simuwatt—A Tablet-Based Electronic Auditing Tool

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Abstract

"simuwatt Energy Auditor™" is a new tablet-based electronic auditing tool that is designed to dramatically reduce the time and cost to perform investment-grade audits and improve quality and consistency. The tool uses the U.S. Department of Energy's OpenStudio modeling platform and integrated Building Component Library to automate modeling and analysis. simuwatt's software-guided workflow helps users gather required data, and provides the data in a standard electronic format that is automatically converted to a baseline OpenStudio model for energy analysis. The baseline energy model is calibrated against actual monthly energy use to ASHRAE Standard 14 guidelines. Energy conservation measures from the Building Component Library are then evaluated using OpenStudio's parametric analysis capability. Automated reporting creates audit documents that describe recommended packages of energy conservation measures. The development of this tool was partially funded by the U.S. Department of Defense's Environmental Security Technology Certification Program. As part of this program, the tool is being tested at 13 buildings on 5 Department of Defense sites across the United States. Results of the first simuwatt audit tool demonstration are presented in this paper.

1 Introduction

Energy audits provide valuable insights into site-specific energy conservation measures (ECMs). ASHRAE "level III" energy audits contain recommendations that can reduce the energy consumption of typical facilities by roughly 30% with a return on investment of less than 10 years (Brown & Dirks, 2011). As part of the overall goal of reducing energy consumption in federal buildings, the U.S. Energy Independence and Security Act of 2007 requires that federal agencies audit 25% of their covered facilities each year (United States Congress, 2007). Audits performed under this mandate are typically ASHRAE level I or II audits, and are estimated to cost the U.S. Department of Defense (DoD) \$0.10–\$0.15/ft^2 (NREL, 2012). Based on the 1.9 billion ft^2 of DoD facilities that are subject to this mandate, we estimate DoD spends \$47.5–\$71.3 million annually for these audits. This is a significant cost compared to the overall DoD facilities energy budget of \$3.9 billion/year to power, heat, and cool buildings (Office of the Deputy Under Secretary of Defense, 2012).

Much of the cost for an energy audit is due to manual processes in which highly trained personnel spend significant time transcribing data, gathering data on equipment, developing calculations, and writing custom reports. Non-standardized processes and reporting between auditors also make it difficult for building portfolio owners to reuse audit data and outcomes for other purposes such as asset management, energy planning, and capital expenditure planning. The simuwatt Energy Auditor™ tool (produced by concept3D, Inc.) provides a software-

guided workflow for data collection, stores audit data in a reusable format, and performs repeatable energy analyses using the U.S. Department of Energy OpenStudio modeling platform and EnergyPlus simulation engine. Component data and ECMs are pulled from the online Building Component Library (BCL) (Fleming, Long, & Swindler, 2012), which decreases audit costs and increases quality by standardizing modeling and analysis inputs for each audit. Once energy analyses are complete, an electronic report is automatically generated. This saves the auditor significant time and improves the consistency of reports delivered to the building owner. Figure 1 shows how these technologies fit together.

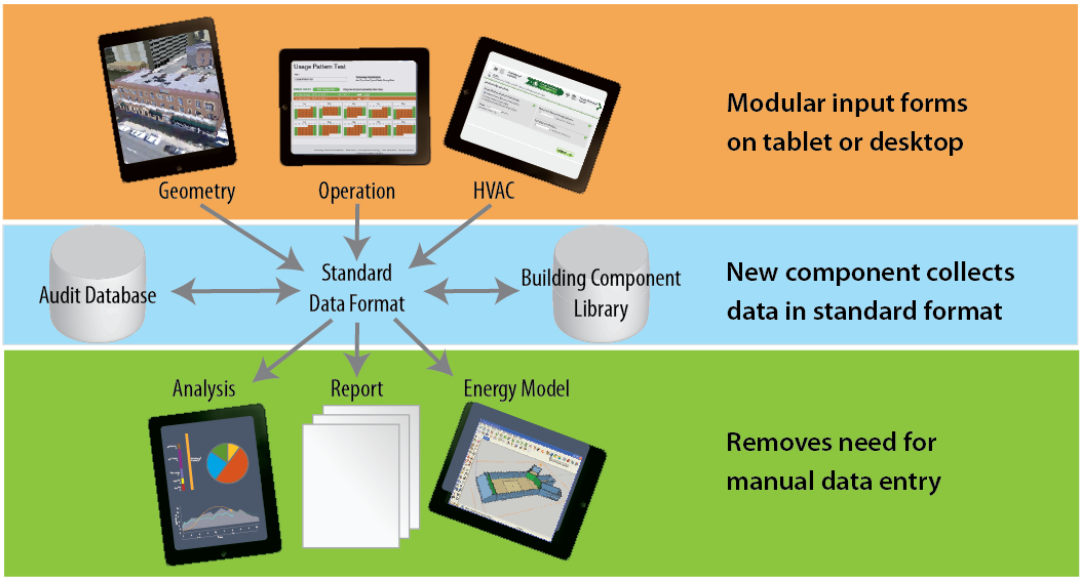


Figure 1: simuwatt Energy Auditor conceptual architecture

This paper describes the application of the simuwatt audit tool at the first demonstration site of DoD's Environmental Security Technology Certification Program (ESTCP), which helped fund its development and demonstration.

2 Initial simuwatt demonstration

2.1 Demonstration site

The first ESTCP demonstration site for the simuwatt Energy Auditor tool was a 9,790-ft^2 military fire station in Colorado Springs, Colorado. The building has a 4,240-ft^2 vehicle bay (see Figure 2), where vehicles and other firefighting equipment are stored. The rest of the building includes offices, living, and other spaces to support firefighting operations. The building is occupied 24 hours per day year round. The vehicle bay area is heated with ceiling-mounted gas unit heaters. The remainder of the building is heated and cooled with a constant air volume (CAV) system with hot water heating and direct expansion cooling. Members of the National Renewable Energy Laboratory's (NREL) commercial building and deployment teams worked with developers from concept3D to perform a simuwatt audit of the building.

Figure 2: Initial demonstration site

2.2 Geometry and location

Once onsite, the audit team used the simuwatt iPad application's drawing tools to define the building geometry, which provides a framework for physical data collection in the simuwatt workflow. The application screenshot in Figure 3 shows that the tool allows the user to trace a building's footprint from satellite mapping imagery, architectural plans, fire escape drawings, building automation system screenshots, or other images; and then to define spaces within the footprint for each level. The drawing tool provides automatic image rectification and snapping to points, lines, and perpendicular angles. In this demonstration, the auditors first traced fire escape plans and then used satellite mapping imagery to scale the floor plan to the correct size.

After the geometry was defined, the auditors created definitions for construction assemblies in the building. Opaque construction assemblies are defined by searching the BCL for common construction materials and then building them up layer by layer. Fenestration construction assembly definitions include complete glazing definitions from the BCL (e.g., double pane, clear glass) along with a frame type. Whole building constructions may be quickly specified by matching assembly definitions to surface types; e.g., all exterior walls. In this case, the exterior walls were constructed as an 8-inch layer brick, wood furring, and ¾-inch gypsum board. However, a construction assembly may also be manually assigned to specific surfaces (see Figure 4). This feature was used to apply the correct constructions for the metal rolling doors in the vehicle bay area.

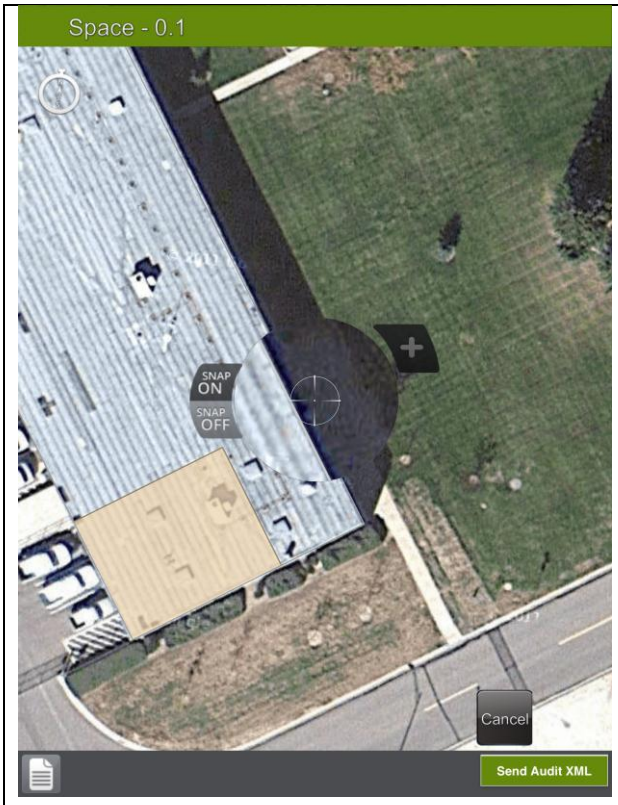


Figure 3: Defining building geometry

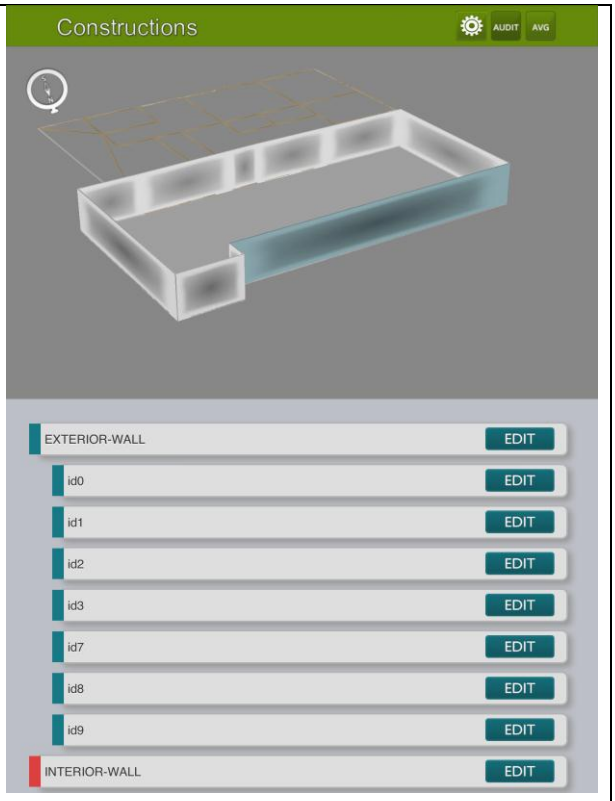


Figure 4: Assigning construction data to surfaces

2.3 Space type definition

After the geometry and constructions were defined, the auditors walked through each space to inventory the occupants (including activity level), lighting, and equipment. When the auditors encountered a new type of equipment; e.g., lighting ballast, they searched the BCL to find the best matching component. Figure 5 shows example BCL search results for magnetic, non-dimming ballasts. If an auditor cannot find a suitable match in the BCL, he or she creates a new BCL component and add it to a personal BCL account. Figure 6 shows a typical BCL component definition for a lighting fixture. As the auditors walk through each space, they can add counts of each type of lighting fixture to that space (see Figure 7). A similar process is repeated for occupants, equipment, and windows. As the audit proceeds, equipment counts per area are averaged across multiple spaces of the same space type to create building-specific space type definitions. These space types can be used for impromptu quality checking; e.g., assessing the reasonability of lighting power density for office space in this building. For larger buildings, they may also be used to save the auditor from having to inventory every space of a particular space type; a user simply specifies the space type, and indicates that the space should have the same average count per area as the other spaces of the same type where counts were taken. In addition to counts, occupants are interviewed and the building automation system scheduling is reviewed to determine occupancy and usage patterns. Resultant schedules are input using the simuwatt schedule tool shown in Figure 8.

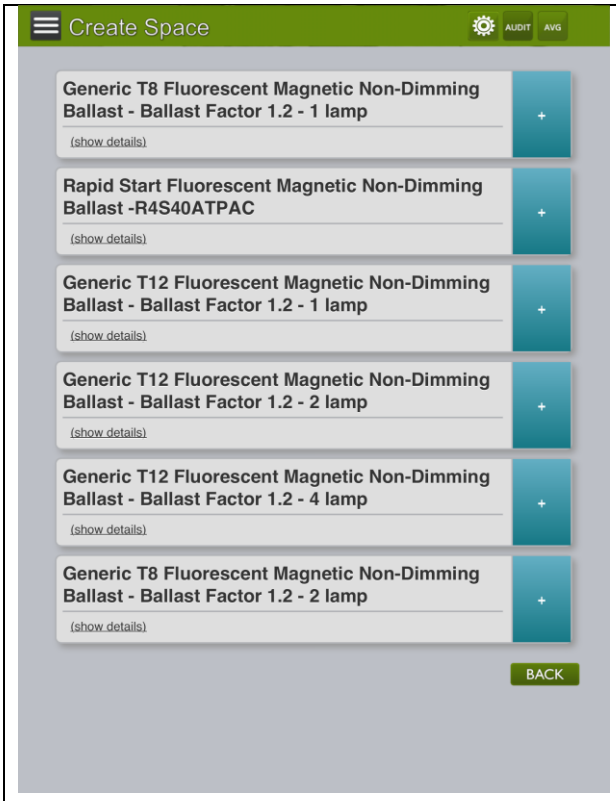


Figure 5: List of ballasts in BCL search results

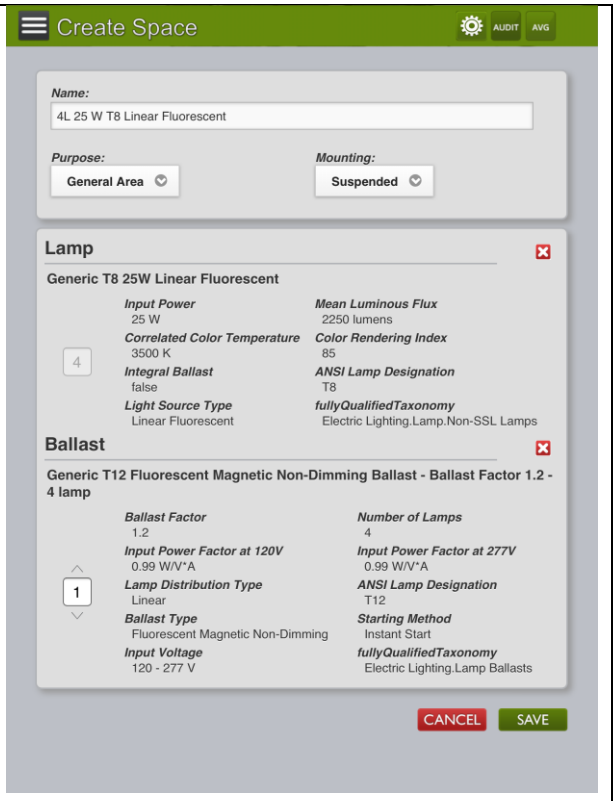


Figure 6: Light fixture definition using lamp and ballast data from BCL

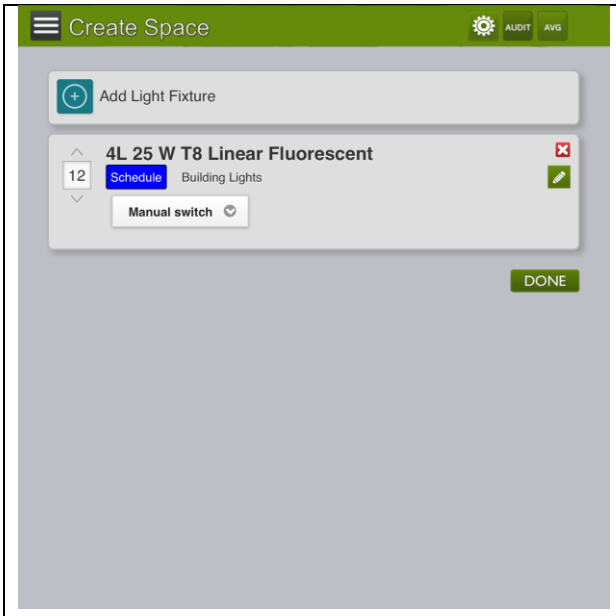


Figure 7: Number of light fixtures in specific space

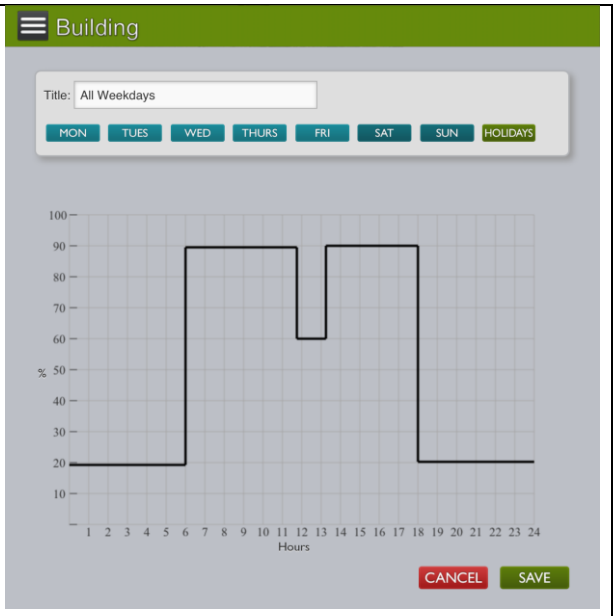


Figure 8: Lighting schedule

2.4 HVAC diagramming

After the space-level audit is completed, the auditors input details about the building's HVAC systems. simuwatt's HVAC interface is flexible enough to accommodate a wide range of systems. A "wizard" input form, partially shown in Figure 9, is used to create basic HVAC system structures. This structure is then populated with more detailed component definitions (see Figure 10). As with lighting and other equipment, the auditor searches the BCL for a suitable match for the specific equipment. If the equipment is not included, the auditor can define a new component and upload it to their personal BCL account. Finally, the auditor adds site-specific data to the BCL component.

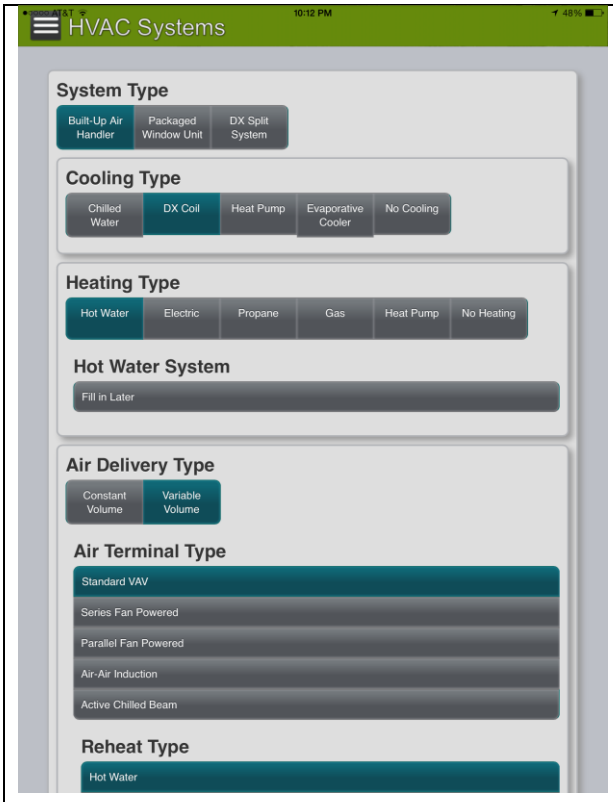


Figure 9: HVAC wizard interface

Figure 10: HVAC detailed interface

2.5 Conversion to OpenStudio model

After the physical audit is completed using the simuwatt app, a custom translator uses the input data to automatically generate a baseline OpenStudio energy model. The auditor can inspect and refine the resulting model using any OpenStudio application, including the OpenStudio Plug-In for Trimble SketchUp (Weaver, Long, Fleming, Schott, Benne, & Hale, 2012). Figure 11 shows the building described in the simuwatt audit tool. Figure 12 shows the data translated into an OpenStudio model and viewed in the OpenStudio SketchUp Plug-In.

Figure 11: simuwatt model

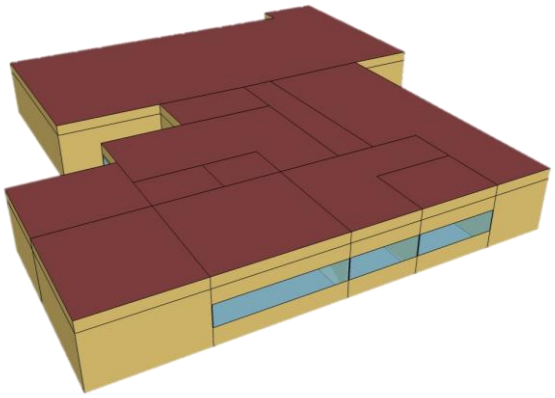
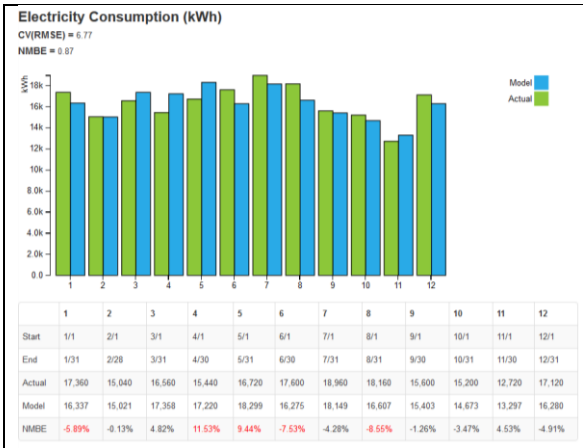


Figure 12: OpenStudio model

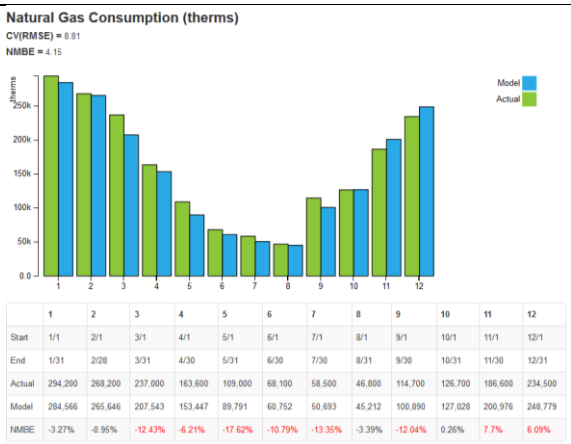
2.6 Model Calibration

After the initial OpenStudio model is exported, it may be calibrated to actual monthly utility data to ensure it is a reasonably good representation of the actual building so resulting recommendations will be also be reasonable. The simuwatt audit tool supports entering utility bill with arbitrary start and end dates, meaning the user doesn't have to move the utility data into monthly bins. Once actual monthly utility data are recorded, they can be compared to simulated energy use over the same time period (see Figure 13 and Figure 14). In this demonstration, the baseline simulation was run using an Actual Meteorological Year weather file purchased from Weather Analytics (Keller & Khuen, 2012) for the actual building location and spanning the same time period as the actual utility data. Several key parameters of the model were tuned based on knowledge of the building captured during the audit as well as professional experience of the NREL deployment auditor. These included lighting and equipment schedules, cooling and heating set points, outdoor air ventilation rates and infiltration, and equipment efficiencies. The details of this calibration process are provided in separate paper presented at this conference, (Hale, et al., 2014). The calibrated model fell within ASHRAE 14-2002 guidelines (ASHRAE, 2002), with coefficient of variation of the root mean squared error CV(RMSE) = 6.77% and normalized mean bias error NMBE = 0.87% for electricity use and CV(RMSE) = 8.81% and NMBE = 4.15% for natural gas use.



	1	2	3	4	5	6	7	8	9	10	11	12
Start	1/1	2/1	3/1	4/1	5/1	6/1	7/1	8/1	9/1	10/1	11/1	12/1
End	1/31	2/28	3/31	4/30	5/31	6/30	7/31	8/31	9/30	10/31	11/30	12/31
Actual	17,360	15,040	16,560	15,440	16,720	17,600	18,960	18,160	15,600	15,200	12,720	17,120
Model	16,337	15,021	17,358	17,220	18,299	16,275	18,149	16,607	15,403	14,673	13,297	16,280
NMBE	-5.89%	-0.13%	4.82%	11.53%	9.44%	-7.53%	-4.28%	-8.55%	-1.26%	-3.47%	4.53%	-4.91%

Figure 13: Comparison of actual with simulated electricity use



	1	2	3	4	5	6	7	8	9	10	11	12
Start	1/1	2/1	3/1	4/1	5/1	6/1	7/1	8/1	9/1	10/1	11/1	12/1
End	1/31	2/28	3/31	4/30	5/31	6/30	7/30	8/31	9/30	10/31	11/30	12/31
Actual	294,200	268,200	237,000	163,600	109,000	68,100	58,500	46,800	114,700	126,700	186,600	234,500
Model	284,566	265,646	207,543	153,447	89,791	60,752	50,693	45,212	100,890	127,828	200,976	248,779
NMBE	-3.27%	-0.95%	-12.43%	-6.21%	-17.62%	-10.79%	-13.35%	-3.39%	-12.04%	0.26%	7.7%	6.09%

Figure 14: Comparison of actual with simulated natural gas use

The total site annual energy use intensity of the calibrated model was 261 kBtu/ft^2, which is higher than the auditors initially expected. However, this does match the utility data provided by the installation and the building is occupied 24 hours per day year round. The annual electrical energy intensity was 19.9 kWh/ft^2 and the annual natural gas energy intensity was 1.93 therms/ft^2. Simulated annual end uses for the calibrated model are shown in Figure 15 and Figure 16.

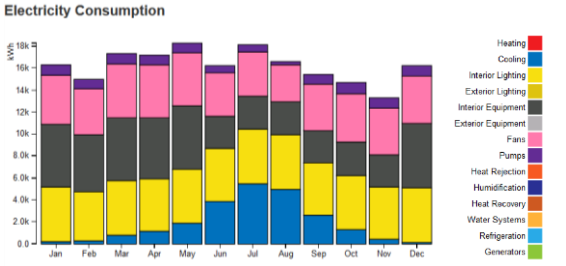


Figure 15: Simulated electricity end uses

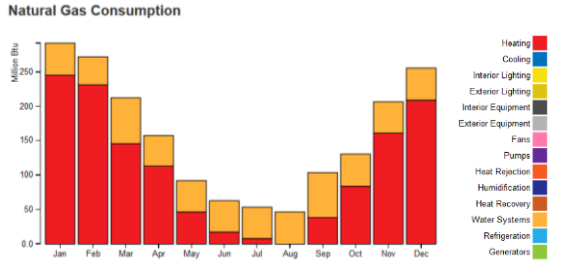


Figure 16: Simulated natural gas end uses

2.7 Energy conservation measure analysis

Once the baseline model is calibrated to actual utility data, it may be used by the OpenStudio Parametric Analysis Tool (PAT). PAT enables easy application of ECMs obtained from the BCL to the baseline model, and comparative analysis using local or cloud computing resources. OpenStudio measures are small Ruby programs that take user inputs and then modify an OpenStudio model in a specific and replicable way (Hale, Macumber, Benne, & Goldwasser, 2012). The PAT user interface allows the user to specify inputs for each measure, define design alternatives using combinations of measures, and then run multiple design alternatives. As described in (Hale, et al., 2014), PAT allows the user to simulate multiple design alternatives in parallel using Amazon EC2 cloud computing resources. Based on professional experience and observations during the audit, the NREL deployment auditor recommended considering the following measures:

- Implement Thermostat Setbacks at Night

- Improve Fan Drive Efficiency
- Install Low-Wattage T8 Lighting
- Replace Desktop Computers With Laptops
- Computer Power Management
- Convert CAV With Reheat to VAV With Reheat
- Convert Constant Speed Pumps to Variable Speed Pumps.

The NREL deployment auditor searched the BCL for a corresponding OpenStudio Measure for each of these ECMs. If the BCL had no suitable OpenStudio Measure, a member of the NREL commercial building team wrote one and added it to the BCL. The NREL deployment auditor then estimated cost and performance inputs for each OpenStudio Measure and entered these in the PAT interface (Figure 17). The specific example is named Improve Fan Drive Efficiency and models changing belts on supply fans for the main packaged VAV system from standard belts to cogged v-belts at a cost of $240 per fan.

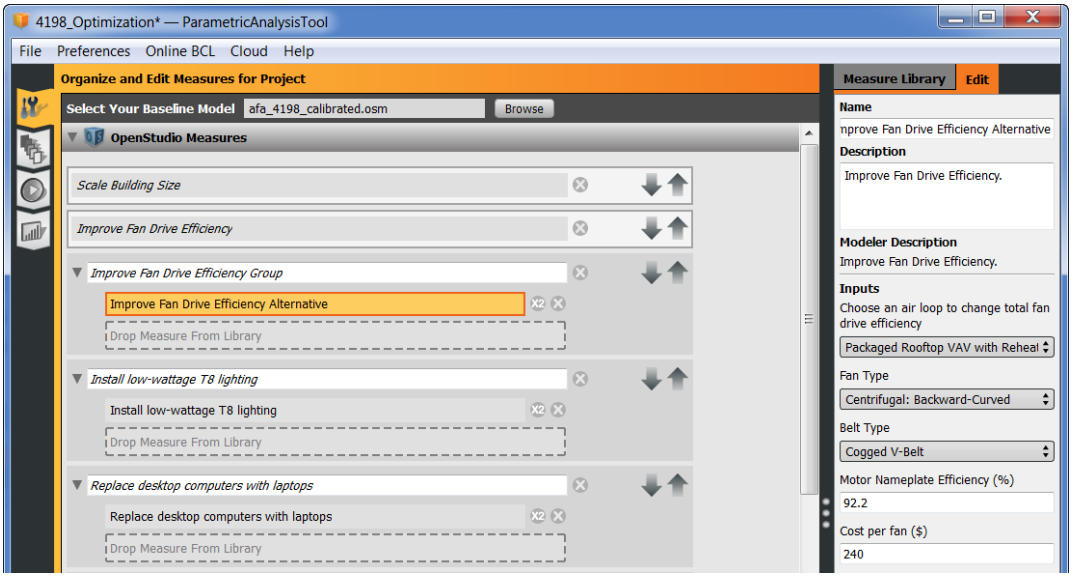


Figure 17: Entering cost and performance data using the PAT interface

Each measure was simulated individually to determine which had the best individual payback. After this initial round, ECM packages were created and analyzed. The energy savings and payback for each measure and package are displayed on the PAT results screen (Figure 18).

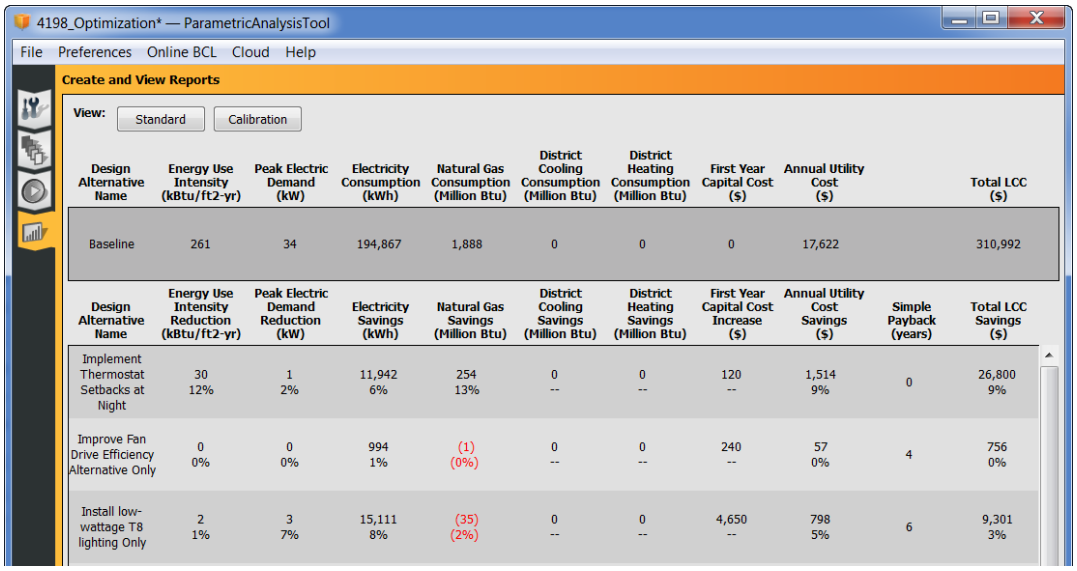


Figure 18: Simulation results

Table 1 summarizes the results for each measure and retrofit design alternative studied. Energy savings and simple payback time are shown for each measure and for each design alternative considered. The design alternative named "Recommended ECMs" includes all measures with simple paybacks of less than 15 years which includes:

- Implement Thermostat Setbacks at Night
- Improve Fan Drive Efficiency
- Install Low-Wattage T8 Lighting
- Computer Power Management.

The design alternative named "All ECMs" includes all measures considered.

Table 1: ECM Performance

Measure or Design Alternative Name	Site Energy Use Intensity Reduction (%)	Simple Payback (years)
Implement Thermostat Setbacks at Night	12	0
Improve Fan Drive Efficiency	0.1	4
Install Low-Wattage T8 Lighting	1	6
Replace Desktop Computers With Laptops	0.4	138
Computer Power Management	0.2	13
Convert CAV With Reheat to VAV With Reheat	3	35
Convert Constant Speed to Variable Speed Pump	0.01	129
Recommended ECMs	12	3
All ECMs	15	27

2.8 Report and recommendations

Once the parametric energy analysis is complete, the auditor exports an XML file from PAT that describes all the measures and packages considered. This file is uploaded to the simuwatt website, which combines the information in the XML with data collected on the mobile application and a Microsoft Word template to automatically produce a draft of the audit report. The draft report is generated in seconds, and includes relevant tables, charts, and other content harvested from the measures and analysis results. This frees the auditor from having to spend substantial amounts of time transcribing data, creating plots, formatting tables and charts, inserting general descriptions of ECMs, and other time-consuming tasks. An example table created by the report generator is shown in Figure 19.

HVAC & DHW Efficiency Measures

Name	Current Condition	Recommended Action
Improve Fan Drive Efficiency Alternative	The building has 1.0 fan system(s) with an average total fan drive efficiency of 0.709479	Improve Fan Drive Efficiency.
CAV with Reheat to VAV with Reheat Air Handler	The building started with 1 CAV air loops.	Add a variable frequency drive (VFD) to the fan on the handler. In a constant volume reheat system, unneeded conditioned air is bypassed directly to the return air stream when the VAV boxes are throttled back. However, energy is still expended moving this air. Installing a VFD on the fan allows the system to lower the fan speed when less cooling is needed, minimizing the amount of air being moved and conditioned.
Constant Speed to Variable Speed Pump Alternative	The building started with 2 constant speed plant loops.	Convert constant speed pumps to variable speed pumps.

Figure 19: Table created by report generator

The final recommendation in this audit report was to implement all the ECMs in the "Recommended ECMs" design alternative. The analysis behind these recommendations showed the potential for 12% energy savings with simple payback in 3 years.

3 Conclusions

This initial demonstration of the simuwatt audit tool validated the concept of the software-guided workflow that includes data collection, automated modeling, ECM analysis, and reporting. The tool successfully captured geometry, location, space type, and HVAC details for the demonstration building. The resulting model was successfully calibrated to ASHRAE 14-2002 guidelines. Recommended measures were applied to the calibrated model and showed the potential for 12% energy savings with simple payback in 3 years. A draft audit report was automatically generated based on these results.

Because this was the first comprehensive demonstration of the approach, a number of software performance, user interface, and workflow issues were identified. Best practice recommendations for the new workflow were also identified; e.g., defining the geometry before the site visit can significantly reduce the time needed onsite. These improvements have been incorporated into the process along with other optimizations found during subsequent field demonstrations at 10 additional DoD buildings spanning 4 sites across the United States. The simuwatt and OpenStudio development team continues to work to streamline the overall process from data collection to report delivery. The ultimate vision is that the auditor should be able to use cloud-based resources for model generation, calibration, measure analysis, and reporting to provide initial analysis results and recommendations to the building owner before leaving the site.

The final demonstration audit for the ESTCP will measure time savings of the simuwatt audit compared to a traditional audit and is scheduled for late February 2014. In this demonstration, two teams from a major energy services company will audit the same set of buildings. One

team will use the simuwatt audit tool and the other team will use its current best practices. Results for this final demonstration will be published when they become available.

4 Acknowledgements

The authors wish to thank the DoD ESTCP for supporting this work as well as all the site personnel who assisted with this first demonstration audit. The authors also appreciate continued support from the U.S. Department of Energy's Buildings Technology Office, which has produced the underlying OpenStudio platform and BCL.

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