Rapid Energy Modeling and Range Analysis, The Value of a Highly Educated Guess

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ABSTRACT

One of the biggest barriers to successful discovery and implementation of energy efficient design measures for buildings is the difficulty of getting informative energy analysis results fast enough and cheap enough. This paper explores rapid approaches to energy modeling (REM) that involve minimal data inputs supplemented by intelligent assumptions and defaults, and early results range analysis to identify what is truly important.

George E.P. Box coined the phrase, "all models are wrong, but some are useful." Still, a common approach to improving models is to increase the precision of the model inputs; perhaps this is not the most useful approach. Even after significant effort, the results are very often still inaccurate when compared to real world buildings, as errors due to uncertainties and operational variations are still present. A skilled modeler can often manage these variations to produce an improved model, but this raises the question of scalability of the process as well as consistency and repeatability between modelers.

The REM workflow generates building energy models very quickly, using consistent, automated assumptions and range analysis to identify what really matters in a particular building. Results address the questions designers need to answer rather than attempting to create a perfect model of real world complexity. Coupled with range analyses (sensitivity and uncertainty analysis), answers to meaningful questions like, "What do I focus on next," or "Where are the building's problem areas," are answered quickly. The research investigated this technique on a sample of 23 government buildings, and then conducted a blind comparison to meter data to assess accuracy, usefulness and scalability.

Introduction

The energy consumed by facilities owned and operated by the U.S. Department of Defense accounts for approximately 80% of the total energy used by Federal buildings (DoD, 2005). The Department of Defense (DoD) measures energy success against regulations and mandated goals for energy reduction and sustainable facility management, including *Energy Policy Act* (2005), *Energy Independence and Security Act of 2007* (EISA 2007 and *Executive Order 13423*. In order to make consistent and well-informed decisions across its entire portfolio of buildings, DoD has a critical need for a consistent, scalable approach for evaluating energy consumption of existing facilities, to compare tradeoffs between energy conservation measures, and to identify facilities that are in greatest need of improvement. However, typical methods of building energy assessment for existing buildings are expensive, time consuming and require a high level of technical sophistication and expertise that takes years to acquire. Consequently, these methods are not scalable for large numbers of buildings.

Determining information about the energy use on military bases is challenging, as buildings have not historically been metered individually. Due to data quality issues and poor access to information, facility managers or resource efficiency managers have difficulty managing their building energy footprints and prioritizing energy retrofit budgets effectively. Typical approaches for rapidly assessing and benchmarking energy use and evaluating proposed energy retrofit measures often fail to acknowledge the complexity of buildings or identify key building performance factors that influence energy use and the effectiveness of retrofit decisions. More comprehensive energy auditing techniques, such as ASHRAE level audits are too costly and time-intensive and require a high level of expertise not widely available.

To address these challenges, Autodesk executed a demonstration of Rapid Energy Modeling (REM) workflows, a modeling process that leverages building information modeling (BIM) and conceptual energy analysis. The project investigated the hypothesis that REM is a viable and scalable method for rapidly generating consistent, repeatable, useful and cost-effective estimates of energy consumption for DoD buildings. The demonstration project used REM for a pilot-scale model of assessment over a one-year period using a sample of energy analyses from 23 buildings across eight different military installations. If successful, REM would provide the DoD numerous benefits, including the ability to: meet federal mandates, increase energy security, enhance the ability to prioritize energy efficiency retrofit projects, track energy use reductions, and manage facilities in new and cost-effective ways. The field demonstration provided lightweight Building Information Models (BIMs) and an easily scalable REM methodology for estimating energy intensity in DoD buildings, with the aim of identifying buildings that would be most responsive to improvements and exploring various Energy Conservation Measures (ECMs) for buildings.

The research methods compared the REM generated energy use simulations to a baseline of metered historical data. The time and cost to produce results with this REM approach were also validated and compared to the cost requirements for other approaches such as energy auditing. Also of note is that the project utilized new production software features, including model auto-zoning and range analysis to evaluate and prioritize ECMs.

Materials and Methods

One characteristic of the REM demonstration is a remote process to capture existing building geometry using satellite photos. Local weather data and the generalized operational and material characteristics for the specific building type and size are automatically appended to the geometry model to generate full energy models that can quickly estimate the expected energy use of the buildings. The effects of many building characteristics not readily identifiable from remote imagery are estimated using range analysis, as addressed below. The results of these useful initial models can help asset managers determine either which buildings are performing poorly compared to expected energy use or which models may be constructed improperly or in what ways the model may need further refinement.

The REM process can involve the following technologies:

- Autodesk® FormIt software is an iOS and Android operating system application for creating 3D models. FormIt captures existing building conditions using satellite images from Google and allows users to create a 3D geo-referenced building model with smart automatic zoning while in the field. The model can be brought into Revit for additional refinement and energy analysis.

- Autodesk® Revit is a Building Information Modeling (BIM) software application with integrated energy and carbon analyses driven by Green Building Studio and DOE 2.2. REM can be completed entirely in Revit, including 3D modeling, designating energy settings, energy analysis using the GBS web service, and viewing of ECMS range analysis using the Potential Energy Savings charts and other energy reports.
- Autodesk® Green Building Studio (GBS) is a web service that runs whole-building energy simulations using the DOE-2.2 engine, typically on models submitted through Revit. This service utilizes modeled global weather data automatically selected for the imported utility data period, generates whole building energy analysis reports with comparisons to imported utility data, and preserves analysis results in a user's GBS online account for further reporting and use. The service also creates multiple automatic simulations exploring potential energy savings and raw results from models using variations of multiple building parameters.

The REM workflow involves three stages: (1) capture of existing conditions, (2) conceptual modeling of building masses, and (3) comparative analysis using results from Green Building Studio. The energy results of these building analyses are represented as annual and monthly energy use and costs for natural gas and electric, and energy use intensity (Figure 1).

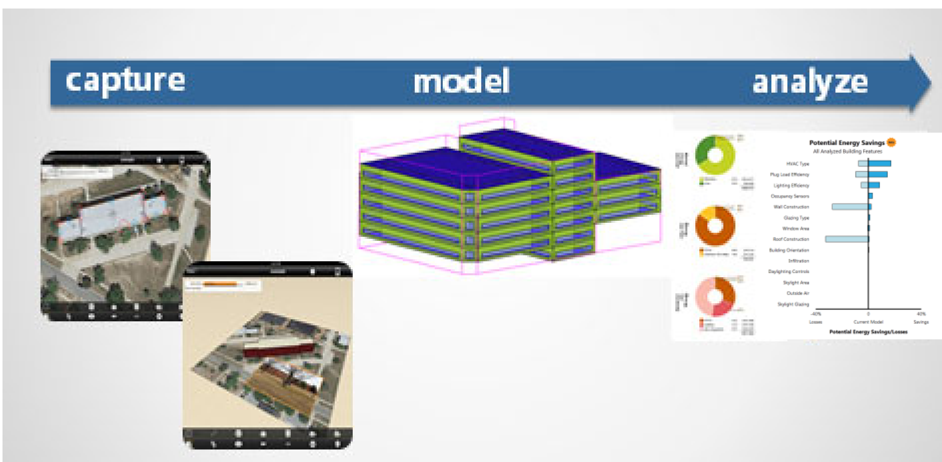

Figure 1. Rapid Energy Modeling (REM) technology components.

REM is proposed as an alternative to energy audits, and to less expensive benchmarking approaches such as Energy Star and CBECS that do not provide building-specific detail or opportunities for savings. These shortcomings limit their practicality for implementation across the DoD. It was beyond the scope of this project to understand the relative technical merits of these applications.

Using a semi-automated approach, REM provides an understanding of the sensitivities of building energy use to selected building attributes, as well as how this use differs from typical buildings. This approach allows one to focus resources on energy conservation work rather than model construction and iteration. The REM workflow can provide advantages for energy assessments by offering a level of detail not obtained through benchmarking and with significantly less cost than energy audits. A limitation is that Rapid Energy Modeling (REM) does not cover some aspects of a Level 2 energy audit (such as equipment inventories and estimating costs for ECMs), although it does include computer simulation often part of only Level 3 audits.

The list of detailed attributes typically required to be defined for the Level 1 or 2 energy audits is not necessarily derived from an understanding of the relative sensitivity of these attributes to energy model performance for a particular building. It is therefore difficult to understand consistently how much of a limitation it is simply to allow a particular attributes to be defined with default values. The REM approach tends to rely on "intelligent default" parameter values based on ASHRAE defaults, CBECS data, values reported in research papers, and expert systems developed by energy modeling professionals. The relative sensitivity and importance of selected parameters is shown using range analysis. The user enters only easily discoverable building parameters, such as critical building geometry, building use categories, glazing ratios, general schedules.

Accurate modeling of building systems is an important factor in developing useful energy models. Several inputs to the energy model in the case of REM are driven by observations from satellite/aerial imagery and survey responses from building managers. Building (or design) and operational attributes of a particular building that are not properly identified by these sources can of course impact modeling results. This is not a limitation unique to REM, but a limitation with simulation and model definition in general. The downside to focusing on refining these building systems and their operation would be that they add a high level of detail to the process, whose goal is to remain rapid and agile, and the information is often not forthcoming or accurate even from those with the best available information. Instead in REM, range analysis provides an understanding of the sensitivities of building attributes, and points to areas where more focus would be useful, and areas where it would not.

Because REM defaults are based on assumptions derived from existing buildings, and the analysis assumes that the subject buildings are operating correctly, the results of the analysis are useful in developing a starting point to understand differences in how the study building is performing and why.

Constructing the initial model using REM can yield substantial time savings versus initial model creation in tools such as eQuest or Energy Plus, which require that these details be defined in some way. REM techniques of remote geometry capture, intelligent defaults, and range analysis allow the analyst to focus their time on refining a model only for relevant parameters and to very quickly move the focus to analysis of conservation measures. Evaluators can look at their portfolio to find outliers, or they can prioritize retrofit budget on buildings and building characteristics where the investment can do the most. Engineers and energy analysts who want to do more detailed analyses can move REM data to eQuest or EnergyPlus for detailed work in those tools, where the additional required expertise and detailed inputs may have value.

Test Design

Researchers selected eight installations and 23 buildings in 5 climate zones (with a mix of heating dominated and cooling dominated) for inclusion in the core analysis of the study. This selection was based on the requirement by U.S. Army Engineer Research and Development Center-Construction Engineering Research Lab (ERDC-CERL), a partner on this project working via a cooperative research and development agreement (CRADA), that a minimum of 12 months of natural gas and electric interval meter data was complete and usable. Site visits included engagement with the installation Point of Contact (POC) and review of a completed energy questionnaire. Publication of installation locations and buildings are pending approval by the client.

This core analysis evaluated the technical performance and the analysis costs for estimating energy consumption of the buildings with a Rapid Energy Modeling (REM) simulation approach. These simulations were compared blindly to historical energy use information for the same buildings. The historical metering data was used as a reference condition to determine the technical performance accuracy of the REM method. ERDC-CERL requested building natural gas and electric meter data at the most granular level available from candidate installations. CERL then conducted a review of this data to ensure that at minimum there were 12 months of reliable natural gas and electric meter data for each building. A third party (ERDC-CERL) reviewed meter data received from the installations prior to comparison with modeled estimates. Several installations provided monthly totals instead of interval meter data as requested, thus in these cases few insights regarding accuracy of schedule assumptions could be gleaned.

Modeled energy results, and metered data were also compared to the US Department of Energy Index for Commercial Buildings, which leverages data from the Energy Information Administration (EIA) 2003 Commercial Buildings Energy Consumption Survey (CBECS) using the Building Energy Data Book tool (DOE, 2012). Relevant search criteria were climate zone and building type, followed by size and vintage if sample sizes were sufficient (n>10) to allow further refinement.

The inputs for the energy model were derived using satellite and aerial imagery and responses to the energy questionnaire, and focused on rapid baseline characterization of the building geometry, operations and systems. The REM workflow does not utilize floorplans or precisely modeled interior walls, opting instead for the automated ASHRAE standard perimeter-core space zoning simplification and a maximum width of the perimeter zone to minimize the error introduced by removing interior partitions. The REM models also do not designate different space utilizations within a building, opting instead for the simplified building type method; so buildings with different space utilizations (i.e. office and lab) are modeled as one building type, similar to the building-wide defaults methods vs. the space-by-space method recommended in ASHRAE 90.1. Though accurate modeling of interior spaces is possible with the software tools, this requires a significant time investment to collect, organize, translate building plans into the model, and would require additional expertise from DoD end users that is not scalable or cost effective. Building schedules are also assumed uniform throughout the building and are applied building wide rather than space-by-space. Researchers used information provided by installation staff to determine schedule selection in the modeling and energy analysis tools. Weather data was derived from modeled data from 3Tier available through the GBS service, and researchers assumed based on 3Tier documentation that weather data for the year of meter data submitted was not anomalous. Microclimate effects were ignored, and for the sake of this study, weather data sensitivity was not part of the study.

Energy use is a frequently cited metric for buildings, yet many DoD buildings do not have electric and/or gas meters installed, meters are not functioning, or data is not usable. In these cases, the response of managers must rely on the energy model results. Rapid energy modeling predicts how buildings should be performing, based on their unique geometry and location, and their generalized use profile, schedules, and construction characteristics for buildings of their type, size and region. Where model input parameters are unknown, intelligent defaults (as discussed previously) are used that are relevant to the building. This approach yields useful results for buildings even where specific information is not available. The REM results provide a rational baseline of information from which to make asset management decisions. A subset of five buildings was further processed with the design alternatives capabilities of Rapid Energy Modeling software tools in order to estimate how much energy could be saved by applying Energy Conservation Measures (ECMs).

Results

The Rapid Energy Modeling workflow proved reasonably accurate for estimating overall EUI for DoD buildings. Overall, the mean absolute percentage error (MAPE) for modeled electric results was 18.12% (n=23) compared to metered baseline data. Correlations in monthly energy use curves were evident in most buildings. Natural gas results for the 23 analyzed buildings had a MAPE of 41.80%. In general, the models appear to be less able to predict actual natural gas usage than electric usage in DoD buildings. However, the natural gas model results align closer with CBECS natural gas values than the metered natural gas values, so results may point to underlying material or operational characteristics of the buildings that differ significantly from normal buildings, which usually points to an opportunity to improve the building rather than the model. It may also be that, in contrast to electricity usage that results from more predictable end uses such as lighting, natural gas usage is sensitive to HVAC settings and usage scenarios that are more volatile. These unique settings such as hot water, heating, reheat, infiltration, mis-estimation of plug loads, very large process loads like a pool orcafeteria are not typically part of a rapid energy model

Overall, metered natural gas values are much higher than modeled values, with the exception of a LEED building, and two barracks buildings with questionable occupancy levels. In REM analysis, large differences between metered data and modeled data are accepted as useful results rather than modeling problems, and point quickly to either errors in the energy model or errors in building operation or commissioning. Most of the issues related to natural gas usage can be checked easily in buildings and are therefore good candidates for quick refinement of the REM energy model or can simply be used to recommend investigating retro-commissioning work. Further discovery of the specific sources of errors in these buildings was mostly outside the scope of this project.

EUI results had a mean absolute percentage error of 22.44% (N=23) compared to the metered baseline. The highest energy use, represented by EUI (kBtu/ft^2), was found in a cafeteria, barracks, and a gymnasium, all building types where gas is potentially a large and less predictable energy use component.

Table 1. Summary data for all analyzed buildings (n=23)

Statistics	Electric	Natural Gas	EUI
Mean Absolute Percentage Error	18.12%	41.80%	22.44%

In most cases, there was closer alignment of simulation data to CBECS results, and researchers attribute the deviation between the model and meter data to buildings that are performing worse than should be expected based on their characteristics, such as poor operation, equipment degradation, or unreported non-standard usage patterns. Since the goal of REM is to identify buildings where improvements could be made, discovering these errors is considered a useful result. To further explore the results, analyses were clustered by building use type and plotted against benchmarking results from the CBECS 2003 survey. Examination of this range of buildings improved the findings of the demonstration by making visible the trends within use categories. The various building types included 13 offices, 5 barracks, 5 special use buildings (fire station, gym, school, auto facility, and cafeteria). (Given confidentiality issues, buildings are referred to by their building codes without reference to the location.)

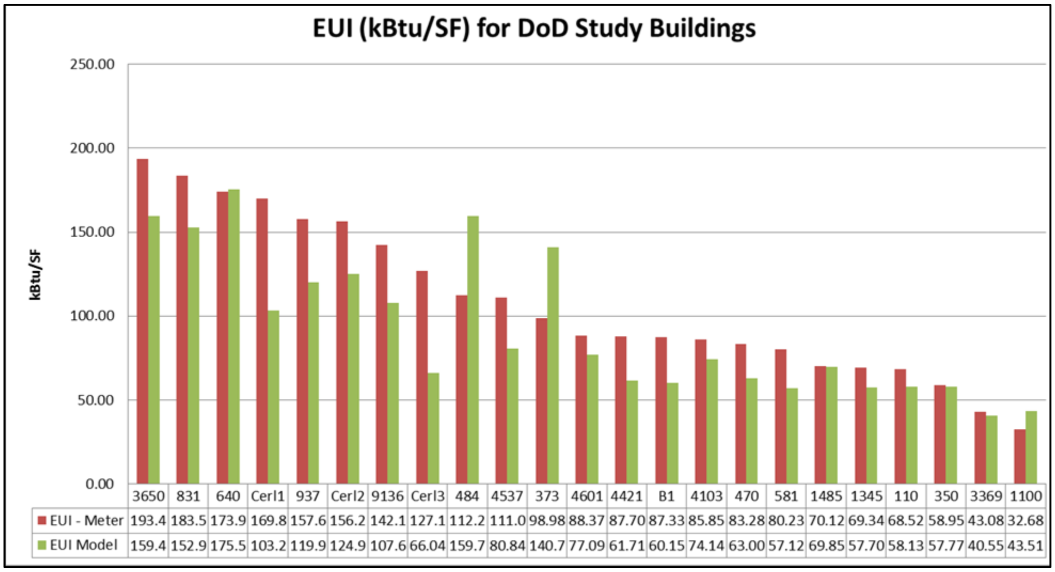

Figure 2. Summary data for 23 study buildings; Comparison of Meter and Model Data in Relative kBtu/ ft².

Offices, Barracks and Specialty Use Building Subsets

In total, 13 offices across seven Army, Navy and Air Force locations participated in the core analysis in the study. The offices ranged in size from 4,800 gross square feet to 281,732 gross square feet. The Rapid Energy Modeling workflow seems reasonably accurate for estimating overall EUI for DoD office buildings. The offices overall averaged a MAPE of 14.2% when comparing modeled estimates for electric data to electric meter data. While modeling results for electric use in offices aligned closely with actual metered usage, natural gas results for offices were on average a MAPE of only 50.52%. Since offices generally operate on more predictable schedules than specialty use buildings, accuracy of natural gas use due to building operations was assumed to be much better in offices. Therefore, the next area of inquiry for the office building type would be to look for non-standard end uses of natural gas.

In all cases, with the exception of one building in the larger set, natural gas meter and EUI data is higher than what was predicted in the models. While the possibility exists that differences could be attributed to natural gas use-related calculations in the models, it should be noted that in general, actual building natural gas usage and EUI were also significantly higher than CBECS values. Researchers attribute the deviation between the model, meter, and CBECS results to buildings that are performing worse than should be expected based on their location and attributes, poorly commissioned HVAC systems (e.g., concurrent heat or reheat and cooling), and unreported specialty uses in the buildings.

Modeled and metered electric results aligned relatively well with CBECS 2003 benchmarking results for office building. The mean absolute error for electric meter data compared to CBECS was 30.13% Natural gas meter data deviated greatly from CBECS with

MAPE of 122.44% while model data was closer aligned to CBECS with MAPE of 42.05%Of 13 offices sampled, the MAPE was 22.66%. Three office buildings were within 10% MAPE, and an additional three were within 20% MAPE. With the exception of one building, all other office buildings had EUI meter data that was higher than predicted EUI for each building.

Of 23 buildings analyzed, five were barracks ranging in size from 25,349 GSF to 96,130 GSF. There were an additional four barracks sampled that were not included in core analysis due to questionable meter data. Overall, barracks electric estimates showed on average a MAPE or 26.75% when compared to meter data. Modeled natural gas predictions averaged a MAPE of 43.34%, including an outlier of 179% error, where the model predicted much higher gas usage than was evident in the meter data. With this outlier removed, natural gas accuracy averaged a mean absolute percentage error of 26.07%.When all five barracks were aggregated, energy model predictions were on average a MAPE of 29.88% for EUI predictions.

Barracks were assumed by defaults to be 100% occupied throughout the year, and this is not a reasonable assumption for the building type upon reviewing the meter data. Detailed modeling to account for this schedule difference was outside the scope of this project. CBECS data for barracks was not useful for comparisons due the small sample of barracks in the 2003 CBECS survey. As a result, CBECS values are based on larger criteria of "lodging" within each climate zone in order to have sample sizes >10 for CBECS values.

The REM workflow is a reasonable approach to predicting electric, natural gas and EUI in barracks buildings that have consistent occupancy throughout the year. Variable occupancy can skew the data significantly. Reduced occupancy levels can be varied in Green Building Studio (GBS) (i.e. 75% occupancy, 50% occupancy) or by exporting the REM model for detailed energy analysis in tools like eQuest or EnergyPlus; however, seasonality of reduced occupancy cannot be accounted for directly in the REM model. Given the highly variable nature of DoD barracks and lack of available information on occupancy levels through the year, the REM workflow for barracks may not be ideal, unless users are comfortable with the assumptions described above.

In addition to offices and barracks, researchers sampled five specialty use buildings including a dining cafeteria, school, fire station, automotive facility and a gym. All buildings were under 45,000 GSF. Overall, energy models for these aggregate specialty use buildings showed a MAPE of 19.42% for electricity estimates. Energy models showed a MAPE of 29.20% for natural gas predictions. Overall, specialty use building energy models were an average mean absolute percentage error of 14.42%. for predicting EUI.

In summary, the REM workflow appears to be a good method for predicting electric usage and a reasonable method for EUI predictions for DoD office buildings when looking at mean absolute percentage errors for the pooled set of office buildings. The high variability in natural gas results for individual buildings and overall mean absolute percentage error for gas use for the pooled set of office buildings needs further investigation, but these results offer a rich area of inquiry for retrofit and retro-commissioning considerations. DoD office buildings are consuming significantly more natural gas and have higher EUI values than predicted by the models and compared to similar buildings in the CBECS database.

Deviations may be attributed to operational and mechanical issues at the individual building level, or they may be due to faulty meter readings, weather anomalies, or unreported conditions at the sites. Next steps should include working with individual building managers to investigate only the particular operations, system configurations and settings identified as important by range analysis, and to explain spikes in usage or other anomalies between modeled and metered data by exploring systems typically involved in the anomalous data.

Range Analysis

A subset of five buildings was selected where comparison results were within 20% CVRMSE for monthly utility costs (better than the prescriptive Whole Building Approach per ASHRAE STD 14), and design alternatives for energy conservation were explored for these buildings. Potential Energy Savings (PES) range analysis tables and charts automatically generated in Green Building Studio (GBS) were used to visualize both the sensitivity of a particular building characteristic and to evaluate the potential effectiveness of Energy Conservation Measures.

For professionals working to reduce a building's energy use during conceptual design, the Potential Energy Savings chart is a tool to focus their limited time on only the features of the building's design, construction, and systems that can save the most energy. For existing building projects such as this REM analysis project, the PES helped to identify what building features are most sensitive, and therefore which may lead to modeling errors if not defined properly, or will be good retrofit candidates. The chart is first used to inform the next level of inquiry for any calibration work. If the analyst is satisfied with the model results, the second reading informs which buildings and building characteristics have the most potential for improvement.

The Potential Energy Savings Analysis works in the following way (see Figure 3):

- GBS receives the model, which contains any specific building feature design options defined in the Revit platform. For any building features that were not specified, GBS inserts appropriate default values for the building type and location and runs energy analysis
- GBS then generates 50 alternative design variations in the cloud with multiple options for each of 14 building parameters. The results of the 51 simulations are displayed in the Potential Energy Savings chart with the center line reflecting the initial or baseline run

Potential Energy Savings Charts were automatically generated from 23 baseline building models to make the process to prioritize energy efficiency easier. Results from an example building are summarized in figure 3. The PES is still in beta, and research done with this study will help to inform further development. Initial recommendations include running analyses on more refined characteristics of HVAC systems, more operational parameters such as occupancy and schedules, weather variations, and allowing users to select parameters.

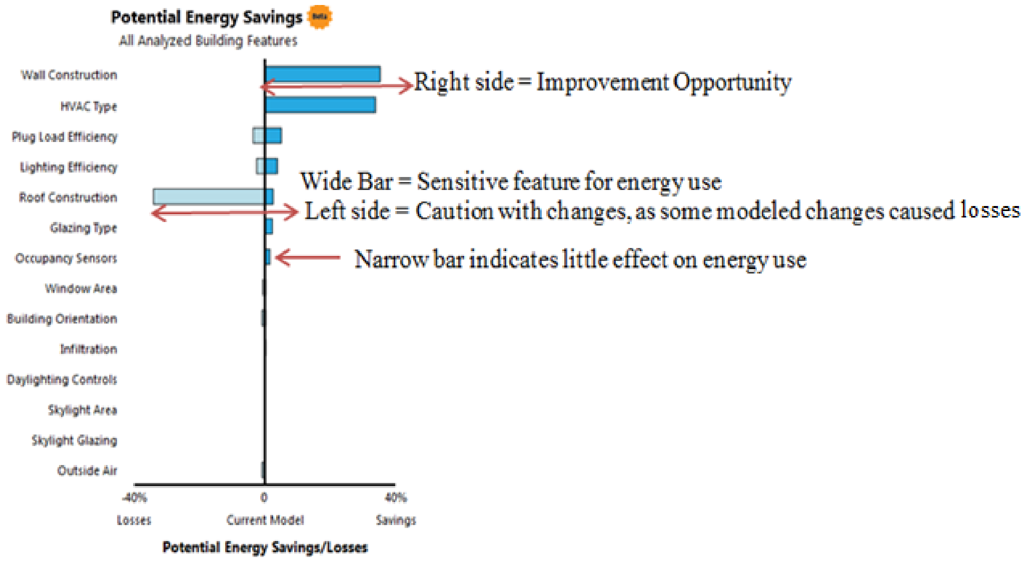

Figure 3. Potential Energy Savings Range Analysis Chart for Building 2; description of results.

Time and Cost to Rapid Energy Model

While constructing BIM models, researchers documented the time required for model creation and energy analysis and compared the time required for each workflow. These time-based tests were completed after a significant period of testing and workflow refinement. The workflow required an average of 17.81 minutes (SD=5.87), using a typical laptop computer including time for model creation, energy analysis and display of the energy reports.

Given the data above, it can be assumed that conceptual energy models and analysis can be executed in one hour or less in most cases. It should be noted that this assumes a remote approach (without a site visit), and does not include time required for installation personnel to answer questions regarding building characteristics and operations. For the purpose of this study, the questionnaire was developed with the intent that the average time required for completing the questionnaire should be approximately 3 hours.

Existing methods employed by the DoD to measure energy consumption and building performance has historically been limited to benchmarking or energy audits. Reported costs for energy audits may vary from $0.12 up to $0.503 per square foot, depending on the size and complexity of the building (Baechler et al. 2011). For the purposes of this study, researchers used the low-range estimate for Level 2 audits. In this study of 23 buildings comprising 1,497,275 ft^2 of conditioned space was modeled. This yields a low-end cost of $179,673 using the value of $0.12 per ft^2 to conduct a Level 2 audit on the population of the studied REM buildings. In comparison, applying the REM process to this population of buildings yielded $0.005 per ft^2 for a total cost of $6,900 to conduct the REM process on the total population of 23 buildings, comprising 1,497,275 ft^2. This represents cost savings of 96.17%. With an assumed time requirement of three hours per building (include survey collection, modeling, and energy analysis), REM provides a significant opportunity for time savings (87.5% low-end, 96.25% high-end) compared to Level 2 auditing approaches which may require 3-10 days.

Researchers are not recommending a wholesale replacement of ASHRAE audits for all DoD facilities, but given the time, expense and expertise required for full ASHRAE audits, REM approaches should certainly be used at early stages of energy analysis to determine which buildings are: poorly performing, the best candidates for retrofits, and may present the best potential opportunities for energy savings. Using REM also provides the added benefit of computer simulation and modeled comparison of energy conservation measures not typically provided by a level 2 audit. REM has also been useful in augmenting audits or detailed models, by quickly highlighting where energy use may be sensitive, identifying where more information should be collected in the audit, highlighting where more focus should be given in the detailed energy model, and identifying where metered data may be faulty.

Discussion

From this project, the REM process has proven to be useful in making energy management decisions. Personnel with little expertise in energy analysis can accomplish the REM process, saving labor cost and increasing the ability to scale. These benefits of REM mean this process can be more cost effective than conducting typical Level 2 audits. With more individuals doing energy assessments, the number of buildings studied can also increase. REM may also precede the standard energy audit process to act as a triage with justifiable recommendations to select the high priority buildings for more detailed study, meaning the typical Level 2 audit process can be conducted with more efficiency and where most effective. With the ability to compare the relative merits of a variety of modeled ECMs, unlike an audit the REM process can act as a quick proxy for informing installations where to concentrate BLCC project cost studies and follow-on detailed actions.

There were several issues in implementation of the project related to comparison of model estimates to meter data. Often the meter data did not exist or was unusable, and there were concerns with the quality of meter data at DoD buildings. Though meter data is germane to the assessment this demonstration pilot as a blind study, it is less significant in future use of REM, which does not require meter data. Meter data does not affect the recommendations of ECMs directly, as ECM recommendations are not based on meter data being available. Indeed, REM helped identify meters that were not functioning correctly. If meter data is available, it increases the transparency of the modeled energy performance of a building and can supplement the ECM decision process in support of the REM ECM recommendations. The results of this project recommend REM as a method to improve DoD building data availability considering the difficulty with the current building energy meter deployments at the Department of Defense.

The recently added Potential Energy Savings (PES) Range Analysis feature within the REM software (Green Building Studio) allows multiple simultaneous energy simulation runs, each varying values for building features. This offers significant benefit in that it automates initial exploration and identification of energy sensitivity and ECMs, allowing users to quickly identify which building parameters have the most influence on energy model results as well as energy consumption and the highest opportunity for potential energy savings. The current project used a beta version of the PES tool, which ran 50 different building simulations. The production version released since this project utilizes 37 parameters and tests extreme values against the baseline mode in the initial model. This format can provide teams with a high level understanding of PES the building energy performance to each measured parameter and can provide a great deal of insight on building sensitivity to various parameters of the buildings performance. Further low-level user control of the input parameters used in the PES is recommended for future improvement of the tool to improve its usefulness for both model calibration and retrofit analysis work.

Electric results were consistently higher in accuracy than gas or EUI results and researchers recommend further exploration around gas results. The project's performance metrics provided insight on accuracy and deviations; however, the close correlation of monthly energy use curves (summarized in full report to be published at a later date) and building use categories provide greater insight on accuracy of results and on variations throughout the year. Deviations observed between meter and modeled data can be used to identify which buildings are not operating as expected and should be prioritized for further investigation and considered for retrofits.

While the technology is new, this process utilizes a category of software tools that are familiar to facility asset managers (Google Earth and CAD/BIM software). The learning curve for this technology is measured in hours, and the startup fees are low. Initial cultural indications are that this method is well received at the installations. This provides support that this technology can be used in production at the installations and move beyond its current prototype status. Future technical studies of REM may prove useful, for instance examining connections to operational asset management and real property databases systems such as U.S. Army Corps of Engineers Builder software, the Military Health Service Defense Medical Logistics Standard Support System (DMLSS) or the Air Force Geo-base system. With these systems, operational, material and geometric attributes of the model may be effectively loaded without operator input, scripting the data-loading phase could scale the process exceptionally. With integration of these systems, the REM process could prove more efficient by working within the context of the daily activities of the installations and would allow for REM analysis on the entire installation at once. This would allow installations to have Energy Independence and Security Act (EISA) type reporting information for the entire energy modeled installation inventory each year, as opposed to 25% annually in current mandates.

Rapid Energy Modeling is a technique that has the potential to help DoD scale energy assessments across the building portfolio, determine which buildings in the portfolio present the best opportunity for retrofits, quickly evaluate relative benefits of energy conservation measures through auto-simulation of potential energy savings, and contribute to energy and cost savings for the DoD. The REM workflows will allow DoD facility managers and energy managers to quickly create building models based on limited information, rapidly assess which buildings are using the most energy, and generate reports. Additionally, using the PES chart and automatic range analysis, staff can quickly see sensitivity of the building to changes in parameters, and the comparative energy cost value of modifications to HVAC, roof, walls, windows, lighting, equipment, etc. REM results can also help energy managers to make informed decisions about which buildings can benefit most from energy retrofits, and may be the most practical to meter and audit in more detail. REM is a technique that offers quick insights from both well-calibrated results through the PES range analysis, and less well matched results such as the natural gas predictions that, with intelligent defaults and range analysis results, point out areas where additional review of building use and commissioning are called for. REM can be immediately useful in estimating electric use, EUI, and evaluating opportunities for energy savings. REM workflows can help scale energy analysis throughout the DoD at a pace that is >90% faster and 95% less expensive than ASHRAE audits. This technique can help DoD to meet existing energy auditing and energy management reporting requirements including EISA 2007.

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