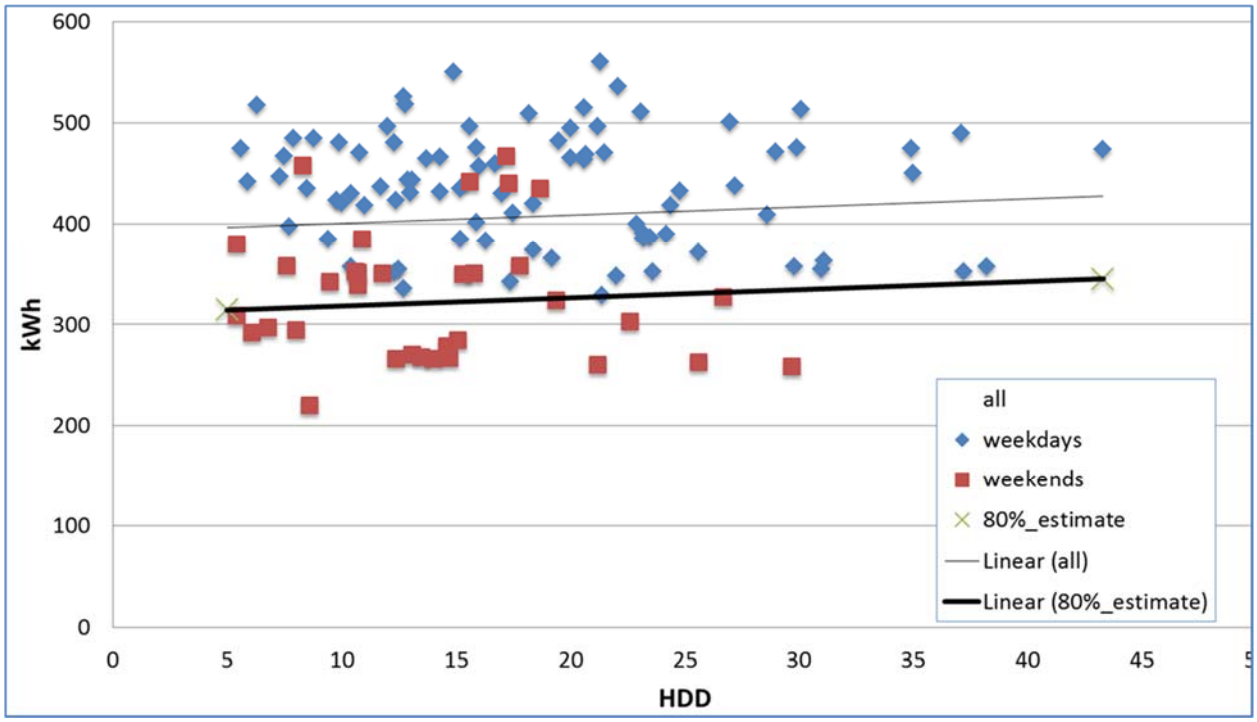


Figure 49: 2450 Estimated Savings Potential based on Electrical HDD Regression

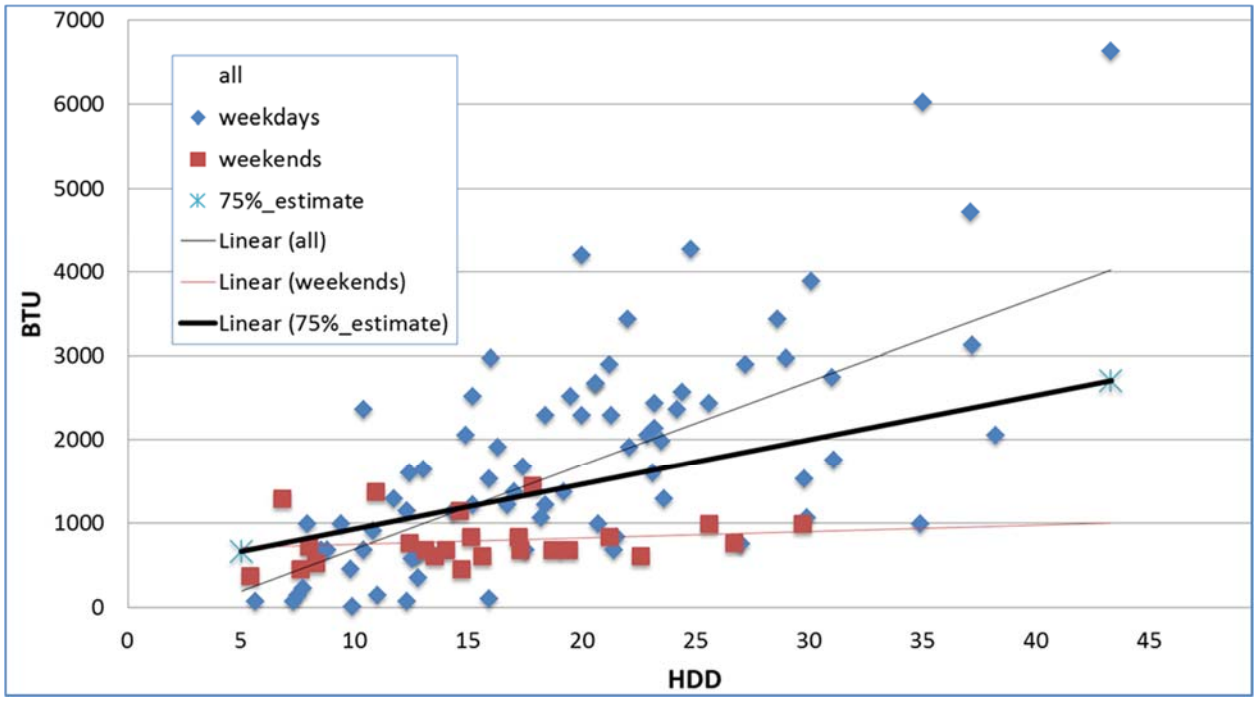


Figure 50: 2450 Estimated Savings Potential based on Gas HDD Regression

Example finding

Figure 52 illustrates a scheduling anomaly which is likely accidental. This VAV has the opposite temperature set back of others, dropping to 60°F for overnight operations. This unit is serving a typical classroom space in this facility.

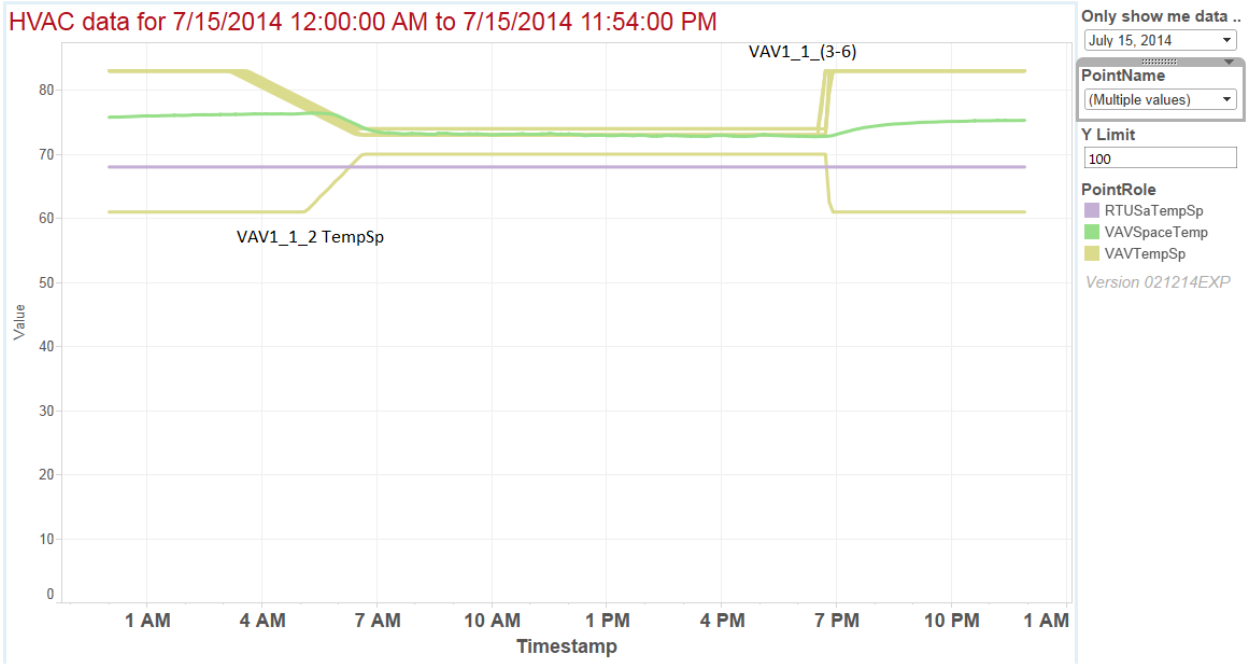


Figure 51: Setback Schedule Anomaly on VAV1_1_2

Estimated Savings Potential in Building 9810 —Soldier Services Facility

Based on conversations with the occupants and manager, normal working hours for this facility average 45 hours per week. However, the building systems shut down briefly from roughly 6-8 pm and then start up and run continuously until roughly 6 am, when systems shut down for approximately one hour before resuming daytime operating parameters.

An overall savings of 15-20% is conservative based on the regression analysis, and observation of operating behavior.

Because gas data is not available for this facility, we can't provide a regression analysis for HDD however, based on the behavior of the systems we anticipate similar savings opportunities based on scheduling for occupancy.

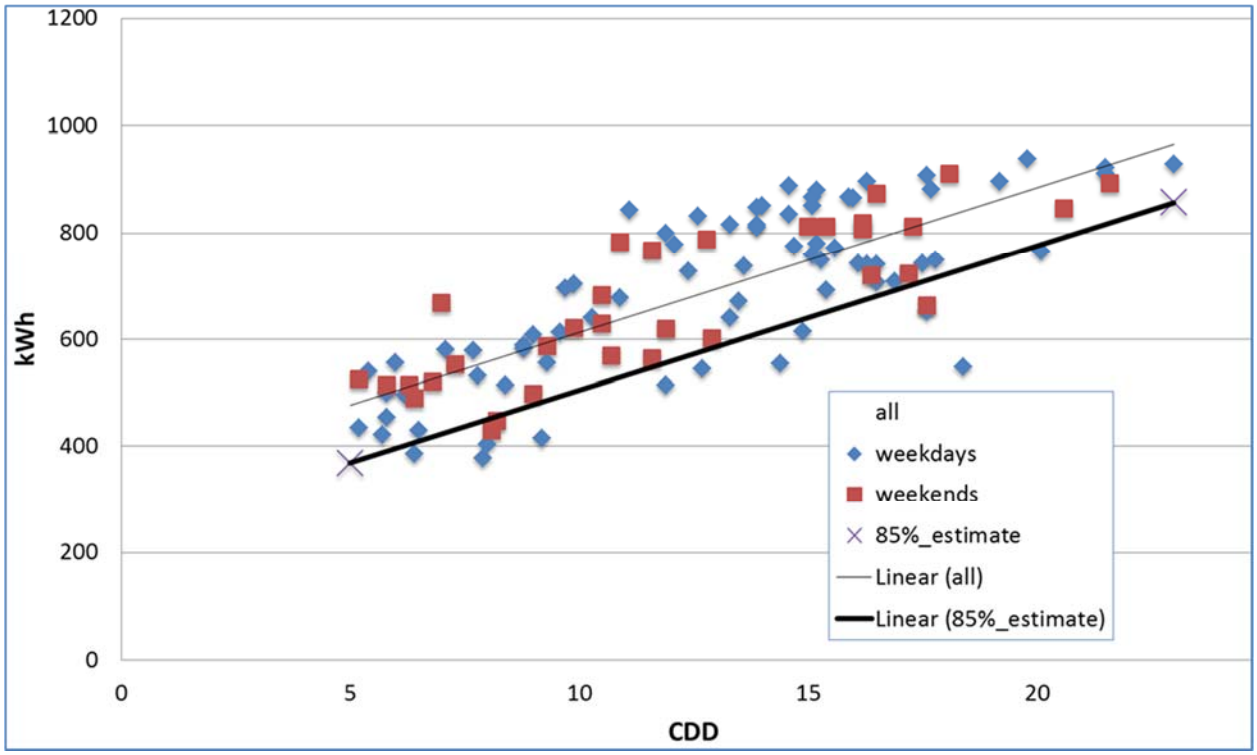


Figure 52: Estimated 9810 Savings Potential Based on CDD Regression

Figure 53: Electrical Profile for 9810 Soldier Services, Oct-Dec 2014.

Estimated Savings Potential in Building 10400-Brigade Headquarters

Due to continuous air delivery to all spaces in 10400, and centralized hot water and chilled water supplies, electrical consumption in this facility is relatively flat, year round. Observations of this facility are detailed in Appendix J, and illustrate the following behaviors that lead to inefficient operation.

- Simultaneous heating and cooling
- 24x7 operation of all spaces including classrooms
- Over cooling of many spaces
- Under-served spaces

Based on the observed behaviors and the regression analyses, we believe that the savings potential in this facility is a minimum 15%, and potentially as much as 25% when accounting for all of the factors that are leading to inefficient operation.

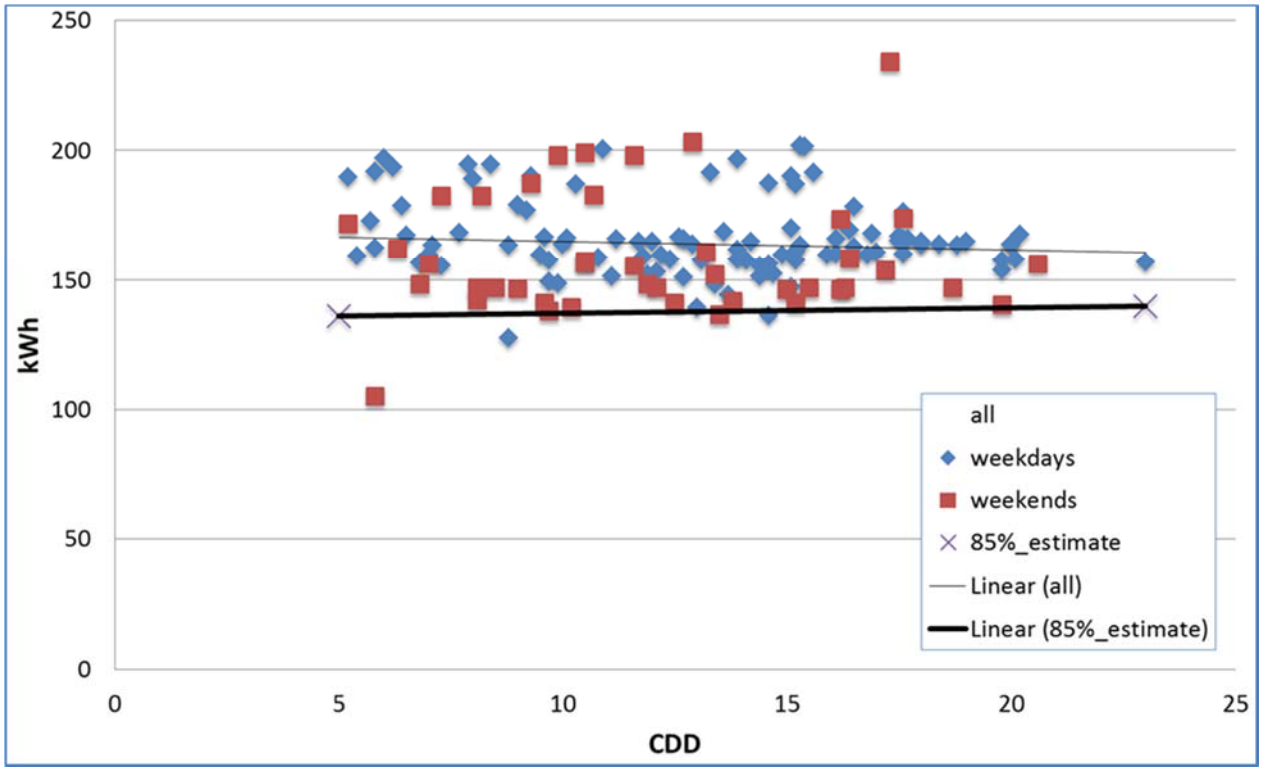


Figure 54: Electrical Savings Potential Based on CDD regression for 10400

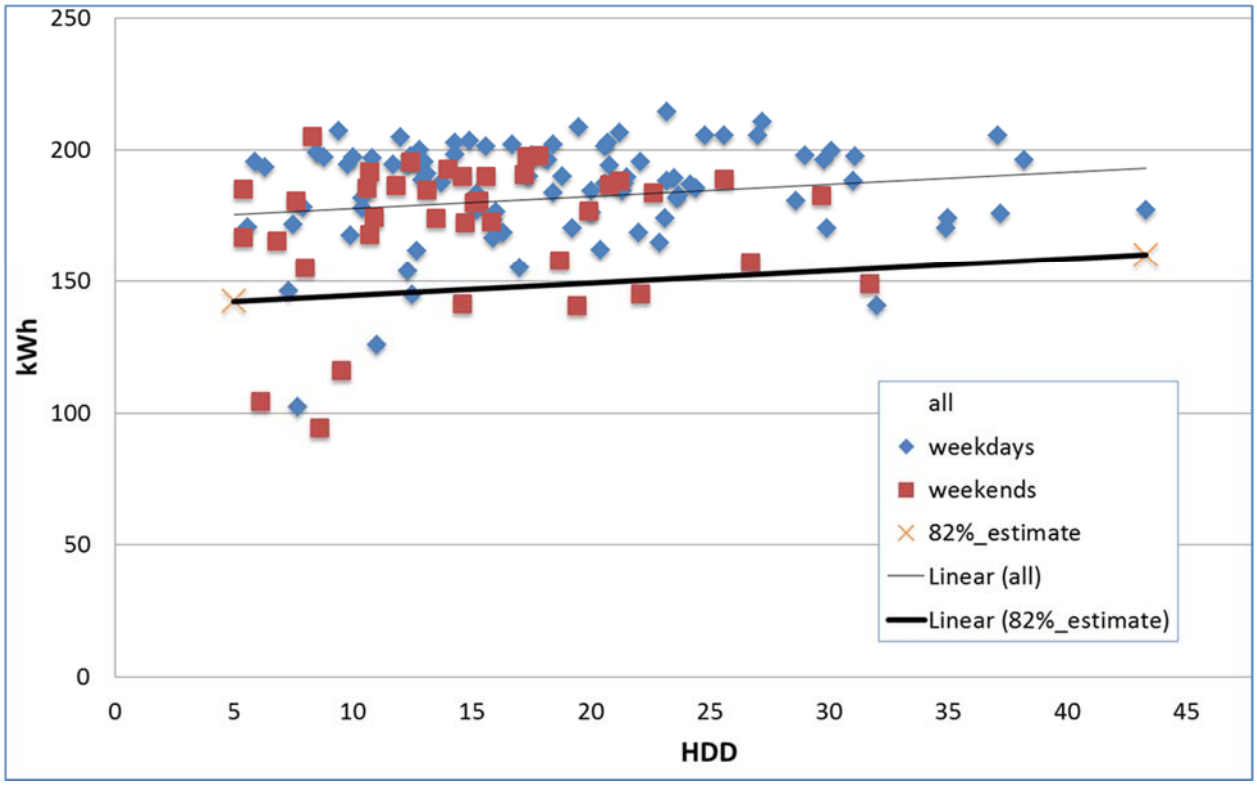


Figure 55: Electrical Savings Potential based on HDD regression for 10400

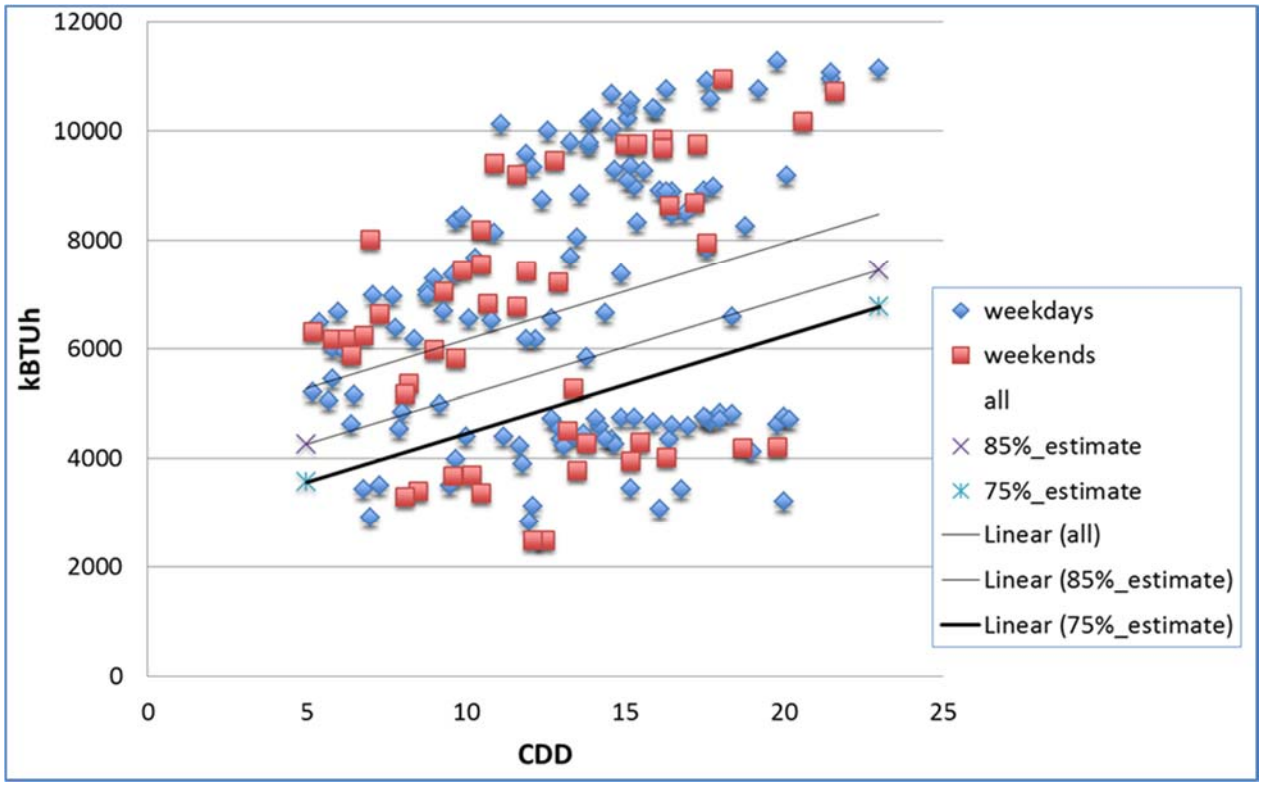


Figure 56: Savings Estimate based on CDD regression of ChilledWater use at 10400

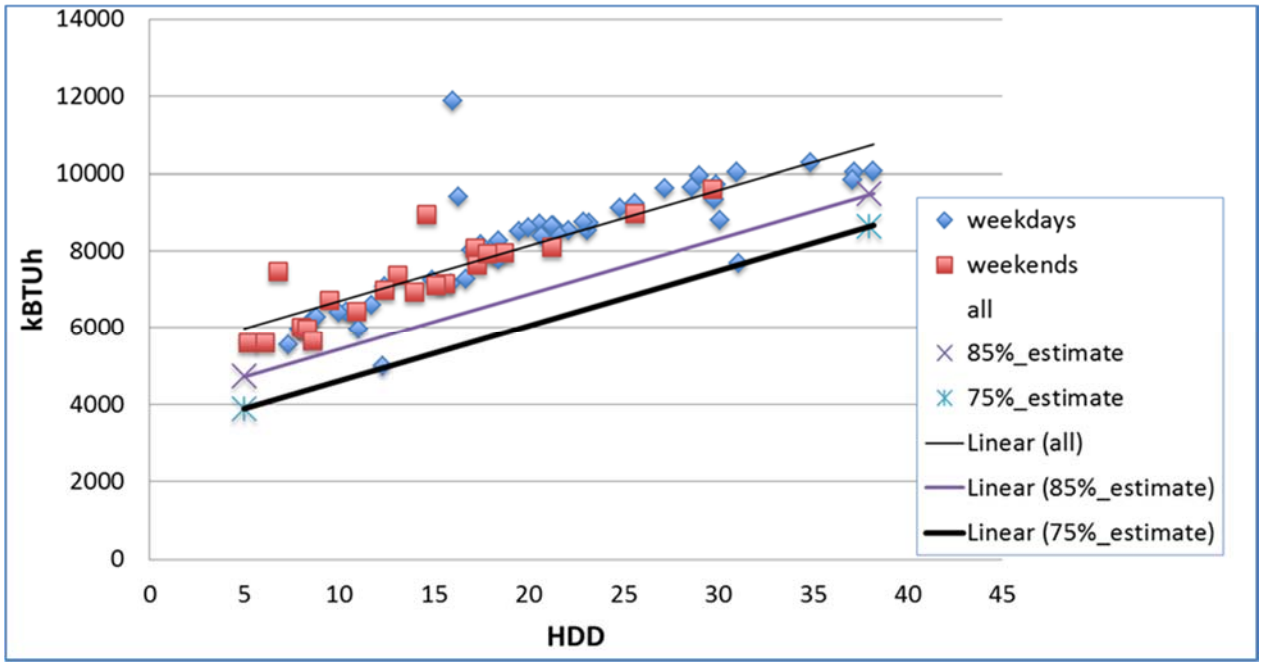


Figure 57: Savings Estimate based on HDD regression of HotWater use at 10400

6.3 PO 3: IMPROVE ENERGY MANAGER VISIBILITY

Associated Performance Objectives	PO3: Improve energy manager visibility into building performance data
Performance Objective Analysis Overview	We collected qualitative feedback via interviews with the energy managers responsible for each building.

The hypothesis that Honeywell has pursued in this study is that providing an integrated view of the arrangement of equipment and spaces, and the relationship between energy use and equipment behavior can lead to better insights and more effective and timely energy management interventions. By using the physical information model provided by BIM, and attaching the operational information provided by the control system, we provide an energy manager and other interested stakeholders with a ready source of rich information about how and why a building performs as it does.

We improve upon the visibility into building performance data by leveraging BIM to put all energy and equipment trend data into context within the structure. All user interface views are standardized, generated dynamically by the underlying BIM data.

The energy manager was very receptive to the information that we could provide about the functioning of the facilities. We met with him approximately every two weeks for a period of about two months. During that time, we reviewed findings, using the tools that we had put in place for him to browse the data directly. Figure 46 through Figure 57 in Section 6.2 represent examples that were reviewed with the energy manager. These meetings had three objectives:

- Validate the configuration of the system: Recognize and address issues with the collection and classification of the information, either with the building model or the data from the building management system.
- Validate the findings: Discuss the anomalies made evident in the trends, and discuss possible solutions to the issues.
- Train the Energy Manager in the use of the tools: Through review of the thought process the tool supports, and the means to navigate from one view to another, the review sessions also served as training.

For the purposes of this pilot, the Energy Manager was equipped with a workstation that could access the systems on the local, dedicated control network. This required the MDEI energy dashboard to be located in a specific location within the DPW offices where this network could be accessed. This workstation was not in the Energy Manager's office, and the data was not readily available from his desktop. [See Section 5 for a network diagram.]

Ultimately, we left the energy manager to use the system as he wanted, and tracked his usage. The energy manager interacted very little with the system once it was installed. This was disappointing, but perhaps to be expected. This system was not part of his normal daily activity. Much like the other HVAC monitoring solutions (both Honeywell and third party solutions) this data would only be accessed when something was going wrong, and HVAC managers were compelled to interrogate the control system for answers. Furthermore, the energy manager could not access this information at will from his own workstation. It could only be accessed at a specific workstation with connectivity to the pilot interface. This setup reflects the typical situation when the control systems are on an isolated network, as is the case at Fort Jackson.

It is difficult to draw conclusions from a single reference example; however, given experiences in this and related pilots, it seems that:

- By integrating the information and presenting it consistently, it is easier to recognize the anomalies identified by the data.
- The typical energy manager at an installation as large as Fort Jackson can't review detailed energy information on a regular basis. The volume of such information is too high.
- To be useful, the identification of actionable situations must be more highly automated.
- If this information is to be useful and effective, it has to be more accessible, and part of a regular routine.
- Addressing the network isolation of energy information systems at DoD bases is critical to enabling ready access to energy managers, both on and off site.

When the demonstration plan was committed to, there was still some expectation that an individual at each facility would be assigned responsibility for energy management at their site. It became obvious early in the execution that these individuals were not going to be easy to engage in our study, even if their role in the management of energy use was suitably formalized. The prevailing reasons why we ended up not engaging these individuals are:

- Chain of command: If there was someone assigned to this role, they are outside the management structure of the DPW, and therefore not readily available to us for this pilot without considerable networking with people in their chain of command.
- Changeover: The amount of movement of people through such positions, especially under the conditions at Fort Jackson, meant that we could not keep the same individuals engaged throughout the pilot.
- Priorities: Operations and energy management are secondary to mission. This would have made it difficult for us to routinely engage with these individuals.

To the extent that it was possible, our team sat down with the local manager responsible for each facility, to inform them about our project and to learn about their concerns, and gain their support for our activities. A summary of the concerns we heard during these interviews is presented in Appendix K.

6.4 PO 4: TRANSFERABILITY TO DOD PORTFOLIO

Associated Performance Objectives	PO4: Transferability of conservation measures to other like assets.
Performance Objective Analysis Overview	The objective is to assess how transferrable the pilot solution is across other DoD installations.
Internal Validity	Make any assumptions about the required characteristics of facilities (for transfer) clear and unambiguous, and consistent with the practices employed.
External Validity	Drawing parallels to commercial application and experience.

Potential Benefits for DoD Facilities

Detection & remedy of HVAC system performance problems in DoD buildings has historically been problematic. It is typically a reactive process, based on occupant complaints, not necessarily analysis of suboptimal performance. It is often difficult to detect the source of a performance deficiency and assess correct solutions. This is typically a manual seek-and-find process. Energy management & maintenance resources are limited on military installations and cannot support labor-intensive efforts. If the Model Driven Energy Intelligence (MDEI) methodology is proven to provide the intended capabilities, it can automate the diagnosis of HVAC systems performance in buildings. It can assist in troubleshooting and diagnosis, identify the problematic HVAC components, and propose remediation measures.

As of 2012, there are roughly 299,000 buildings in the DoD inventory, roughly 205,000 owned by the DoD and the remainder occupied through leasing or other arrangements such as public/private ventures. The question is how much of the DoD building inventory can benefit from application of BIM-Builder and MDEI methodology? That is, what is the transferability of BIM Builder and MDEI throughout DoD?

Transferability

Virtually any building that consumes energy, and therefore can waste energy – can potentially benefit from the BIM Builder/MDEI methodology. However, one must distinguish between being technically possible and being feasible; where feasibility suggests a worthwhile benefit value; a significant reduction of energy consumption.

Many independent variables can help define which facilities will benefit from MDEI. However, these variables cannot all be analyzed simultaneously. Two of these factors are critical and are cited as the primary determinates for transferability to DoD facilities:

1. A BIM is available for the building. A building's design may include development of a BIM, or a BIM may be developed based on existing CAD files. Either way, a BIM must exist.
2. The building has a utility monitoring control system (UMCS) with a direct digital control (DDC) system and the necessary DDC system communications and software infrastructure to connect buildings.

The DDC system alone is not sufficient for MDEI application. Together, the DDC system and communications infrastructure provide real-time or historical trend data access to HVAC system data. In addition to the building-level DDC system (such as the local controls, including sensors, for an air handling unit) this likely needs to include a common base-wide front-end operator

workstation where the MDEI resides such that a single MDEI software can access and operate on data from multiple buildings. DoD facilities typically have a single operator (such as a DPW Energy Manager) serving the entire post/base, not one per building.

Other factors will contribute to the beneficial application of the MDEI to a building. These include building age, construction type, size, location, occupancy type, occupancy schedule, HVAC configuration, energy consumption, and others. However, these factors help indicate the degree to which the BIM-Builder/MDEI can benefit buildings, that is more beneficial or less beneficial, as opposed to a fundamental necessity. The following discussions, therefore, relate to identifying buildings that have both BIM and DDC systems.

Unfortunately, there is no single source within DoD that provides exactly this data. Therefore, the basis for evaluating transferability is based on published data on the DoD building inventory, ERDC-CERL researchers' knowledge of the implementation of CAD and BIM requirements into Army facilities programs, and ERDC-CERL researchers' knowledge of Army facilities HVAC and control systems. The Army owns almost half of the DoD building inventory; therefore, it seems reasonable to extrapolate known data from the Army building inventory to the total DoD building inventory.

Related Policy

The National Energy Policy Act (EPAct) of 2005 is frequently cited as a driver for installing energy metering and possibly an indicator of how many facilities can benefit from MDEI. EPAct 2005 requires metering in Federal buildings by 1 October, 2012. The following is cited from an article in The Military Engineer (see http://themilitaryengineer.com/index.php/item/134-the-army-metering-program).

> "Installation of advanced electric meters began in FY08 on facilities that were deemed cost effective to meter based upon Office of the Secretary of Defense criteria that state buildings that consume and estimated $35,000 annually in electrical costs are economically justified for metering. For army planning and budgeting purposes, the $35,000 per year electrical cost equates to buildings of 29,000 ft^2 and larger.
>
> 'This translates to approximately 6,700 Army, Army Reserve, and Army National Guard facilities to be metered at more than 480 sites worldwide,' said Lawson (Stan) Lee, Chief of the Facility Support Division, Huntsville Center. 'Electricity, natural gas, water and steam or high-temperature water will all be metered. To determine the exact number of meters required, all installations are currently being surveyed in phases. The anticipated scope is a total of 13,000 advanced meters.'
>
> By the end of FY09, the Army had installed advanced electric meters on 47% of facilities economically justified for metering, according to David Purcell, Army Energy Program Manager for OACSIM's Facilities and Policy Division. This amounts to 3,151 out of 6,700 required by the end of FY12.
>
> In December 2009, Huntsville Center awarded the contract for the Meter Data Management System that will receive meter readings from across the Army."

The DoD Facility Inventory

The DoD Facility Inventory is described in the Department of Defense Base Structure Report, which is published annually. The 2012 Baseline is used as primary data source for this assessment (see http://www.acq.osd.mil/ie/download/bsr/BSR2012Baseline.pdf). This report tabulates all DoD buildings worldwide that are owned, leased, and occupied under "other" arrangements such as public-private ventures. The 2012 report includes both building count for all DoD services as well as square foot totals by Facility Class as shown in Table 19. Knowing the Facility Class is critical to this assessment. The 2013 and 2014 Base Structure Reports do not include building count by Facility Class. The total DoD building inventory is 4.9% lower in 2014 (see http://www.acq.osd.mil/ie/download/bsr/Base%20Structure%20Report%20FY14.pdf) than it is in 2012. The Army, in particular, has been aggressive in removing WWII-era buildings, which would not have been good candidates for MDEI application. For the purpose of approximating the numbers of DoD buildings that may potentially benefit from MDEI, the 2012 data should suffice.

Table 19: DoD Building Inventory by Facility Class (2012 DoD Base Structure Report)

Facility Class	Owned	Leased	Other	TOTAL
Family Housing	30,387	7,635	69,077	107,099
Supply	51,493	125	3,763	55,381
Maintenance & production	21,293	86	1,233	22,612
Troop housing & mess	13,458	282	2,203	15,943
Administrative	14,023	483	1,670	16,176
Operation & training	30,150	255	1,883	32,288
Community facilities	22,557	178	2,836	25,571
Research	5,720	51	50	5,821
Hospital & medical	1,720	24	188	1,932
Utility & ground improvements	14,140	34	1,900	16,074
GRAND TOTAL	204,941	9,153	84,803	298,897

Not all facility types are suitable for energy systems monitoring and control. Family Housing is currently developed and managed by private partners in all DoD services where the HVAC systems are controlled by occupants, not the installation. Also, Utility & grounds improvements are not necessarily enclosed, conditioned buildings.

Table 20: DoD Building Inventory by Service (excluding Family Housing and Utilities and Ground Improvements)

Service	Owned	Leased	Other	TOTAL
Army	91,341	6,119	43,913	141,373
Navy	44,063	967	21,126	66,156
Air Force	57,800	1,804	5,369	64,973
Marines	11,629	135	14,395	26,159
WHS	108	128	-	236
GRAND TOTAL	204,941	9,153	84,803	298,897

Removing these facility types leaves approximately 176,000 buildings that are likely to be space conditioned.

BIM & CAD in the Current Building Inventory

The existence of a BIM is a prerequisite for applying the MDEI methodology. A BIM is the basis on which the MDEI identifies HVAC components and the spatial relationships among the components. In the BIM, the location of monitored points (such as sensor data), the location of specific individual components, and the relationships of components to each other (upstream and downstream, controlled by, etc.) are determined. It is the basis on which anomalies in HVAC performance can be diagnosed and corrective measures recommended when performance monitoring and data is provided.

BIM was first required for the Army's Military Transformation (MT) program in 2008. This program constituted the bulk of Military Construction, Army (MCA) program. Actual construction of the 2008 MT buildings was completed in 2012. ERDC-CERL and Headquarters, U.S. Army Corps of Engineers (HQUSACE) estimated approximately 550 Army construction projects were developed with BIM from 2007 to 2012. Since many of these projects entail multiple buildings, this constitutes approximately 3-3.5% of all Army buildings. The Army now requires BIM for all new design beginning in 2013. The Air Force has required BIM for all new designs beginning in 2010. The Navy is phasing in BIM beginning FY 2015.

Applying 0.7% to the DoD building inventory of 176,000 suggests roughly 6,100 BIM exist for DoD buildings as of 2012. This is a negligible number. However, BIM will be developed in the future for all new DoD construction projects. Developing BIM should also be preferred by the design professions for major building conversion/repurposing projects in the future.

While development of a BIM as part of a building's design development is preferred, a BIM can be generated with the BIM-Builder from CAD files. CAD emerged as a common practice in the Architecture/Engineering/Construction (A/E/C) industry in the early 1990s. CAD was applied to the majority of Army & DoD new design and construction projects by 1995. Using data from the Army's General Fund Enterprise Business System (GFEBS) and Headquarters Installation Information System (HQIIS), it was calculated that approximately 20% of all Army facilities were constructed between 1995 and 2012. Applying 20% to the DoD inventory of 176,000 buildings, CAD files should exist for over 40,000 buildings. Therefore, BIM can potentially be developed for over 40,000 DoD buildings. Note, however, that CAD files will not always be

current. Modifications over time may not always be accurately recorded in CAD files. This can inhibit development of BIM through BIM-Builder.

Most existing buildings will be upgraded in the future. There is no data to conclude how many or at what time. However, buildings of a certain age will be due major upgrades, in HVAC systems at least. Approximately 11 % of all Army buildings were built 1985 – 1994, before CAD was required for Army facilities. CAD will almost certainly be applied to these upgrade projects. Applying 11% to the DoD building inventory of 176,000 suggests over 19,000 additional buildings are likely to have, or will have, CAD files in the foreseeable future. It is, however, important to note that some of these buildings will already have been upgraded and will in all likelihood have CAD files. Counting all 19,000 as potentially being scheduled for upgrade work, and therefore CAD files developed, would double-count the number of potential CAD files. Suffice it to say some portion of 19,000 buildings will have CAD files developed for them in the foreseeable future. These projects will all employ CAD and BIM.

Considering existing buildings and buildings for which major upgrades ought to be performed, CAD files should be available for roughly 60,000 buildings DoD wide, or roughly one-third of all DoD all buildings. Therefore, BIM can potentially be developed for up to roughly 60,000 DoD buildings. The CAD estimate is based on buildings designed from 1995 onwards.

Note that to be useful CAD files must be vector-based. They must be able to include geometric data and establish relationships in space. Raster images of floor plans only provide a simple graphic image, not digital geometric and spatial data. The quality of the CAD file will also affect the application of BIM-Builder. It is critical that the program be consistent in observing CAD standards; levels or layers, symbology, and naming conventions. However, CAD programs produced in the last 10 years should be consistent and useable.

BIM will be developed for all future new construction projects. However, at this time, few new construction projects are being initiated. The Army is anticipating roughly a dozen new projects in each of the next several years. Therefore, the numbers of new construction projects throughout DoD in the near future will still number only in the dozens.

Direct Digital Control Systems in the Current Building Inventory

The MDEI methodology depends on the existence of appropriate sensors/instrumentation along with access to that the sensor data suggesting that a DDC system in the building is a necessity along with appropriate software and infrastructure to access the needed data. DDC provides access to historical data and/or real-time data. Older systems that use technologies such as pneumatic or electric controls cannot provide or generate data that can be monitored in real-time or recorded and stored as historical trend data; therefore, MDEI cannot use them.

The DDC system must have a communications network. It must include all HVAC equipment such as air handlers, chillers, boilers, and terminal unit equipment (such as VAV boxes and fan coil units). Ideally, it should also extend to other technologies such as lighting and power distribution systems.

DDC system communications network ideally will use an industry standard communications protocol/technology such as LonWorks® or BACnet®. A standard protocol can facilitate BIM accessibility to needed data. If it is not a standard protocol, the DDC system protocol must otherwise be readable/usable by the MDEI.

The data needs to be accessible to the MDEI. One issue is that a DDC system might well have the 'points' inherent to it. The points must be exposed or available for trending or real-time access. In the case of trend data, it must be stored by or at an accessible front-end computer or in a web server. The data points required for the various 'Use Cases' must be recorded and accessible.

Numerically, not all Army buildings will have DDC-grade controlled HVAC systems. The Army, for example, possesses many buildings that are small, remote, or occupied intermittently. These buildings might have a unit ventilator or a heater and/or window air-conditioning unit. Many are shelters that are not conditioned at all. The MDEI methodology would not be applicable to these buildings.

A sampling of major Army installations (Forts Bragg, Jackson, Hood, and Leonard Wood) indicates roughly 38% of all buildings (per the BSR definition of a building) on-post are likely to be climate controlled and large enough (at a breakpoint is 4,000 square feet) to justify implementation of a DDC system connected to a front-end operator workstation. MDEI would be a potential software application.

Applying this 38% to a pool of 176,000 DoD buildings, roughly 67,000 buildings would be DDC candidates.

The sampling of the Army installations also indicates roughly 15-50% currently have DDC systems. Applying this range to the DoD inventory of 67,000 conditioned buildings, roughly 10,000 to almost 33,000 buildings are likely to have DDC systems installed. (Note that, if DDC systems were installed in or after 1995, those buildings should also have CAD files.) Not all of these DDC systems have the communication infrastructure and front end operator workstation at this time. However, an assumption is made that were the MDEI methodology to be applied, the necessary communication and operator infrastructure will also be installed.

Demonstration use cases

In general, the four use cases presented in this demonstration should apply to the majority of Army (and DoD) facilities. These are:

- **#1.** HVAC equipment running when it shouldn't be; for example, cooling when the building is unoccupied.
- **#2.** Excessive consumption by HVAC equipment caused by the introduction of excessive or inadequate outside air.
- **#3.** Excessive HVAC consumption through a failure of the equipment to meet comfort goals; for example, supply air temperature(s) too high.
- **#4.** Unusual patterns of operation, such as high consumption during unoccupied hours when compared to buildings of the same type and occupancy schedule.

There are, however, possible exceptions that may occur on a case-by-case basis. For example, for Use Case #1 may not apply to medical facilities and research/laboratory facilities where HVAC systems may not be turned off afterhours.

Use Case #2, "excessive or inadequate outside air," would not apply in facilities where the climate is warmer and more humid. Use Case 2 includes an airside economizer — because only a malfunctioning economizer can consume excessive energy because of *inadequate* outside air ("Excessive" refers to consuming more energy than if the economizer were working properly.) Airside economizers are not ordinarily used in warmer and more humid climates.

Conclusions about the transferability of MDEI

While not a large portion of the existing DoD building inventory, potential application to up to roughly 33,000 buildings is not insignificant. A portion of another 19,000 older buildings would be subject to major upgrades or repurposing or conversion in the foreseeable future. These are likely to include new HVAC systems and UMCS systems, along with BIM and/or CAD files. While new construction in DoD buildings will be limited in number for the near future, MDEI should be applicable to new DoD buildings. ERDC-CERL estimates that upwards of 40,000 buildings within DoD could be suitable for the application of MDEI.

6.5 PO 5: BIM TOOL EFFICIENCY

Performance Objective	**PO5:** Efficiency of the BIM tools for effective site survey and medium-fidelity BIM generation.
Success Criteria	An experienced user produces the BIM at ~20% the typical cost of a BIM produced by traditional means (Brucker, 2009).

Performance Objective 5 focuses on the **e**fficiency of the Honeywell BIM Builder tool for generating medium-fidelity BIM for operations on existing facilities. BIM Builder works by recognizing the significant architecture and MEP object and network connections represented by vectors in the CAD drawing. Relationships between spaces and the equipment that serve them are recognized by tracing the ductwork from the original supplying equipment (e.g., AHU) all the way to the diffusers that deliver air to a specific space. This supports the identification of the critical relationships between equipment, as well as relating equipment to the spaces that are served.

The assessment of efficiency was conducted in three parts:

1. The performance of the Honeywell expert user of BIM Builder was recorded during the development of the Fort Jackson models. This performance is detailed in Appendix I.
2. The Honeywell expert user was also timed on the creation of the BIM model for a Brigade headquarters building, which was also used in a timed trial with CERL participants.
3. ERDC-CERL resources also conducted a timed trial using experienced Revit users (separate architecture and MEP experts) modeling the same Brigade Headquarters that was used for the novice trial.

The team at CERL-ERDC selected the Brigade Headquarters building for the controlled test because, unlike the Fort Jackson facilities, it offered the advantage of having a completed BIM that could be used as a benchmark against the generated BIM. It also met these characteristics that were important for the trial: it was small enough for the time-limited study and it was two-story, which presents unique challenges. We acknowledge Fort Hood, for contributing the model of their Brigade Headquarters in support of this study, and the team at ERDC-CERL for participating in the exercise of the tool.

According to our testing on this pilot, BIM Builder provides the best performance advantage over the prevailing method when modeling large buildings, due to the economies of scale provided by bulk extraction of like objects from the CAD sources. Figure 58 illustrates that as the building gets larger, the efficiency of modeling (sq ft modeled per hour) increases. Figure 59

shows that the time required to model a facility in BIM Builder is not a function of the size of the facility.

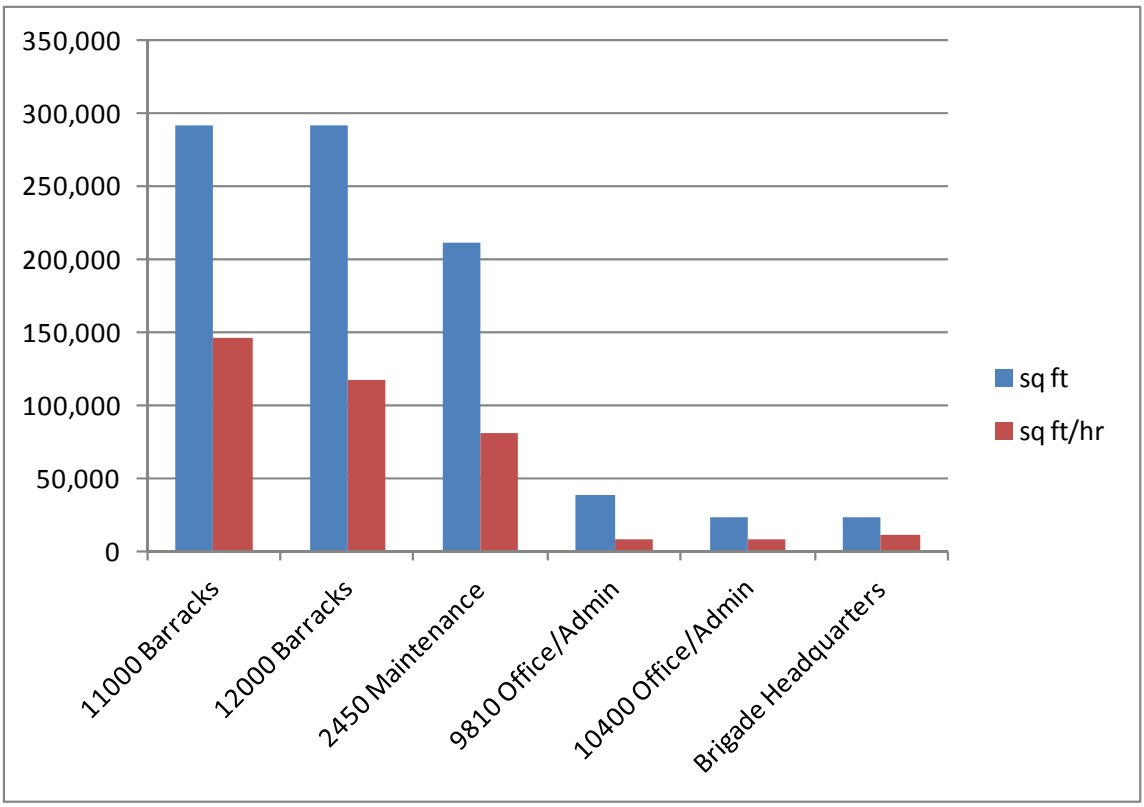


Figure 58: Modeling Performance of BIM Builder Expert on Test Facilities. Measured in Square Feet per Hour by Facility Size.

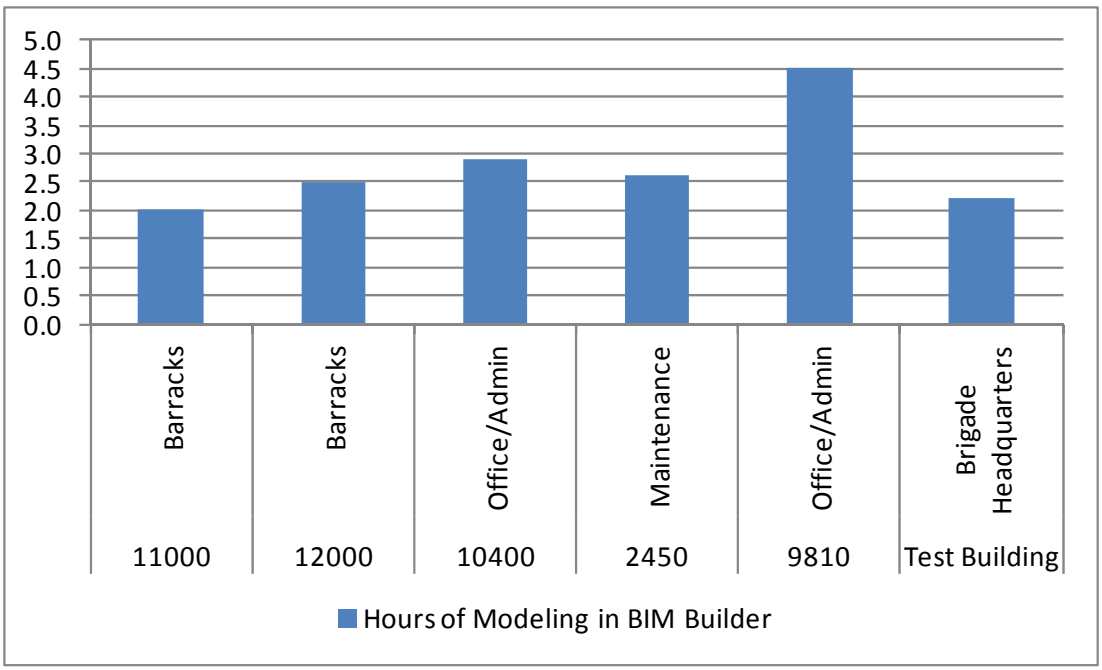


Figure 59: Hours spent on each building by BIM Builder Expert

- Note that 2450 has 120K total sq ft, but for the purposes of comparison, only parts of the facility with comparable model complexity were used for this evaluation (45K $ft^{2)}$.
- The features of the facilities and supporting data that likely influenced the performance for each facility are noted in Appendix I.

Results

Performance Objective 5 hypothesized that "An experienced user produces the BIM at ~20% the typical cost of a BIM produced by traditional means (Brucker, 2009)." After further consideration, we realized that, the 2009 study may not provide a wholly suitable comparison for the purposes of measurement on this pilot due to differing objectives and level-of-detail goals that underlie the cost figures related to that study. Therefore, our results are presented in relation to a comparative exercise conducted by ERDC-CERL using Revit tools.

Expert performance using BIM Builder

Expert performance using BIM Builder was measured in terms of the time required by a Honeywell engineer, extremely familiar with the tool, to extract a BIM from AutoCAD files for each of the five buildings at Fort Jackson. Any issues with the building structure or with the tools were also noted during this exercise and are reported in Appendix I.

The engineer who performed these BIM extraction time trials was familiar with BIM and IFC, as well as HVAC and mechanical concepts, functions, and drawings. This expert acquired proficiency in interpreting CAD as they worked with the tool. The engineer had not participated in the original developments that lead to BIM Builder. However, she had worked with tool developers to refine the BIM Builder, correct bugs, etc. prior to its use on this project. She could be considered an expert user of the tools for purposes of this research.

Though the sample size in this study is not sufficient to provide a statically valid measure of performance, the results of these trials support the conclusion that BIM Builder may present a

considerable model generation efficiency advantage on large facilities. On the buildings in the pilot, the expert BIM Builder user averaged 93K sq ft per hour on buildings larger than 45K sq ft. (11000, 12000, 2450) For the smaller facilities, and in the single comparable Revit measure that we have in this study, the performance of the BIM Builder approach was comparable to existing practice using Revit, with efficiency figures averaging 8.8K sq ft per hour.

The study sample size is too small and the facility size differential too large, to learn where the inflection point is with respect to building and system complexity, but we feel that it is reasonable to say that for buildings over 45K sq ft, there is likely to be a performance advantage using the BIM Builder tool, and under 45K sq feet, performance with BIM Builder may be comparable to performance in Revit.

A comparison of the BIM development processes for each modeling approach is presented below. While both tools support the import of CAD, a Revit user uses the CAD underlay as a guide to place new Revit objects in the new model. BIM Builder users identify features of interest (specific graphical primitives) that represent interesting features; it then validates and improves the results of the bulk extraction of these common features. The BIM Builder processing time tends to be a function of the number of unique **types of features** that need to be extracted, while the Revit process is likely to be a function of the size of the facility and **the number of items to be placed** in the model. On average, the BIM Builder expert expended 2-3 hours to execute the process, regardless of the size of the facility.

In both cases, since the starting point is the as-built CAD drawings for a facility, the resulting models will only be as accurate as the CAD input. Thus, both processes require some validation by someone who knows the site or can visit the site to confirm the configuration of rooms and equipment. For the purposes of this pilot, two Honeywell researchers and two ERDC-CERL researchers visited each building to validate the results of the models. An average of 2-3 hours was spent on each of the smaller facilities, and 3-4 hours on the Starship barracks, 11000 and 12000. This time is not calculated in the BIM generation time, as it would be required regardless of the method used to generate the model. The impact of this additional cost is discussed in Section 7.0.

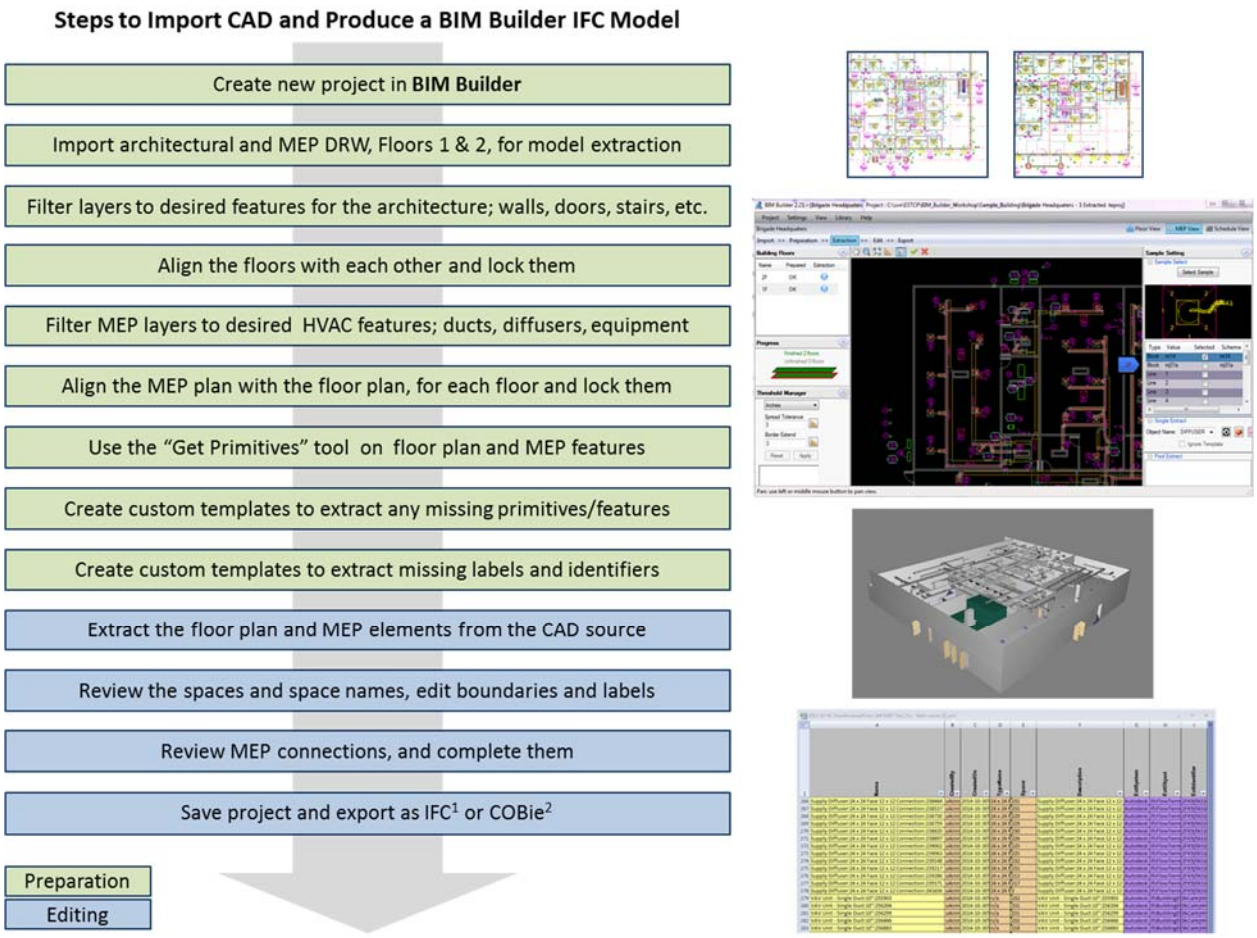


Figure 60: BIM Builder processing steps

Figure 60 illustrates, in a linear fashion, the basic steps that are required to use BIM Builder to generate BIM from CAD. BIM Builder generates an approximation of the correct 3D geometry from clues found in the files, or user settings for wall thickness, duct size, and similar features. The tool will attempt to automatically identify some common elements, but the user can also define custom templates that correspond to the CAD practices of the original drafter. The extracted equipment is identified by Type and Name in IFC. Spaces are identified by name, associated floor, and area. BIM Builder does not classify spaces by type today, as this information is not generally present. If classification data is available in the source, this information can also be extracted and populated in IFC. Appendix F provides a detailed evaluation by ERDC-CERL about the general quality of this IFC output, and recommendations for improving it to improve data transferability. Honeywell has determined that the issues identified by CERL-ERDC can be addressed with minimal investment to make the BIMBuilder output fully compatible with the interoperability standards laid out by IFC, and COBie, as well as other public or third party standards that may be of interest.

Figure 61 illustrates the steps that must be taken to use Revit to create a new 3D model from older CAD-based input. In this method, the CAD may be used as an underlay so that the user can trace the features in the CAD file to place the objects in the 3D environment more quickly.

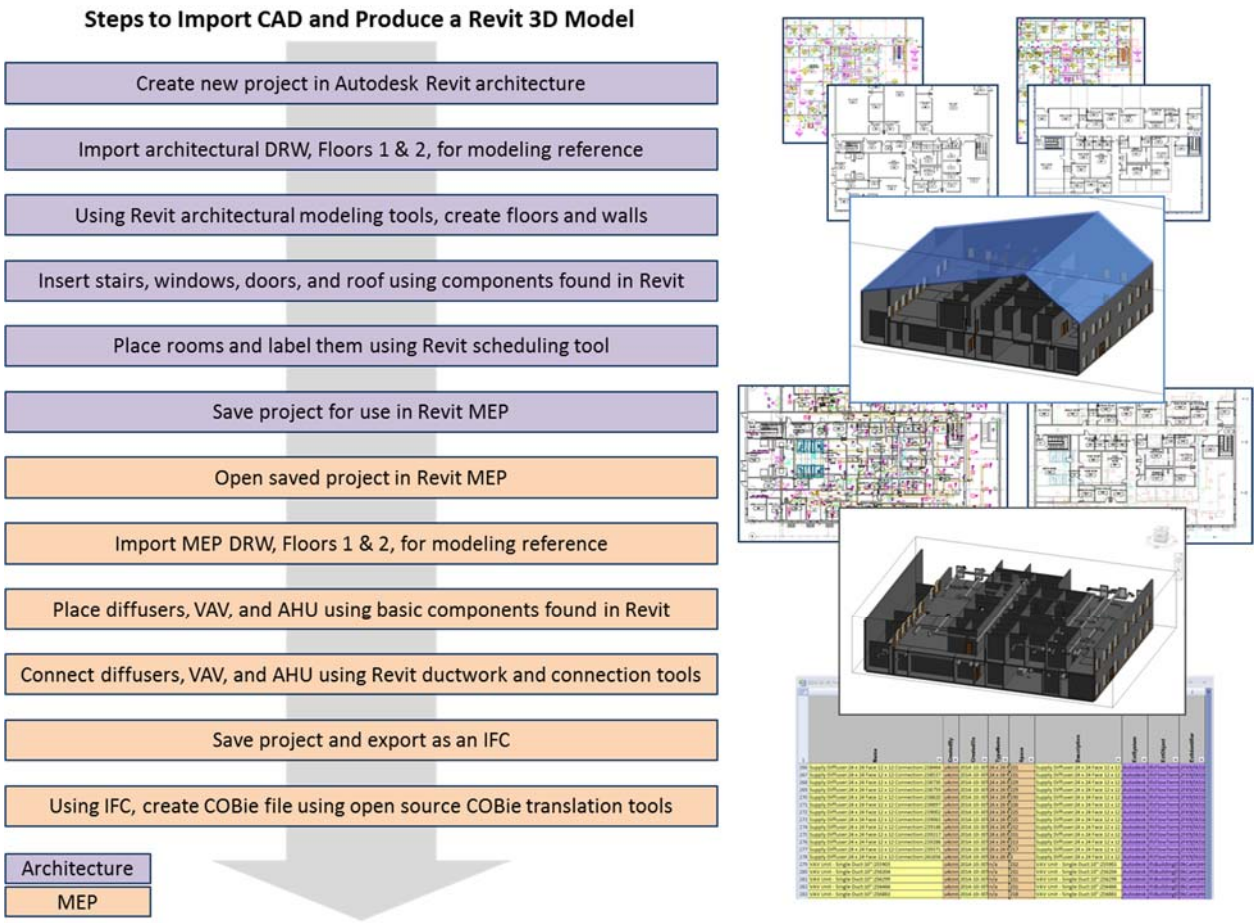


Figure 61: Revit Processing Steps

Aside from these processes, Revit projects have many characteristics that are different from the output of BIM Builder, and it is not possible to reasonably compare the Revit model to the BIM Builder model.

BIM Builder is not intended to replace modeling applications such as Revit, but to perform a different type of service in support of a more rapid expansion of BIM-enabled applications post-construction. The output of BIM Builder is standard IFC, so the BIM Builder model could be imported to any application that can read IFC, including Revit and a host of third party tools that display or edit IFC.

BIM Builder Workshop, Demonstration, and Novice Performance

Hands-on testing of the Honeywell BIM Builder was completed with five test subjects at ERDC-CERL in Champaign, IL. The building selected by CERL for the demonstration and test was a Brigade Headquarters facility; comprising 22.4K sq feet on two floors. It is a combination of open office, command and secure information space. It includes 141 diffusers, 40 VAVs, 3 AHUs, and 3main supply ducts.

The study was conducted over two days. Day 1 consisted of a series of training exercises to ensure a certain minimum level of competency with the tool. Day 2 consisted of two time-controlled exercises to determine the efficiency of the tool in the hands of these novice users, on

two measured sub-tasks. These subtasks were conducted in 2-3 hour work sessions. The background of the CERL participants was quite varied in terms of expertise, current work, and AutoCAD experience; subject experience is summarized in Table 21. For the purposes of privacy, the names of each individual are not shared in this report.

Table 21: Background of CERL BIM Builder training and test participants

Participant 1	Mechanical Engineering and Community Planning with experience in GIS and other engineering IT applications
Participant 2	Civil Engineering with SMS BUILDER and facility/installation sustainment management experience
Participant 3	Architect with experience in CAD, BIM, GIS, SMS BUILDER, COBie, IFCs, and other facility acquisition, design, and management applications
Participant 4	Facility Architect with experience in CAD, facility/installation master planning, and facility maintenance/management
Participant 5	Civil Engineering with COBie, IFCs, and facility design review experience

Results. Results from the test with five CERL participants are described below in terms of three key areas of BIM extraction performance:

1) HVAC object extraction,
2) Correct association of VAVs to building spaces,
3) Correct attachments of each equipment object to equipment objects upstream of it in the MEP supply relationship.

Object extraction performance- Object extraction with BIM Builder requires the user to select a sample object from the building as a template and identify it by its class. BIM Builder then uses image processing to find all the objects like the template and extract them. Table 22 shows object extraction performance by the Honeywell expert and the five test users. It can be seen that the level of object extraction performance was very high, nearly that of the expert user in all five test participants. Since it is not possible to compare the speed of performance between the expert and novice users, we use only the quality of the output as the point of comparison.

Table 22: BIM Builder Workshop Extraction of Equipment Objects

Equipment	Expert	Test User				
		M1	M2	M3	M4	M5
Floor1						
diffusers	77	77	77	77	77	76
Vav	21	21	21	21	21	21
vav name	21	21	21	21	21	21
supplyduct	2	2	0	2	2	2
ahu	2	2	2	2	2	2
ahu name	2	2	2	2	2	2
Floor 2						
diffusers	64	62	64	62	64	61
vav	19	19	19	19	19	19
vav name	19	19	19	19	19	19
supplyduct	1	1	1	1	1	1
ahu	1	1	1	1	1	1
Ahu name	1	1	1	1	1	1
Correct	230	228	228	228	230	227

Association of VAVs to Building Spaces- For each of the 40 VAVs there are one or more spaces that the VAV serves. There are 85 of these VAV-to-space relationships. The BIM Builder tool will automatically find these relationships when the spaces have been properly detected and named and the VAVs have been named and correctly connected through ducting to the diffusers that serve the spaces. The user is responsible for checking and correcting the space boundaries, VAV names, and the duct connections. Table 23 shows the test results.

Table 23: BIM Builder Workshop Association of Rooms/Spaces with VAV's

Participant	Actual number of spaces	Number of spaces correctly associated	VAV extra spaces	VAV missing spaces	% identified correctly
Participant 1	85	73	13	14	86
Participant 2	85	69	10	16	81
Participant 3	85	80	6	5	94
Participant 4	85	69	8	16	81
Participant 5	85	32	4	53	38
Median	**85**	**69**	**8**	**16**	**81**

Most of the missed relationships noted in the fourth column came from not completing the duct work verification and edits. The user with highest number of misses (53) was using a slower machine that was having problems with crashing. So part of this performance was not believed to be user error.

When the BIM Builder model generated by the expert user was examined, 6 errors were found in the relationships. This was traced to a bug in the BIM Builder program in which the edited space boundaries were not being used in the final algorithm. It is believed that this bug may have impacted the results of the five test users, as well. However, all the users were using the same release of the software so we are still presenting the results for comparison here.

Finding relationships between equipment objects- The HVAC equipment in the test building were connected in the following ways:

1. All diffusers were served by a VAV
2. All VAVs were downstream of a Supply duct
3. All Supply ducts were downstream of an AHU

The BIM created by the expert user contained 141 diffusers, 40 VAVs, and 3 Supply Ducts for a total of 184 equipment objects each of which was attached to the equipment object upstream of it in the supply relationship. Figure 62 shows the performance of the test users. The user with the highest number of nonattached objects was the user with the faulty computer.

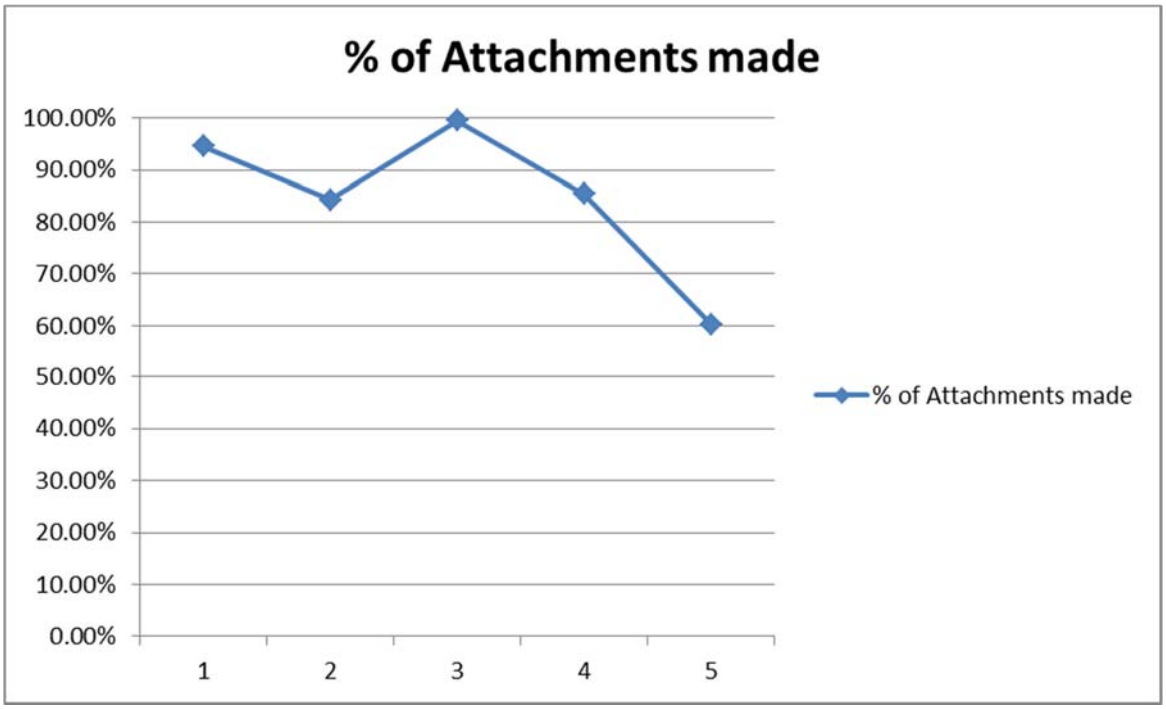


Figure 62: Percent of Unattached Equipment Objects among Test Users.

Discussion. The results of the test are considered promising given that the test users had not used the tool before the one day of training, were not directly familiar with the building they were using, and did not have an ideal match to the skills identified as the most likely BIM Builder skilled user.

The most likely skilled user would be one with understanding of the CAD methods for indicating MEP equipment by graphic and naming conventions. They would understand how MEP systems are layed out and configured. They would be competent with drawing and graphic editing tool conventions and would have familiarity with the building or style of building they are modeling. The user comments during the training and testing sessions highlight some of these desired traits.

The ERDC-CERL test subjects also provided valuable feedback on how the tool was useful and how it could be improved. These comments and the evaluation itself will help Honeywell to improve the BIM Builder. A summary of this user feedback has been provided in Appendix I.

6.6 PO 6: PARTIALLY AUTOMATED CLASSIFICATION

Performance Objective	PO6: Partially automated identification and standardized classification of control points.
Success Criteria	Enable correct identification and classification of pertinent telemetry from one or more buildings within 4 hours.
Analysis Overview	Time required to correctly classify 500 points relevant to advanced analytics

This objective demonstrates a capability to map DCS points, to roles and assets (equipment) using a partially-automated process which leverages semantic standards. This tool supports energy analysis, with respect to classifying points, and therefore equipment, into group behavior (roles), which helps identify the key performance indicators and attempt to associate those with the correct entity as identified by BIM, as well as standardizing how visualizations represent this data.

The tool currently accepts a list of points (named variables) from a singular entity, such as a building, through a web-based interface. Each individual point name is initially inserted into a Trie data structure, with additional properties assigned to every node (single character of the point name) in the Trie, for example a count of how many times that node has been accessed during the construction of the Trie. Every point name also goes through various processes of analysis after being inserted to the Trie, including basic string parsing algorithms which break apart the point name into ‘tokens’. Finally, a unique (patented) set of algorithms perform various forms of analysis over the broader set of results from the first set of algorithms, to generate additional tokens and metadata for the point names. These results are queried against a standard set of system aspects to find the best matching roles for any given point name.

To support the process of matching and for the purposes of this pilot project, a discrete set of point roles were identified as relevant to energy intelligence and analysis, as well as visualization requirements.

Table 24 lists the complete set of point roles utilized in this pilot (Unique LongFormRole), and how many points for each of the buildings were mapped into each role.

Table 24: Point Role Classification Summary

Unique LongFormRole	2450	9810	10400	11000	12000
AirHandlingUnitBinaryState	0	0	0	9	0
AirHandlingUnitColdDeckSupplyTemperature	0	3	0	0	0
AirHandlingUnitColdDeckSupplyTemperatureSetPoint	0	3	0	0	0
AirHandlingUnitCoolingTemperatureSetPoint	0	0	0	26	0
AirHandlingUnitCoolingValvePosition	0	4	1	26	0
AirHandlingUnitExhaustAirFanBinaryState	0	9	0	0	40
AirHandlingUnitExhaustAirTemperature	0	0	2	0	0
AirHandlingUnitExhaustAirVariableFrequencyDriveCFM	0	0	2	0	0
AirHandlingUnitExhaustAirVariableFrequencyDriveStatus	0	0	4	0	0
AirHandlingUnitHeatingRequired	0	1	0	0	0
AirHandlingUnitHeatingValvePosition	0	5	1	0	0
AirHandlingUnitHotDeckSupplyTemperature	0	3	0	0	0
AirHandlingUnitHotDeckSupplyTemperatureSetPoint	0	3	0	0	0
AirHandlingUnitMixedAirTemperature	0	0	0	0	15
AirHandlingUnitOutsideAirDamperPosition	0	1	2	0	0
AirHandlingUnitOutsideAirFanBinaryState	0	0	0	26	0
AirHandlingUnitOutsideAirRelativeHumidity	0	1	0	1	0
AirHandlingUnitOutsideAirTemperature	0	1	2	1	5
AirHandlingUnitOutsideAirVariableFrequencyDriveCFM	0	0	2	0	0
AirHandlingUnitOutsideAirVolumetricFlowRate	0	0	0	3	0
AirHandlingUnitPreheatCoilTemperature	0	0	1	0	0
AirHandlingUnitReturnAirDamperPosition	0	0	0	24	0
AirHandlingUnitReturnAirFanBinaryState	0	0	0	3	0
AirHandlingUnitReturnAirRelativeHumidity	0	0	0	0	10
AirHandlingUnitReturnAirTemperature	0	1	3	0	15
AirHandlingUnitServicedSpaceDamperPosition	0	12	0	0	0
AirHandlingUnitServicedSpaceTemperature	0	14	0	3	0
AirHandlingUnitServicedSpaceTemperatureSetPoint	0	14	0	0	0
AirHandlingUnitStatus	0	0	0	0	10
AirHandlingUnitSupplyAirFanStatus	0	6	3	0	13
AirHandlingUnitSupplyAirTemperature	0	2	3	3	15
AirHandlingUnitSupplyAirTemperatureSetPoint	0	0	3	0	0
AirHandlingUnitSupplyAirVariableFrequencyDriveStatus	0	0	4	0	0
AirHandlingUnitTemperature	0	0	0	0	80
AirHandlingUnitVariableFrequencyDriveBinaryState	0	0	0	20	0
AirHandlingUnitVariableFrequencyDriveSpeedControl	0	0	0	6	0
BoilerHotWaterSupplyEnBinaryState	2	0	0	0	0
BoilerHotWaterSupplyTemperature	1	0	0	0	0
BoilerOutsideAirEnTemperatureSetPoint	1	0	0	0	0

Unique LongFormRole	2450	9810	10400	11000	12000
ChilledWaterPlantChilledWaterSupplyTemperature	0	1	1	1	0
ChilledWaterReturnTemperature	0	1	1	1	0
ChilledWaterSupplyPumpStatus	0	1	0	2	0
ExhaustAirFanStatus	0	0	2	0	0
HeatExchangerHeatExchangeValvePosition	0	0	0	1	0
HotWaterPlantHeatingValvePosition	0	0	1	0	0
HotWaterPlantHotWaterSupplyTemperature	0	1	0	0	0
HotWaterPlantHotWaterSupplyTemperatureSetPoint	0	1	1	0	0
HotWaterSupplyPumpBinaryState	2	2	2	2	0
HotWaterReturnTemperature	0	1	0	0	0
HWPBoilerOaTemp	1	0	0	0	0
PrimaryHotWaterReturnLoopTemperature	0	0	1	0	0
PrimaryHotWaterSupplyLoopTemperature	0	0	1	1	0
RoofTopUnitCooling	1	0	0	0	0
RoofTopUnitOutsideAirTemperature	1	0	0	0	0
RoofTopUnitServicedSpaceTemperature	1	0	0	0	0
RoofTopUnitSupplyAirFanBinaryState	6	0	0	0	0
RoofTopUnitSupplyAirTemperature	3	0	0	0	0
RoofTopUnitSupplyAirTemperatureSetPoint	2	0	0	0	0
RoofTopUnitZoneSupplyTemperatureSetPoint	1	0	0	0	0
SecondaryHotWaterReturnLoopTemperature	0	0	1	0	0
SecondaryHotWaterSupplyLoopTemperature	0	0	1	1	0
UnitHeaterServicedSpaceTemperature	0	0	0	7	22
UnitHeaterSupplyAirTemperature	0	0	0	7	22
VariableAirVolumeDamperPosition	0	0	13	0	10
VariableAirVolumeOutsideAirDamperPosition	0	0	0	0	1
VariableAirVolumeOutsideAirFanBinaryState	0	0	0	0	1
VariableAirVolumeOutsideAirTemperature	0	0	0	0	2
VariableAirVolumeOutsideAirVolumetricFlowRate	0	0	0	0	1
VariableAirVolumeReheatPosition	48	0	0	0	0
VariableAirVolumeReheatValvePosition	0	0	13	0	0
VariableAirVolumeServicedSpaceTemperature	48	0	13	39	121
VariableAirVolumeSupplyAirDamperPosition	0	0	0	0	101
VariableAirVolumeSupplyAirFanBinaryState	0	0	0	0	121
VariableAirVolumeSupplyAirRelativeHumidity	0	0	0	0	20
VariableAirVolumeSupplyAirTemperature	48	0	0	39	111
VariableAirVolumeTemperatureSetPoint	48	0	0	0	0
VariableAirVolumeVolumetricFlowRate	48	0	0	0	111

Table 25 summarizes the results of the partially automated classification of points by the AutoContext tool. The results are very positive for a few buildings, especially building 12000, which on its own, provides sufficient classification matches to satisfy the performance objective of classifying at least 500 points within 4 hours. Variability in the results stems largely from the variability in the underlying naming convention that was used to identify data in the original system. Naming conventions that reduce many of the key concepts to single characters (e.g., T for Temp or F for Fahrenheit) require additional manual processing, either in tuning the processing input parameters, or in post-processing the results.

Given a discrete set of roles to map points to, the results for each point can be compared to that list of roles to see if there is an exact match, and if so, a "flag" is set, equal to 1, and highlighted in a spreadsheet, which is the output the user will utilize to verify if the roles are correct. A sample of the output is shown in the Table 26, which is a subset of the results for building 9810. The column, "LongFormRole (Automated)" shows the 'answer' from the AutoContext tool for the given PointName, "LongFormRole (Expected)," the second column, is the manually validated mapping. The match column shows when the automation successfully matched the expected result.

Table 25: AutoContext Point Role and Equipment Classification Results

Building	**2450**	**9810**	**10400**	**11000**	**12000**	**Total**
Total Points	542	243	650	252	861	2296
Configured Points +	262	91	84	252	847	1536
Auto-Context Correct Point Roles	205	77	23	51	653	1009
% Correct Role Classification	78.24%	84.62%	27%	20.24%	77.10%	
% Correct Equipment Classification	92.75%	91.21%	88.10%	10.32%	94.21%	
Time to Generate Point Roles (sec) ^	25	14	26	14	40	

+ Number of points that are mapped and available through the Building Control System, and utilized in this pilot

^ Total Points list used in Auto-Context application

Referencing Table 26, it can be seen that a building energy manager/controls engineer would be able to quickly validate the roles given by the AutoContext tool, and also rectify those roles which are incorrect. A timed exercise was performed by a Honeywell team member and an onsite Honeywell engineer to complete the verification of roles for building 12000. The result was 126 minutes, which is well below the 4 hour objective.

Table 26: AutoContext Point Role Matching Example

PointName	LongFormRole (Expected)	LongFormRole (Automated)	Match
9810_AH1_CDTemp	AirHandlingUnitColdDeckSupplyTemperature	AirHandlingUnitColdDeckSupplyTemperature	1
9810_AH1_ChwVlv	AirHandlingUnitCoolingValvePosition	AirHandlingUnitValveChilledWaterPosition	0
9810_AH1_Ex12Fan	AirHandlingUnitExhaustAirFanBinaryState	AirHandlingUnitExhaustAirFanBinaryState	1
9810_AH1_HtgVlv	AirHandlingUnitHeatingValvePosition	AirHandlingUnitHeatingValvePosition	1
9810_AH1_SaFanSts	AirHandlingUnitSupplyAirFanBinaryState	AirHandlingUnitSupplyAirFanBinaryState	1
9810_AH1_Zn1Dmpr	AirHandlingUnitServicedSpaceDamperPosition	AirHandlingUnitServicedSpaceDamperPosition	1
9810_AH1_Zn1Temp	AirHandlingUnitServicedSpaceTemperature	AirHandlingUnitServicedSpaceTemperature	1
9810_AH4_HtgRqd	AirHandlingUnitHeatingRequired	AirHandlingUnitHeating	0
9810_AH4_HtgVlv	AirHandlingUnitHeatingValvePosition	AirHandlingUnitHeatingValvePosition	1
9810_AH4_RaTemp	AirHandlingUnitReturnAirTemperature	AirHandlingUnitReturnAirTemperature	1
9810_AH5_DaTemp	AirHandlingUnitSupplyAirTemperature	AirHandlingUnitSupplyAirTemperature	1
9810_AH5_OaRh	AirHandlingUnitOutsideAirRelativeHumidity	AirHandlingUnitOutsideAirRelativeHumidity	1
9810_AH5_OaTemp	AirHandlingUnitOutsideAirTemperature	AirHandlingUnitOutsideAirTemperature	1
9810_CHWS_ChwpSts	ChilledWaterSupplyPumpStatus	ChillWaterSupplyBinaryState	0
9810_CHWS_RetTemp	ChilledWaterReturnTemperature	ChillWaterSupplyChilledWaterTemperature	0

6.6.1 Standardizing Data with BIM

Another essential outcome of the AutoContext tool is the matching of points to a piece of equipment, which is related to an entity (equipment) identified through the BIM Builder process. This is important, as a user navigates through the MDEI-UI by interacting with entities or pieces of equipment, and the ‘Energy’ views are generated based on which entity is currently selected by the user. All points for a building are mapped to an entity that exists in the BIM data. Therefore, by automatically identifying the equipment name that the point belongs to, a simple relational table can be constructed which maps point data to BIM entities, which resolves differences in naming of equipment between these two automated processes. The following table provides a subset of the equipment matches made for building 12000.

Table 27: AutoContext Equipment Name Identification

PointName	EquipmentName	EquipmentType
AHU10_LN01Spyder2:nvoDischAirTemp	AHU10	AirHandlingUnit
AHU10_LN01Spyder2:nvoMixedAirTemp	AHU10	AirHandlingUnit
AHU10_LN01Spyder2:nvoRA_Humidity	AHU10	AirHandlingUnit
BCU1_APU1Spyder2:nvoAPUFanStat	BCU1	null
BCU1_APU1Spyder2:nvoBCUStatus	BCU1	null
BCU1_APU1Spyder2:nvoSpaceTemp	BCU1	null
CUH_24LMOBJ1:nvoDischAirTemp	CUH_24	UnitHeater
CUH10LMOBJ1:nvoDischAirTemp	CUH10	UnitHeater
CUH-12LMOBJ1:nvoSpaceTemp	CUH-12	UnitHeater
OAVAV_216Spyder2:nvoDamperPos	OAVAV_216	VariableAirVolume
OAVAV_216Spyder2:nvoDaTemp	OAVAV_216	VariableAirVolume
VAV_F205Spyder2:nvoDaTemp	VAV_F205	VariableAirVolume
VAV_F205Spyder2:nvoSFanStatus	VAV_F205	VariableAirVolume

Table 28 shows the relational table constructed which provides a quick look-up for entity names given by the BIM Builder process, and those assigned through the AutoContext tool. If a piece of equipment is selected within the 3D BIM view of the UI, the entities' name is found in this table, and then the corresponding NamePoint value is returned to the web application to retrieve associated point data for that equipment. The NamePoint value is what is also used to dynamically generate the menu in the UI. Therefore, if the user selects equipment through the menu, that value is queried against this table to find the corresponding NameBIM value, which is then sent to the 3D BIM view to highlight the selected entity. The table below shows the necessity of this relational data, as the NameBIM and NamePoint, assigned by BIM Builder and AutoContext respectively, do not exactly match.

Table 28: Equipment Name Relational Table Example

BuildingID	NameBIM	NamePoint
12000	VAV-F203	VAV_F203
12000	VAV-F205	VAV_F205
12000	VAV-F206	VAV_F206
12000	AHU10	AHU10
12000	AHU11	AHU11
12000	CUH10	CUH10
12000	CUH11	CUH11
12000	CUH-12	CUH-12

BIM delivers a very important missing link for building context management. The example data points provided above may be associated with their appropriate assets relatively easily.

However, most control systems do not sufficiently encode information to describe upstream and downstream dependencies between assets in a system. Typically, this gap has to be filled manually by someone familiar with the facility. No baseline measures of this task were conducted in this pilot, but our experience on other projects shows a high degree of variability from site-to-site, making this an unpredictable cost factor. The process might take anywhere from 1 to 8 hours, depending upon the building size, system complexity, and the degree of documentation available.

One product of the BIM Builder is an output file (partially COBie compliant – See Appendix F) which contains valuable information about the relationships between named entities (served / served-by, services). A subset of that data is provided in the following figure, which was generated for Building 2450. The table on the left is a snapshot of the 'Equipment' tab within the output sheet, and the table on the right is a snapshot of the MEP Supply Relationship tab.

Name	Floor Name	Served Space	Associated AHU
VAV-1-2-08	2F	207	RTU1
VAV-1-2-07	2F	207	RTU1
VAV-1-2-03	2F	204	RTU1
VAV-1-2-04	2F	204	RTU1
VAV-1-2-16	2F	217	RTU1
VAV-1-2-05	2F	205	RTU1
VAV-2-2-07	2F	225	RTU2
VAV-2-2-07	2F	226	RTU2
VAV-2-2-02	2F	223	RTU2
VAV-2-2-03	2F	223	RTU2
VAV-2-2-04	2F	224	RTU2
VAV-2-2-05	2F	222	RTU2

Equipment tab

RTU2	SupplyDuct3	VAV-2-2-02	Diffuser114
RTU2	SupplyDuct3	VAV-2-2-02	Diffuser104
RTU2	SupplyDuct3	VAV-2-2-02	Diffuser117
RTU2	SupplyDuct3	VAV-2-2-02	Diffuser105
RTU2	SupplyDuct3	VAV-2-2-02	Diffuser103
RTU2	SupplyDuct3	VAV-2-2-02	Diffuser102
RTU2	SupplyDuct3	VAV-2-2-07	Diffuser136
RTU2	SupplyDuct3	VAV-2-2-07	Diffuser148
RTU2	SupplyDuct3	VAV-2-2-07	Diffuser147
RTU2	SupplyDuct3	VAV-2-2-07	Diffuser146
RTU2	SupplyDuct3	VAV-2-2-07	Diffuser145
RTU2	SupplyDuct3	VAV-2-2-07	Diffuser137
RTU2	SupplyDuct3	VAV-2-2-07	Diffuser135
RTU2	SupplyDuct3	VAV-2-2-07	Diffuser134
RTU1	SupplyDuct1	VAV-1-1-01	Diffuser3
RTU1	SupplyDuct1	VAV-1-1-01	Diffuser45
RTU1	SupplyDuct1	VAV-1-1-01	Diffuser2
RTU1	SupplyDuct1	VAV-1-1-08	Diffuser9

MEP Supply Relationship tab

Figure 63: BIM Builder Output Data

Post-processing expanded and normalized the data found in the MEP Supply Relationship tab for use in the MDEI navigation scheme. The resulting table, EquipmentRelationship (Figure 64), allows the web application to quickly and easily request the necessary relationship data for any entity, and seamlessly navigate the visualizations using either the physical model or the data-driven navigation pane

BuildingId	Object1	ObjectType1	Object2	ObjectType2	Relationship
2450	VAV-1-2-04	Equipment	Diffuser236	Equipment	Supplies
2450	VAV-1-2-03	Equipment	Diffuser234	Equipment	Supplies
2450	VAV-1-2-03	Equipment	Diffuser233	Equipment	Supplies
2450	VAV-1-2-03	Equipment	Diffuser232	Equipment	Supplies
2450	VAV-1-2-03	Equipment	Diffuser231	Equipment	Supplies
2450	VAV-1-2-03	Equipment	Diffuser230	Equipment	Supplies
2450	VAV-1-2-03	Equipment	Diffuser229	Equipment	Supplies
2450	VAV-1-2-03	Equipment	Diffuser228	Equipment	Supplies
2450	VAV-1-2-03	Equipment	Diffuser235	Equipment	Supplies
2450	VAV-1-2-07	Equipment	Diffuser212	Equipment	Supplies
2450	VAV-1-2-07	Equipment	Diffuser211	Equipment	Supplies
2450	VAV-1-2-07	Equipment	Diffuser210	Equipment	Supplies
2450	VAV-1-2-07	Equipment	Diffuser209	Equipment	Supplies
2450	VAV-1-2-07	Equipment	Diffuser200	Equipment	Supplies
2450	VAV-1-2-07	Equipment	Diffuser198	Equipment	Supplies

Figure 64: EquipmentRelationship Table Extract

6.7 PO 7: GAP ANALYSIS

Associated Performance Objectives	**PO7:** Conduct gap analysis of the content and quality of data represented in the generated BIM with respect to BUILDER database
Performance Objective Analysis Overview	Determine the degree to which the output of the demonstration may be used to populate BUILDER data fields.
Statistical Methodologies	Statistical analysis of the percent of useful/transferrable data
Anecdotal Perspectives	Users of BUILDER were asked to offer anecdotal observations about the usefulness of BIM data for BUILDER objectives.
Internal Validity	We were careful to review the analysis to ensure that the fields being compared were correctly identified and represent equivalent information.

BIM Builder to BUILDER SMS

DOD has recently mandated the use of BUILDER SMS, a web-based tool designed by the Construction Engineering Research Laboratory to assist facility managers and technicians in deciding how to best maintain their building assets on military installations. Given a BUILDER SMS business case, it is in Honeywell's interest to explore the possibility of transferring data from BIM Builder to BUILDER SMS. To achieve this exchange of information, BIM Builder must be able to export the building information created and stored in the system in a format that BUILDER SMS can use. Currently, BUILDER SMS cannot use information in any external format; however, an exploratory phase has been started to investigate the possibility of achieving interoperability with external systems using the COBie format.

The preliminary effort to explore information exchange with BUILDER SMS using COBie compared two main aspects, the type of information supported by each tool and the data fields

where the information will be stored. First, the data fields of both tools were evaluated to determine the overlapping on data fields. Then, the building elements were evaluated to determine information gaps among the data stored in COBie versus the data required by BUILDER SMS. Building elements were evaluated using the ASTM Uniformat II classification system. A comparison with the information typically included in USACE design BIMs was also included in this preliminary stage. A summary of the findings are detailed on Table 34 and Table 35, below. Assuming that such information exchange proves achievable and BUILDER SMS is able to use data in COBie format, then BIM Builder need the capability to export a COBie file with the information to be transfer to BUILDER SMS. An alternate possibility to producing a COBie file is to export the information into an IFC file and utilize the free, publicly available transform tool to produce a COBie file from an IFC file.

Assuming BIM Builder can achieve an export capability, it will not only open the possibility of exchanging information with BUILDER SMS but also with other systems used by building managers to maintain and operate the facilities. Another potential use could be utilizing such exported information as the based to develop a BIM using available design software for building re-purposing or reconstruction. In terms of design, most major design software vendors are currently able to use IFC data. A number of current tools and software for facility managers can use data formatted in COBie.

BIMBuilder captures information about the spaces identified in a model, as well as the assets, and also the relationships between assets and spaces so that both asset location and service dependency can be derived. Presently, there is a failing in the way that this data is presented in the two available export forms (COBie, and IFC), such that the data is not presented in the form that the current tools expect, even though that data is present.

We have assessed the findings from ERDC-CERL and estimate that it will cost roughly $25K for the necessary improvements to the information export tools to make the output of BIMBuilder fully compatible with existing DoD tooling for information interoperability, and fully compliant with current IFC standards.

The details of the availability of data and the current state of the data exchange potential is detailed in Appendix F, a report from ERDC-CERL on the transferability and interoperability of data between BIM Builder and DoD solutions such as BUILDER.

6.8 EW-201260 JOINT TASK RELATED TO SIMUWATT DATA EXCHANGE

Honeywell and NREL/Concept3D – Collaboration with ESTCP 201260

Test Phase: Phase VI: Collaboration with ESTCP 201260

Collaboration with ESTCP 201260: Electronic Auditing Tool with Geometry Capture.

ESTCP identified a related research program awarded in 2012 to NREL and a commercial partner, concept3d, where the objective of the program, titled "*Electronic Auditing Tool with Geometry Capture*" ESTCP 201260, is to produce a tool that may be used to develop a simple spatial model of a facility, during a standard physical energy audit in the field. The Simuwatt tool is particularly attractive in cases where there is no suitable as-built CAD model to use as input. We explored the potential of integrating these complimentary solutions (simuwatt Energy Audit and BIM Builder) to improve the ability to generate spatial reference models for buildings without existing documentation of the architecture and assets. Each team shared data from their

processes and tools, and explored the merits and challenges of combining the different approaches.

OpenStudio gbXML to BIM Builder

The mobile audit tool, simuwatt, utilized OpenStudio to generate the spatial model of a facility. The format of the data produced by their tool is gbXML, providing 3D spatial information about the captured spaces from an audit. BIM Builder currently requires 2D drawings (.DWG) as its native input in order to begin constructing a model of the facility. Therefore, the exported gbXML data would require a form of translation into a readable .DWG file. Three software packages, DDS-CAD Viewer version 8.0 (Data-Design-System) and Autodesk AutoCAD (2013 and 2014 releases) & Revit (2013 release), were tested for their ability to read in gbXML data, and save the information in a DWG format.

DDS-CAD Viewer was able to read in the gbXML file and provided functionality to export the project as a .DWG. The resulting .DWG was used as the source drawing for a new building model in BIM Builder, which was successfully read by BIM Builder during the import stage, but with significant loss of information. Exterior and interior walls were displayed well enough to portray the correct shape of the facility, but when attempting to utilize the imported drawing data, the required vector primitives could not be found by the Honeywell software. It was determined that the DWG data retained the 3D information during translation, and these 3D faces / surfaces could not be discovered and extracted by the current version of BIM Builder. Similar results occurred when using the Autodesk software tools.

There are a few options which could be explored that would enable these tools to exchange data effectively.

Create a gbXML import plug-in for BIM Builder: The plug-in would read gbXML and translate it directly to the required data set(s) so that the basic IFC model can be constructed.

Generate a gbXML file from BIM Builder: A gbXML export tool could be added to BIM Builder so that this data could be imported into simuwatt to use in field audits.

Create an IFC plug-in for BIM Builder: An IFC plug-in could be utilized in the case where gbXML data is first translated into IFC format from another software tool, and that IFC is then read by BIM Builder.

Create an IFC import plug-in for simuwatt: If simuwatt is the preferred tool for energy performance analysis, significant time could be saved in the field by pre-loading simuwatt with an existing model of the facility. It might be helpful for simuwatt to accept IFC input as there are other sources of IFC data.

Summary:

Both tools produce suitable light-weight models for energy analysis and asset management. While simuwatt is useful in the absence of CAD, BIM Builder is most useful when a reasonably consistent as-built model can be obtained, reducing the manual effort of creating and calibrating a model from scratch. Both tools eventually depend upon review by someone who can walk the facility to confirm the location and condition of the assets, but both should contribute to substantially reduce the cost of field audits through greater efficiency and consistency.

The data from these models can only be combined effectively if the DoD determines the form in which they want to manage building geometry data for the long-term. Some pros and cons are presented in the Table 29.

Table 29: Pros and Cons of Combining Data from Differing Model Formats

	PROS	CONS
BIM/IFC	Compatible with multiple shareware tools for IFC visualization Comprehensive and highly consistent model of building concerns Compatible with COBie and that family of information exchange extensions Highly extensible with strong methodology Can be applied to many facility management concerns across the lifecycle Strong foundation on ISO standards	Complex model Still relatively early in the maturity cycle of IFC with respect to control, since many changes were introduced in IFC 2x4 Many common BIM solutions do not provide full import/export support for IFC Verbose
gbXML	Concise description of concerns related to energy management Preferred for import/export by a number of energy management tools today (insert reference)	Inconsistent description of concerns from one type of system to another (HVAC, Chilledwater) Does not have a strong abstraction paradigm to create internally consistent extensions for new domains of interest Presently has limited application outside energy and asset performance

Translation to and from IFC / gbXML can only be as good as the content of the originating model. However, since IFC provides wider coverage of concerns, it is likely that the expressiveness of gbXML is the limiting factor in the exchange. IFC data that does not have a place in gbXML will be lost in the translation. gbXML will create a sparsely populated IFC model which can be enhanced by other tools.

Honeywell has chosen to use IFC as our standard representation because we feel it will be more extensible to more concerns as more building data becomes available in this form. While IFC data may be transformable to gbXML with several utilities, our experiments have shown that the current translation tools may be somewhat lacking. The best long-term solution for BIM Builder to support greater interoperability would be to generate a gbXML file natively from the underlying data model.

7.0 COST ASSESSMENT

This section presents a cost assessment of the Model-Driven Energy Intelligence technology. Some general guidance about costs and an example life cycle cost comparison are discussed in this section, but both costs and impact will be site-specific.

7.1 COST MODEL

The primary cost elements in a field implementation of Model-Driven Energy Intelligence technology are listed in Table 30. These estimates are based on start-up and maintenance of a five-building installation. Estimated costs for additional buildings are noted.

Table 30: Cost Elements

Cost Element	Data Tracked During this Demonstration	Est. Start-up Cost	Est. Recurring Cost (Annual)
Monitoring hardware capital costs	Start-up cost estimate is based on component costs for demonstration and related experience. It includes improvements to data instrumentation where existing systems require maintenance. This is a one-time start-up cost to restore or enhance existing services for a five-building pilot.	$50K	See Maintenance
Data services installation costs	Start-up costs included augmenting data collection (transmission and storage) from specific buildings and meters and the installation of the data processing servers on site at Fort Jackson. It includes data configuration of the first five monitored sites. This assumes the prior existence of a communication network.	$100K[1]	See Maintenance
Facility operational costs	Estimated annual costs, for 5 facilities, related to assessing and following recommendations to realize energy savings based on observed behaviors. This estimate is based on average implementation prices for instrumentation and programming changes to DDC/UMCS systems. See Table 31.	$41K	$29K
Maintenance	Estimated maintenance costs to keep services operational and troubleshoot drops in data transmission.	n/a	$25K
Hardware lifetime	Renewal of local data servers roughly every three years.[1]	n/a	$25K
Operator training	Annual cost estimate based on an expectation of attrition of skilled users. Estimated based on our experience.	n/a	$10K
Estimated start-up costs per additional building	Includes improvements to instrumentation, and data collection, BIM generation, and data integration and validation. Costs will vary based on the state of existing control and communication infrastructure, and building size.[2]	$10K	$2K
MDEI server software maintenance	Server-based software support and maintenance costs after first year. [3]	n/a	$50K

Cost Element	Data Tracked During this Demonstration	Est. Start-up Cost	Est. Recurring Cost (Annual)
BIM Builder licensing	Annual support and renewal costs for 5 BIM Builder licenses, assuming that this tool is employed by some centralized USACE resource. (not licensed site-by-site)[3]	n/a	$5K

[1]This cost assumes a localized data collection and data services environment such as the one piloted at Fort Jackson. The pricing model for centralized data collection at a common DoD data warehouse would be considerably different. This cost does not address DIACAP network certification of all the necessary software components.

[2] The cost of each additional building is non-linear. Up to some threshold, the addition of new facilities to the monitoring program does not modify the underlying cost structure. For the purposes of this estimate, we treat the scale factor as a block of 50 facilities per unit of infrastructure (server installation).

[3] The Honeywell tools and services fielded in this pilot are not yet formally priced for sale by Honeywell. All costs are based on our best estimate of actual installation and service costs based on experience with related products and services, as well as experience on this pilot.

All other costs are estimated as a function of normal operations and maintenance activities that might be identified or directed as a direct consequence of such monitoring.

Capital improvements to major HVAC equipment or services (e.g., replacing a chiller, for example), or building improvements (e.g., new roof) is not included as a cost of this program. It is presumed that this program would not modify capital budgets in any way, but might help to improve the prioritization of capital improvements.

7.2 COST DRIVERS

Cost drivers that affect the economics of a field implementation of MDEI technology include the following:

- The status of the data collection infrastructure at the site. Fort Jackson had an existing infrastructure for meter data collection and building control data collection that we could leverage to keep initial costs lower.
- The availability of CAD data sources for the facilities on the site, and the relative quality of those original CAD files.

The impacts of the above cost drivers are site-specific. These issues should be investigated as part of an energy and economic study in planning an application of MDEI. Such a study (to identify the energy savings opportunities, assess the economic potential, and assist in planning the implementation) can be performed by Honeywell Building Solutions (HBS). Funding for an installation of MDEI would be available through MILCON or other DoD energy improvement programs.

7.3 COST ANALYSIS

The project team performed a life-cycle cost analysis of the MDEI technology, based on available and estimated data. The analysis utilized the FEMP Building Life Cycle Cost (BLCC) Program http://www1.eere.energy.gov/femp/information/download_blcc.html#blcc. The analysis was performed as a MILCON Analysis, ECIP Project. The Life Cycle Cost Analysis covers the initial cost for creating the BIM for five buildings at Fort Jackson totaling 766,450 ft^2 and the maintenance of the BIM, the initial system configuration and ongoing system licensing, and the estimated cost of implementing typical energy conservation recommendations for building control, such as the cost of installation or relocation of sensors to improve the performance of the system.

The purpose of providing energy analytics is to identify inefficient operations. Energy conservation recommendations often, but not always, result in actions that incur some costs to correct the situation related to operations. These costs can include:

- Replacing faulty sensors or repositioning sensors that were badly placed. For example, outdoor air temperature sensors located in the sun or near the exhaust of another piece of equipment. Badly placed sensors negatively affect the behavior of the control system.
- Desirable modifications to control strategies for which the DPW may incur some support costs. Modifications can include schedule changes or better control strategies to balance available resources, such as better balancing of airflow to multiple VAVs. They may entail only an hour or two of engineering time from DPW staff or they might require vendor support.

This demonstration project did not include funding needed to pay for modifications to the site, such as those mentioned above. However, in a true life cycle cost analysis, one assumes that the recommendations must be acted upon to realize the expected savings. Therefore, estimates of these costs are included in the life cycle cost analysis. We have based the frequency of such modifications on our experience with commercial customers.

Table 31: BLCC Input Data

Analysis Type:	**MILCON Analysis, ECIP Project**	
Project Name:	Model-Driven Energy Intelligence	
Project Location:	South Carolina	
Base Date:	1-Sept-13	
Real Discount Rate: *	0% (5 yr), 1.0% (10 yr), 1.6% (20 yr)	
Energy Savings	**Price per Unit ****	**Annual Savings**
Electricity	$0.087 / kWh	976,189.2 kWh
Demand Charge ***		$39,037
CHW	$11.00 / MBtu	5,313.0 MBtu
HW	$13.00 / MBtu	13,503.2 MBtu
Heating	$0.875 / therm	20,471.9 therm

* Real discount rates were taken from OMB Circular A-94 (most recent revision, dated December 2013) www.whitehouse.gov/omb/circulars/a094/a94_appx-c.html

** Prices reflect actual rates for Fort Jackson

***Reflects local demand charges as published by the South Carolina Electric and Gas Company, as pubished at https://www.sceg.com/paying-my-bill/rates

7.3.1 System / Software Configuration, Maintenance and Licensing

As this product has not been fully commercialized, exact pricing figures are not yet available. We have estimated a likely price for 5 buildings, based on our experience with similar offerings:

- The initial system configuration is estimated at $100,000
- Yearly system licensing is estimated at $50,000
- Additional facilities, up to 50 total (on the same basic infrastructure), can be accommodated at an incremental cost adjusted for building size and condition.

7.3.2 BIM Generation and Maintenance*

We have used a generous figure for data quality maintenance, which covers extending the model with new information sources as new use cases and new data requirements are identified over time. Our experience shows there is significant return on the continued investment in data quality.

- Initial BIM modeling (in labor only) cost $3,800 for the five buildings in this study ($.50/100 sq ft on average). Our experiments suggest that the cost to implement a similar BIM using prevailing BIM tools may be closer to $.90 per 100 sq ft, or ~$6,900). BIM Builder provides a potential savings of $3,100 over the prevailing approach to modeling. It also has the potential to generally improve building documentation and audit costs over the approach detailed in a 2009 CERL study (Brucker, 2009); this approach incurred costs of $5.32/100 sq ft, or approximately $44,607.39 for the same total area of building asset inventory, but is not directly comparable.
- DPW/DoD maintenance of BIM and Asset Data is estimated at $10,000 per year. At scale, the modeling activity is expected to be carried out by trained DoD USACE personnel, or other civilian staff. This cost is included in the annual maintenance cost model. Such services could also be contracted from a third party.

7.3.3 Building Control and Equipment Changes*

- Two hours per month per building are estimated for setpoint, schedule, or override changes made by the DPW at a cost of $6000 per year.
- For the first year, one programming change requiring vendor support per building per month is estimated at a cost of $14,400. Following years are expected to be half the cost of the first year.
- For the first year, two sensor additions or movements requiring vendor support per building per year is estimated at a cost of $4,800. The following years are expected to incur half the cost of the first year.
- Capital equipment and repair/replacement costs are anticipated to be the same (no change in overall budget) with or without the BIM-enabled energy analysis, barring other institutional changes to maintenance practices. The outcome of such monitoring helps to prioritize the projects that are budgeted.

Energy monitoring and analysis*

- This LCCA is geared toward self-performers. It is expected that the DPW will review the energy reports monthly and make recommendations. Two hours per month per building is estimated at a cost of $6000 per year.*Purchasing energy analysis services through a performance contract arrangement at 10% of savings would reduce the monetary saving by 10%, moving the payback period out to between 14 and 16 months.
- The DoD is enhancing centrally monitored services through additions such as MDMS, described in Section 1. We do not have insight into how these costs would be distributed by the DoD to benefiting sites, but the assumptions may be similar to those for outsource monitoring as noted above.

* Vendor hourly rates are estimated at $120 per hour. DPW staff hourly rates are estimated at $50 per hour (Brucker, 2009).

These costs are also summarized in Table 32.

Table 32: Non-Energy Input Data

Annually Recurring Cost – System-Wide	Year 1	Subsequent Years
Vendor Software Maintenance / Licenses	($50,000)	($50,000)
DPW Maintenance of BIM and Asset Data	($10,000)	($10,000)
DPW Monthly Review of Energy Reports	($6,000)	($6,000)
Vendor Supported Programming Changes	($14,400)	($7,200)
Vendor Supported Sensor Addition or Move	($4,800)	($2,400)
DPW Setpoint, Schedule, Override Changes	($6,000)	($3,000)
Non-Annually Recurring Costs		
DPW Model Driven Energy Intelligence BIM generation	($3,832)	$0
Vendor Initial System Configuration	($100,000)	$0

The NIST BLCC tool calculates the simple payback period for BIM-enabled energy monitoring to be less than one year with a savings-to-investment ratio greater than ten over 5, 10, and 20 years. This payback period is feasible in buildings that are not already being monitored for anomalous energy use. (Anderson, 2007) and (Mills). This analysis estimates a 1.27 kWh/ft2 annual savings through implementation of the control and sensor recommendations identified by the Model-Driven Energy Intelligence (MDEI). We estimate that this savings could be applied to roughly 40,000 of the DoD facilities (see Section 6.7), or roughly 13.4% or 129M square feet. This amounts to roughly 163,830 MWhr annually.

This savings applied across just 50% of the 962.5 million square feet of DoD buildings with facility class of Administrative, Operation & Training, Troop Housing and Mess Facilities, and Community Facilities (DoD Base Structure Report) would reduce energy consumption by over 600,000 MWhr annually.

The results of the life-cycle cost analysis are summarized in Table 33 and further detailed in Appendix L.

Table 33: BLCC ECIP Summary Results

Annual Energy and Cost Savings			
Electricity Annual Energy Savings:			8,992 MBtu
Electricity Annual Cost Savings:			$152,261
Electricity Demand Annual Cost Savings:			$39,037
Natural Gas Annual Energy Savings:			4,822 MBtu
Natural Gas Annual Cost Savings:			$53,727
Annual Non-Energy Costs			
Non-recurring MDEI BIM Generation Cost:			($3,832)
Annually Recurring Costs:			($78,600)
ECIP Results	**Economic Study Period**		
	5 years	**10 years**	**20 years**
Electricity Discounted Cost Savings	$775,988	$1,505,509	$2,795,005
Electricity Demand Discounted Cost Savings	$198,951	$385,989	$716,596
Natural Gas Discounted Cost Savings	$306,754	$639,772	$1,304,680
Discounted Recurring Costs	($598,800)	($1,135,585)	($2,040,537)
First year savings	$120,658	$121,042	$121,234
Simple Payback Period (in years)	0.93 years	0.93 years	0.93 years
Total Discounted Operational Savings	$679,061	$1,391,854	$2,771,911
Savings to Investment Ratio (SIR)	6.03	12.36	24.62
Adjusted Internal Rate of Return (AIRR)	43.28%	29.89%	19.25%

This BLCC calculation was performed based on the cost estimates and benefits with respect to the pilot structure; that is the benefit to apply this technology to five facilities, totaling 766,450 sq ft; this translates to roughly $0.16 cents saved per sq foot in the first five years. Start-up costs are not linear with respect to additional facilities; that is, the software infrastructure costs will scale for many more facilities without significant additional investment in infrastructure. For an incremental startup cost of $50K for five additional facilities of similar footprint, the energy savings in the first year would double.

8.0 IMPLEMENTATION ISSUES

During the course of the program we encountered the following concerns that represent potential hurdles, opportunity for improvement, or unaddressed needs that might be addressed by future programs:

Infrastructure and Installation:

It has been discussed in the document that this program was meant to leverage the existing data infrastructure at sites where data collection was already in progress from both metering and DCS solutions. Unfortunately, maintenance of such systems is not always part of any on-going contract, and the infrastructure was not as robust as we anticipated.

- The DoD should be concerned about the long-term maintenance of investments in monitoring.
- Teams should be advised to budget for unexpected gaps in the data collection infrastructure.
- It was sometimes necessary to deal with multiple vendors with active contracts at the site to resolve simple issues, or track down the warranty status of pieces of the infrastructure to discuss repair.

Data Collection and Security

- Activities such as the development of the MDMS will hopefully streamline data collection for enhanced energy management across the DoD.
- Information security is likely the leading issue to be addressed to extract the value that can be gained through integrated energy management environments such as MDEI.
- Information interoperability for enterprise level energy management is a nascent issue that is being addressed by several major standards bodies. Much work is needed here to enhance the current state of the art.

BIM for Operations

- No solution is useful unless it becomes part of work practice. Energy visualizations of any type need to be presented directly in the working environment of the Energy manager or other end user to deliver value. This relates back to data collection and network security practices around the collection of control and energy data.
- Existing tools are geared toward designers and the construction process. When 3D models are put in the hands of new end users in facility management, new navigation requirements are uncovered. Current visualization tools for BIM are not well suited for these new use cases. Movement through the model is too free-form, and requires some skill.
- When these models start to be used, a seamless way to keep them up-to-date will be necessary to ensure that they remain living and vital with respect to current facility conditions. This requires both new processes and tools and a cultural ecosystem that encourages maintenance of the information.

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APPENDICES

A. Points of Contact

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Karen Harmon	Honeywell HBS	803-445-6927 Karen.Harmon@Honeywell.com	Manager
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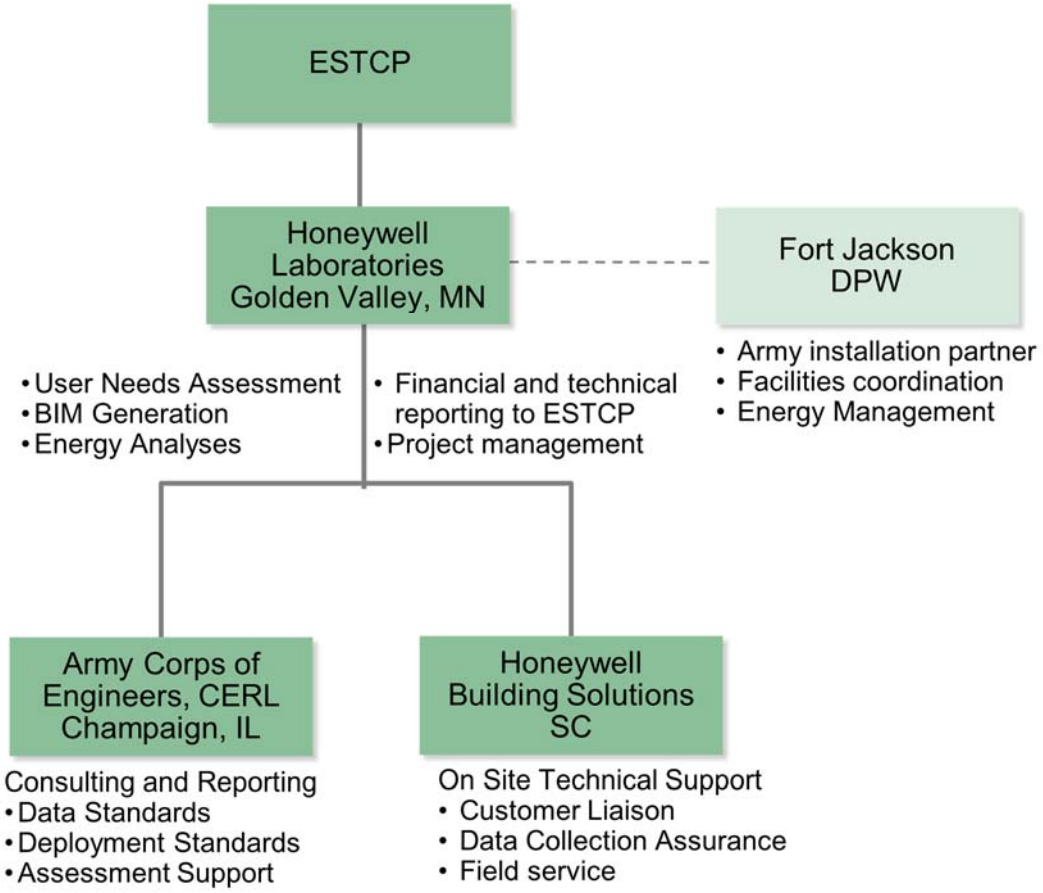
Justine Kane	ERDC-CERL	Justine.A.Kane@usace.army.mil	Sustainability
David Schwenk	ERDC-CERL	217-373-7241 David.M.Schwenk@usace.army.mil	Energy Management
Lance Marrano	ERDC-CERL	217-373-4465 Lance.R.Marrano@usace.army.mil	BUILDER SMS


ESTCP
Honeywell Laboratories Golden Valley, MN
Fort Jackson DPW
• Army installation partner
• Facilities coordination
• Energy Management
• User Needs Assessment
• BIM Generation
• Energy Analyses
• Financial and technical reporting to ESTCP
• Project management
Army Corps of Engineers, CERL Champaign, IL
Consulting and Reporting
• Data Standards
• Deployment Standards
• Assessment Support
Honeywell Building Solutions SC
On Site Technical Support
• Customer Liaison
• Data Collection Assurance
• Field service

B. BIM Builder Technical Background

Honeywell has filed several patent applications describing a method to generate a multidimensional model of a building and its related systems through geometric semantic processing and optical character recognition. This process supports the recognition of physical systems such as doors and walls; distribution systems, such as HVAC ventilation ductwork and water distribution systems; and data network systems. The diagrams can be spatially accurate, such as scale floor plans showing the path of ductwork, or they may be only functionally accurate, such as the schematic models of a control system. It may require a combination of sources to build up an accurate representation. This capability provides significant advantage because most 2D geometry sources describe a set of vectors that do not carry identity (no semantic description) though they have correct 2D spatial geometry. A 2D CAD file does not readily support extractions to a relational data model or interpretation of the arrangement of items in a networked system.

Figure 65 illustrates elements of the system for object recognition and conversion. A number of technical disciplines are applied in succession to identify, classify, organize, encode, and display the information processed from 2D CAD drawings.

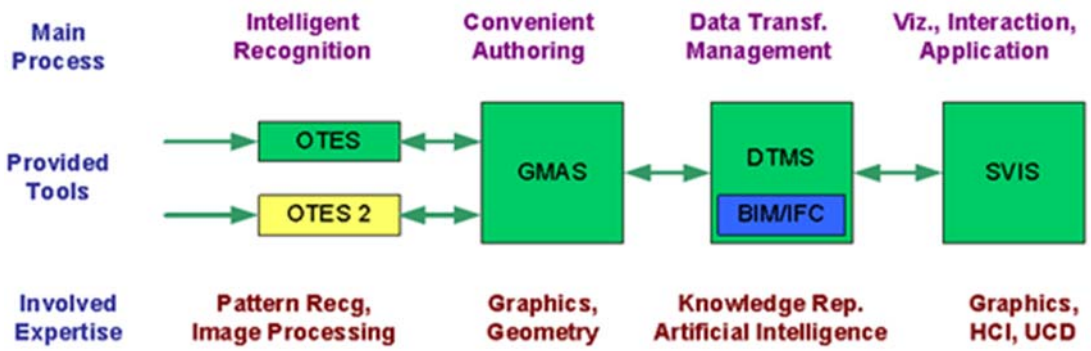


Figure 65: Functional Steps in the Extraction and Conversion of 2D Features

In the first step, common patterns representing objects of interest are identified in re-usable templates within the **Object and Topology Extraction System (OTES)**. These templates allow for the automatic identification of objects that match based on the alignment of and relationship of a set of vectors. In the second step, the geometry is augmented for 3Dby using the **Geometric Model Authoring System (GMAS)**. For example, in-line equipment is represented as having the same dimension as the ductwork. Ductwork, if not otherwise indicated, is represented using industry standard duct dimensions. These geometrically correct objects are then translated into an IFC Express format within the **Data Transformation and Management System (DTMS)**, and finally, the whole is rendered by the **Stereo Visualization and Interaction System (SVIS)**.

The information sources for a building typically include blue prints or floor plans, schematics, text documents (digital or paper-based), and other structure databases where facility management information has been collected. Textual data can be recognized by matching text patterns to the patterns identified in the domain model. We use semantic matching means to recognize domain-specific elements, whether they are referred to with precisely matching terms, or through commonly used abbreviations. This method can be tuned to a site-specific set of semantics, or to another language. The recognized elements can be categorized and organized using relations

described by the BIM, and by the process control diagrams, both of which describe how elements are networked. Data fusion is used to combine information from different sources to improve the accuracy and completeness of the resulting model.

Figure 66 shows a portion of the 2D CAD source file for the mechanical system of a large office building. Figure 67 on the right shows the integration of the extracted and converted IFC objects into the design model of the same building, viewed in Autodesk Navisworks®.

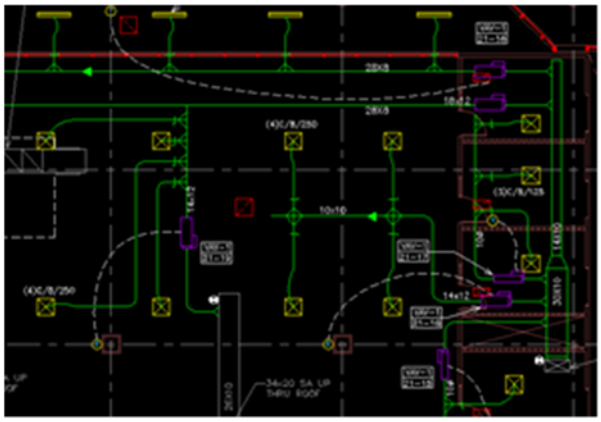


Figure 66: Mechanical Drawing of Ventilation System

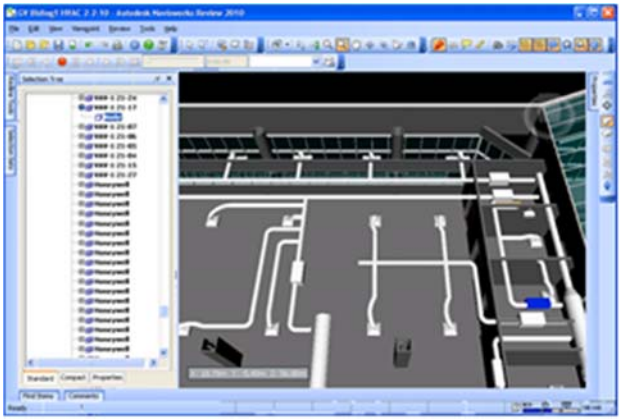


Figure 67: Mechanical Layer After Conversion and Incorporation

Additional information may be extracted from the building management system (BMS), or other asset management or facility management systems. This includes information about space functions, space labels, requirements for comfort control, building occupancy schedules, and asset maintenance information. This information may come in the form of proprietary databases or printed documents. Import from these sources can be partially automated through the use of tools such as COBie and ELie.

C. MDEI User Interface

This appendix is a detailed discussion of the MDEI user interface, which is described briefly in Section 5.

One disadvantage that most installation energy managers face is the inconsistencies in accessing and displaying trend data across a variety of control systems. Such inconsistencies create artificial barriers by forcing the energy manager to recall how information is displayed in each system and what this means.

A goal for MDEI was to ensure that the end user could quickly become comfortable reading the charts without needing to reference the legend each time to remember "*Which one is the red line?*" The goal is to help the user to intuitively recognize the points of interest and reduce the time to orient to each new trend display.

To standardize colors across the contexts of interest, we established this set of usability philosophies.

- Controlled or controllable behavior should have darker saturation than setpoints.
- Setpoints should be in the same color family as the process variable that is being driven, but less saturated.
- Positions (e.g., damper setting, valve setting) should have thinner lines than the effect of the setting (e.g., temperature).
- Outside data, such as weather, should be displayed in gray shades.

The color palette illustrated in Figure 68 was established for all charts from the Tableau Desktop application. Because the palette supported by Tableau is limited, color assignment to display points is not unique.

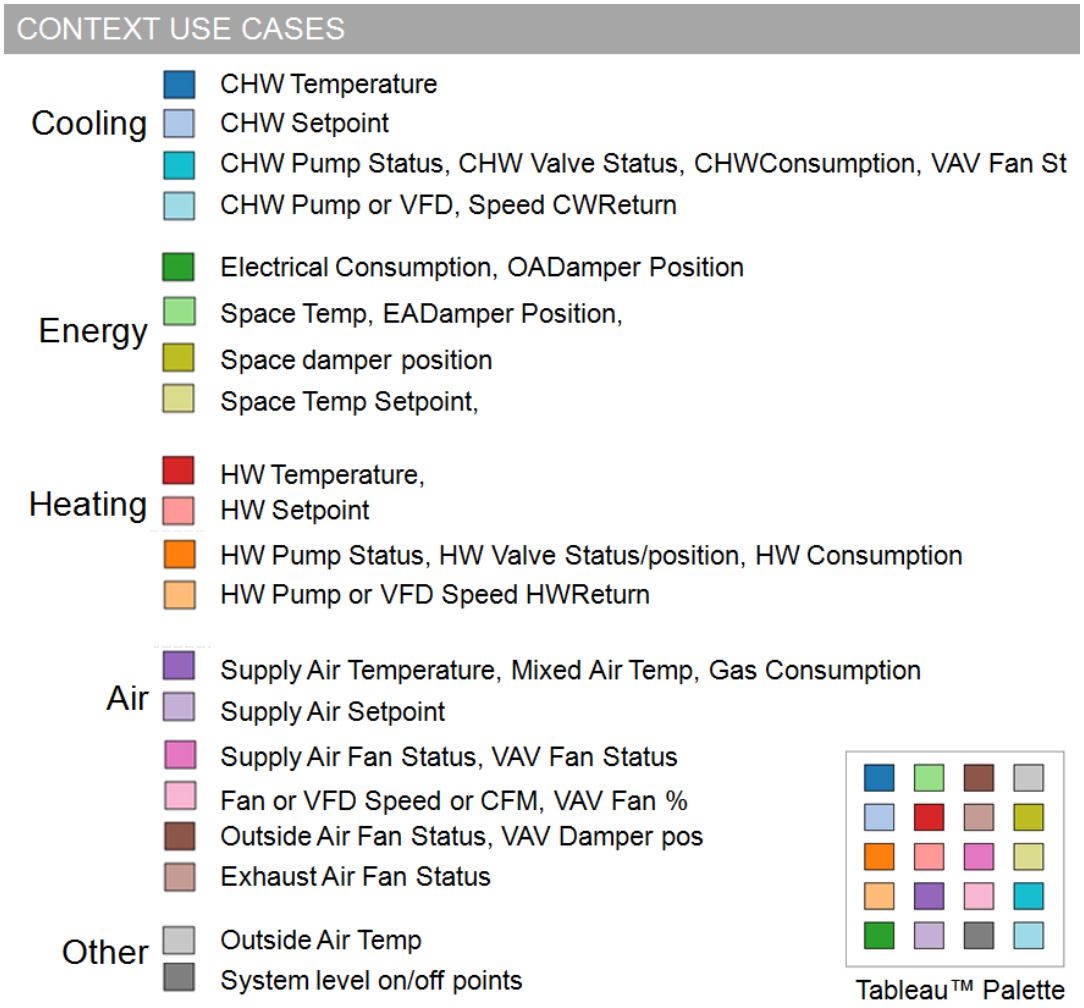


Figure 68. Context assignment to color ranges in the Tableau palette

The following sections describe the data exploration environment in further detail, including navigation and data selection options.

After logging in through a simple dialog that requests username and password, the user sees the main FM Dashboard web service page shown in Figure 69.

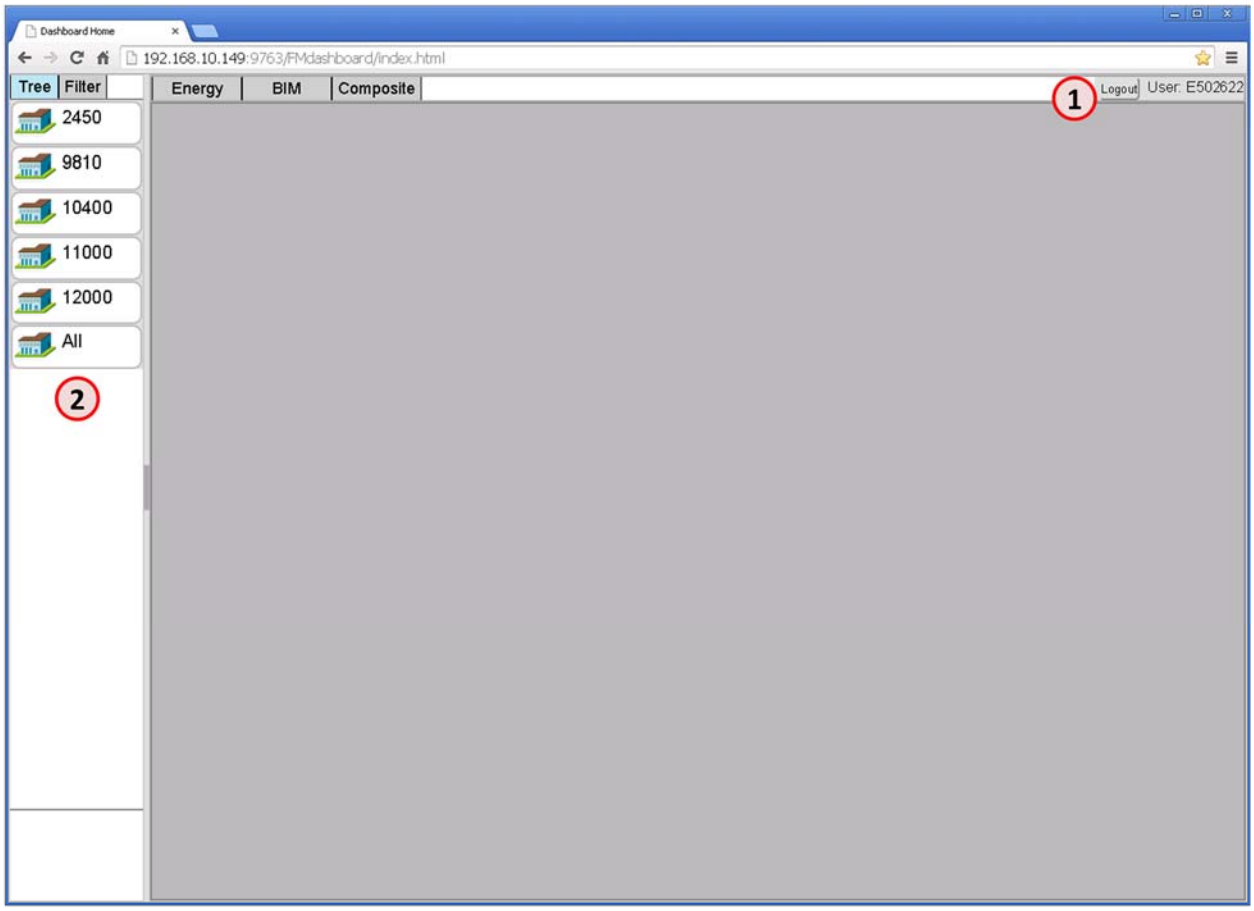


Figure 69: Front Page of FM Dashboard Web Service

Callouts in Figure 69:

3. The name of the logged-in user is displayed to the right of the Logout button.
4. The initial menu is constructed dynamically for the requested data service. The request returns the current set of buildings in the database.

Figure 70 shows the MDEI UI after a user selects a building. Note that for the remaining figures in this appendix, all five buildings are displayed at least once in their initial view (front).

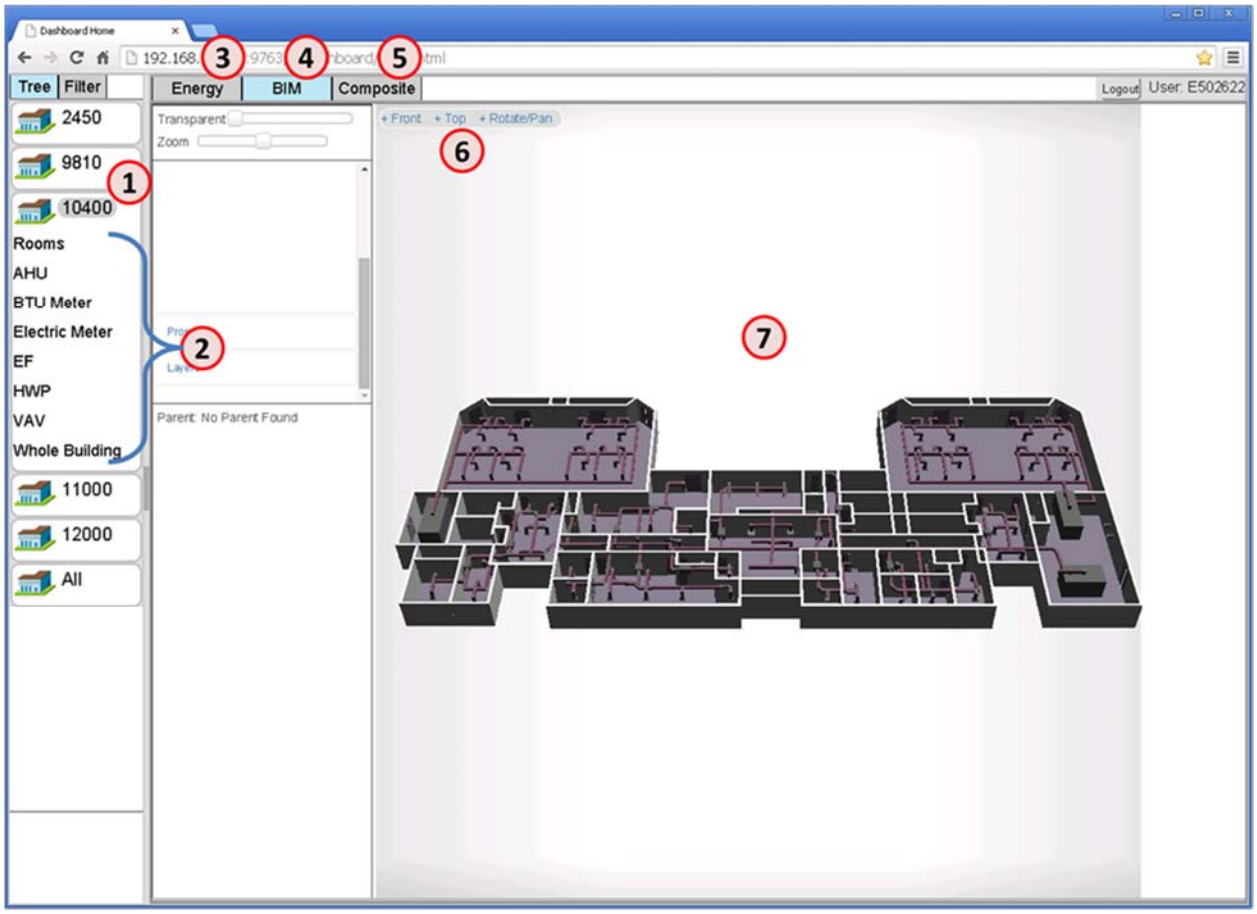


Figure 70: UI Generation after Building Selection

Callouts in Figure 70:

1. The user selected building 10400. The selection expands a submenu displaying elements specific to that building.
2. The submenu of the building's elements, created dynamically based on BIM-generated data in the database.
3. The Energy tab allows the user to navigate to an energy-related view (Tableau dashboard) for selected elements. See Figure 72
4. The BIM tab lets the user navigate to the 3D BIM view of the selected building. When the user selects a building, the view defaults to this tab.
5. The Composite tab tiles the Energy and BIM views on the same page. See Figure 74 for an example.
6. Preset views for the 3D BIM: Front (shown in the figure), Top gives top-down view of the building (like a floor plan); Rotate/Pan toggles the way a mouse-drag on the view manipulates the 3D model.
7. Selected content display area. In the figure, the BIM tab is selected (Callout 4), which updates this display area to show the 3D BIM. This area changes based on which tab is selected.

Figure 71 shows the UI after a user has selected a specific element of a building.

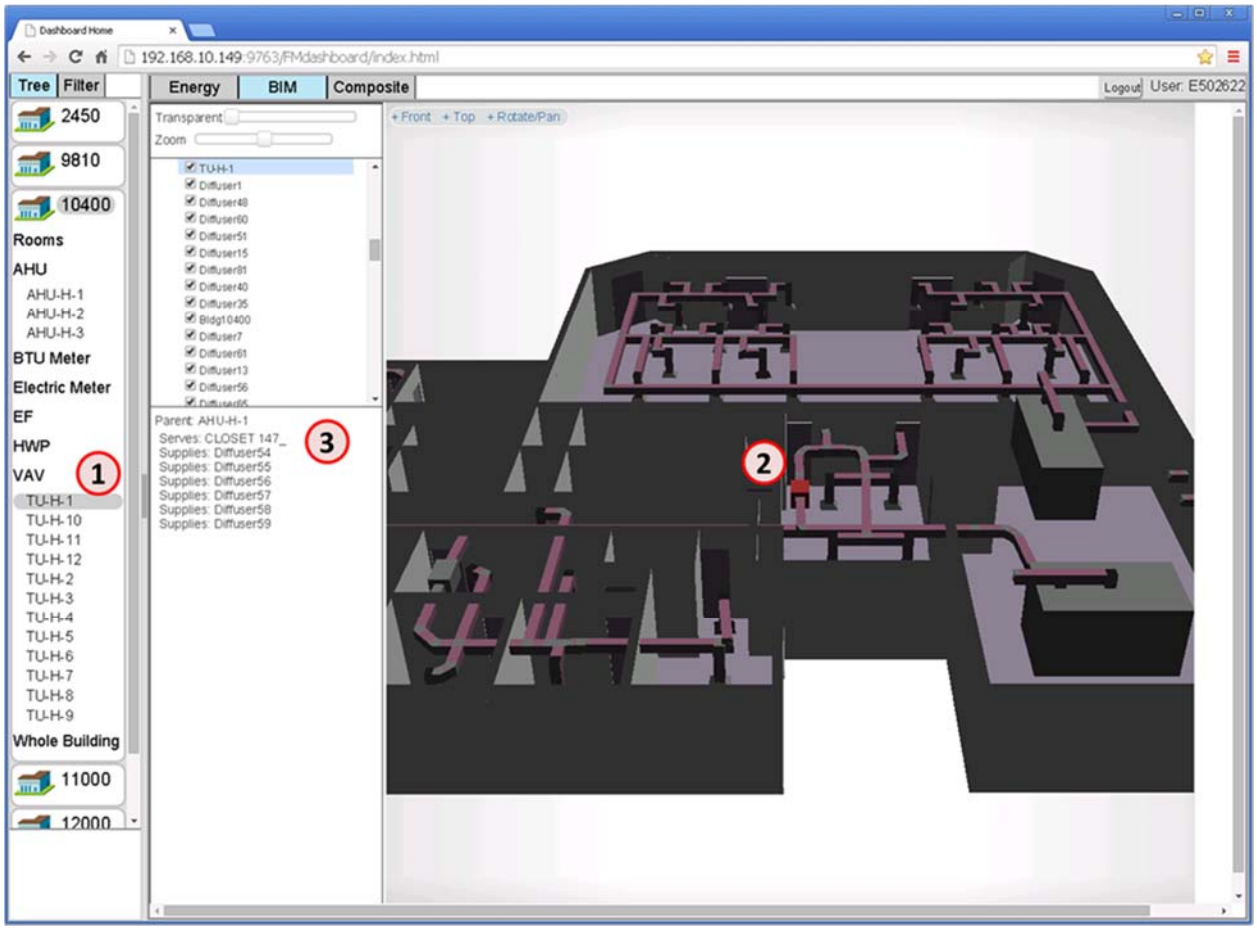


Figure 71: UI Generation after Building Element Selection

Callouts in Figure 71:

1. Building element TU-H-1 has been selected. This element has no further 'children,' as it is a concrete building element, and so no further submenus are generated.
2. Display area (BIM view) updates automatically based on selection in 1. The viewer highlights the piece of equipment and pans and zooms into it for a closer view. Note the view was zoomed-out slightly to show better spatial context.
3. Parent, Supplies, Supplied-by, Serves relationship data populates this area of the display. In the case of the figure above, TU-H-1 has parent equipment, AHU-H-1, that supplies it, and itself supplies multiple diffusers throughout the building. The underlying data which automatically builds this list is from the BIM.

The user can also select entities in the 3D BIM view, which will highlight it red, pan-zoom to it, and the menu and relationship areas will update accordingly. The 3D BIM view will remain focused from the 'front' of the building, similar to what is displayed in the figure. The user can rotate the view for a different angular view, zoom in and out, and pan the view.

Figure 72 shows how the UI updates when the user selects the Energy tab.

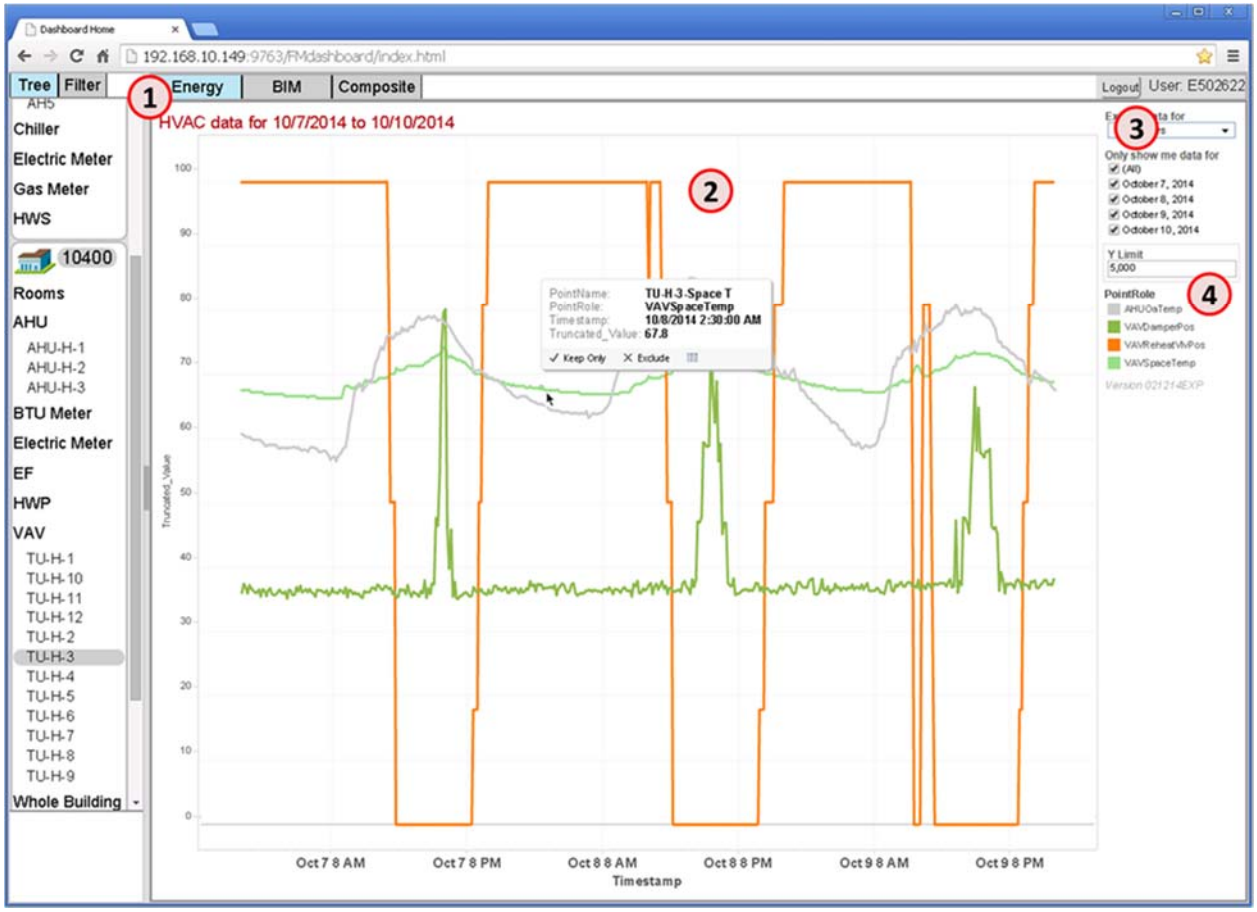


Figure 72: UI Generation when Selecting [Energy] Tab

Callouts in Figure 72:

1. The Energy tab was selected. This action was carried out after equipment selection, as shown in the previous figure. Note that TU-H-3 is still highlighted in the menu.
2. The content display area is filled with a Tableau dashboard, graphing energy data for the selected equipment.
3. Date and Date-Range filtering of the dashboard. By default, all energy views display the "Last 7 Days" of data. The user can change this range and also select specific days to graph by (un)checking the boxes next to each date. In this figure, only the last four days were selected for display to simplify the figure.
4. PointRole legend. All equipment points are assigned to specific roles, and each role is assigned specific colors to standardize the graphical view.

This figure shows that the user can move the mouse over any colored graph line to get a pop-up window. The pop-up gives information about point data behind that line at that particular date and time, specifically the name of that point and its value.

Also, the legend (Callout 4) can be used to toggle point roles on/off, such that the display will highlight only the selected role, while the others are dimmed for ease of viewing specific behaviors.

Finally, while in this Energy view, the user can select multiple pieces of equipment in the left menu to generate energy graphs together in the same view. This ability is useful when equipment with served, supplied-by, supplies relationships to be graphed together for additional context on the behavior of an equipment chain. Figure 73 demonstrates this ability, where TU-H-3 is selected along with AHU-H-1, which is the entity that supplies it, as shown in the relationship area (Callout 3) of Figure 72.

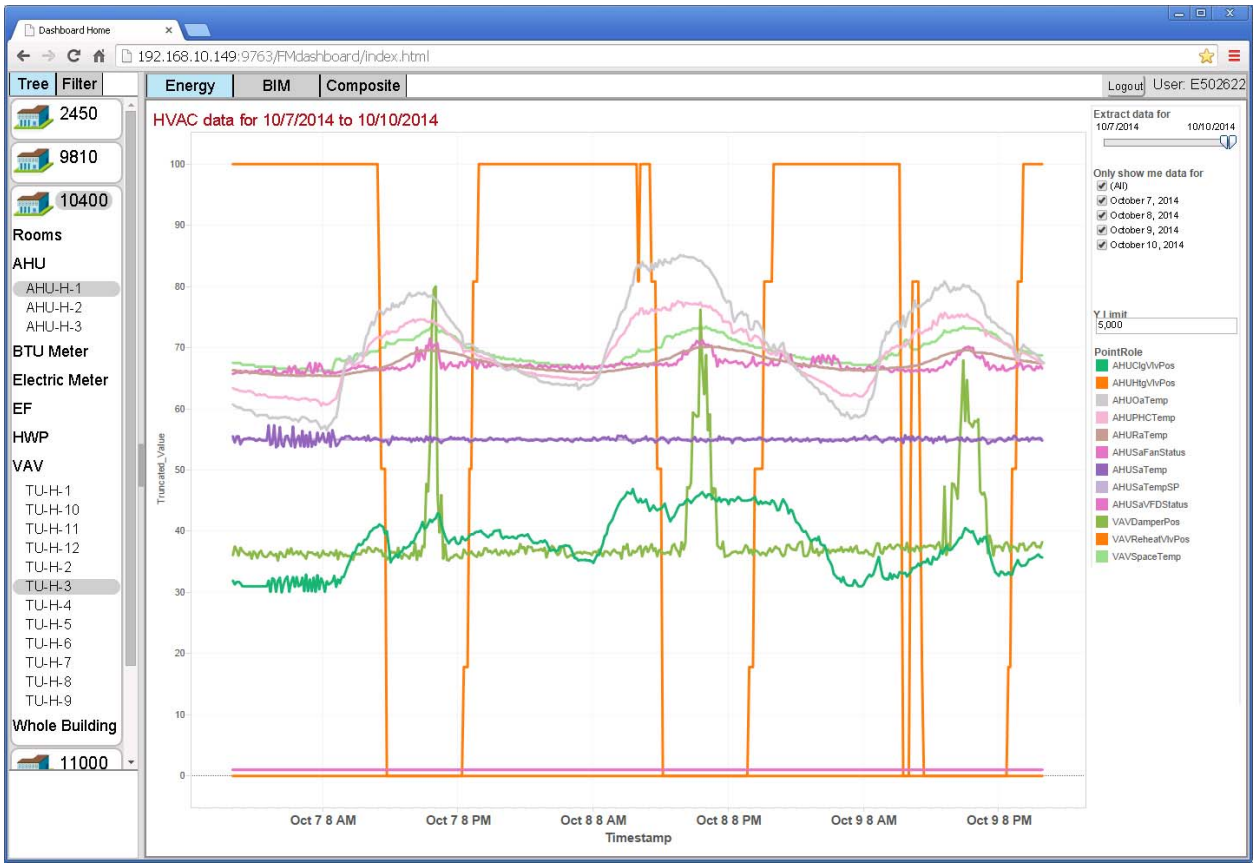


Figure 73: UI Generation for Energy View with Multiple Entities Selected

An example of the content area of the Composite view is shown in Figure 74.

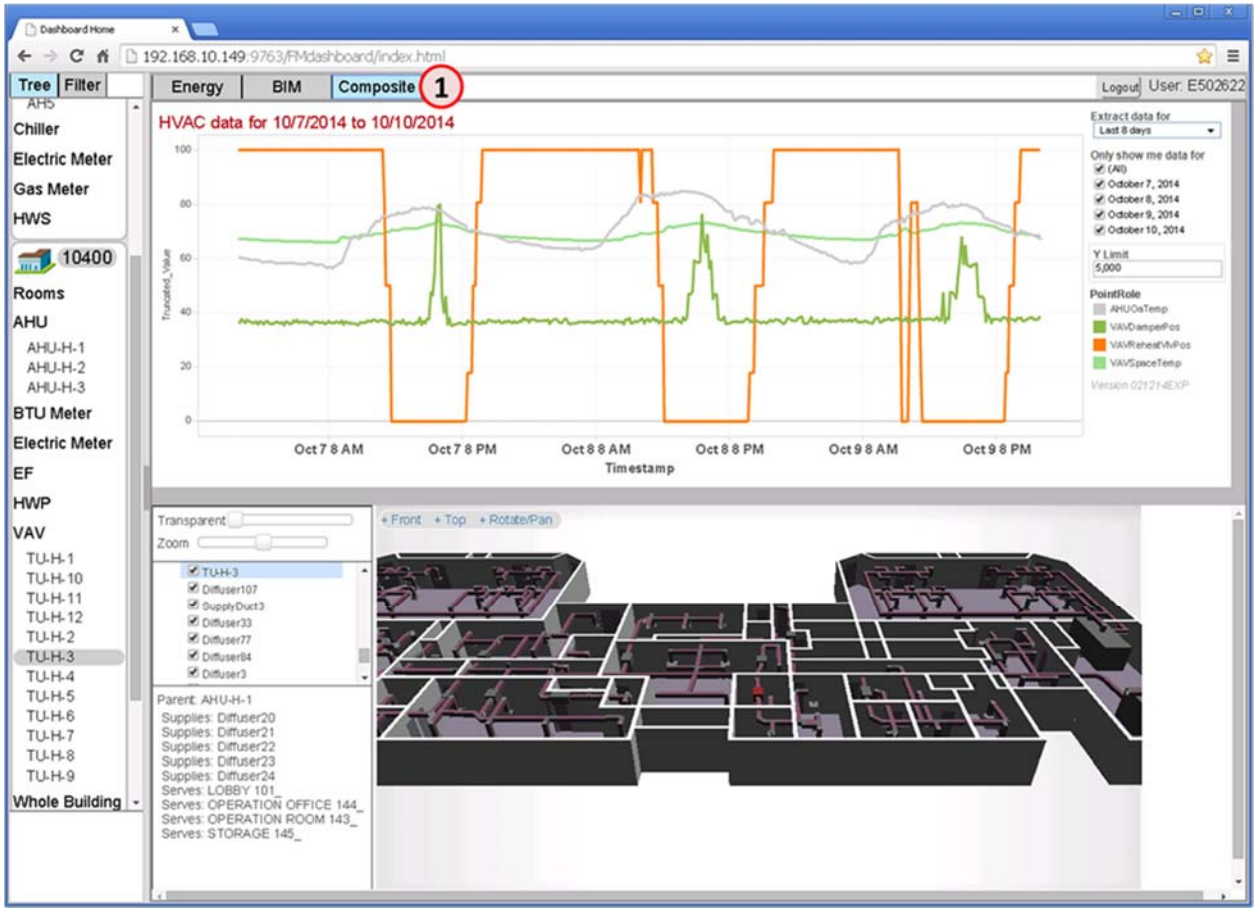


Figure 74: UI Generation for Composite View

In Figure 74, the user has selected the Composite tab (Callout 1), which updates the content display area to show both the BIM view and the Energy view together in a tiled format. The user can select a different building element at any time, via the menu or 3D BIM, and both views will update accordingly.

The next two figures show how the UI works when viewing buildings 11000 and 12000. The BIM models for these buildings were too large when converted to JSON format for rendering in the BIMsurfer view. Each was broken into two sections, one file containing the center office and classroom spaces, and one for all five wings of the barracks.

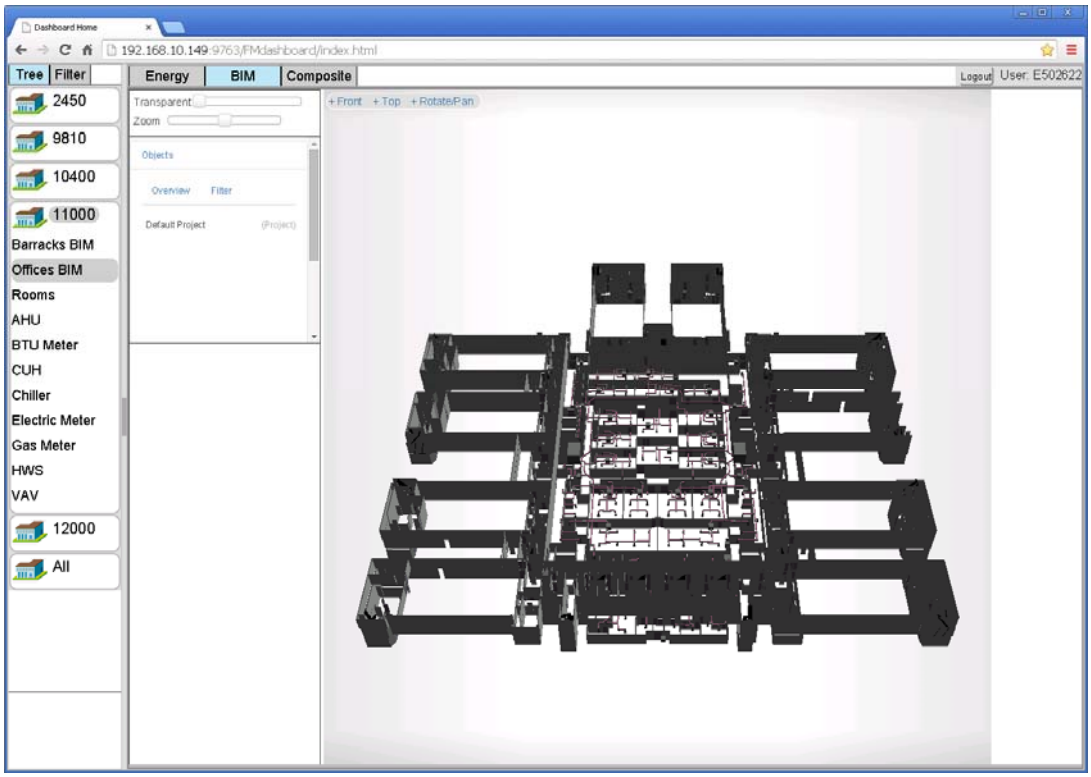


Figure 75: UI Generation BIM View for Building 11000 – Offices

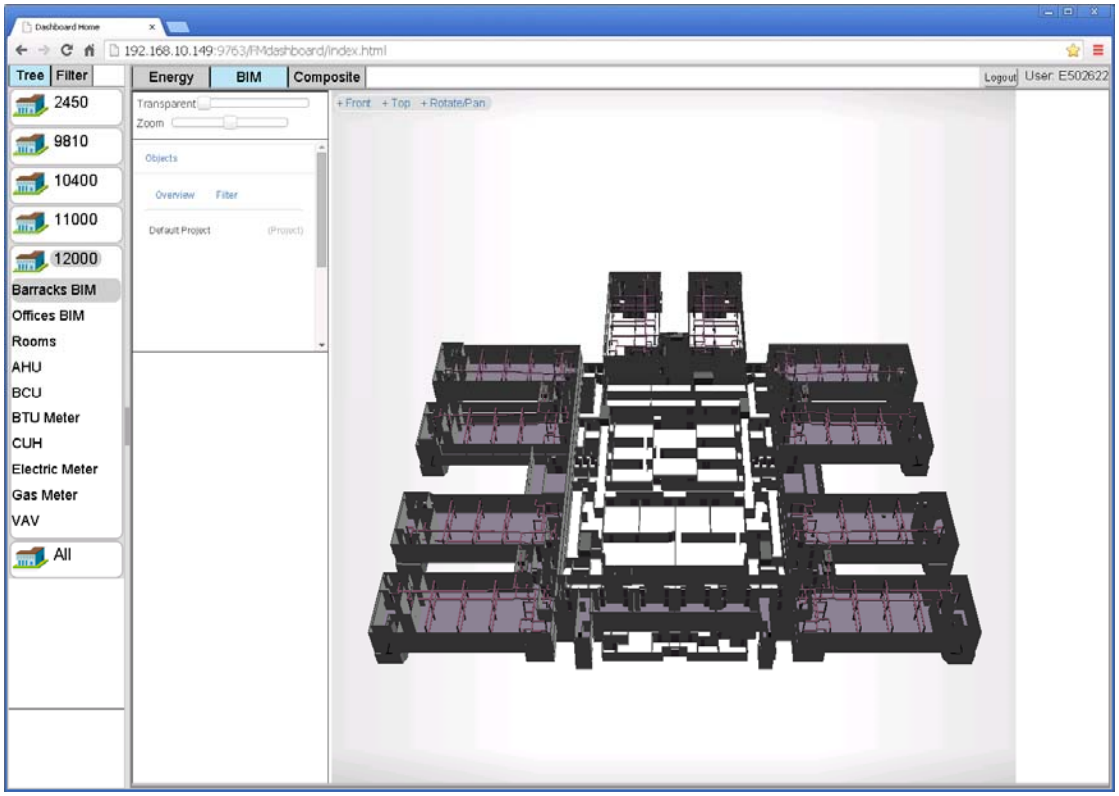


Figure 76: UI Generation BIM View for Building 12000 – Barracks

For completeness, the next two figures show the main view for buildings 2450 and 9810.

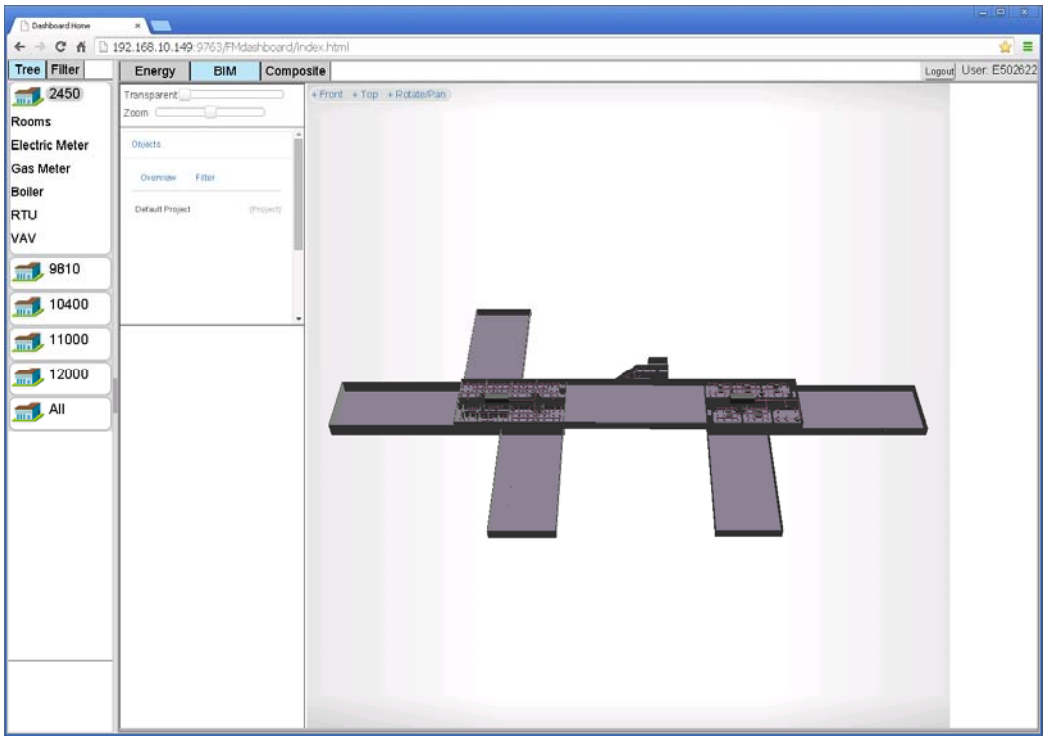


Figure 77: UI Generation for Building 2450 3D BIM Front View

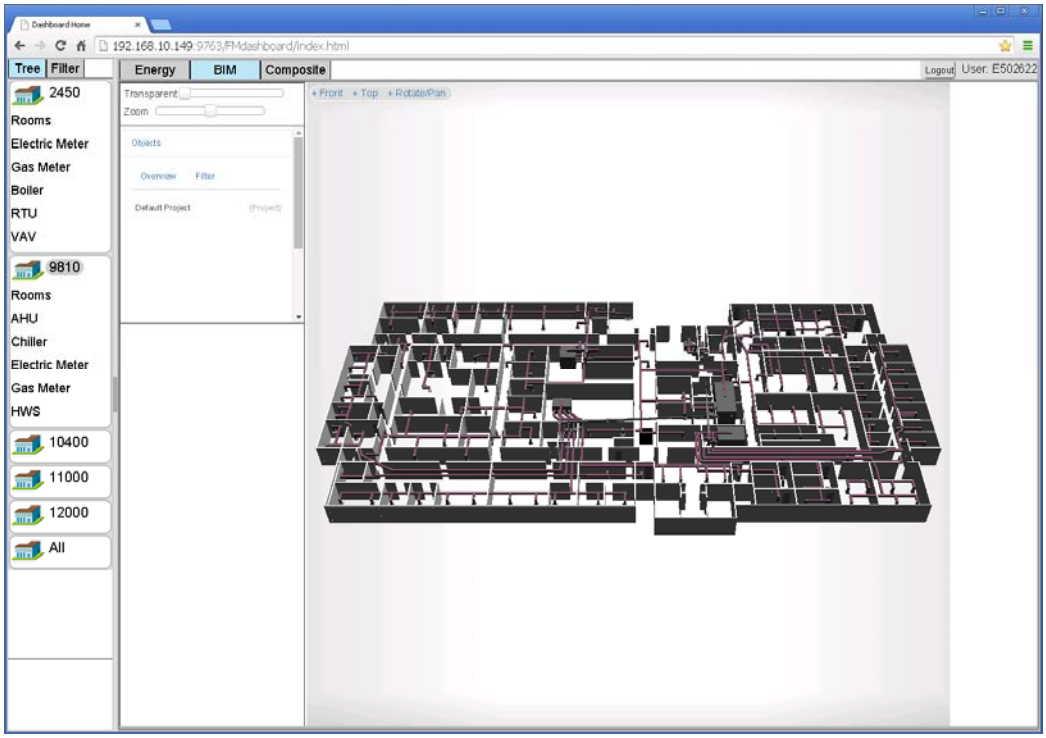


Figure 78: UI Generation for Building 9810 3D BIM Front View

Figure 79 through Figure 81 show how meter energy is viewed. Note that they show only electrical views, but the same views are available for gas meters. Figure 79 shows the high-level calendar view which provides quick and easy understanding of daily meter energy usage. Figure 80 shows a scatter plot of the same type of data, but hourly data is aggregated into daytime and nighttime/weekend totals. Figure 81 provides an energy profile, which is similar to the scatter plot view, but can help identify patterns of energy usage in a different way.

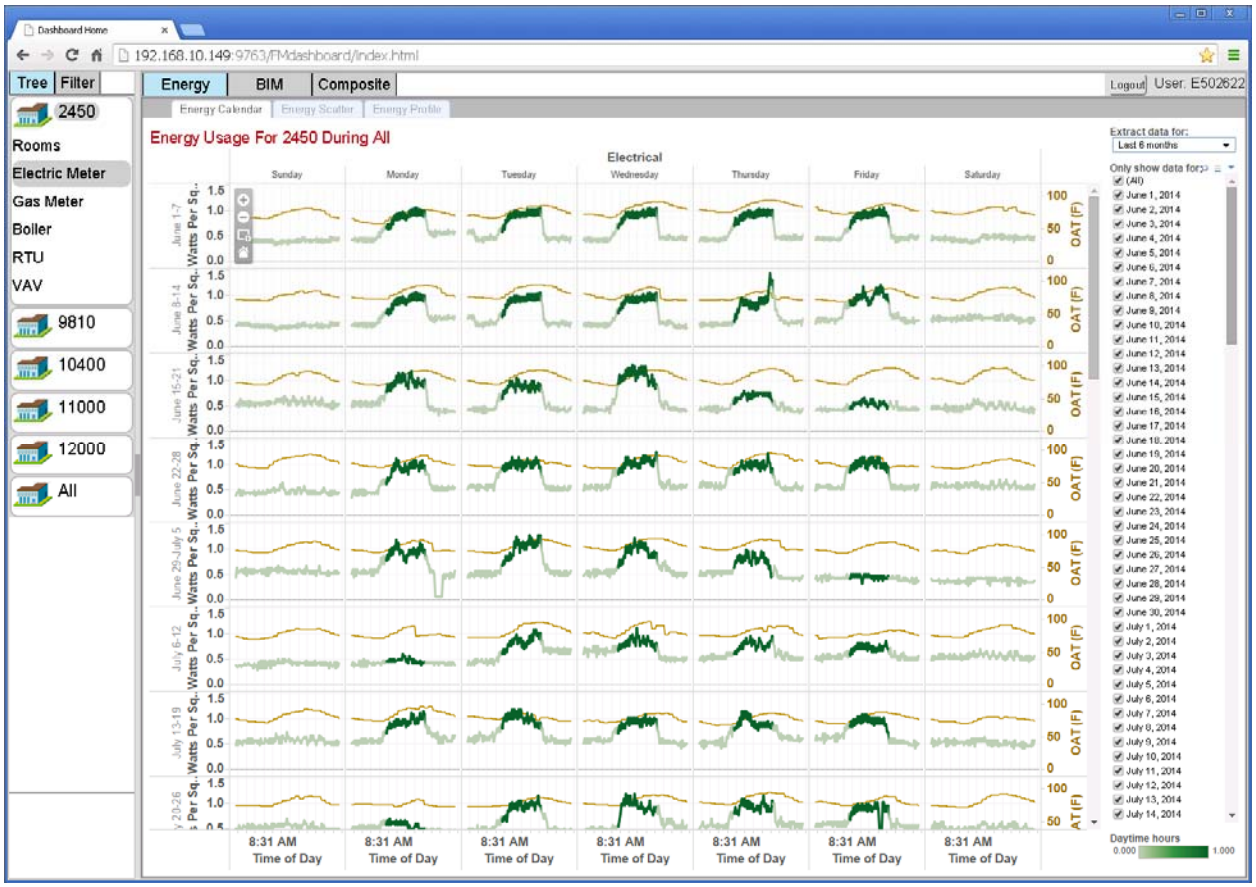


Figure 79: UI Generation – Energy Calendar

Figure 80: UI Generation – Energy Scatter Plot

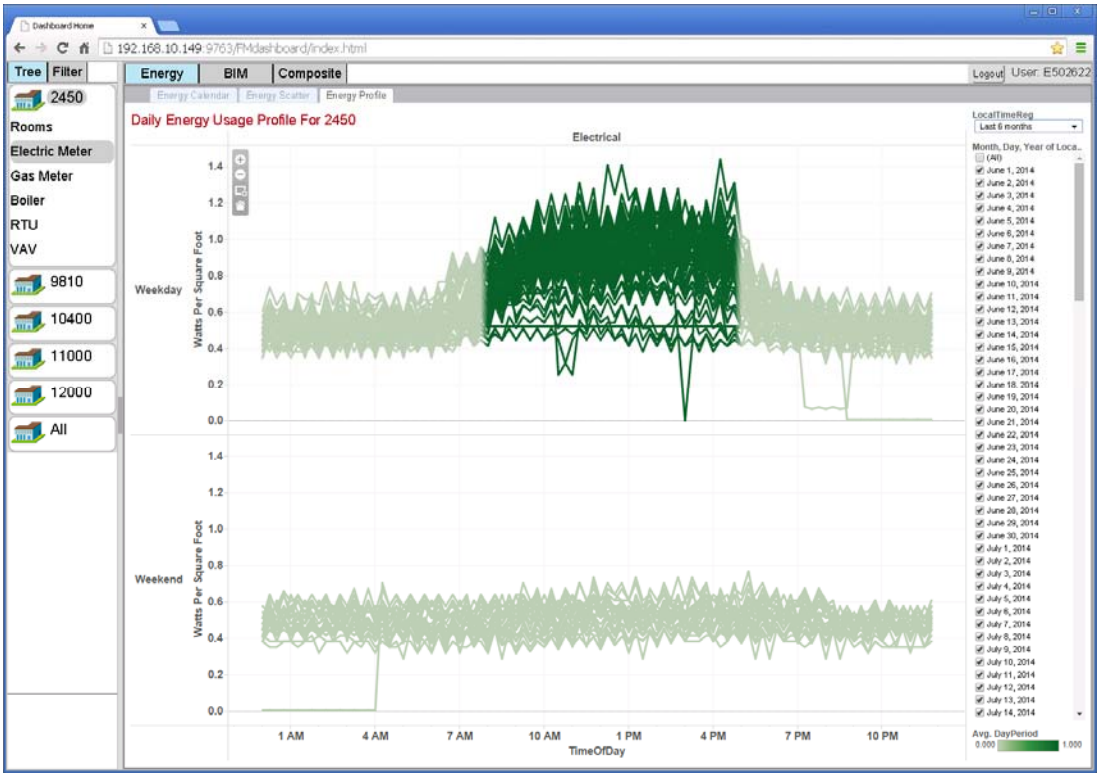


Figure 81: UI Generation – Energy Profile

BIM Builder Data Linking

One product of the BIM Builder output is a COBie-like file which contains valuable information for linking entities (served / served-by, services), and the names of those entities. A subset of that data is provided in Figure 82, which was generated for Building 2450. The table on the left is a snapshot of the Equipment tab on the output sheet, and the table on the right is a snapshot of the MEP Supply Relationship tab.

Name	Floor Name	Served Space	Associated AHU
VAV-1-2-08	2F	207	RTU1
VAV-1-2-07	2F	207	RTU1
VAV-1-2-03	2F	204	RTU1
VAV-1-2-04	2F	204	RTU1
VAV-1-2-16	2F	217	RTU1
VAV-1-2-05	2F	205	RTU1
VAV-2-2-07	2F	225	RTU2
VAV-2-2-07	2F	226	RTU2
VAV-2-2-02	2F	223	RTU2
VAV-2-2-03	2F	223	RTU2
VAV-2-2-04	2F	224	RTU2
VAV-2-2-05	2F	222	RTU2

Equipment tab

RTU2	SupplyDuct3	VAV-2-2-02	Diffuser114
RTU2	SupplyDuct3	VAV-2-2-02	Diffuser104
RTU2	SupplyDuct3	VAV-2-2-02	Diffuser117
RTU2	SupplyDuct3	VAV-2-2-02	Diffuser105
RTU2	SupplyDuct3	VAV-2-2-02	Diffuser103
RTU2	SupplyDuct3	VAV-2-2-02	Diffuser102
RTU2	SupplyDuct3	VAV-2-2-07	Diffuser136
RTU2	SupplyDuct3	VAV-2-2-07	Diffuser148
RTU2	SupplyDuct3	VAV-2-2-07	Diffuser147
RTU2	SupplyDuct3	VAV-2-2-07	Diffuser146
RTU2	SupplyDuct3	VAV-2-2-07	Diffuser145
RTU2	SupplyDuct3	VAV-2-2-07	Diffuser137
RTU2	SupplyDuct3	VAV-2-2-07	Diffuser135
RTU2	SupplyDuct3	VAV-2-2-07	Diffuser134
RTU1	SupplyDuct1	VAV-1-1-01	Diffuser3
RTU1	SupplyDuct1	VAV-1-1-01	Diffuser45
RTU1	SupplyDuct1	VAV-1-1-01	Diffuser2
RTU1	SupplyDuct1	VAV-1-1-08	Diffuser9

MEP Supply Relationship tab

Figure 82: BIM Builder COBie-Like Output Data

Two-post processing steps made it possible to use this data with the MDEI UI and link it to point data. First, on the Equipment tab, entity names (first column) were matched to equipment names (generated as part of the building automation point data auto-context work). Since BIM Builder automatically generates entity names, they are not guaranteed to match—they may not even exist—the name given for the building automation point. Therefore, to link the BIM 3D model objects to building point data, we created a simple cross-reference table, EquipmentNameConversion, containing three columns: BuildingId, NameBIM, and NamePoint. The first two columns are simply generated from the BIM Builder output, and the NamePoint column is completed by extracting the name from the MonitoredPointSummary table (this table is explained further in the next section). Figure 83 shows an extract of the EquipmentNameConversion table. As can be seen, the name given by BIM Builder is slightly different than the name extracted from the building point name. This table is utilized whenever the user selects an entity from 3D BIM view. The entity name is found in the NameBIM column and then the associated NamePoint value is returned to be used by the web application to drive changes to the rest of the UI.

BuildingId	NameBIM	NamePoint
2450	VAV-1-2-09	VAV1_2_9
2450	VAV-2-1-01	VAV2_1_1
2450	VAV-2-1-02	VAV2_1_2
2450	VAV-2-1-03	VAV2_1_3
2450	VAV-2-1-04	VAV2_1_4
2450	VAV-2-1-05	VAV2_1_5
2450	VAV-2-1-06	VAV2_1_6
2450	VAV-2-1-07	VAV2_1_7
2450	VAV-2-1-08	VAV2_1_8
2450	VAV-2-1-09	VAV2_1_9
2450	VAV-2-2-01	VAV2_2_1
2450	VAV-2-2-02	VAV2_2_2
2450	VAV-2-2-03	VAV2_2_3

Figure 83: BIM – Building Point Entity Naming

The second post-processing step used a simple vb-script within Excel to expand and normalize the data found in the MEP Supply Relationship tab. The resulting table, EquipmentRelationship (Figure 84), allows the web application to quickly and easily request the necessary relationship data for any entity.

BuildingId	Object1	ObjectType1	Object2	ObjectType2	Relationship
2450	VAV-1-2-04	Equipment	Diffuser236	Equipment	Supplies
2450	VAV-1-2-03	Equipment	Diffuser234	Equipment	Supplies
2450	VAV-1-2-03	Equipment	Diffuser233	Equipment	Supplies
2450	VAV-1-2-03	Equipment	Diffuser232	Equipment	Supplies
2450	VAV-1-2-03	Equipment	Diffuser231	Equipment	Supplies
2450	VAV-1-2-03	Equipment	Diffuser230	Equipment	Supplies
2450	VAV-1-2-03	Equipment	Diffuser229	Equipment	Supplies
2450	VAV-1-2-03	Equipment	Diffuser228	Equipment	Supplies
2450	VAV-1-2-03	Equipment	Diffuser235	Equipment	Supplies
2450	VAV-1-2-07	Equipment	Diffuser212	Equipment	Supplies
2450	VAV-1-2-07	Equipment	Diffuser211	Equipment	Supplies
2450	VAV-1-2-07	Equipment	Diffuser210	Equipment	Supplies
2450	VAV-1-2-07	Equipment	Diffuser209	Equipment	Supplies
2450	VAV-1-2-07	Equipment	Diffuser200	Equipment	Supplies
2450	VAV-1-2-07	Equipment	Diffuser198	Equipment	Supplies

Figure 84: EquipmentRelationship Table Extract

Building Control System Point Selection and Configuration

The on-site Energy Center Honeywell team extracted a list of available control/status points from each building's control system. The team used two approaches to identify which points were required to support this project. Both Honeywell teams (Energy Center and Golden Valley) conducted a manual review of each list was conducted. The work was coordinated so that the GV team identified points needed for energy analysis, and the EC team helped validate which points would satisfy those requirements. It was not always clear just by looking at point names which points would satisfy particular analytic functional needs, which is why both teams were required to review the lists. The second approach used the semi-automated process of the Context Discovery Service to help classify points. Context Discovery attempts to classify points into their roles. Certain roles are known requirements for energy analysis (e.g., equipment temperature setpoints, equipment valve or damper positions, equipment on/off status), which allowed the team to quickly filter points in the list. See Section 6.6 for further details about the Auto-Context application.

After the points for each building were identified, they were loaded into a MonitoredPointSummary table (part of the MDEI-DW), with additional context—the equipment name and type to which that point belongs. The additional data are used to help build the menu in the UI and to provide the essential linkage between points and entities, particularly for the 3D BIM model view. Figure 85 shows an extract of the MonitoredPointSummary table.

BuildingNumber	EquipmentType	EquipmentName	PointName	PointId	Parameter
2450	RoofTopUnit	RTU1	2450_CTL2RTU1:nvi2450_RTU1OaTemp	2450_CTL2RTU1	nvi2450_RTU1OaTemp
2450	RoofTopUnit	RTU1	2450_CTL2RTU1:nvo2450_RTU1DaTemp	2450_CTL2RTU1	nvo2450_RTU1DaTemp
2450	RoofTopUnit	RTU1	2450_CTL2RTU1:nvo2450_RTU1SaFan.state	2450_CTL2RTU1	nvo2450_RTU1SaFan.state
2450	RoofTopUnit	RTU1	2450_CTL2RTU1:nvo2450_RTU1SaFanSts.state	2450_CTL2RTU1	nvo2450_RTU1SaFanSts.state
2450	RoofTopUnit	RTU2	2450_CTL3RTU2:nvi2450_RTU2SaFan.state	2450_CTL3RTU2	nvi2450_RTU2SaFan.state
2450	RoofTopUnit	RTU2	2450_CTL3RTU2:nvo2450_RTU2DaTemp	2450_CTL3RTU2	nvo2450_RTU2DaTemp
2450	RoofTopUnit	RTU2	2450_CTL3RTU2:nvo2450_RTU2DaTempSp	2450_CTL3RTU2	nvo2450_RTU2DaTempSp
2450	RoofTopUnit	RTU2	2450_CTL3RTU2:nvo2450_RTU2SaFanSts.state	2450_CTL3RTU2	nvo2450_RTU2SaFanSts.state
2450	HotWaterPlant	Blr	2450_CTL4HWB:nvi2450_BlrOaTempEnSp	2450_CTL4HWB	nvi2450_BlrOaTempEnSp
2450	HotWaterPlant	Blr	2450_CTL4HWB:nvo2450_BlrHwp1.state	2450_CTL4HWB	nvo2450_BlrHwp1.state
2450	HotWaterPlant	Blr	2450_CTL4HWB:nvo2450_BlrHwp1Sts.state	2450_CTL4HWB	nvo2450_BlrHwp1Sts.state
2450	HotWaterPlant	Blr	2450_CTL4HWB:nvo2450_BlrLvgHwTemp	2450_CTL4HWB	nvo2450_BlrLvgHwTemp
2450	HotWaterPlant	Blr	2450_CTL4HWB:nvo2450_BlrSysEn.state	2450_CTL4HWB	nvo2450_BlrSysEn.state
2450	HotWaterPlant	Blr	2450_CTL4HWB:nvo2450_OaTemp	2450_CTL4HWB	nvo2450_OaTemp
2450	RoofTopUnit	RTU3	2450_CTL4RTU3:nvo2450_RTU3DaTemp	2450_CTL4RTU3	nvo2450_RTU3DaTemp
2450	RoofTopUnit	RTU3	2450_CTL4RTU3:nvo2450_RTU3SaFan.state	2450_CTL4RTU3	nvo2450_RTU3SaFan.state
2450	RoofTopUnit	RTU3	2450_CTL4RTU3:nvo2450_RTU3SaFanSts.state	2450_CTL4RTU3	nvo2450_RTU3SaFanSts.state
2450	VariableAirVolume	VAV1_1_1	2450_VAV1_1_1VAV:nvoBoxFlow	2450_VAV1_1_1VAV	nvoBoxFlow
2450	VariableAirVolume	VAV1_1_1	2450_VAV1_1_1VAV:nvoDischAirTemp	2450_VAV1_1_1VAV	nvoDischAirTemp
2450	VariableAirVolume	VAV1_1_1	2450_VAV1_1_1VAV:nvoEffectSetPt	2450_VAV1_1_1VAV	nvoEffectSetPt
2450	VariableAirVolume	VAV1_1_1	2450_VAV1_1_1VAV:nvoReheatPos	2450_VAV1_1_1VAV	nvoReheatPos
2450	VariableAirVolume	VAV1_1_1	2450_VAV1_1_1VAV:nvoSpaceTemp	2450_VAV1_1_1VAV	nvoSpaceTemp
2450	VariableAirVolume	VAV1_1_2	2450_VAV1_1_2VAV:nvoBoxFlow	2450_VAV1_1_2VAV	nvoBoxFlow

Figure 85: MonitoredPointSummary Table Extract

Building Point Roles and Coloring

In order to generate "standardized" visualizations with Tableau, each building point was assigned to an appropriate point role. Each point role was assigned a particular color, with some

attention given to notional concepts: for example, ‘hot’ is equivalent to the color red and ‘cold’ is equal to blue. Figure 86 shows excerpts from two database tables in the MDEI-DW that relate points to roles and roles to colors. When Tableau receives a list of points to graph from the web application, it queries these tables to determine what color to use for graphing a particular point. A full listing of point roles and colors are provided in Appendix D, which also gives a general view of what the colors look like for each role.

BuildingId	PointName	PointRoleFriendlyName
2450	2450_CTL2RTU1:nvi2450_RTU1OaTemp	RTUOaTemp
2450	2450_CTL2RTU1:nvo2450_RTU1DaTemp	RTUSaTemp
2450	2450_CTL2RTU1:nvo2450_RTU1DaTempSp	RTUSaTempSp
2450	2450_CTL2RTU1:nvo2450_RTU1SaFan.state	RTUSaFanState
2450	2450_CTL2RTU1:nvo2450_RTU1SaFanSts.state	RTUSaFanState
2450	2450_CTL3RTU2:nvi2450_RTU2SaFan.state	RTUSaFanState
2450	2450_CTL3RTU2:nvo2450_RTU2DaTemp	RTUSaTemp
2450	2450_CTL3RTU2:nvo2450_RTU2DaTempSp	RTUSaTempSp
2450	2450_CTL3RTU2:nvo2450_RTU2SaFanSts.state	RTUSaFanState
2450	2450_CTL4HWB:nvi2450_BlrOaTempEnSp	BlrOaEnTempSp
2450	2450_CTL4HWB:nvo2450_BlrEn.state	BlrEnState
2450	2450_CTL4HWB:nvo2450_BlrHwp1.state	HWPumpStatus
2450	2450_CTL4HWB:nvo2450_BlrHwp1Sts.state	HWPumpStatus
2450	2450_CTL4HWB:nvo2450_BlrLvgHwTemp	BlrHWSTemp
2450	2450_CTL4HWB:nvo2450_BlrSysEn.state	BlrEnState
2450	2450_CTL4HWB:nvo2450_OaTemp	BoilerOaTemp
2450	2450_CTL4RTU3:nvo2450_RTU3DaTemp	RTUSaTemp
2450	2450_CTL4RTU3:nvo2450_RTU3SaFan.state	RTUSaFanState
2450	2450_CTL4RTU3:nvo2450_RTU3SaFanSts.state	RTUSaFanState
2450	2450_RTU3TraneLMOBJ1:nvoEffectSetpt	RTUTempSp

PointPointRole

PointRole	Color
AHUCDTemp	R:31 G:180 B:119
AHUCDTempSp	R:174 G:199 B:232
AHUClgTempSp	R:174 G:199 B:232
AHUClgVlvPos	R:31 G:180 B:119
AHUEaTemp	R:199 G:199 B:199
AHUEaVFDCFM	R:247 G:182 B:210
AHUEaVFDStatus	R:140 G:86 B:75
AHUExFanStatus	R:196 G:156 B:148
AHUHDTemp	R:214 G:39 B:40
AHUHDTempSp	R:255 G:152 B:150
AHUHtgReq	R:255 G: 187 B:120
AHUHtgVlvPos	R:255 G:127 B:14
AHUMaTemp	R:148 G:103 B:189
AHUOaDamperPos	R:44 G:160 B:44
AHUOaFanState	R:140 G:86 B:75
AHUOaFlow	R:196 G:156 B:148
AHUOaHumidity	R:200 G:170 B:200
AHUOaTemp	R:200 G:200 B:200

PointRoleColors

Figure 86: Building Point Roles and Colors

D. Point Role Colors

The following table matches color assignments with the distinct point roles.

Color	ShortFormRole	Unique LongFormRole
R:127 G:127 B:127	AHUState	AirHandlingUnitBinaryState
R:31 G:180 B:119	AHUCDTemp	AirHandlingUnitColdDeckSupplyTemperature
R:174 G:199 B:232	AHUCDTempSp	AirHandlingUnitColdDeckSupplyTemperatureSetPoint
R:174 G:199 B:232	AHUClgTempSp	AirHandlingUnitCoolingTemperatureSetPoint
R:31 G:180 B:119	AHUClgVlvPos	AirHandlingUnitCoolingValvePosition
R:196 G:156 B:148	AHUExFanStatus	AirHandlingUnitExhaustAirFanStatus
R:199 G:199 B:199	AHUEaTemp	AirHandlingUnitExhaustAirTemperature
R:247 G:182 B:210	AHUEaVFDCFM	AirHandlingUnitExhaustAirVariableFrequencyDriveCFM
R:140 G:86 B:75	AHUEaVFDStatus	AirHandlingUnitExhaustAirVariableFrequencyDriveStatus
R:255 G: 187 B:120	AHUHtgReq	AirHandlingUnitHeatingRequired
R:255 G:127 B:14	AHUHtgVlvPos	AirHandlingUnitHeatingValvePosition
R:214 G:39 B:40	AHUHDTemp	AirHandlingUnitHotDeckSupplyTemperature
R:255 G:152 B:150	AHUHDTempSp	AirHandlingUnitHotDeckSupplyTemperatureSetPoint
R:148 G:103 B:189	AHUMaTemp	AirHandlingUnitMixedAirTemperature
R:44 G:160 B:44	AHUOaDamperPos	AirHandlingUnitOutsideAirDamperPosition
R:140 G:86 B:75	AHUOaFanState	AirHandlingUnitOutsideAirFanBinaryState
R:200 G:170 B:200	AHUOaHumidity	AirHandlingUnitOutsideAirRelativeHumidity
R:200 G:200 B:200	AHUOaTemp	AirHandlingUnitOutsideAirTemperature
R:196 G:156 B:148	AHUOaVFDCFM	AirHandlingUnitOutsideAirVariableFrequencyDriveCFM
R:196 G:156 B:148	AHUOaFlow	AirHandlingUnitOutsideAirVolumetricFlowRate
R:247 G:182 B:210	AHUPHCTemp	AirHandlingUnitPreheatCoilTemperature
R:140 G:86 B:75	AHURaDamperPos	AirHandlingUnitReturnAirDamperPosition
R:127 G:127 B:127	AHURaFanState	AirHandlingUnitReturnAirFanBinaryState
R:216 G:156 B:168	AHURaHumidity	AirHandlingUnitReturnAirRelativeHumidity
R:196 G:156 B:148	AHURaTemp	AirHandlingUnitReturnAirTemperature
R:188 G:189 B:34	AHUSpaceDamperPos	AirHandlingUnitServicedSpaceDamperPosition
R:152 G:223 B:138	AHUSpaceTemp	AirHandlingUnitServicedSpaceTemperature
R:219 G:219 B:141	AHUSpaceTempSp	AirHandlingUnitServicedSpaceTemperatureSetPoint
R:127 G:127 B:127	AHUStatus	AirHandlingUnitStatus
R:227 G:119 B:194	AHUSaFanStatus	AirHandlingUnitSupplyAirFanStatus
R:148 G:103 B:189	AHUSaTemp	AirHandlingUnitSupplyAirTemperature
R:197 G:176 B:213	AHUSaTempSP	AirHandlingUnitSupplyAirTemperatureSetPoint
R:227 G:119 B:194	AHUSaVFDStatus	AirHandlingUnitSupplyAirVariableFrequencyDriveStatus
R:152 G:223 B:138	SpaceTemp	AirHandlingUnitTemperature
R:127 G:127 B:127	AHUVFDState	AirHandlingUnitVariableFrequencyDriveBinaryState
R:247 G:182 B:210	AHUVFDSpCntl	AirHandlingUnitVariableFrequencyDriveSpeedControl
R:127 G:127 B:127	BlrEnState	BoilerHotWaterSupplyEnBinaryState
R:214 G:39 B:40	BlrHWSTemp	BoilerHotWaterSupplyTemperature

R:196 G:156 B:148	BlrOaEnTempSp	BoilerOutsideAirEnTemperatureSetPoint
R:31 B:119: G:180	CHWSupTemp	ChilledWaterPlantChilledWaterSupplyTemperature
R:255 G:187 B:120	CHWRetTemp	ChilledWaterReturnTemperature
R:23 G:190 B:207	CHWSPumpStatus	ChilledWaterSupplyPumpStatus
R:196 G:156 B:148	ExFanStatus	ExhaustAirFanStatus
R:255 G:127 B:14	HXVlvPosition	HeatExchangerHeatExchangeValvePosition
R:255 G:127 B:14	HWPlantHeatingVlvPos	HotWaterPlantHeatingValvePosition
R:214 G:39 B:40	HWSupplyTemp	HotWaterPlantHotWaterSupplyTemperature
R:255 G:152 B:150	HWSupplyTempSP	HotWaterPlantHotWaterSupplyTemperatureSetPoint
R:127 G:127 B:127	HWSPumpStatus	HotWaterSupplyPumpBinaryState
R:255 G:187 B:120	HWSReturnTemp	HotWaterReturnTemperature
R:200 G:200 B:200	BoilerOaTemp	HWPBoilerOaTemp
R:255 G:152 B:150	PrimaryHWRLoop	PrimaryHotWaterReturnLoopTemperature
R:255 G:152 B:150	PrimaryHWSLoop	PrimaryHotWaterSupplyLoopTemperature
R:127 G:127 B:127	RTUClg	RoofTopUnitCooling
R:200 G:200 B:200	RTUOaTemp	RoofTopUnitOutsideAirTemperature
R:152 G:223 B:138	RTUSpaceTemp	RoofTopUnitServicedSpaceTemperature
R:127 G:127 B:127	RTUSaFanState	RoofTopUnitSupplyAirFanBinaryState
R:148 G:103 B:189	RTUSaTemp	RoofTopUnitSupplyAirTemperature
R:197 G:176 B:213	RTUSaTempSp	RoofTopUnitSupplyAirTemperatureSetPoint
R:219 G:219 B:141	RTUTempSp	RoofTopUnitZoneSupplyTemperatureSetPoint
R:255 G:152 B:150	SecondaryHWRLoop	SecondaryHotWaterReturnLoopTemperature
R:255 G:152 B:150	SecondaryHWSLoop	SecondaryHotWaterSupplyLoopTemperature
R:152 G:223 B:138	SpaceTemp	ServicedSpaceTemperature
R:148 G:103 B:189	UHSaTemp	UnitHeaterSupplyAirTemperature
R:140 G:86 B:75	VAVDamperPos	VariableAirVolumeDamperPosition
R:140 G:86 B:75	VAVOaDamperPos	VariableAirVolumeOutsideAirDamperPosition
R:127 G:127 B:127	VAVOaFanState	VariableAirVolumeOutsideAirFanBinaryState
R:200 G:200 B:200	VAVOaTemp	VariableAirVolumeOutsideAirTemperature
R:247 G:182 B:210	VAVOaFlow	VariableAirVolumeOutsideAirVolumetricFlowRate
R:152 G:223 B:138	VAVSpaceTemp	VariableAirVolumeServicedSpaceTemperature
R:140 G:86 B:75	VAVSaDamperPos	VariableAirVolumeSupplyAirDamperPosition
R:127 G:127 B:127	VAVSaFanState	VariableAirVolumeSupplyAirFanBinaryState
R:216 G:156 B:168	VAVSaHumidity	VariableAirVolumeSupplyAirRelativeHumidity
R:148 G:103 B:189	VAVSaTemp	VariableAirVolumeSupplyAirTemperature
R:247 G:182 B:210	VAVSaFlow	VariableAirVolumeSupplyAirVolumetricFlowRate
R:255 G:127 B:14	VAVReheatPos	VariableAirVolumeZoneReheatPosition
R:255 G:127 B:14	VAVReheatVlvPos	VariableAirVolumeZoneReheatValvePosition
R:219 G:219 B:141	VAVTempSp	VariableAirVolumeZoneSupplyTemperatureSetPoint
R:247 G:182 B:210	VAVFlow	VariableAirVolumeZoneSupplyVolumetricFlowRate
R:247 G:182 B:210	Flow	VolumetricFlowRate

E. Data Collection

The following table summarizes the data types and sizes of products related to BIM data.

Building	CAD		BIM Builder			
	Files	**Sizes**	**Project File (.teproj)**	**COBie (.xlsx)**	**IFC (.ifc)**	**JSON**
2450	2450_M-1 HVAC plan.dwg	987 KB	3.7 MB	340 KB	6.7 MB	10.7 MB
	2450_M-2 HVAC plan.dwg	524 KB				
	2450_M-3 HVAC plan.dwg	801 KB				
9810	9810 M1-M2 HVAC NEW WORK.dwg	1.5 MB	2.0 MB	335 KB	4.4 MB	6.6 MB
	9810 M3 ENLARGED PLAN.dwg	427 KB				
	9810 MD1-HVAC DEMO.dwg	1.6 MB				
10400	JCPM101.dwg	341 KB	1.2 MB	330 KB	3.2 MB	4.9 MB
	JCPM401.dwg	201 KB				
	JCPM501.dwg	96 KB				
	JCPM601.dwg	107 KB				
11000	Architectural: PN_70617FJ11K_A-*.dwg * = 100, 101A, 101B, 101C, 104, 110A, 110B, 110C, 201, 301, 302, 401, 402, 403, 501, 502, 503, 504, 601, D101A, D101B, D201, D202. PN_70617FJ11K_G-001, -002, -003.dwg	16.0 MB total	Offices: 37.4 MB	370 KB	17 MB	28.2 MB
	Mechanical: PN_70617FJ11K_M-*.dwg * = 001, 101, 102, 103, 104, 301, 501, 502, 503, 504, 601, 602, 603, 604, 605, 606, 607, 608, 609, 701, 702, D101, D201	39.2 MB	Barracks: 37.5 MB	375 KB	21.1 MB	34.4 MB
	Structural: PN_70617FJ11K_S-*.dwg * = 001, 002, 101C, 104A, 104B, 114, 201, 202, 203, D101C, D301A. PN_70617FJ11K_BS.dwg	8.4 MB				

	Interiors: PN_70617FJ11K_I-*.dwg * = 001, 002, 003, 101, 101A, 101B, 101C, 101D, 201, 201A, 201B, 201C, 301, 301A, 301B, 301C, 401, 402, 403, 500, 501.	67.1 MB				
12000	Architectural: PN_70617FJ11K_A-*.dwg * = 100, 101A, 101B, 101C, 104, 110A, 110B, 110C, 201, 301, 302, 401, 402, 403, 501, 502, 503, 504, 601, D101A, D101B, D201, D202. PN_70617FJ11K_G-001, -002, -003.dwg	16.0 MB total	Offices: 47.1 MB	385 KB	13.9 MB	21.5 MB
	Mechanical: PN_70617FJ12K_M-*.dwg 001, 101A - 101H, 102A - 102F, 103A - 103F, 104, 401, 402.	77.2 MB	Barracks: 47.3 MB	387 KB	17.3 MB	28.5 MB
	Civil: PN_70617FJRT_C-406, _CG404.dwg	47.6 MB				
	Electrical: PN_70617FJ11K_ED101.1, .2.dwg	2.9 MB				
	Interiors: PN_70617FJ11K_I-*.dwg * = 001, 002, 003, 101, 101A, 101B, 101C, 101D, 201, 201A, 201B, 201C, 301.	45.7 MB				

F. ERDC-CERL Report on BIM Content and Data Transferability

In the construction industry many programs, systems, and technology tools have been developed to assist contributors in each phase of the project. Very often, these programs and systems do not communicate or exchange information with each other, which can result in redundant information, and in some cases, loss of information between the phases. This problem creates an opportunity to develop tools to achieve interoperability[2] among the systems and tools for the industry. Several approaches can achieve interoperability. One approach is to create a link between two specific systems. Another approach is to develop open standards through collaboration of a group of representing all interests within a specific industry. Open standards are not proprietary and are available for public use.

The construction industry and the vendors and developers of building information modeling (BIM) tools have adopted and used open standards in their efforts to achieve interoperability—specifically, the Industry Foundation Classes (IFC). Given BIM Builder's capability to generate a BIM for existing buildings, it is in their best interest to explore the possibility exchanging information with other external systems used in construction. This appendix discusses this possibility in the context of using open standards, especially IFC and COBie.

Industry Foundation Classes (IFC)

IFC is a neutral data model specification to describe and exchange information, adopted internationally for Open BIM. This data schema, typically used within the building and facility management industry is registered with the International Standardization Organization (ISO) as ISO16739 (ISO 2013). Many commercial software applications commonly used in the project life cycle have adopted IFC and are now able exchange information using IFC format. Depending on the applicability of the tool, a software product can consume and/or produce data formatted in IFC[3].

Construction Operation Building Information Exchange

COBie is an IFC-based specification to capture and exchange information related to building assets throughout the project life cycle. It became part of the National BIM Standard for United States (NBIM-US) in its second version in 2012. This information exchange tool is mandated in the UK and can be viewed and used in three different formats: IFC STEP, ifcxml, and SpreadsheetML. SpreadsheetML provides the ability to view and modify data using Microsoft Excel. A free toolkit is available[4] to convert files from and to the supported formats. COBie seeks to eliminate redundant entry of information throughout the project life cycle by transferring information needed by facility managers from the design to construction to commissioning phases of the project. Since 2008, different commercial software applications for design construction and facility management have demonstrated their ability to use and/or produce data in COBie format[5].

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[2] Interoperability by definition is the capability of two systems or programs to exchange information and/or communicate with each other.

[3] http://www.buildingsmart-tech.org/implementation/implementations

[4] http://projects.buildingsmartalliance.org/files/?artifact_id=5466

[5] http://www.nibs.org/?page=bsa_cobiemm

BIM Builder to BUILDER SMS

DOD has recently mandated the use of BUILDER SMS, a web-based tool designed by the Construction Engineering Research Laboratory to assist facility managers and technicians in deciding how to best maintain their building assets on military installations. Given a BUILDER SMS business case, it is in Honeywell's interest to explore the possibility of transferring data from BIM Builder to BUILDER SMS. To achieve this exchange of information, BIM Builder must be able to export the building information created and stored in the system in a format that BUILDER SMS can use. Currently, BUILDER SMS cannot use information in any external format; however, an exploratory phase has been started to investigate the possibility of achieving interoperability with external systems using the COBie format.

The preliminary effort to explore information exchange with BUILDER SMS using COBie compared two main aspects, the type of information supported by each tool and the data fields where the information will be stored. First, the data fields of both tools were evaluated to determine the overlapping on data fields. Then, the building elements were evaluated to determine information gaps among the data stored in COBie versus the data required by BUILDER SMS. Building elements were evaluated using the ASTM Uniformat II classification system. A comparison with the information typically included in USACE design BIMs was also included in this preliminary stage. A summary of the findings are detailed on Table 34 and Table 35, below. Assuming that such information exchange proves achievable and BUILDER SMS is able to use data in COBie format, then BIM Builder need the capability to export a COBie file with the information to be transfer to BUILDER SMS. An alternate possibility to producing a COBie file is to export the information into an IFC file and utilize the free, publicly available transform tool to produce a COBie file from an IFC file.

Assuming BIM Builder can achieve an export capability, it will not only open the possibility of exchanging information with BUILDER SMS but also with other systems used by building managers to maintain and operate the facilities. Another potential use could be utilizing such exported information as the based to develop a BIM using available design software for building re-purposing or reconstruction. In terms of design, most major design software vendors are currently able to use IFC data. A number of current tools and software for facility managers can use data formatted in COBie.

To clarify, BIM Builder is a tool developed by Honeywell that has no relationship to BUILDER, SMS, which is a tool developed by the DoD. They are not related in any way.

Table 34: COBie/BUILDER Data Fields Comparison

Alingment Matrix			
COBie2.4	**IFC**	**BUILDER SMS**	
Facility.Name	IfcBuilding.Name	**Facility Number**	**Building**
Facility.Project Name	*IfcProject.Name*	**Facility Name**	
Attribute towards Facility or Facility.Reference	*IfcProperty with Name = "Real Property Unique ID"*	**Real Property Unique ID**	
System.Name?/COBie.TypeName	*IfcRoot.Name (the abstract base type that has "Name")*	**Name (Opt.)**	**Section**
System.Category?	*IfcClassificationReference.Name*	**Classification Type**	
Facility.CreatedOn Type.CreatedOn	*IfcPropertySet Pset_BuildingCommon.YearOfConstruction for whole building...depends for others*	**Year Constructed**	
A matter of filter for EA	*n/a*	**Quantity**	
Only for EA	*n/a*	**Quantity Unit of Measure**	
Type.Finish	*IfcTypeObject IfcPropertySet with Name "COBie_Specification," IfcProperty with name "Finish"*	**Painted (Opt.)**	
COBie.Attribute.Name	*IfcProperty with Name ="Paint Type"*	**Paint Type (Opt.)**	
COBie.Attribute.Name	*IfcProperty with Name ="Paint Year"*	**Paint Year (Opt.)**	
Component.Name	*IfcRoot.GlobalID*	**ID Number**	**Section Details (Opt.)**
Type.Description	*IfcTypeObject.Name*	**Type**	
Type.Manufacturer	*IfcProperty with Name = "Manufacturer" in IfcPropertySet with Name "Pset_ManufacturerTypeInformation"*	**Manufacturer**	
Attribute towards Type Attribute.Name=Make/Attribute.Value/Attribute.Unit	*IfcProperty with name ="Make"*	**Make**	
Type.ModelNumber	*IfcProperty with Name "ModelLabel" in IfcPropertySet with Name "Pset_ManufacturerTypeInformation"*	**Model**	
Component.SerialNumber	*IfcPropertySet Pset_ManufacturerOccurence.SerialNumber*	**Serial No.**	
Attribute.Name=Capacity/Attribute.Value/Attribute.Unit		**Capacity**	
Type.WarrantyGuarantorParts	*IfcPropertySet Pset_Warranty.PointOfContact*	**Warranty Co.**	
Compoanet.WarrantyStartDate	*IfcPropertySet Pset_Warranty.WarrantyStartDate*	**Warranty Date**	
Type.WarrantyGuarantorLabor	*IfcPropertySet Pset_Warranty.PointOfContact*	**Warranty Co. 2**	
Compoanet.WarrantyStartDate	*IfcPropertySet Pset_Warranty.WarrantyStartDate*	**Warranty Date 2**	
Component.Space	*IfcSpace.Name*	**Location**	
Attribute.Name=DateManufactured/Attribute.Value/Attribute.Unit	*IfcPropertySet Pset_ManufacturerTypeInformation.ProductionYear*	**Date Manufactured**	
Component.Type	*IfcProperty with name "Control Type/Make"*	**Control Type/Make**	
Component.InstalltionDate	IfcPropertySet with Name "COBie_Component," IfcProperty with name "InstallationDate"	**Year Installed**	

Table 35: Building Elements Available on COBie, Builder, and Revit

System capability to store information related to different building elements.			
Building Element	**COBie**	**Builder**	**Revit**
A10 - Foundations		X	X
A1010 - Standard Foundations		X	X
A1030 - Slab on Grade		X	X
A20 - Basement Construction			
B10 - Superstructure		X	X
B1010 - Floor Construction		X	X
B1020 - Roof Construction		X	X
B20 - Exterior Enclosure		X	X
B2010 - Exterior Walls		X	X
B2020 - Exterior Windows	X	X	X
B2030 - Exterior Doors	X	X	X
B30 - Roofing		X	X
B3010 - Roof Coverigs		X	X
C10 - Interior Construction		X	X
C1010 - Partitions		X	X
C1020 - Interiors Doors	X	X	X
C1030 - Specialties		X	X
C20 - Stairs		X	X
C2010 - Stair Construction		X	X
C30 - Interior Finishes	X	X	X
C3010 - Wall Finishes	X	X	X
C3020 - Floor Finishes	X	X	X
C3030 - Ceiling Finishes	X	X	X
D10 - Conveying Systems	X	X	X
D1010 - Elevators	X	X	X
D20 - Plumbing	X	X	X
D2010 - Plumbing Fixtures	X	X	X
D2020 - Domestic Water Distribution	X	X	X
D2030 -Sanitary Waste	X	X	X
D30 - HVAC	X	X	X
D3020 - Heat Generating System	X	X	X
D3030 - Cooling Generating Systems	X	X	X
D3040 - Disribution System	X	X	X
D3050 - Terminal & Package Units	X	X	X
D40 - Fire Protection	X	X	X
D4010 - Fire Alarm and Detection System	X	X	X
D4020 - Fire Supp Water Supply/Equipment	X	X	X
D4030 - Stand-Pipe System	X	X	X
D4040 - Sprinklers	X	X	X
D50 - Electrical	X	X	X
D5010 - Electrical Service & Distribution	X	X	X
D5020 - Lighting & Branch Wiring	X	X	X
D5090 - Other Electrical Services	X	X	X
E10 - Equipment	X		X
E20 - Furnishings	X		X

Test Files

The project used five military buildings to create and test the BIM Builder tool. AutoCAD drawings, in dwg format, were provided for a two training barracks, a reserve center, and two other military buildings. The same drawings were used to generate COBie files that reflected the design stage for each of the buildings. The COBie files, created by ERDC-CERL and provided to Honeywell, contained information related to HVAC equipment, including VAV boxes, air handling units, fans, valves, air conditioning units, boilers and chillers among other. Screenshots of the initial COBie file created for the trainee barracks, building 12000, are shown in Figure 87, Figure 88, and Figure 89.

Name	CreatedBy	CreatedOn	Category	FloorName	Description	ExtSystem	ExtObject	ExtIdentifier	RoomTag	UsableHeight	GrossArea	
A118B	mariangel	2013-09-19T1	13-75 11 11: Storage Room	Floor 1	STORAGE	n/a	n/a	n/a	n/a	n/a	n/a	n/a
A119	mariangel	2013-09-19T1	13-81 21 17: Mechanical Room	Floor 1	MECH. ROOM	n/a	n/a	n/a	n/a	n/a	n/a	n/a
A120	mariangel	2013-09-19T1	13-41 11 14 34: Laundry Room	Floor 1	LAUNDRY	n/a	n/a	n/a	n/a	n/a	n/a	n/a
A121	mariangel	2013-09-19T1	13-85 21 11: Stairway	Floor 1	STAIR VESTIBULE	n/a	n/a	n/a	n/a	n/a	n/a	n/a
B101	mariangel	2013-09-19T1	13-41 11 14 11: Bathroom	Floor 1	MEN BATHROOM	n/a	n/a	n/a	n/a	n/a	n/a	n/a
B102	mariangel	2013-09-19T1	13-41 11 14 11: Bathroom	Floor 1	WOMEN BATHROOM	n/a	n/a	n/a	n/a	n/a	n/a	n/a
B103	mariangel	2013-09-19T1	13-11 11 31: Reception Space	Floor 1	RECEPTION	n/a	n/a	n/a	n/a	n/a	n/a	n/a
B104	mariangel	2013-09-19T1	13-15 11 34: Administrative Spaces	Floor 1	CQ	n/a	n/a	n/a	n/a	n/a	n/a	n/a
B105	mariangel	2013-09-19T1	13-15 11 34 11: Office	Floor 1	BATTERY COMMANDER	n/a	n/a	n/a	n/a	n/a	n/a	n/a
B106	mariangel	2013-09-19T1	13-75 11 11: Storage Room	Floor 1	STORAGE	n/a	n/a	n/a	n/a	n/a	n/a	n/a
B107	mariangel	2013-09-19T1	13-85 11 11: Corridor	Floor 1	CORRIDOR	n/a	n/a	n/a	n/a	n/a	n/a	n/a
B107A	mariangel	2013-09-19T1	13-75 11 11: Storage Room	Floor 1	STORAGE	n/a	n/a	n/a	n/a	n/a	n/a	n/a
B108	mariangel	2013-09-19T1	13-15 11 34 11: Office	Floor 1	OFFICE	n/a	n/a	n/a	n/a	n/a	n/a	n/a
B109	mariangel	2013-09-19T1	13-85 21 11: Stairway	Floor 1	STAIR	n/a	n/a	n/a	n/a	n/a	n/a	n/a
B109A	mariangel	2013-09-19T1	13-81 21 21: Electrical Room	Floor 1	ELEC. ROOM	n/a	n/a	n/a	n/a	n/a	n/a	n/a
B110	mariangel	2013-09-19T1	13-11 21 11: Meeting Room	Floor 1	ARMS ROOM	n/a	n/a	n/a	n/a	n/a	n/a	n/a
B111	mariangel	2013-09-19T1	13-11 21 11: Meeting Room	Floor 1	ISSUE ROOM	n/a	n/a	n/a	n/a	n/a	n/a	n/a
B112	mariangel	2013-09-19T1	13-75 11 27: Supply Room	Floor 1	SUPPLY ROOM	n/a	n/a	n/a	n/a	n/a	n/a	n/a
B113	mariangel	2013-09-19T1	13-31 31 21: Training Space	Floor 1	COVERED TRAINING	n/a	n/a	n/a	n/a	n/a	n/a	n/a
B113A	mariangel	2013-09-19T1	13-75 11 11: Storage Room	Floor 1	STORAGE	n/a	n/a	n/a	n/a	n/a	n/a	n/a
B113B	mariangel	2013-09-19T1	13-75 11 11: Storage Room	Floor 1	STORAGE	n/a	n/a	n/a	n/a	n/a	n/a	n/a
B114	mariangel	2013-09-19T1	13-85 21 11: Stairway	Floor 1	STAIR VESTIBULE	n/a	n/a	n/a	n/a	n/a	n/a	n/a
B115	mariangel	2013-09-19T1	13-41 11 14 34: Laundry Room	Floor 1	LAUNDRY	n/a	n/a	n/a	n/a	n/a	n/a	n/a
B116	mariangel	2013-09-19T1	13-81 21 17: Mechanical Room	Floor 1	MECH. ROOM	n/a	n/a	n/a	n/a	n/a	n/a	n/a
B117	mariangel	2013-09-19T1	13-31 31 21: Training Space	Floor 1	COVERED TRAINING	n/a	n/a	n/a	n/a	n/a	n/a	n/a
B117A	mariangel	2013-09-19T1	13-75 11 11: Storage Room	Floor 1	STORAGE	n/a	n/a	n/a	n/a	n/a	n/a	n/a
B117B	mariangel	2013-09-19T1	13-75 11 11: Storage Room	Floor 1	STORAGE	n/a	n/a	n/a	n/a	n/a	n/a	n/a
B118	mariangel	2013-09-19T1	13-81 21 17: Mechanical Room	Floor 1	MECH. ROOM	n/a	n/a	n/a	n/a	n/a	n/a	n/a
B119	mariangel	2013-09-19T1	13-41 11 14 34: Laundry Room	Floor 1	LAUNDRY	n/a	n/a	n/a	n/a	n/a	n/a	n/a

Instruction | Contact | Facility | Floor | Space | Zone | Type | Component | System | Assembly | Connection | Spare | Resource | Job | Impact | Document | Attribute

Figure 87: COBie.Space Worksheet - Building 12000

Name	CreatedBy	CreatedOn	Category	Description	AssetType
Exhaust Fan	mariangel	2013-09-2	23-75 35 17 11: Fans for Air Ductwork	Exhaust Fan	Fixed
Heater-Cabinet Unit	mariangel	2013-09-2	23-75 70 17 34: Unit Heaters	Cabinet Unit Heater (CUH)	Fixed
Heater-Unit	mariangel	2013-09-2	23-75 70 17 34: Unit Heaters	Unit Heater (UH)	Fixed
Variable Air Volume	mariangel	2013-09-2	23-75 70 21 24 14: Variable Volume Air Terminal Units	Variable Air Volume Unit (VAV)	Fixed
Variable Air Volume-Type02	mariangel	2013-09-2	23-75 70 21 24 14: Variable Volume Air Terminal Units	Outside Air Shut Off Variable Air Volume Unit (VAV	Fixed
Air Handling Unit	mariangel	2013-09-2	23-75 35 14: Air Handling Units	Air Handling Unit (AHU)	Fixed
Outdoor Air Unit	mariangel	2013-09-2	23-75 10 24 21 27 14: Packaged Rooftop Air Conditioning Unit	Dedicated Outdoor Air Unit (OAU)	Fixed
Return Air Device-Roof Top	mariangel	2013-09-2	23-75 70 21 31: Exhaust Terminals	Roof Top Return Air Device (RA)	Fixed

Figure 88: COBie.Type Worksheet - Building 12000

Name	CreatedBy	CreatedOn	TypeName	Space	Description	ExtSystem
EF-58	mariangelica.c	2013-09-23	Exhaust Fan	A117	Exhaust Fan	n/a
EF-59	mariangelica.c	2013-09-23	Exhaust Fan	A119	Exhaust Fan	n/a
EF-51	mariangelica.c	2013-09-23	Exhaust Fan	A105	Exhaust Fan	n/a
CUH-16	mariangelica.c	2013-09-23	Heater-Cabinet Unit	A115	Cabinet Unit Heater (CUH)	n/a
CUH-15	mariangelica.c	2013-09-23	Heater-Cabinet Unit	A121	Cabinet Unit Heater (CUH)	n/a
UH-2	mariangelica.c	2013-09-23	Heater-Unit	A119	Unit Heater (UH)	n/a
CUH-1	mariangelica.c	2013-09-23	Heater-Cabinet Unit	A104	Cabinet Unit Heater (CUH)	n/a
VAV-A101	mariangelica.c	2013-09-23	Variable Air Volume	A101	Variable Air Volume Unit (VAV)	n/a
UH-1	mariangelica.c	2013-09-23	Heater-Unit	A117	Unit Heater (UH)	n/a
VAV-B112	mariangelica.c	2013-09-23	Variable Air Volume	B112	Variable Air Volume Unit (VAV)	n/a
CUH-3	mariangelica.c	2013-09-23	Heater-Cabinet Unit	B109	Cabinet Unit Heater (CUH)	n/a
EF-72	mariangelica.c	2013-09-23	Exhaust Fan	B109	Exhaust Fan	n/a
VAV-B105	mariangelica.c	2013-09-23	Variable Air Volume	B105	Variable Air Volume Unit (VAV)	n/a
VAV-B104	mariangelica.c	2013-09-23	Variable Air Volume	B104	Variable Air Volume Unit (VAV)	n/a
CUH-2	mariangelica.c	2013-09-23	Heater-Cabinet Unit	A113	Cabinet Unit Heater (CUH)	n/a
CUH-17	mariangelica.c	2013-09-23	Heater-Cabinet Unit	B120	Cabinet Unit Heater (CUH)	n/a
UH-19	mariangelica.c	2013-09-23	Heater-Unit	B118	Unit Heater (UH)	n/a
EF-60	mariangelica.c	2013-09-23	Exhaust Fan	B116	Exhaust Fan	n/a
EF-61	mariangelica.c	2013-09-23	Exhaust Fan	B118	Exhaust Fan	n/a
UH-18	mariangelica.c	2013-09-23	Heater-Unit	B116	Unit Heater (UH)	n/a
CUH-18	mariangelica.c	2013-09-23	Heater-Cabinet Unit	B114	Cabinet Unit Heater (CUH)	n/a
EF-63	mariangelica.c	2013-09-23	Exhaust Fan	C122	Exhaust Fan	n/a
UH-21	mariangelica.c	2013-09-23	Heater-Unit	C122	Unit Heater (UH)	n/a
CUH-19	mariangelica.c	2013-09-23	Heater-Cabinet Unit	C124	Cabinet Unit Heater (CUH)	n/a
EF-62	mariangelica.c	2013-09-23	Exhaust Fan	C120	Exhaust Fan	n/a
UH-20	mariangelica.c	2013-09-23	Heater-Unit	C120	Unit Heater (UH)	n/a
CUH-20	mariangelica.c	2013-09-23	Heater-Cabinet Unit	C118	Cabinet Unit Heater (CUH)	n/a
CUH-4	mariangelica.c	2013-09-23	Heater-Cabinet Unit	C101A	Cabinet Unit Heater (CUH)	n/a
CUH-5	mariangelica.c	2013-09-23	Heater-Cabinet Unit	C105	Cabinet Unit Heater (CUH)	n/a

Instruction | Contact | Facility | Floor | Space | Zone | Type | **Component** | System | Assembly | Connection | Spare | Resource | Job | Impact | Doc

Figure 89: COBie.Component Worksheet - Building 12000

BIM Builder Export Deliverables

Data created and stored using BIM Builder was delivered in two different formats: a Microsoft Excel and IFC. Both files were evaluated following the alternatives for export and possible information exchange with BUILDER SMS described earlier on this section. The Microsoft

Excel file contained the worksheets similar to those in a COBie file along with two additional sheets (Equipment and MEP Supply Relationship). In this file, the Floor, Space, Equipment and MEP Supply Relationship worksheet were populated. The Floor sheet contained floor name and floor height; the Space sheet contained space name, floor name, usable height, gross area, and net area. These two sheets were formatted similarly to COBie.Floor and COBie.Space sheets. The other two worksheets, Equipment and MEP Supply Relationship, contained the main information related to the equipment in the building and its connection relationships within the MEP system. The equipment sheet listed the equipment name, floor where equipment is located, served space, and associated RTU or AHU. The MEP Supply Relationship sheet listed the relationship between the AHU's, VAV's, TU-H's, supply duct, diffusers, etc., according to existing equipment in the specific building. Screenshots of the output Excel file from BIM Builder for Building 12000 are shown Figure 90, Figure 91, and Figure 92.

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	Name	CreatedBy	CreatedOn	Category	FloorName	Description	ExtSystem	ExtObject	ExtIdentifier	RoomTag	UsableHeight	GrossArea	NetArea
2	GROOMING F302				1	utodesk Revit Archit	IfcSpace				144	343174.63	343174.63
3	ASSIGNED SPACE #8 F307				1	utodesk Revit Archit	IfcSpace				144	100688.56	100688.56
4	ASSIGNED SPACE #7 F306				1	utodesk Revit Archit	IfcSpace				144	98755.21	98755.21
5	ASSIGNED SPACE #6 F305				1	utodesk Revit Archit	IfcSpace				144	98498.00	98498.00
6	ASSIGNED SPACE #5 F304				1	utodesk Revit Archit	IfcSpace				144	101048.91	101048.91
7	Space1991				1	utodesk Revit Archit	IfcSpace				144	8069.44	8069.44
8	Space1992				1	utodesk Revit Archit	IfcSpace				144	10177.62	10177.62
9	Space1993				1	utodesk Revit Archit	IfcSpace				144	3389.74	3389.74
10	Space1994				1	utodesk Revit Archit	IfcSpace				144	10164.24	10164.24
11	Space1995				1	utodesk Revit Archit	IfcSpace				144	7859.67	7859.67
12	Space1996				1	utodesk Revit Archit	IfcSpace				144	9741.66	9741.66
13	Space1997				1	utodesk Revit Archit	IfcSpace				144	10150.30	10150.30
14	Space1998				1	utodesk Revit Archit	IfcSpace				144	5587.42	5587.42
15	LOCKERS/ SHOWERS F303				1	utodesk Revit Archit	IfcSpace				144	25788.55	25788.55
16	LOCKERS/ SHOWERS F311				1	utodesk Revit Archit	IfcSpace				144	25878.09	25878.09
17	MECH RM 2 B316				1	utodesk Revit Archit	IfcSpace				144	51105.23	51105.23
18	VEST. B319				1	utodesk Revit Archit	IfcSpace				144	6655.46	6655.46
19	PLATOON SLEEPING BAY B306				1	utodesk Revit Archit	IfcSpace				144	705161.85	705161.85
20	Space2004				1	utodesk Revit Archit	IfcSpace				144	4327.27	4327.27
21	STAIR B303				1	utodesk Revit Archit	IfcSpace				144	50631.55	50631.55
22	PLATOON SLEEPING BAY A315				1	utodesk Revit Archit	IfcSpace				144	726506.45	726506.45
23	VEST. A319				1	utodesk Revit Archit	IfcSpace				144	5877.56	5877.56
24	MECH RM 4 A316				1	utodesk Revit Archit	IfcSpace				144	47746.57	47746.57
25	STAIR A303				1	utodesk Revit Archit	IfcSpace				144	57384.79	57384.79
26	PLATOON SLEEPING BAY A306				1	utodesk Revit Archit	IfcSpace				144	715846.23	715846.23
27	PLATOON SLEEPING BAY D315				1	utodesk Revit Archit	IfcSpace				144	726061.68	726061.68
28	VEST. D318				1	utodesk Revit Archit	IfcSpace				144	7174.19	7174.19
29	MECH RM 4 D316				1	utodesk Revit Archit	IfcSpace				144	48950.24	48950.24
30	PLATOON SLEEPING BAY D306				1	utodesk Revit Archit	IfcSpace				144	726759.71	726759.71
31	STAIR D303				1	utodesk Revit Archit	IfcSpace				144	55113.21	55113.21
32	MECH RM 5 E316				1	utodesk Revit Archit	IfcSpace				144	51042.56	51042.56
33	PLATOON SLEEPING BAY E306				1	utodesk Revit Archit	IfcSpace				144	705830.20	705830.20
34	VEST. E319				1	utodesk Revit Archit	IfcSpace				144	6358.86	6358.86
35	Space2020				1	utodesk Revit Archit	IfcSpace				144	4289.39	4289.39
36	PLATOON SLEEPING BAY E315				1	utodesk Revit Archit	IfcSpace				144	717413.94	717413.94
37	STAIR E303				1	utodesk Revit Archit	IfcSpace				144	52820.12	52820.12
38	PLATOON SLEEPING BAY C315				1	utodesk Revit Archit	IfcSpace				144	712611.99	712611.99
39	MECH RM 1 C316				1	utodesk Revit Archit	IfcSpace				144	50020.53	50020.53
40	VEST. C319				1	utodesk Revit Archit	IfcSpace				144	7005.32	7005.32
41	PLATOON SLEEPING BAY C306				1	utodesk Revit Archit	IfcSpace				144	730774.77	730774.77

Instruction | Contact | Facility | Floor | **Space** | Equipment | MEP Supply Relationship | Zone | Type | Component | System | Assembly | Co

Ready

Figure 90: BIM Builder Space - Building 12000

I34

	A	B	C	D	E	F
10	CabinetUnitHeater15					
11	CabinetUnitHeater14					
12	CabinetUnitHeater13					
13	CabinetUnitHeater12					
14	CabinetUnitHeater11					
15	CabinetUnitHeater10					
16	CabinetUnitHeater9					
17	CabinetUnitHeater8					
18	CabinetUnitHeater7					
19	CabinetUnitHeater6					
20	CabinetUnitHeater5					
21	CabinetUnitHeater4					
22	CabinetUnitHeater3					
23	CabinetUnitHeater2					
24	CabinetUnitHeater1					
25	BlowerCoilUnit10	Diffuser90				
26		Diffuser89				
27		Diffuser88				
28		Diffuser87				
29		Diffuser86				
30		Diffuser85				
31	BlowerCoilUnit9	Diffuser84				
32		Diffuser83				
33		Diffuser82				
34		Diffuser81				
35		Diffuser80				
36		Diffuser79				
37	BlowerCoilUnit8	Diffuser77				
38		Diffuser76				
39		Diffuser75				
40		Diffuser74				
41		Diffuser73				
42		Diffuser72				
43	BlowerCoilUnit7	Diffuser71				
44		Diffuser70				
45		Diffuser69				
46		Diffuser68				
47		Diffuser67				

Instruction | Contact | Facility | Floor | Space | Equipment | MEP Supply Re

Figure 91: BIM Builder MEP Supply Relationship - Building 12000

	A	B	C	D	E
1	Name	Floor Name	Served Space	Associated AHU	Description
2	VAV-C316	1	n/a	AHU11	
3	VAV-C315	1	PLATOON SLEEPING BAY C315 Space2063 DRILL SGTS C301 LATRINE C312	AHU11	
4	VAV-C306	1	PLATOON SLEEPING BAY C306 LATRINE C304 DRILL SGTS C305 SHOWER C310	AHU11	
5	VAV-E316	1	n/a	AHU15	
6	VAV-E306	1	PLATOON SLEEPING BAY E306 LATRINE E309 LATRINE E304 DRILL SGTS E305	AHU15	
	VAV-E315	1	PLATOON SLEEPING BAY E315 DRILL SGTS E301 LATRINE	AHU15	

Instruction Contact Facility

Figure 92: BIM Builder Equipment - Building 12000

The data as provided in an Excel file is not equivalent to a COBie file, as it does not follow the format and relationship established by the COBie standard. For example, the two sheets that contain most of the information are not COBie sheets. No equipment types are listed, the relation

of equipment to spaces is one-to-many as opposed to one-to-one as in COBie, with the exception of architectural elements such as doors. Also, not all equipment is listed within one sheet; it is split between Equipment and MEP Supply Relationship. We suggest reorganizing the provided data to make it closer to a COBie export as follows:

- Eliminate Equipment and MEP Supply Relationship worksheets
- List all equipment on the Component tab
- Create a type on COBie.Type for all components of the same type
- Use the Assembly tab to achieve a relationship between components similar to the list on the current MEP Supply Relationship sheet
- Information such as "Served Space" and "Associated AHU" can be input as attributes to the components or can be add as columns to the right on COBie.Component

Assuming that BUILDER SMS reaches the point in which the system is able to consume information in COBie format, the system will still not be able to use the data exported from BIM Builder in its Excel format. The exported data will be useful for BUILDER SMS only if a proprietary link is developed to support the information exchanges between both systems.

The second deliverable was data exported in IFC format. In order to evaluate it, the provided IFC file was converted to a COBie file using the free, publicly available transform tool to produce a COBie file from an IFC file. The transformed COBie file contained information in the following worksheets: Contact, Facility, Floor, Space, Component, and Connection. A comparison between the populated sheets is shown in Table 36.

Table 36: Data Comparison of Excel-formatted Deliverables

Submitted COBie File	Contain Data?	Submitted IFC File converted to COBie	Contain Data?
Instruction	X	Instruction	X
Contact	-	Contact	X
Facility	-	Facility	X
Floor	X	Floor	X
Space	X	Space	X
Zone	-	Zone	-
Type	-	Type	-
Component	-	Component	X
System	-	System	-
Assembly	-	Assembly	-
Connection	-	Connection	X
Spare	-	Spare	-
Resource	-	Resource	-
Job	-	Job	-
Impact	-	Impact	-
Document	-	Document	-
Attribute	-	Attribute	-
Additional Worksheets not found in COBie			
Equipment	X		
MEP Supply Relationship	X		

The space information in the transformed file was formatted in a similar way to the data exported from BIM Builder directly to Excel; however, the transformed file does not provide the floor with which the space is associated, the space usable height, gross area, or net area. As expected, all equipment was listed on the component worksheet. No type data was available and there were no spaces associated with the individual pieces of equipment in the transformed file. A screen shot of the component sheet on the transformed file for building 12000 is shown in Figure 93. BUILDER SMS groups equipment into sections that can be defined by type, floor, and systems, among others. Assuming BUILDER SMS is developed to be able to use an IFC file, it could use the data from BIM Builder in its IFC format. Based on the data viewed as a COBie file, BUILDER SMS could only be able to create sections by grouping equipment based on its overall type (i.e., VAV, AHU, door, diffuser, etc.).

	A	B	C	D	E	F	G	H	I	J	K
1	Name	CreatedBy	CreatedOn	TypeName	Space	Description	ExtSystem	ExtObject	ExtIdentifier	SerialNumber	InstallationDate
385	VAV-F207	E000000	2013-12-16T07:53:49	n/a	n/a	VAV-F207	IFCToolSet	IfcFlowController	1P_M3TTj1F1wX9j0n9VKKW	n/a	n/a
386	VAV-F208	E000000	2013-12-16T07:53:49	n/a	n/a	VAV-F208	IFCToolSet	IfcFlowController	39CY1vkvb6XPNXWba_j1yw	n/a	n/a
387	VAV-F203	E000000	2013-12-16T07:53:49	n/a	n/a	VAV-F203	IFCToolSet	IfcFlowController	2f1V6G2_L7bfqqAnRy_AXa	n/a	n/a
388	VAV-F211	E000000	2013-12-16T07:53:49	n/a	n/a	VAV-F211	IFCToolSet	IfcFlowController	1vLOjbPHvCvPR59ZJo_SPQ	n/a	n/a
389	AHU4	E000000	2013-12-16T07:53:49	n/a	n/a	AHU4	IFCToolSet	IfcBuildingElementProxy	1IYRN9i4j7kegrLsuoFLT3	n/a	n/a
390	AHU4SupplyDuct	E000000	2013-12-16T07:53:49	n/a	n/a	AHU4SupplyDuct	IFCToolSet	IfcBuildingElementProxy	0Sr8Y0gf51SRD1oOV1kJBV	n/a	n/a
391	VAV-B112	E000000	2013-12-16T07:53:49	n/a	n/a	VAV-B112	IFCToolSet	IfcFlowController	0EAGir1nz4JwiKeBi7nHtz	n/a	n/a
392	VAV-G128	E000000	2013-12-16T07:53:49	n/a	n/a	VAV-G128	IFCToolSet	IfcFlowController	0Yqstf1SP6FAUsjyBwpHLs	n/a	n/a
393	VAV-B104	E000000	2013-12-16T07:53:49	n/a	n/a	VAV-B104	IFCToolSet	IfcFlowController	2CYfQD5vL9RPWfAYPD0tvw	n/a	n/a
394	VAV-G125	E000000	2013-12-16T07:53:49	n/a	n/a	VAV-G125	IFCToolSet	IfcFlowController	3XuX74TObs5qxkZTLEtcsoV	n/a	n/a
395	VAV-G123	E000000	2013-12-16T07:53:49	n/a	n/a	VAV-G123	IFCToolSet	IfcFlowController	0WlbK7vnLCyQkzLF1TlR5U	n/a	n/a
396	VAV-B105	E000000	2013-12-16T07:53:49	n/a	n/a	VAV-B105	IFCToolSet	IfcFlowController	3NcvpZDZzCxhSTLCR8Xc_5	n/a	n/a
397	VAV-C102	E000000	2013-12-16T07:53:49	n/a	n/a	VAV-C102	IFCToolSet	IfcFlowController	3ZT0gkxr97VQ4uVHIT$iE3	n/a	n/a
398	VAV-F140	E000000	2013-12-16T07:53:49	n/a	n/a	VAV-F140	IFCToolSet	IfcFlowController	00hYL$7fz3nOtQ7ywyqm$H	n/a	n/a
399	VAV-F141	E000000	2013-12-16T07:53:49	n/a	n/a	VAV-F141	IFCToolSet	IfcFlowController	3tYY6_TG91COvhksPTGai9	n/a	n/a
400	VAV-F142	E000000	2013-12-16T07:53:49	n/a	n/a	VAV-F142	IFCToolSet	IfcFlowController	2p0ziAhyvCoR4uJowWcp$s	n/a	n/a
401	VAV-G117	E000000	2013-12-16T07:53:49	n/a	n/a	VAV-G117	IFCToolSet	IfcFlowController	1K7UABm3zEzQQgeWtNgn58	n/a	n/a
402	VAV-G113	E000000	2013-12-16T07:53:49	n/a	n/a	VAV-G113	IFCToolSet	IfcFlowController	2i2II2rC94FgqVlcH116WF	n/a	n/a
403	VAV-G132	E000000	2013-12-16T07:53:49	n/a	n/a	VAV-G132	IFCToolSet	IfcFlowController	2WTAEbBKzEFftYY314a$Rq	n/a	n/a
404	VAV-G134	E000000	2013-12-16T07:53:49	n/a	n/a	VAV-G134	IFCToolSet	IfcFlowController	0svyVDvWbFTO0678rCR$qz	n/a	n/a
405	VAV-G116	E000000	2013-12-16T07:53:49	n/a	n/a	VAV-G116	IFCToolSet	IfcFlowController	0VNEOpr319ygjAArY6UEAd	n/a	n/a
406	VAV-G115	E000000	2013-12-16T07:53:49	n/a	n/a	VAV-G115	IFCToolSet	IfcFlowController	3EBVajaz14rwP$gYCxH_Mf	n/a	n/a
407	VAV-G120	E000000	2013-12-16T07:53:49	n/a	n/a	VAV-G120	IFCToolSet	IfcFlowController	1MZJYGOK50qfJLbrNuFr55	n/a	n/a
408	VAV-G130	E000000	2013-12-16T07:53:49	n/a	n/a	VAV-G130	IFCToolSet	IfcFlowController	06guAypTrA4ujBE_FKC7D_	n/a	n/a
409	VAV-G131	E000000	2013-12-16T07:53:49	n/a	n/a	VAV-G131	IFCToolSet	IfcFlowController	0ZWyqzFsn72x2_IOR5LKBe	n/a	n/a
410	VAV-B108	E000000	2013-12-16T07:53:49	n/a	n/a	VAV-B108	IFCToolSet	IfcFlowController	3KmHQ2YQ9ABe_bQyYhobFI	n/a	n/a
411	Diffuser292	E000000	2013-12-16T07:53:49	n/a	n/a	Diffuser292	IFCToolSet	IfcFlowTerminal	32jk0sv2P8jvlFlJBZSxCQ	n/a	n/a
412	Diffuser294	E000000	2013-12-16T07:53:49	n/a	n/a	Diffuser294	IFCToolSet	IfcFlowTerminal	0VRV5aAw59CRjQvzViZ1Ws	n/a	n/a
413	Diffuser266	E000000	2013-12-16T07:53:49	n/a	n/a	Diffuser266	IFCToolSet	IfcFlowTerminal	1HOnXuu6fFfvHyl1AE49NT	n/a	n/a

Instruction | Contact | Facility | Floor | Space | Zone | Type | Component | System | Assembly | Connection | Spare | Resource | Job | Impact | Document

Figure 93: COBie.Component from Transformed IFC File - Building 12000

After evaluating both files exported from BIM Builder, it is evident that the file in Microsoft Excel format contains more information useful to BULDER SMS than the converted IFC file, as it contains information about relationships between equipment and spaces as well as within equipment. However, this format will require the development of a proprietary link to successfully perform the information exchange with BUILDER SMS. If BULDER SMS reaches the point of using information with open standards such as IFC and COBie, BIM Builder will have to rely on the data found in its IFC export, which contains the least amount of information.

G. Revit Time Study

During this project, we discussed the lack of data about cost or development time required by the levels of development (LODs) for a building information model (BIM). We focused BIM efforts on what closely meets a concept design BIM or what the American Institute of Architects (AIA) defines as LOD 200, a model consisting of "generalized systems or assemblies with approximate quantities, size, shape, location and orientation."

While studying and testing Honeywell's BIM Builder application, a question arose of how much time it takes to develop a LOD 200 BIM in Honeywell's BIM Builder versus Autodesk's Revit BIM commercial off-the-shelf (COTS) product. Since we were already timing the model development in BIM Builder, we decided measure the development time for the same model in Revit for comparison.

We used the as-built construction computer aided design (CAD) documents of the Fort Hood Brigade Headquarters, a 22,400 square foot, two-story building chosen for the BIM Builder study as reference in Revit to develop the model for the time study. Two architects who trained with Revit during college were asked to participate in this study. The users do not use Revit on a daily basis, but are quite familiar with the tool. Use One created the architectural model in Revit Architecture and then passed it along to User Two to complete the HVAC portion of the model using Revit MEP. The rendered sections of the model are shown in Figure 94 and Figure 95.

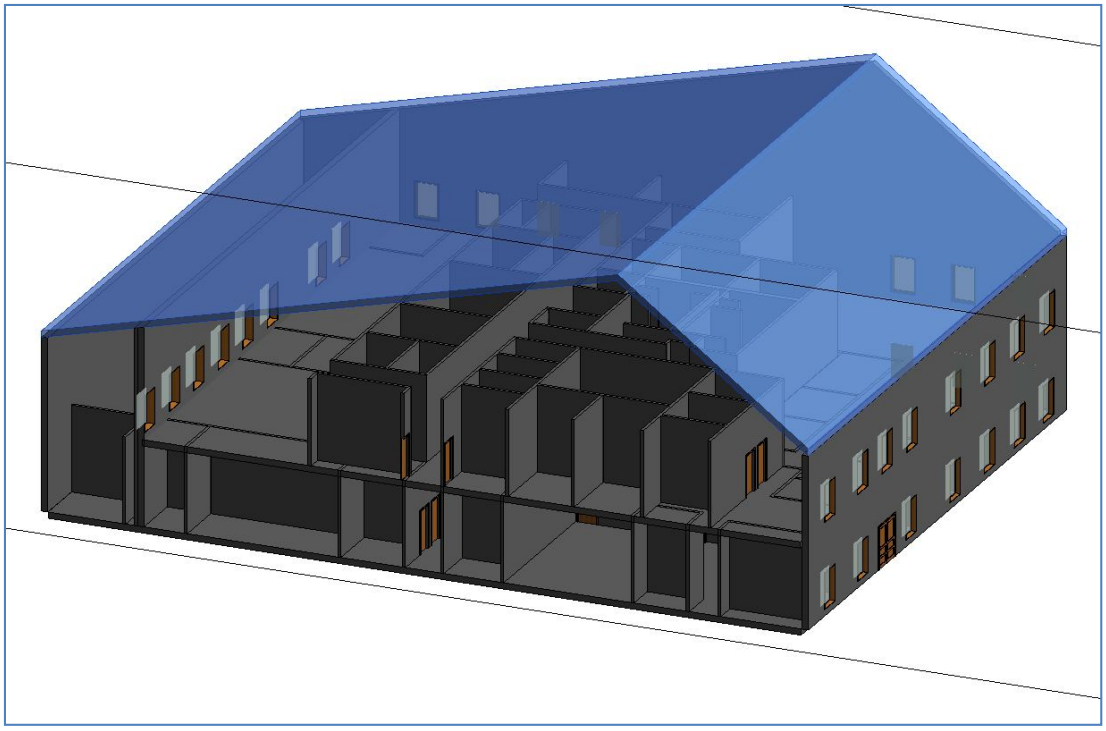

Figure 94: Revit 2014 – Section of Architectural Model

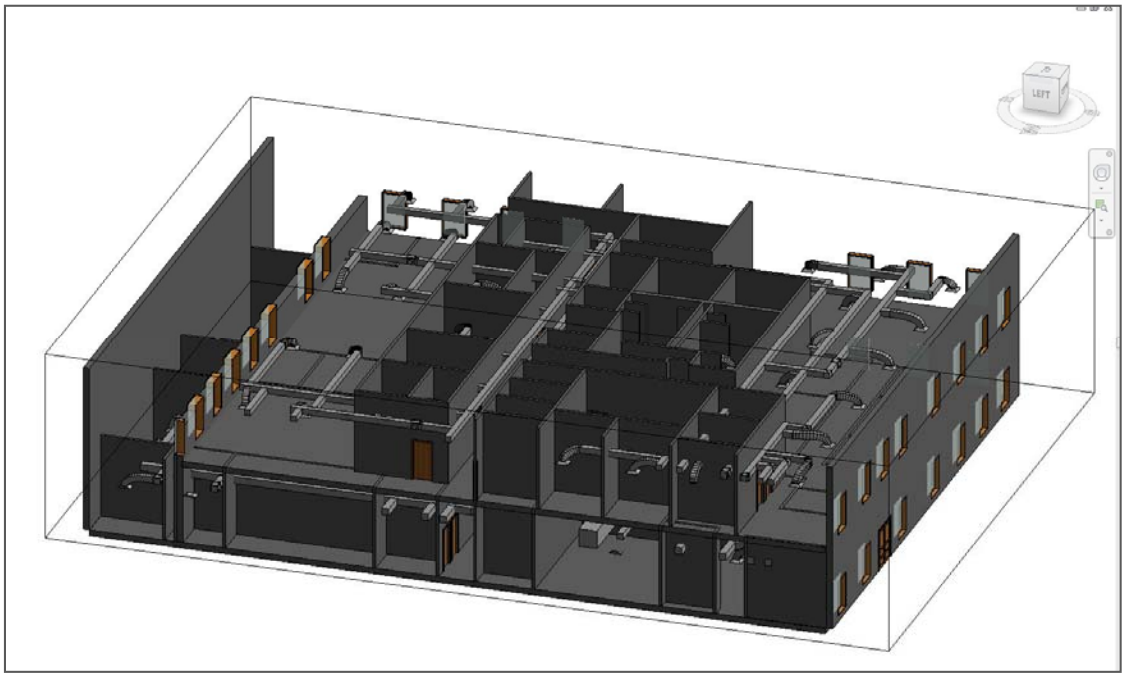

Figure 95: Revit 2014 (MEP) – Section of HVAC Model

Before the architects began modeling, we developed Table 37 to determine tasks and the elements to be modeled and timed for both floors of the building. It was important to model as

closely as possible the same LOD as modeled in BIM Builder. Since one of the main focuses of this ESTCP project was to evaluate the Industry Foundation Class (IFC) and Construction Operations Building information exchange (COBie) interoperability formats, it was important to model the rooms as well as architectural and HVAC components. The COBie format requires the linkage or containment of rooms/spaces to the modeled components in the room. The following numbers of IFC components were placed in the model for this study.

Table 37: IFC Components Placed in the Brigade Headquarters Building Model

Floors	Named Spaces	Air Handling Devices	VAVs	Diffusers	Doors	Windows
2	82	12	34	143	83	39

As noted in Table 38 below, it took 72 minutes to develop the architectural model, including floors, walls, doors, openings, stairs, elevator, roof and rooms. It took 70 minutes to develop the HVAC model, including diffusers, variable air volume, air handling units, ductwork, and connections.

At the completion of the modeling, the Revit IFC export tool was used to create the IFC file. The total time to complete the model and export to IFC was approximately 143 minutes, or 2 hours and 23 minutes. This IFC file was then run through the COBie translation tools to create the COBie file. See COBie Space and Component tabs in Figure 96 and Figure 97. Note that Revit exported the modeled rooms as an IFC space and determined the IFC components that were contained in that space.

Table 38: Revit Actions and Time Study

Action	Start	Finish	Time (Minutes)
ARCH			
File Setup (Scaling, Levels)	1410	1413	3
Place Floor	1413	1417	4
Place Walls	1417	1435	18
Place Doors/Openings	1435	1454	19
Place Stairs	1454	1457	3
Place Roof if needed	1505	1510	5
Place Rooms	1515	1517	2
Room Name/Number Input for IFC/COBie	1517	1535	18
Total ARCH			72
MEP			
File Setup (Scaling, Levels)	1331	1337	6
Place Diffusers	1337	1352	15
Place VAV	1352	1408	10
Place AHU	1408	1412	4
Place Ductwork/Connections	1412	1445	33
Place Other	1445	1447	2
Total HVAC			70
Export IFC	1447	1448	1
Total Time			143

2014-10-30_TransforemedFrom_Jeff MEP Test_JYu - Beth rooms.xml

1	Name	CreatedBy	CreatedOn	Category	FloorName	Description	ExtSystem	ExtObject	ExtIdentifier	RoomTag	UsableHeight	GrossArea	NetArea
29	119	u4cnr	2014-10	n/a	Level 1	WOMEN"S RESTROOM	Autodesk Revit	IfcSpace	2kxsv	n/a	n/a	230.971	230.971
30	121	u4cnr	2014-10	n/a	Level 1	MEN"S RESTROOM	Autodesk Revit	IfcSpace	2kxsv	n/a	n/a	241.639	241.639
31	122	u4cnr	2014-10	n/a	Level 1	ELECTRICAL ROOM	Autodesk Revit	IfcSpace	2kxsv	n/a	n/a	185.072	185.072
32	123	u4cnr	2014-10	n/a	Level 1	MECHANICAL ROOM	Autodesk Revit	IfcSpace	2kxsv	n/a	n/a	621.954	621.954
33	124	u4cnr	2014-10	n/a	Level 1	TELE/COMM ROOM	Autodesk Revit	IfcSpace	2kxsv	n/a	n/a	141.813	141.813
34	125	u4cnr	2014-10	n/a	Level 1	SIPRNET	Autodesk Revit	IfcSpace	2kxsv	n/a	n/a	73.958	73.958
35	126	u4cnr	2014-10	n/a	Level 1	SUPPLY STORAGE	Autodesk Revit	IfcSpace	2kxsv	n/a	n/a	106.315	106.315
36	127	u4cnr	2014-10	n/a	Level 1	ELEVATOR EQUIPMENT	Autodesk Revit	IfcSpace	2kxsv	n/a	n/a	54.283	54.283
37	128	u4cnr	2014-10	n/a	Level 1	S-4 STORAGE	Autodesk Revit	IfcSpace	2kxsv	n/a	n/a	55.09	55.09
38	129	u4cnr	2014-10	n/a	Level 1	S-1 STORAGE	Autodesk Revit	IfcSpace	2kxsv	n/a	n/a	44.218	44.218
39	130	u4cnr	2014-10	n/a	Level 1	CLOSET	Autodesk Revit	IfcSpace	2kxsv	n/a	n/a	38.117	38.117
40	131	u4cnr	2014-10	n/a	Level 1	NOC ROOM	Autodesk Revit	IfcSpace	2kxsv	n/a	n/a	1589.704	1589.704
41	132	u4cnr	2014-10	n/a	Level 1	S-6	Autodesk Revit	IfcSpace	2kxsv	n/a	n/a	149.045	149.045
42	133	u4cnr	2014-10	n/a	Level 1	ISM OFFICE	Autodesk Revit	IfcSpace	2kxsv	n/a	n/a	116.802	116.802
43	134	u4cnr	2014-10	n/a	Level 1	SERVER ROOM	Autodesk Revit	IfcSpace	2kxsv	n/a	n/a	300.002	300.002
44	135	u4cnr	2014-10	n/a	Level 1	VESTIBULE ENTRY	Autodesk Revit	IfcSpace	2kxsv	n/a	n/a	122.919	122.919
45	136	u4cnr	2014-10	n/a	Level 1	VESTIBULE ENTRY	Autodesk Revit	IfcSpace	2kxsv	n/a	n/a	123.229	123.229
46	137	u4cnr	2014-10	n/a	Level 1	OPEN NOC	Autodesk Revit	IfcSpace	2kxsv	n/a	n/a	1406.615	1406.615
47	138	u4cnr	2014-10	n/a	Level 1	VESTIBULE ENTRY	Autodesk Revit	IfcSpace	2kxsv	n/a	n/a	135.057	135.057
48	139	u4cnr	2014-10	n/a	Level 1	CONFERENCE ROOM	Autodesk Revit	IfcSpace	2kxsv	n/a	n/a	309.182	309.182
49	140	u4cnr	2014-10	n/a	Level 1	SIGINT	Autodesk Revit	IfcSpace	2kxsv	n/a	n/a	319.264	319.264
50	141	u4cnr	2014-10	n/a	Level 1	SCIF OPEN OFFICE	Autodesk Revit	IfcSpace	2kxsv	n/a	n/a	2431.008	2431.008
51	142	u4cnr	2014-10	n/a	Level 1	VESTIBULE ENTRY	Autodesk Revit	IfcSpace	2kxsv	n/a	n/a	95.096	95.096
52	143	u4cnr	2014-10	n/a	Level 1	SERVER ROOM	Autodesk Revit	IfcSpace	2kxsv	n/a	n/a	161.762	161.762
53	201	u4cnr	2014-10	n/a	Level 2	TELE/COMM ROOM	Autodesk Revit	IfcSpace	2kxsv	n/a	n/a	99.117	99.117
54	202	u4cnr	2014-10	n/a	Level 2	TEAM ROOM	Autodesk Revit	IfcSpace	2kxsv	n/a	n/a	145.413	145.413
55	203	u4cnr	2014-10	n/a	Level 2	TEAM ROOM	Autodesk Revit	IfcSpace	2kxsv	n/a	n/a	152.533	152.533
56	204	u4cnr	2014-10	n/a	Level 2	OPENS SOTRAGE	Autodesk Revit	IfcSpace	2kxsv	n/a	n/a	103.687	103.687
57	205	u4cnr	2014-10	n/a	Level 2	OPNS OFFICE	Autodesk Revit	IfcSpace	2kxsv	n/a	n/a	102.263	102.263
58	206	u4cnr	2014-10	n/a	Level 2	OPNS OFFICE	Autodesk Revit	IfcSpace	2kxsv	n/a	n/a	104.344	104.344
59	207	u4cnr	2014-10	n/a	Level 2	OPNS CONFERENCE ROOM	Autodesk Revit	IfcSpace	2kxsv	n/a	n/a	344.622	344.622
60	208	u4cnr	2014-10	n/a	Level 2	OPNS STORAGE	Autodesk Revit	IfcSpace	2kxsv	n/a	n/a	65.0	65.0
61	209	u4cnr	2014-10	n/a	Level 2	RECYCLE ROOM	Autodesk Revit	IfcSpace	2kxsv	n/a	n/a	65.0	65.0
62	210	u4cnr	2014-10	n/a	Level 2	RECYCLE ROOM	Autodesk Revit	IfcSpace	2kxsv	n/a	n/a	62.5	62.5
63	211	u4cnr	2014-10	n/a	Level 2	WOMEN"S RESTROOM	Autodesk Revit	IfcSpace	2kxsv	n/a	n/a	232.89	232.89

Instruction | Contact | Facility | Floor | **Space** | Zone | Type

Figure 96: COBie Space Data from Revit Model through IFC Export

2014-10-30_TransforemedFrom_Jeff MEP Test_JYu - Beth rooms (2).xml

1	Name	CreatedBy	CreatedOn	TypeName	Space	Description	ExtSystem	ExtObject	ExtIdentifier
266	Supply Diffuser:24 x 24 Face 12 x 12 Connection:238464	u4cnn	2014-10-30T	24 x 24 F	231	Supply Diffuser:24 x 24 Face 12 x 12	Autodesk	IfcFlowTerm	2FK9jfA51
267	Supply Diffuser:24 x 24 Face 12 x 12 Connection:238537	u4cnn	2014-10-30T	24 x 24 F	231	Supply Diffuser:24 x 24 Face 12 x 12	Autodesk	IfcFlowTerm	2FK9jfA51
268	Supply Diffuser:24 x 24 Face 12 x 12 Connection:238730	u4cnn	2014-10-30T	24 x 24 F	229	Supply Diffuser:24 x 24 Face 12 x 12	Autodesk	IfcFlowTerm	2FK9jfA51
269	Supply Diffuser:24 x 24 Face 12 x 12 Connection:238759	u4cnn	2014-10-30T	24 x 24 F	229	Supply Diffuser:24 x 24 Face 12 x 12	Autodesk	IfcFlowTerm	2FK9jfA51
270	Supply Diffuser:24 x 24 Face 12 x 12 Connection:238820	u4cnn	2014-10-30T	24 x 24 F	230	Supply Diffuser:24 x 24 Face 12 x 12	Autodesk	IfcFlowTerm	2FK9jfA51
271	Supply Diffuser:24 x 24 Face 12 x 12 Connection:238897	u4cnn	2014-10-30T	24 x 24 F	226	Supply Diffuser:24 x 24 Face 12 x 12	Autodesk	IfcFlowTerm	2FK9jfA51
272	Supply Diffuser:24 x 24 Face 12 x 12 Connection:239002	u4cnn	2014-10-30T	24 x 24 F	225	Supply Diffuser:24 x 24 Face 12 x 12	Autodesk	IfcFlowTerm	2FK9jfA51
273	Supply Diffuser:24 x 24 Face 12 x 12 Connection:239063	u4cnn	2014-10-30T	24 x 24 F	225	Supply Diffuser:24 x 24 Face 12 x 12	Autodesk	IfcFlowTerm	2FK9jfA51
274	Supply Diffuser:24 x 24 Face 12 x 12 Connection:239148	u4cnn	2014-10-30T	24 x 24 F	232	Supply Diffuser:24 x 24 Face 12 x 12	Autodesk	IfcFlowTerm	2FK9jfA51
275	Supply Diffuser:24 x 24 Face 12 x 12 Connection:239217	u4cnn	2014-10-30T	24 x 24 F	231	Supply Diffuser:24 x 24 Face 12 x 12	Autodesk	IfcFlowTerm	2FK9jfA51
276	Supply Diffuser:24 x 24 Face 12 x 12 Connection:239286	u4cnn	2014-10-30T	24 x 24 F	213	Supply Diffuser:24 x 24 Face 12 x 12	Autodesk	IfcFlowTerm	2FK9jfA51
277	Supply Diffuser:24 x 24 Face 12 x 12 Connection:239371	u4cnn	2014-10-30T	24 x 24 F	217	Supply Diffuser:24 x 24 Face 12 x 12	Autodesk	IfcFlowTerm	2FK9jfA51
278	Supply Diffuser:24 x 24 Face 12 x 12 Connection:241656	u4cnn	2014-10-30T	24 x 24 F	3	Supply Diffuser:24 x 24 Face 12 x 12	Autodesk	IfcFlowTerm	2FK9jfA51
279	VAV Unit - Single Duct:10":255903	u4cnn	2014-10-30T	n/a	232	VAV Unit - Single Duct:10":255903	Autodesk	IfcBuildingEl	0kCaHrjHH
280	VAV Unit - Single Duct:10":256204	u4cnn	2014-10-30T	n/a	231	VAV Unit - Single Duct:10":256204	Autodesk	IfcBuildingEl	0kCaHrjHH
281	VAV Unit - Single Duct:10":256299	u4cnn	2014-10-30T	n/a	231	VAV Unit - Single Duct:10":256299	Autodesk	IfcBuildingEl	0kCaHrjHH
282	VAV Unit - Single Duct:10":256466	u4cnn	2014-10-30T	n/a	231	VAV Unit - Single Duct:10":256466	Autodesk	IfcBuildingEl	0kCaHrjHH
283	VAV Unit - Single Duct:10":256883	u4cnn	2014-10-30T	n/a	218	VAV Unit - Single Duct:10":256883	Autodesk	IfcBuildingEl	0kCaHrjHH
284	VAV Unit - Single Duct:10":257332	u4cnn	2014-10-30T	n/a	225	VAV Unit - Single Duct:10":257332	Autodesk	IfcBuildingEl	0kCaHrjHH
285	VAV Unit - Single Duct:10":257411	u4cnn	2014-10-30T	n/a	226	VAV Unit - Single Duct:10":257411	Autodesk	IfcBuildingEl	0kCaHrjHH
286	VAV Unit - Single Duct:10":257552	u4cnn	2014-10-30T	n/a	229	VAV Unit - Single Duct:10":257552	Autodesk	IfcBuildingEl	0kCaHrjHH
287	VAV Unit - Single Duct:10":258673	u4cnn	2014-10-30T	n/a	231	VAV Unit - Single Duct:10":258673	Autodesk	IfcBuildingEl	0kCaHrjHH
288	VAV Unit - Single Duct:10":258804	u4cnn	2014-10-30T	n/a	231	VAV Unit - Single Duct:10":258804	Autodesk	IfcBuildingEl	0kCaHrjHH
289	VAV Unit - Single Duct:10":258867	u4cnn	2014-10-30T	n/a	231	VAV Unit - Single Duct:10":258867	Autodesk	IfcBuildingEl	0kCaHrjHH
290	VAV Unit - Single Duct:10":258925	u4cnn	2014-10-30T	n/a	203	VAV Unit - Single Duct:10":258925	Autodesk	IfcBuildingEl	0kCaHrjHH
291	VAV Unit - Single Duct:10":258949	u4cnn	2014-10-30T	n/a	204	VAV Unit - Single Duct:10":258949	Autodesk	IfcBuildingEl	0kCaHrjHH
292	VAV Unit - Single Duct:10":259213	u4cnn	2014-10-30T	n/a	8	VAV Unit - Single Duct:10":259213	Autodesk	IfcBuildingEl	0kCaHrjHH
293	VAV Unit - Single Duct:10":259374	u4cnn	2014-10-30T	n/a	207	VAV Unit - Single Duct:10":259374	Autodesk	IfcBuildingEl	0kCaHrjHH
294	VAV Unit - Single Duct:10":262552	u4cnn	2014-10-30T	n/a	132	VAV Unit - Single Duct:10":262552	Autodesk	IfcBuildingEl	1xJVN1W0
295	VAV Unit - Single Duct:10":262708	u4cnn	2014-10-30T	n/a	133	VAV Unit - Single Duct:10":262708	Autodesk	IfcBuildingEl	1xJVN1W0
296	VAV Unit - Single Duct:10":262833	u4cnn	2014-10-30T	n/a	137	VAV Unit - Single Duct:10":262833	Autodesk	IfcBuildingEl	1xJVN1W0

Instruction | Contact | Facility | Floor | Space | Zone | Type | Component | System

Figure 97: COBie Component Data Demonstrating link to Space/Room from Revit Model

H. Report of BIM Development for Fort Jackson Pilot Facilities

This appendix reports the results of using BIM Builder to develop BIMs for the five buildings studied in the pilot demonstration.

Buildings 11000 and 12000

Buildings 11000 and 12000 are large barracks buildings, very similar in design and layout, as seen in Figure 98. They have six branches of two-story cadre office and living quarters, as well as a large, single-story office headquarters and classroom facility. Their total floor area is ~290,481 square feet. The HVAC configuration in each of these facilities is widely varied, as they were remodeled and re-commissioned with different equipment and strategies. They are challenging for BIM development by any method because of their very large size, number of HVAC objects and MEP complexity.

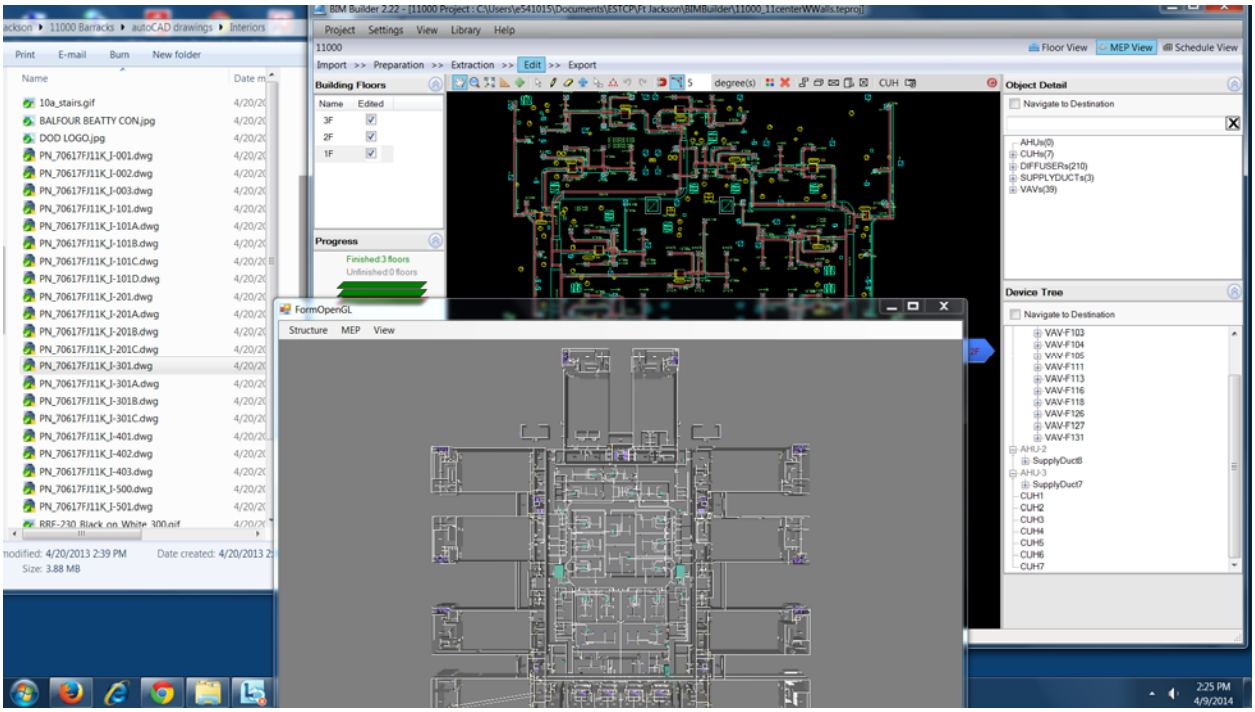

Figure 98: Buildings 11000 and 12000

Files

Honeywell received a large, but incomplete set of dwg files for these two buildings. The as-built CAD files were the result of a multi-phase remodeling project conducted over two years on the two facilities. The Phase 1 drawings gave us information on the barracks. The Phase 2 interior drawings represented only the central part of the building. But only the drawings for 12000 had the latest front-office layout, and the same drawing was used to create the model for both facilities. Outside of this common office area design, the buildings varied considerably.

Issues

The HVAC configuration of Building 11000 was substantially different from Building 12000. The extraction was performed first on Building 12000.

Result

Table 39 enumerates the spaces and equipment identified in the extraction. The expert required 2 hours, 31 minutes to complete the base extraction into a BIM for Building 12000. Two hours were required for the extraction on the second building, Building 11000.

Table 39: Buildings 11000 and 12000 Spaces and Equipment Identified by Name and Connections

Building	Floors	Named Spaces	Air Handling Devices	VAVs	Diffusers
11000	Three barrack floors	469	29	51	687
12000	Three barrack floors	516	15	111	782

Building 2450

Building 2450 (Figure 99) is a vehicle maintenance training facility, occupying 125,000 sq ft on two floors. It is a combination of classroom spaces, offices, and large repair bays with high ceilings. It includes 302 diffusers, 48 VAVs, 3 RTUs, and 5 supply ducts.

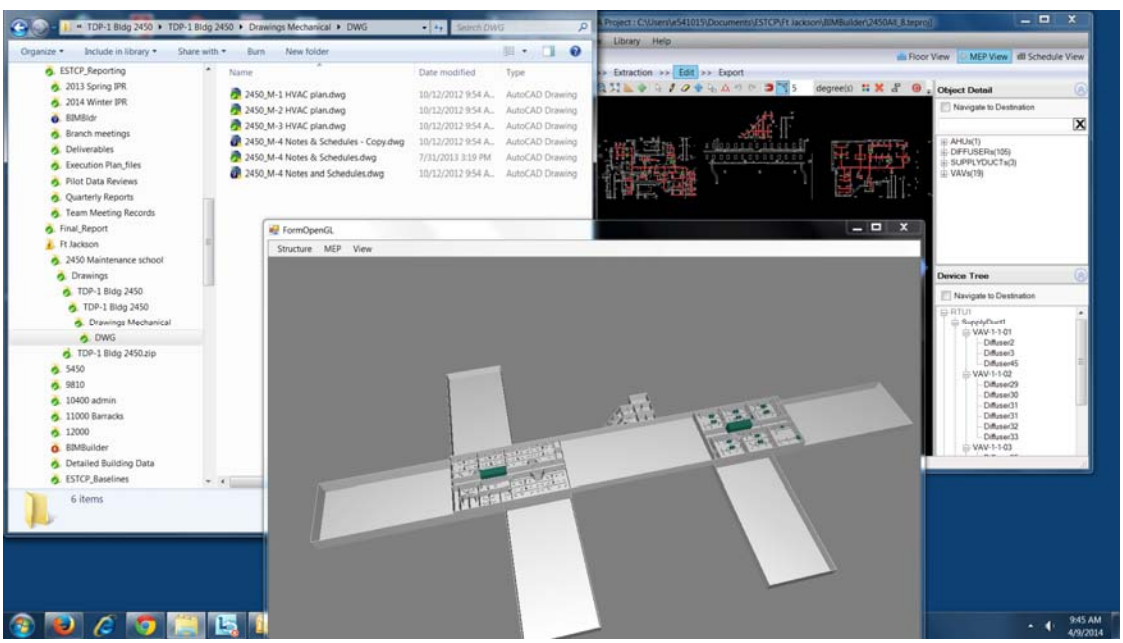

Figure 99: Building 2450

Files

Honeywell received a small set of the mechanical files for Building 2450, a maintenance training facility. The files also contained the floor plans but not all the room names. The three files in the format 2450_M-# HVAC plan.dwg contained the HVAC equipment and floor plans for the two-story portions of the building and the small office space off the central vehicle bays. We also received the mechanical schedules.

Issues

The two-story portions of the building had the plans for both floors on the same dwg. We required additional time to separate the plans and align the floors.

- The space names for some of the floors were not in the dwg files.
- The names of the VAVs were not in the dwg files.
- The dwg files did not have layers for hidden ductwork and walls, so the BIM Builder algorithm had difficulty extracting the walls and ducts.
- The wall heights were different on the vehicle bays, so the tool had to be modified to allow the user to add wall heights.

Result

Table 40 enumerates the spaces and equipment identified in the extraction. The expert required 2 hours, 25 minutes to complete the base extraction into a BIM for Building 2450.

Table 40: Building 2450 Spaces and Equipment Identified by Name and Connections:

Floors	Named Spaces	Air Handling Devices	VAVs	Diffusers
Two classroom floors	114	3	48	302

Building 9810

Building 9810 (Figure 100) is a soldier services facility, occupying 37,310 sq feet on one floor. It is a combination of classroom spaces and offices that includes 156 diffusers, connected via 13 zoned supply ducts to 4 AHUs.

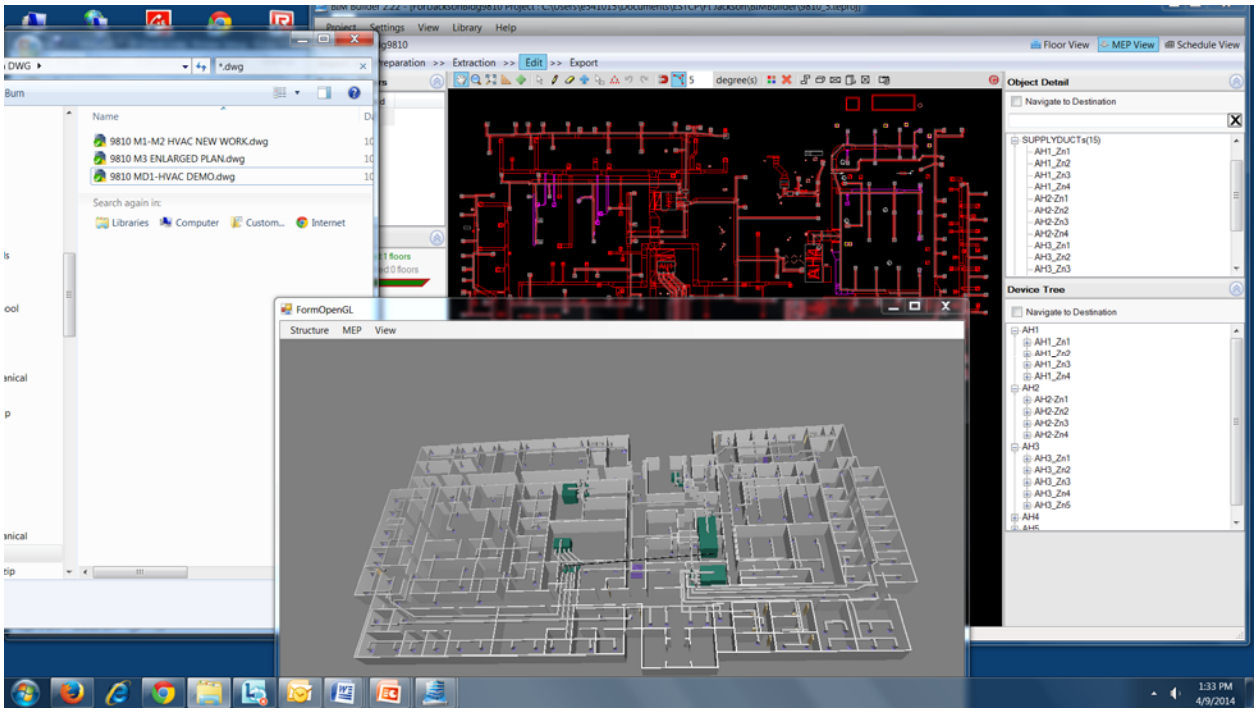

Figure 100: Building 9810

Files

Honeywell received three files for the 9810 building. One file contained the new plan for two areas within the building, one contained the old plan, and one was a close view of a mechanical space. No schedules were provided.

Issues

- There are two floor heights within the building, so BIM Builder needed to be modified to allow the user to vary floor height.
- There are no VAVs in this building. Zones are done as separate duct runs from the AHUs. This situation also required a change in the tool to accommodate this use case.
- The density of the ductwork near the AHU at first posed a problem for the duct detection algorithm until further improvements in the algorithm were made.
- This facility had considerable modifications not presented in the as-built CAD used for the import. More extensive editing was required.

Recommendation

Add a function that allows for showing zones based on duct runs and user definition of spaces within a zone.

Result

Table 41 enumerates the spaces and equipment identified in the extraction. The expert required 4 hours, 30 minutes to complete the base extraction into a BIM for Building 9810.

Table 41: Building 9810 Spaces and Equipment Identified by Name and Connections

Floors	Named Spaces	Air Handling Devices	Zones	Diffusers
Single story, split level	119	5	13	156

Building 10400

Building 10400 (Figure 101) is a training battalion headquarters facility, occupying 23,178 sq feet on one floor. It is a combination of classroom spaces and offices. It includes 116 diffusers, 13 VAVs, 3 AHUs, and 4 supply ducts.

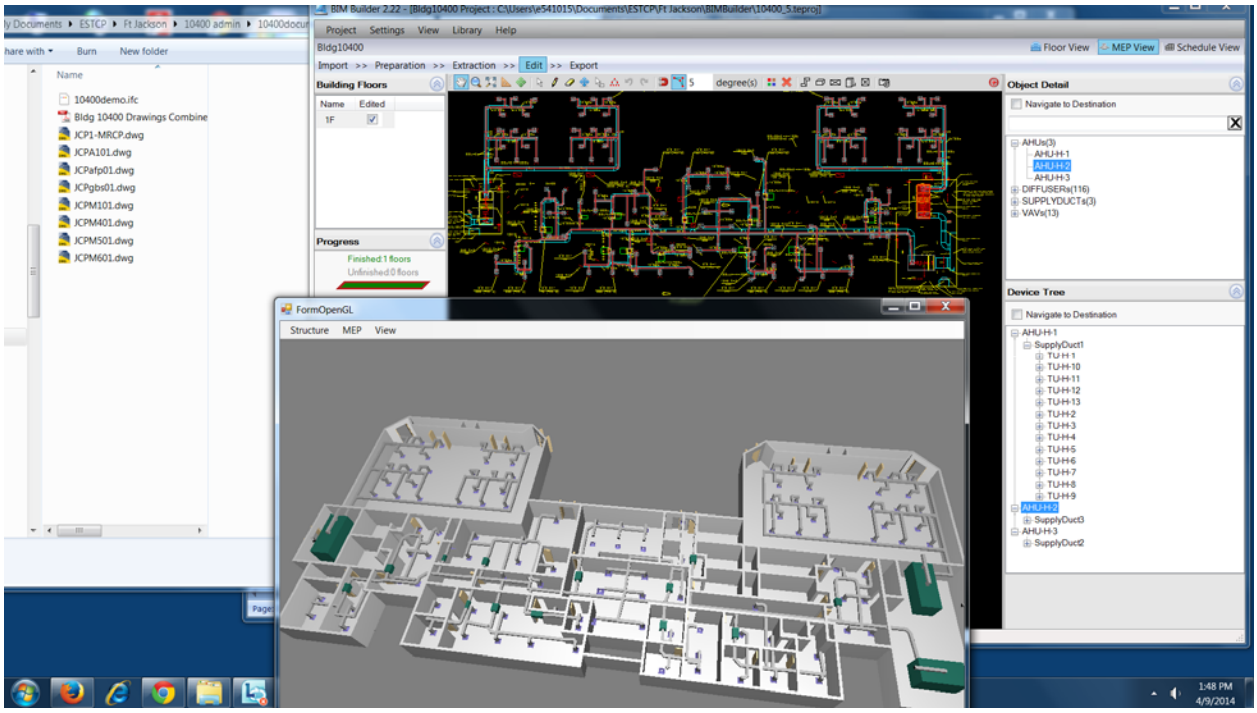

Figure 101: Building 10400

Files

Honeywell received separate files for the architectural and MEP layouts, a close view of the mechanical spaces, and a schedule.

Issues

- The classroom walls are a different thickness than much of the building, so a single wall thickness threshold was not effective for the extract. This characteristic resulted in several phantom spaces being detected in the wall/space detection algorithm that the user needed to delete.
- The AHU for the classrooms had no VAV in the duct line. There are dampers to control the flow of air to those spaces.

Recommendation

Add dampers as standard HVAC equipment that is included by the algorithm in the equipment supply relationships.

Result

Table 42 enumerates the spaces and equipment identified in the extraction. The expert required 2 hours, 55 minutes to complete the base extraction into a BIM for Building 10400.

Table 42. Building 10400 Spaces and Equipment Identified by Name and Connections

Floors	Named Spaces	Air Handling Devices	VAVs	Diffusers
1 floor	50	3	13	116

I. Summary of Test Subject Feedback on BIM Builder

Five participants at ERDC-CERL tested BIM Builder on April 8 & 9, 2014. Their review comments about the experience are recorded below. The comments are sorted into general categories.

Usability

- Process was logical, although remembering modes didn't come naturally
- After initial difficulties with set up, "connecting the ductwork segments to each other and to the diffusers and air handlers was quite simple and fun, especially when you could go to 3d view"
- Matching room names in drawing with those in the extracted list was cumbersome.
- Most difficult part was finding which layers to turn on.
- It was hard to determine if the ducts were snapped to the correct line. (Might have been easier to draw the ducts than to use the automated drawing.)

Learning Curve

- Testers expect that, after a little practice (and some bug fixes), a user could extract items for an average two-story building in an hour or two. An acceptable amount of time for capturing the type and detail of this information when compared to collecting this information on the fly in the field to build the component inventory model, which is how BUILDER SMS information is typically collected.
- Most participants were able to perform at a decent level with just the 8 hour training

Suggested Enhancements

- Additional items of particular interest include exterior windows, as well as getting wall, floor, and ceiling finishes by linking with schedules (and door/window types from those schedules).
- If it were also expanded to capture electrical items (switchboard, panels, transformers, and lighting fixtures), plumbing items (heating and heat exchanger equipment, storage tanks, plumbing fixtures, and the piping in between them) similar to how it currently captures HVAC, then that would comprise a majority of the main components that are typically collected in a system such as BUILDER SMS.
- Make it possible to draw duct lines so that if the pipe on which one is working is selected, the whole line and the next connecting line is colored slightly different to show how the connection works. so the user can quickly click a link and see the flow.
- Arrange the room name list by room number
- Build additional algorithms to autogenerate the distribution runs for the piping or wiring, but even without this, the tool's ability to capture a collection of like entities from a drawing would be extremely useful.

Potential Use

- Extract component-level building information from a set of flat CAD files.
- A lot of potential to feed asset management processes such component inventory management, condition assessment, work generation, and enhanced planning. This includes interfacing with tools such as BUILDER Sustainment Management System (SMS), or Maximo/Trirega computerized maintenance management systems (CMMS).

Comparison with Other Tools

- BIM Builder vs. COTS: A better time comparison should be perform between experts in both tools for different size facilities. The time getting the right layers to show up and editing/exporting might be similar to importing the CAD into Revit and draw on top of it (this assuming just one generic object will be used for each piece). Perhaps the advantage and benefit is on bigger facilities. Also keep in mind that COTS design tools now offer export to IFC and COBie as well.
- A comparison by facility size (SF) might be warranted. Honeywell needs to demonstrate fairly significant time savings from traditional BIM development process and their process.

COBie Export

- Look into the assembly worksheet. Tester believes none of the current design companies that are COBie compliant have tested the use of assembly; therefore, this might be a distinguishing element in the export.
- Are the programmers writing their own export or are they using the IFC to COBie tools developed by ERDC?

Over All

- Appeared the tool has integrated well with the IFC standard.
- Might need to take a look at a converted .dwg that came from a .dgn to ensure the conversions are working consistently and levels/layers/symbols/blocks coming out correctly.
- When calculating time for developing the BIM in the tool, should also take into consideration that the archived/as-built cad files might need to be converted to .dwg

J. Detailed analysis of 10400, using the MDEI Energy Dashboard

The energy calendar view of the Energy Dashboard (Figure 42) provides a snapshot of the total electrical consumption behavior of one building over time. This view provides an instant overview of several aspects of energy consumption patterns that reveal where issues may lie.

- Are building systems shutting down effectively during unoccupied hours?
- Is there a regular pattern of energy use weekday/weekend?
- Where are the anomalies in the pattern of usage?
- What is the relationship between energy use and weather (via Outside Air Temperature)?

In Figure 102 nominal business hours for this administrative facility are indicated by the darker green portion of the energy consumption trend line. These business hours are somewhat evident from the energy signature, but were also verified in the interview with the managers and occupants of this facility.

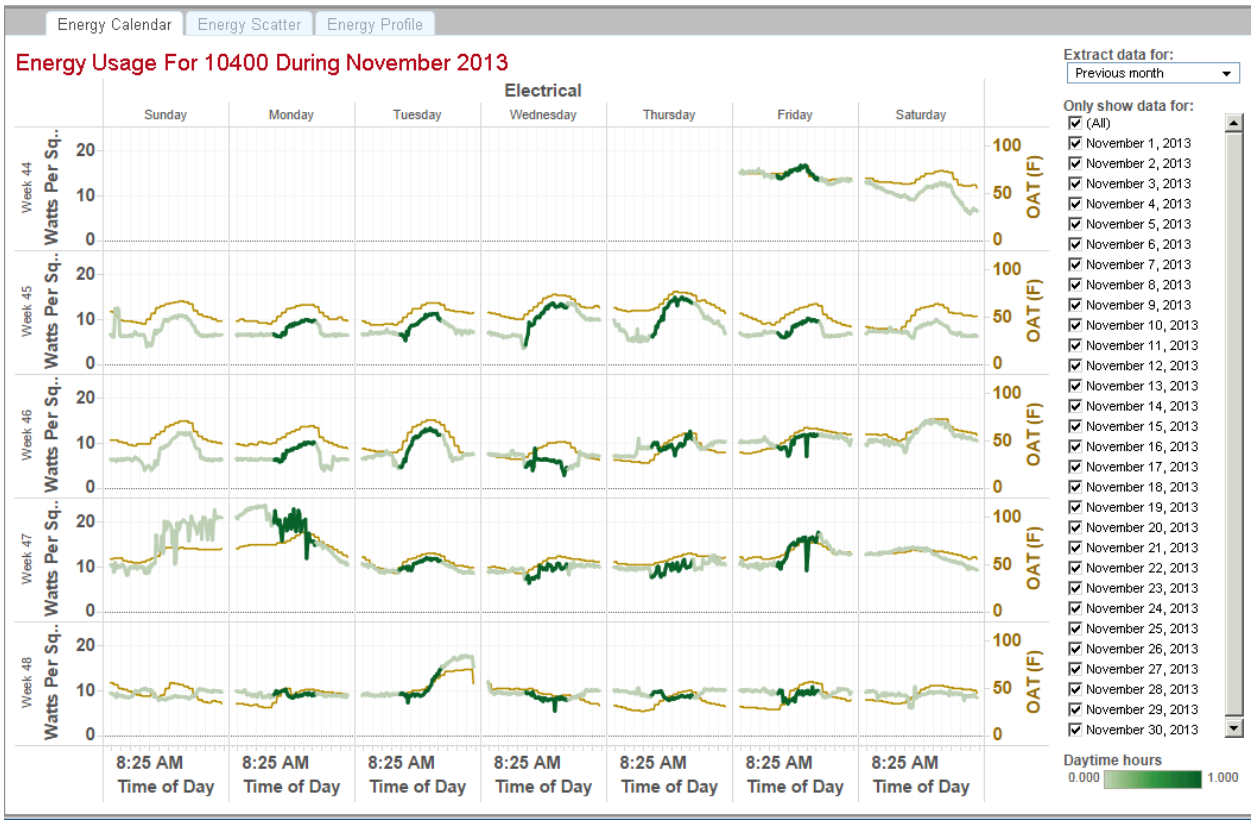

Figure 102: Energy use calendar for Building 10400, Nov. 1, 2013–Nov. 30, 2013

In this energy calendar, we can note a few things about the operation of this facility:

- The energy consumption is highly dependent on outside temperature, every day of the week.
- There are some anomalies in consumption, as illustrated Sunday-Monday on week 47 (November 17-18).
- Though this building is not very large (23K sq ft), the base load is unusually high, even overnight.

Figure 103 shows weekday and weekend high temperature dependency for building 10400.

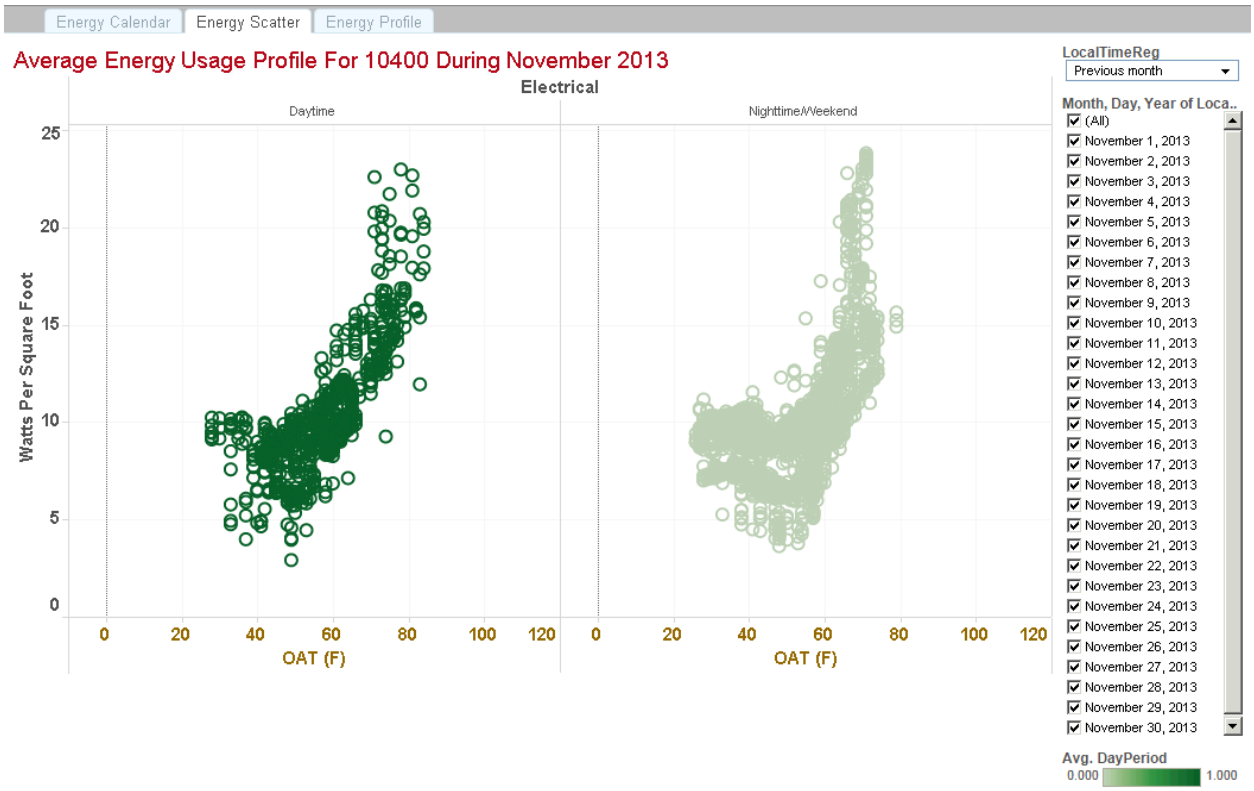

Figure 103: High temperature dependency of building operations on both weekdays and weekends.

An energy manager looking at only this data must identify where the problem might lie. Outside of making scheduling changes, it is unclear what is contributing to the high base-load, or the unusually high consumption.

Linking energy behavior to equipment behavior

Faced with this information, an energy manager would need to assign someone to review the control settings for this facility to determine what might be happening. They can sit down at the management console for the building control system and review available trend logs, setpoints and schedules. This experience will be different based on which vendor's system is in place. Furthermore, this is labor-intensive and time-consuming, luxuries a DPW cannot afford.

To address this and make the data available seamlessly, we set up collection of relevant BMS data from each of the facilities so that the operating behavior of the equipment can be visualized as easily as the energy profile.

The data we included is the data that we typically use for detailed energy monitoring which reveals the following types of behavior:

- **Demand for heating/cooling** (fan operation, damper positions, valve positions, and space temperatures)

- **Overall operation of the major loads that treat air** (Air Handling Units, Chilled Water and Hot Water systems)

By analyzing this data, we can reveal the behavior of specific systems or subsystems that are affecting energy use in the facility, and assess the likely impact of modifications in that behavior.

Figure 104 shows a composite view of a facility and a subset of the trended data.

Figure 104: Composite view of the facility and the trended data for Dec. 18-28, 2013

The chart in Figure 104 includes these features:

- It is December, and the Outside Air Temperature (grey line) is 60 at its highest point over two days.
- The SupplyAir temperature (Purple Line) from AHU-H-1 maintains at 55 degrees 24 hours per day
- A fairly constant room temperature is being maintained (series of light green lines), even overnight, with the Supply Air VFD running at a fairly consistent 75% of capacity (pink line).
- Significant chilled water is being used even during low temperature periods (darker green line).
- A few space temperatures are clustered around 71 degrees F, but several spaces are significantly colder, and one is significantly warmer than the rest.

Next, let's look at the demand side. What is happening in these individual spaces? Let's look at the warmest and hottest spaces being served by terminal units TU-H-8 (always running hot) and TU-H-4 (always far colder than comfortable), shown in Figure 105.

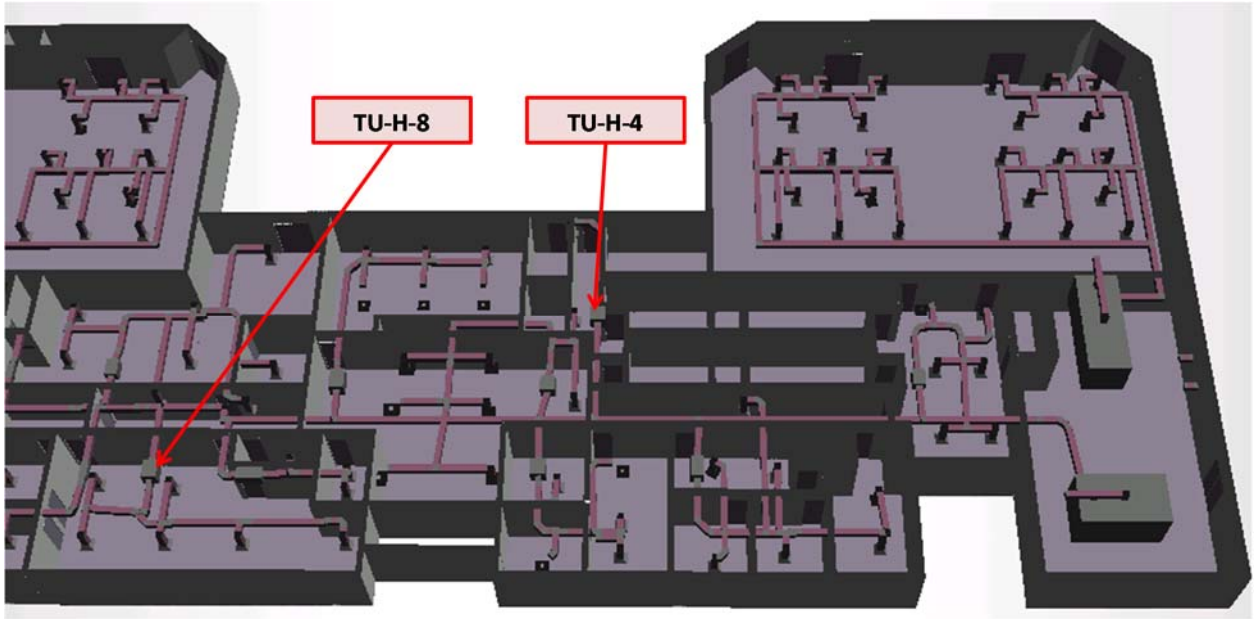

Figure 105: Floor Plan Indicating the Location of TU-H-8 and TU-H-4

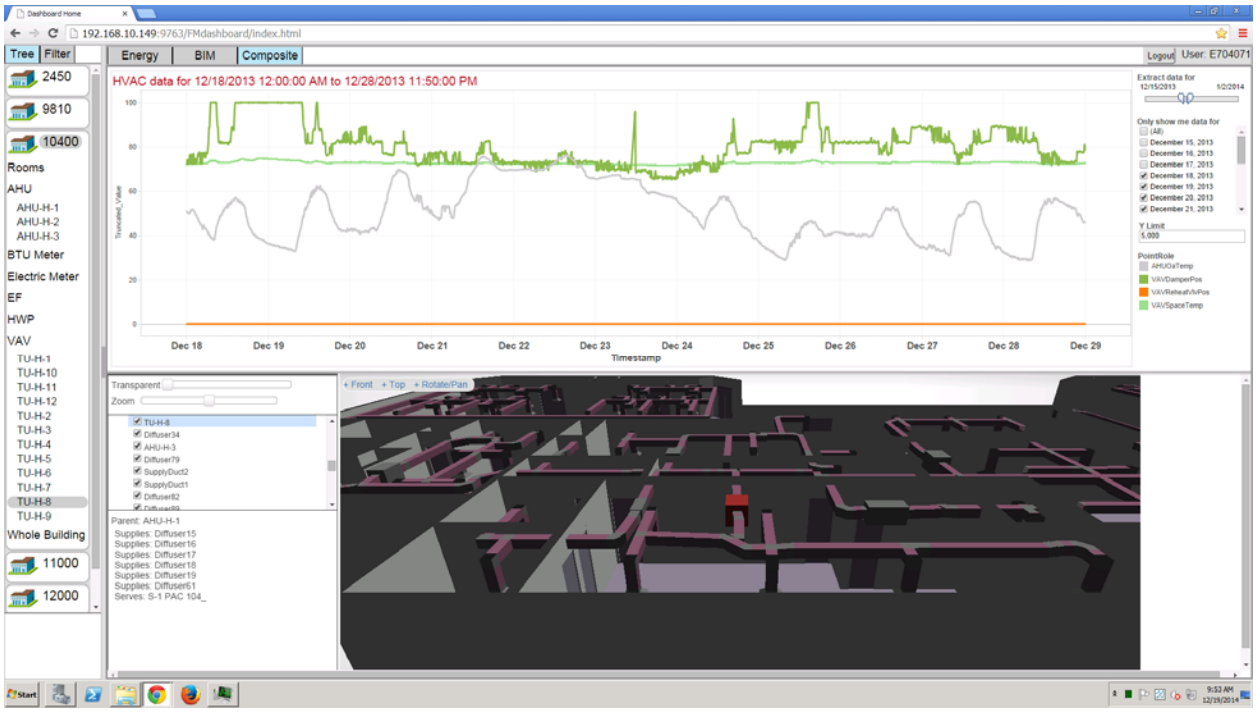

Figure 106: Behavior of Terminal Unit 8

In the floor plan in Figure 106, we can see that this unit serves an open office space, S-1 PAC 104_. The following facts can be discerned from the trend.

- The system is maintaining a constant set point of roughly 72 degrees, 24x7, even through the holiday.
- No reheat is being requested for comfort in the zone served by TU-8.

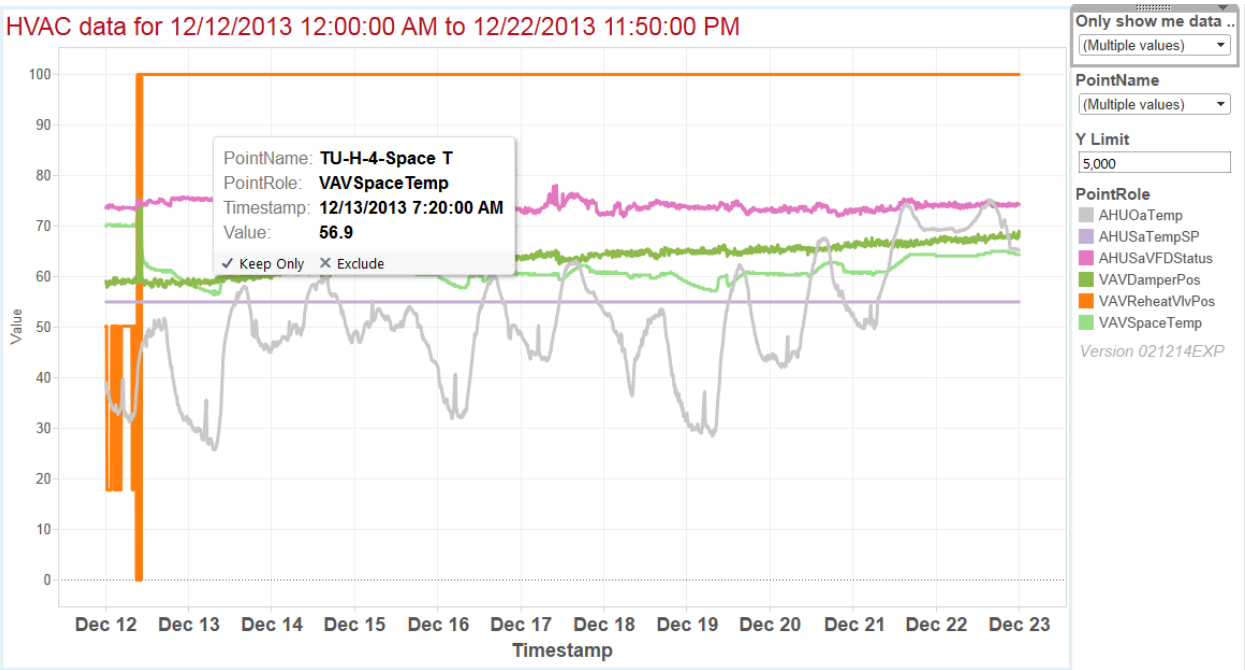

Figure 107: Behavior of Terminal Unit 4 from Dec 12–23, 2013

Figure 107 shows that Terminal Unit 4 behaves very differently. In this case, the temperature is being maintained considerably below normal comfort levels, as low as 56.9 degrees at the selected point. However, the Reheat Valve has opened to 100% and remained open for a long period. Thus, the heating and cooling are fighting each other.

In the images above, showing days in December of 2013, we see that:

- The space temperature affected by TU-H-8 is being maintained at slightly above the typical setpoint for this building. (72-75 degrees F). During many parts of the day, the demand for cool air to this space is very high, independent of Outside Air temperature. This is evidenced by the damper position at 100%.
- Conversely, the space temperature affected by TU-H-4 is barely being maintained at 60 degrees F, and significant re-heating is being called upon except when OAT is higher than 50 degrees F.

Many of the terminal units are demanding reheating (heating valve open) a significant amount of the time. However, an investigation of the HotWaterSupply shows that the hot water valve from the central plant is not open and thus no heating is being delivered. The result is that the majority of occupants in this facility are uncomfortable. A few are too hot, but most spaces are too cold.

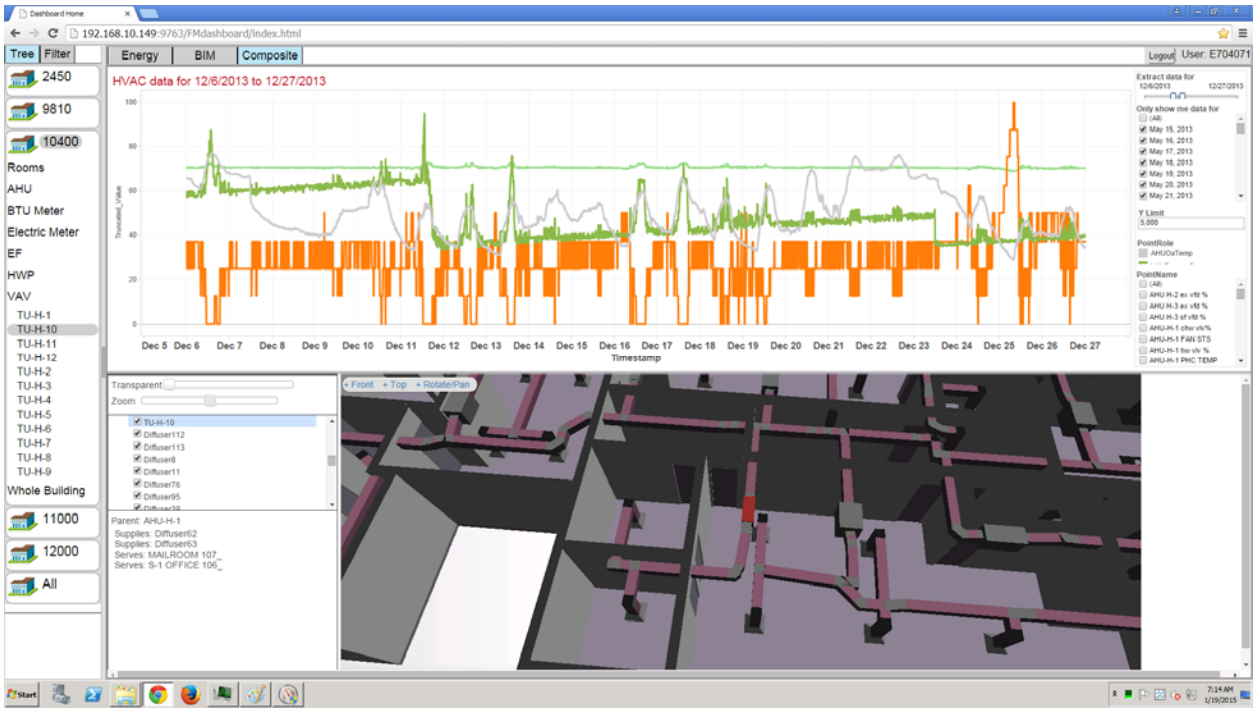

Figure 108: Behavior of TU-10

Figure 108 illustrates that the adjacent spaces to S-1 PAC 104 are over-served and nearly continuously requesting reheat. It shows space temperatures and reheating demands for most of the spaces in Building 10400.

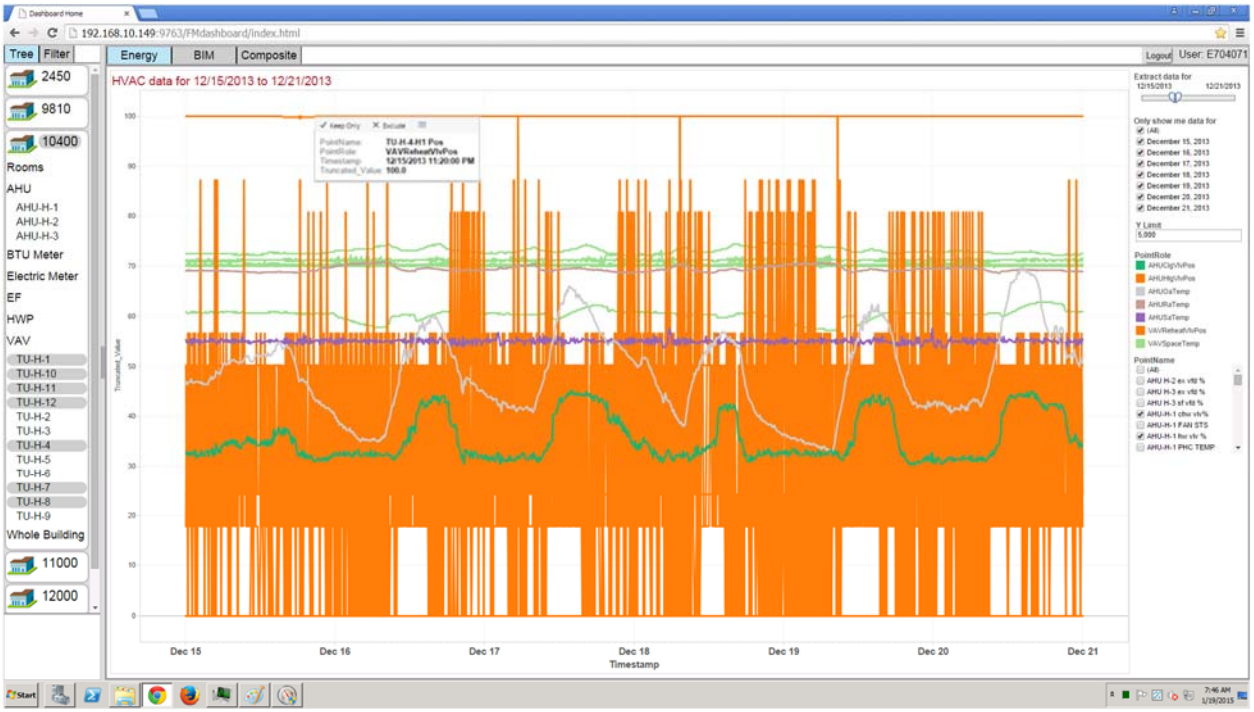

Figure 109: Building 10400 Temperatures and Reheating Demand

In Figure 109, the following features are notable:

- Reheating is occurring even during the warmest parts of the day, as well as overnight. The composite reheat demand is the prominent orange pattern.
- Several of the spaces run consistently higher than the 71º F at any time of the day, never achieving desired comfort settings. This is evidenced by the set of light green space temperature tends, most of which hover at 70 º F +/- 4 degrees.
- Several of the spaces are continuously colder than 71º F, despite calling nearly continuously for reheating. For one space, TU-1, the heating valve position is 100%, 100% of the time.
- One of these cold spaces, the space served by TU-4, appears to be a computer room as it maintains a significantly lower temperature than other spaces, around 70 º F. Figure 107 indicates that the TU-4 is demanding reheat for that space, while another dedicated system is attempting to cool it.
- Significant cooling is being supplied continuously throughout the building, as shown by AHU1's Cooling Valve position the green line that tracks outside air temperature (gray).

Figure 110 shows that HotWater was flowing from December through April, when the Hot Water Valve was closed (100% closed), and the temperature of the internal water flows dropped to ambient temperatures.

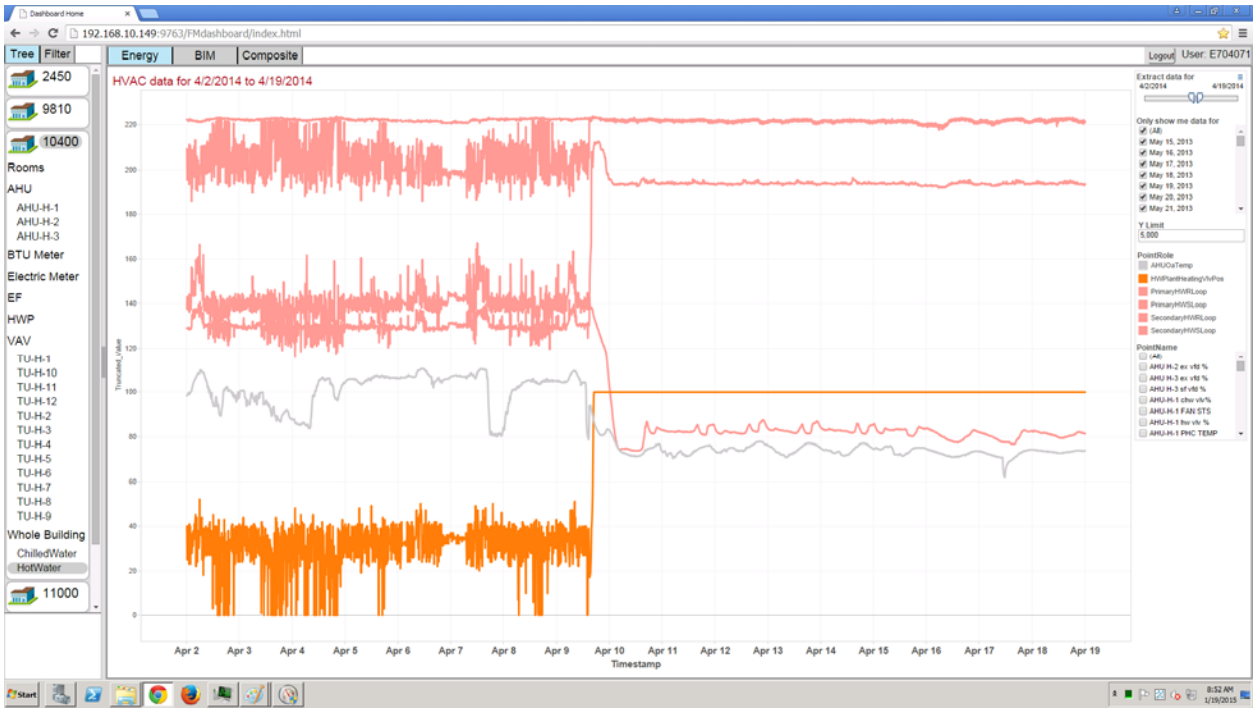

Figure 110: Central Hot Water flows for 10400

K. Building Manager Interview Responses

Building Use

Building/Role	Notes
9810 DPW	Building 9810 is largely civilian, and the occupants are not billed for energy use.
9810 Bldg Ops	**Occupants/Usage:** About 1/2 the facility is the Army Substance Abuse Program (ASAP), other 1/2 is a mix of services including the Red Cross, Army Family Assistance Program, WTU. It is an old Army Reserve building. **Schedule:** The building has normal operating hours of 0700-1700 Monday-Fridays, almost never open on weekends. On the ASAP side of the building, only about 24 people normally working. The other side of the building can have 200 people. There are a lot of offices built on non-ASAP side, that weren't in the original building design. The WTU will occasionally process people on weekends. There is a high volume event once per year, where samples are collected from all soldiers on the base. Note that there is a plan to make this building into post headquarters
2450 Bldg Ops	School house environment. 41 permanent cadre occupants. Beyond this, the load varies. **Schedule:** Classroom areas are only occupied Monday-Wednesday for training. Every other Saturday, they have a training class; otherwise, the building is unoccupied on weekends. There are usually 34-40 soldiers in these classes. Most soldiers are gone by 5pm on weekdays. **Control:** No local control, so these large spaces are unused but still fully controlled for comfort.
12000 Bldg Ops	**General:** This facility was renovated in November 2011, gutted and refurbished. **Usage/Occupancy:** This was the dining facility, but now has been split into classrooms. There are 19 classrooms on paper, but really only 4 that will fit a whole company (roughly 200 soldiers). There are typically 1250 trainees in the barracks during rotations and 140 permanent (cadre) staff. Chaplain uses large classroom for services. **Schedule.** The S-3 staff member schedules all of the classrooms. • A typical day is laid out as: 0545 Physical exercise, 0715 Completed, By 0800 showered and in uniform, always leave facility by 9am so the barracks are unoccupied during this period. Around 1700 return for dinner, dinner is complete by 1800-1830. • Training is usually 6 days per week. The classrooms are usually empty by 6pm each day. Saturdays have less physical training. Sunday is usually a day of rest, laundry, etc. • Training schedule runs through 3 phases: RED (3 weeks), WHITE (3.5 weeks), BLUE (4 weeks). Most classroom time is in the RED phase, by the BLUE phase, very little time in the classroom. • During week 8-9, the group is completely out of the facility.

Building/Role	Notes
	• Weekend usage of the classrooms is minimal. The chaplain uses the large classrooms; post uses the classrooms occasionally, maybe 5 times during 3 months. • Staff is always here, in the front part of the building.
10400 Observation	Building has large classrooms, intermittently used. Each one has a temperature and RH sensor. These rooms are 116A, 116B, 132A, 132B. There is local reheat for each classroom, one for each site.
10400 DPW	Building 10400 is officers, administration building. Was built in 2004. The main concern in this building is the soldiers that they are training.

Process

Role/Building	Notes
DPW	On the post, there are 100+ meters across the buildings. There are about 20 paying customers where the meter is used for costs. A few buildings do have more than one meter.
DPW	DPW head is able to see the servers in the Energy Center from his desktop.
DPW	The Garrison Commander is serious about improving energy performance.
9810 Bldg Ops	**Comfort/DPW interaction:** When the building is uncomfortable, we make a couple checks before issuing the hot/cold call with the DPW. We'll check the temperature, and check on the chiller -- then we'll call DPW. DPW sorts out whether this is their issue to address or not. When arriving at the building, the DPW representative will come to see Bldg Ops first. This facility has a long history of problems -- high humidity, mold issues.
12000 Bldg Ops	When making requests to DPW, we can make emergency calls for soldier comfort. Head of building ops will interact with the DPW as needed -- the S-4 staff member typically enters hot/cold calls into the system. Head of building ops will intervene when action is not being taken.

HVAC Use and Issues

Role/Building	Notes
DPW	• Fort Jackson uses the GFIBS system for tracking hot/cold & maintenance calls (SAP based). We received a snapshot of GFIBS data for the buildings we are monitoring. There is a closeout process in GFIBS, but from what we can see, the intermediate steps are not tracked. • As far as DPW knows, the primary plan with Noresco is to put in schedules. • DPW has EBI access to 8 buildings, can monitor trends & actuate valves remotely. Most of the EBI interaction deals with hot/cold calls.
9810 Bldg Ops	• Two chillers for the facility, about 50-60 tons each. • The building has heating and cooling issues. • Speculation that the controls weren't working right. DPW has been here frequently. Had to replace compressors, and recently replace condenser coils.
2450 Bldg Ops	• In the lab area, we have control over the heaters. The IR heaters work well in the winter, and in the summer we can open the doors, use swamp coolers and industrial fans. The fans that are there in the classrooms are really there for backup. • The side of the building with the broken A/C always had trouble keeping up with demand. • No hot water to the building has been a long term problem. They have a work order in to the DPW to fix this, but the DPW response has been slow.
12000 Bldg Ops	• The classrooms get really hot when soldiers are in class. Hallways tend to get uncomfortable as well. • Would be good to precool the classrooms to improve comfort.
10400 Observation	• A condensing unit is used for the server room only. This unit uses local thermostat control, and is probably a 2-3 kW electrical load. • One of the VFDs on both AHU-2 and AHU-3 was off (0%), when the supply fan was running at 60%. Both of these were in auto mode (why?). • AHU-1 supplies most of the building, AHU-2 supplies classroom 2 (132 A/B), AHU-3 supplies classroom 1 (116 A/B)

Energy Use/Conservation Efforts

Role/Building	Notes
DPW	• Act Earth signage minimally in the buildings, really not widely deployed. • DPW would like to identify the opportunities that are low hanging fruit, low cost. • To support DPW in reviews with the steering committee, it would be useful to have a comparison between buildings. DPW believes that competition would be a good idea. • Building managers have no real energy instruction yet. • The buildings typically only track energy consumption at the reimbursable level, don't really use the meters beyond reimbursables.
9810 Bldg Ops	• A green emphasis across the base. • We had an energy study done, using Hobo sensors. • As far as energy conservation, the Garrison Commander is responsible for all infrastructure. He emphasizes "being good steward of resources," and we are encouraged to be more efficient. It is most important to measure energy in $$, money really talks. • People make sure to turn out the lights.
2450 Bldg Ops	• Security lights were out for a couple of years. They are repaired now, and have a timer on them to control energy. • As far as energy conservation efforts, we do a pretty good job closing down the building. We try to keep doors closed when we can. Instructors have implied tasks for closing down a classroom when leaving.
12000 Bldg Ops	• There are potential energy improvements in this building, but really no incentives to improve energy consumption. • Heating/cooling is not shut down during the breaks between rotations. • **Lighting:** All lighting in the conference rooms is automated. • The barracks don't have any automated lighting.

L. RAW BLCC Data

NIST BLCC 5.3-13: ECIP REPORT (5 YEAR)

Consistent with Federal Life Cycle Cost Methodology and Procedures, 10 CFR, Part 436, Subpart A. The LCC calculations are based on the FEMP discount rates and energy price escalation rates updated on April 1, 2013.

Location:	South Carolina	**Discount Rate:**	0%
Project Title:	Model-Driven Energy Intelligence	**Analyst:**	Honeywell
Base Date:	September 1, 2013	**Preparation Date:**	Mon Feb 23 10:39:50 CST 2015
BOD:	September 1, 2013	**Economic Life:**	5 years 0 months
File Name:	C:\svn\ESTCP\ESTCP_Reporting\Final_Report\LifeCycleCostAnalysis\23FEB2015\EW-201263_LCCA_FinalReport_5yr(23FEB2015).xml		

1. Investment

Construction Cost	$112,600
SIOH	$0
Design Cost	$0
Total Cost	$112,600
Salvage Value of Existing Equipment	$0
Public Utility Company	$0
Total Investment	$112,600

2. Energy and Water Savings (+) or Cost (-)

Base Date Savings, unit costs, & discounted savings

Item	Unit Cost	Usage Savings	Annual Savings	Discount Factor	Discounted Savings
Electricity	$16.93192	8,992.5 MBtu	$152,261	5.096	$775,988
Natural Gas	$11.14070	4,822.6 MBtu	$53,727	5.710	$306,754
Demand Savings			$39,037	5.096	$198,951
Energy Subtotal		13,815.1 MBtu	$245,025		$1,281,694
Water Subtotal		0.0 Mgal	$0		$0
Total			$245,025		$1,281,694

3. Non-Energy Savings (+) or Cost (-)

Item	Savings/Cost	Occurrence	Discount Factor	Discounted Savings/Cost
Annually Recurring	-$123,600	Annual	4.845	-$598,800
Non-Annually Recurring				
Model Driven Energy Intelligence BIM generation	-$3,832	0 years 0 months	1.000	-$3,832
Non-Annually Recurring Subtotal	-$3,832			-$3,832
Total	-$127,432			-$602,632

4. First year savings	$120,658	
5. Simple Payback Period (in years)	0.93	(total investment/first-year savings)
6. Total Discounted Operational Savings	$679,061	
7. Savings to Investment Ratio (SIR)	6.03	(total discounted operational savings/total investment)
8. Adjusted Internal Rate of Return (AIRR)	43.28%	(1+d)*SIR^(1/n)-1; d=discount rate, n=years in study period

NIST BLCC 5.3-13: ECIP REPORT (10 YEAR)

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

The LCC calculations are based on the FEMP discount rates and energy price escalation rates updated on April 1, 2013.

Location:	South Carolina	**Discount Rate:**	1%
Project Title:	Model-Driven Energy Intelligence	**Analyst:**	Honeywell
Base Date:	September 1, 2013	**Preparation Date:**	Mon Feb 23 10:47:24 CST 2015
BOD:	September 1, 2013	**Economic Life:**	10 years 0 months
File Name:	C:\Users\E704071\Desktop\ESTCP_-LCCA\EW-201263_10YR_PROJ.XML		

1. Investment

Construction Cost	$112,600
SIOH	$0
Design Cost	$0
Total Cost	$112,600
Salvage Value of Existing Equipment	$0
Public Utility Company	$0
Total Investment	$112,600

2. Energy and Water Savings (+) or Cost (-)

Base Date Savings, unit costs, & discounted savings

Item	Unit Cost	Usage Savings	Annual Savings	Discount Factor	Discounted Savings
Electricity	$16.93192	8,992.5 MBtu	$152,261	9.888	$1,505,509
Natural Gas	$11.14070	4,822.6 MBtu	$53,727	11.908	$639,772
Demand Savings			$39,037	9.888	$385,989
Energy Subtotal		13,815.1 MBtu	$245,025		$2,531,271
Water Subtotal		0.0 Mgal	$0		$0
Total			$245,025		$2,531,271

3. Non-Energy Savings (+) or Cost (-)

Item	Savings/Cost	Occurrence	Discount Factor	Discounted Savings/Cost
Annually Recurring	-$123,600	Annual	9.188	-$1,135,585
Non-Annually Recurring				
Model Driven Energy Intelligence BIM generation	-$3,832	0 years 0 months	1.000	-$3,832
Non-Annually Recurring Subtotal	-$3,832			-$3,832
Total	-$127,432			-$1,139,417

4. First year savings	$121,042	
5. Simple Payback Period (in years)	0.93	(total investment/first-year savings)
6. Total Discounted Operational Savings	$1,391,854	
7. Savings to Investment Ratio (SIR)	12.36	(total discounted operational savings/total investment)
8. Adjusted Internal Rate of Return (AIRR)	29.89%	(1+d)*SIR^(1/n)-1; d=discount rate, n=years in study period

NIST BLCC 5.3-13: ECIP REPORT (20 YEAR)

Consistent with Federal Life Cycle Cost Methodology and Procedures, 10 CFR, Part 436, Subpart A, the LCC calculations are based on the FEMP discount rates and energy price escalation rates updated on April 1, 2013.

Location:	South Carolina	**Discount Rate:**	1.6%
Project Title:	Model-Driven Energy Intelligence	**Analyst:**	Honeywell
Base Date:	September 1, 2013	**Preparation Date:**	Mon Feb 23 10:45:47 CST 2015
BOD:	September 1, 2013	**Economic Life:**	20 years 0 months
File Name:	C:\Users\E704071\Desktop\-ESTCP_LCCA\EW-201263_20YR_PROJ.XML		

1. Investment

Construction Cost	$112,600
SIOH	$0
Design Cost	$0
Total Cost	$112,600
Salvage Value of Existing Equipment	$0
Public Utility Company	$0
Total Investment	$112,600

2. Energy and Water Savings (+) or Cost (-)

Base Date Savings, unit costs, & discounted savings

Item	Unit Cost	Usage Savings	Annual Savings	Discount Factor	Discounted Savings
Electricity	$16.93192	8,992.5 MBtu	$152,261	18.357	$2,795,005
Natural Gas	$11.14070	4,822.6 MBtu	$53,727	24.284	$1,304,680
Demand Savings			$39,037	18.357	$716,596
Energy Subtotal		13,815.1 MBtu	$245,025		$4,816,281
Water Subtotal		0.0 Mgal	$0		$0
Total			$245,025		$4,816,281

3. Non-Energy Savings (+) or Cost (-)

Item	Savings/Cost	Occurrence	Discount Factor	Discounted Savings/Cost
Annually Recurring	-$123,600	Annual	16.509	-$2,040,537
Non-Annually Recurring				
Model Driven Energy Intelligence BIM generation	-$3,832	0 years 0 months	1.000	-$3,832
Non-Annually Recurring Subtotal	-$3,832			-$3,832
Total	-$127,432			-$2,044,370

4. First year savings	$121,234	
5. Simple Payback Period (in years)	0.93	(total investment/first-year savings)
6. Total Discounted Operational Savings	$2,771,911	
7. Savings to Investment Ratio (SIR)	24.62	(total discounted operational savings/total investment)
8. Adjusted Internal Rate of Return (AIRR)	19.25%	(1+d)*SIR^(1/n)-1; d=discount rate, n=years in study period

M. South Carolina Rates

SOUTH CAROLINA ELECTRIC & GAS COMPANY — ELECTRICITY

RATE 24

LARGE GENERAL SERVICE
TIME-OF-USE
(Page 1 of 2)

AVAILABILITY

This rate is available to any customer using the Company's standard service for power and light requirements and having a contract demand of 1,000 KW or over. It is not available for resale service.

CHARACTER OF SERVICE

Alternating Current, 60 hertz, three phase, metering at the delivery voltage which shall be standard to the Company's operation.

RATE PER MONTH

I. Basic Facilities Charge:	$ 1,800.00	
II. Demand Charge:		
A. On-Peak Billing Demand		
1. Summer Months of June-September @	$ 16.78	per KW
2. Non-Summer Months of October-May @	$ 11.77	per KW
B. Off-Peak Billing Demand		
1. All Off-Peak Billing Demand @	$ 5.12	per KW
III. Energy Charge:		
A. On-Peak kWh		
1. Summer Months of June-September @	$ 0.08025	per kWh
2. Non-Summer Months of October-May @	$ 0.05826	per kWh
B. Off-Peak kWh		
1. All Off-Peak @	$ 0.04478	per kWh

BILLING DEMAND

The billing demands will be rounded to the nearest whole KW. If the power factor of the customer's current month maximum integrated fifteen minute KW demand for the on-peak and off-peak time periods are less than 85%, then the Company will adjust same to 85%. The maximum integrated fifteen minute demand for any period may be recorded on a rolling time interval.

For the summer months, the on-peak billing demand shall be the maximum integrated fifteen minute demand measured during the on-peak hours of the current month.

For the non-summer months, the on-peak billing demand will be the greater of: (1) the maximum integrated fifteen minute demand measured during the on-peak hours of the current month, or (2) eighty percent (80%) of the maximum integrated demand occurring during the on-peak hours of the preceding summer months.

The off-peak billing demand shall be the greatest of the following positive differences: (1) the maximum integrated fifteen minute demand measured during the off-peak hours minus the on-peak billing demand, or (2) the contract demand minus the on-peak billing demand, or (3) 1,000 KW minus the on-peak billing demand.

DISCOUNT

A discount of $0.60 per KW of on-peak and off-peak billing demand will be allowed when the service is supplied at a delivery voltage of 46,000 volts or higher.

DETERMINATION OF ON-PEAK HOURS

A. On-Peak Hours During Summer Months:

June-September:

The on-peak summer hours are defined as the hours between 1:00 p.m.-9:00 p.m., Monday-Friday, excluding holidays.*

B. On-Peak Hours During Non-Summer Months:

May and October:

The on-peak non-summer hours are defined as the hours between 1:00 p.m.-9:00 p.m., Monday-Friday, excluding holidays.*

November-April:

The on-peak non-summer hours are defined as those hours between 6:00 a.m.-12:00 noon and 5:00 p.m.-9:00 p.m., Monday-Friday, excluding holidays.*

C. Off-Peak Hours:

The off-peak hours in any month are defined as all hours not specified as on-peak hours.

*Holidays are: New Year's Day, Memorial Day, Independence Day, Labor Day, Thanksgiving Day and Christmas Day.

Effective For Bills Rendered On And After
The First Billing Cycle Of August 2012

MINIMUM CHARGE

The monthly minimum charge is the demand as determined above. The Company may allow a buildup period not to exceed six months for new and expanding accounts during which time the contract demand and/or the minimum demand specified in the rate schedule may be waived. The Company shall not commit itself to a buildup period exceeding six months without prior approval of the Commission for the specific account involved.

ADJUSTMENT FOR FUEL AND VARIABLE ENVIRONMENTAL COSTS

Fuel costs of $.03584 per kWh are included in the energy charge and are subject to adjustment by order of the Public Service Commission of South Carolina.

DEMAND SIDE MANAGEMENT COMPONENT

The energy charges above include a DSM component of $.00012 per kWh for Demand Side Management expenses.

STORM DAMAGE COMPONENT

Inclusion of a storm damage component has been indefinitely suspended until further order of the Public Service Commission of South Carolina.

SALES AND FRANCHISE TAX

To the above will be added any applicable sales tax, franchise fee or business license tax which may be assessed by any state or local governmnetal body.

PAYMENT TERMS

All bills are net and payable when rendered.

SPECIAL PROVISIONS

The Company will furnish service in accordance with its standard specifications. Non-standard service will be furnished only when the customer pays the difference in costs between non-standard service and standard service or pays to the Company its normal monthly facility charge based on such difference in costs.

TERM OF CONTRACT

The contract terms will depend on the conditions of service. No contract shall be written for a period of less than five (5) years. A separate contract shall be written for each meter at each location.

GENERAL TERMS AND CONDITIONS

The Company's General Terms and Conditions are incorporated by reference and a part of this rate schedule.