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ABSTRACT

The paper describes the application of a methodology and tools for early assessment of integrated system solutions for deep retrofit with a potential of 30-50% energy reductions across large building portfolio as well as at an individual building scale using information only about building characteristics, usage type and climate. The building energy consumption is estimated using a simple building description, and then the impact of energy conservation measures (ECMs) are estimated individually and in combination as integrated system packages. We demonstrate the tool application with two types of cases from the Department of Defense (DoD) real property database. The results illustrate both statistical analysis of the potential for deep retrofits at DoD portfolio level, which comprises nearly 250,000 facilities in the U.S., and also for a few representative existing DoD buildings.

1. INTRODUCTION

It is well known that buildings represent over 40% of total energy consumption in the United States. Furthermore, the replacement rate of old building with new more efficient structures is only on the order of 1-2% per year. Therefore, if the energy consumption of nation's building stock is to be substantially reduced, retrofitting of the existing building stock represents the opportunity with the largest and quickest impact. However the current retrofit delivery process is manually intensive and expensive, focused on equipment selection for initial cost and not energy performance, and the design tools are not amenable to integrated systems solutions that have the potential for substantially reducing energy consumption in buildings. Systems methodology and tools are necessary to deliver effective deep retrofits. The main limitations of the current practice are:

- Screening is conservative and limited to energy efficiency measures with easily quantifiable first order effects, which in turn constrains the achievable savings (< 30% reduction)
- Detailed simulations are required for whole building energy performance assessment and limited to few configurations
- Critical parameters for retrofit system concept design are not well understood prior to installation

This paper describes the use of a new methodology and tool chain to assess integrated system solutions for deep retrofit with potential site energy reductions of 30-50% at an early stage of the design and assessment process. The tool chain was used to evaluate energy savings across a portfolio of buildings, as well as at an individual building level using basic information about building characteristics, usage type and climate; this is typically accessible in a level 1 or 2 facility audit. Building energy consumption is estimated without requiring utility bills, and then the impact of individual energy conservation measures (ECMs) are calculated individually and in combination, i.e. when integrated as systems. We refer to this tool as the Deep Retrofit Assessment Tool (DRAT).

The rapid and automated exploration of a large design space for system solutions, involving several options for component assembly, is enabled by the use of a low order building load and energy performance estimation model. The baseline energy modeling is followed by the evaluation of several energy conservation measures (ECMs), such as upgraded insulation and windows, daylighting, natural ventilation, chiller plant optimization, ground source heat pumps, and their combinations, resulting in identification of system configurations (or "packages") with a potential for site and source energy reduction.

The Deep Retrofit Assessment Tool was applied to two types of cases for the Department of Defense (DoD) building stock: 1) statistical analysis at the portfolio level, comprising nearly 250,000 facilities in the U.S., of the deep energy efficiency retrofit potential, and 2) analysis for individual DoD buildings. The stock tool primary site energy use intensity (EUI) predictions at portfolio level are within 30% of reported energy data in 2009 US DoD Annual Energy Management Report. Based on clustering the building stock by Commercial Buildings Energy Consumption Survey (CBECS)-based primary usage categories and ASHRAE climate zones, we select a representative building from each cluster (building use type and climate combination) based on energy usage, square footage, number of floors and envelope properties. This is followed by evaluation of ECMs and their combinations, resulting in deep retrofit packages for a cluster of buildings. Based on this analysis, we identify clusters with the largest potential for energy use reduction. For the second use case, DRAT is applied to 6 DoD buildings for which more detailed building information (such as obtained from Level 1 or 2 audit) is used. The baseline energy use estimates are within 15% of metered or simulated data from high fidelity calculations. We then apply ECM analysis to each building and generate climate-adaptive system packages, i.e. systems tailored to the external weather and indoor usage of a particular building or cluster, for 30% or higher savings in site energy use.

This paper is organized as follows. In Section 2, we briefly describe the key building attributes required for energy modeling in DRAT. Section 3 gives a brief overview of the building load and energy performance model, energy conservation measures calculations, and approaches to assemble retrofit system and packages. In Section 4, we detail the application of DRAT to the DoD Real Property Asset Database (RPAD), and few representative DoD buildings. We conclude in Section 5 and outline future work to enhance the accuracy and flexibility of DRAT.

2. BUILDING INPUTS

Building Data Requirement for Energy Modeling

Below is a list of key building attributes required for energy modeling in the tool:

- Building location: geographical coordinates, address, time zone and weather
- Building geometry: floor area, number of floors, building exterior shape and floor plan, or exterior dimensions, overall height or floor-to-floor height, glazing fractions
- Construction materials, from which properties including wall and roof thermal conductance, capacitance, thickness and mass density, glazing thermal conductance, solar heat gain coefficient (SHGC, spectral average) and visible transmittance can be estimated
- Equipment configurations: HVAC system type, fan and pump power, primary cooling equipment type and COP, primary heating equipment type and efficiency and heat rejection (condenser) type and efficiency
- Peak occupancy rate and time varying schedule fuel type use
- Peak loads including plug loads or type/number of equipment, lighting power density, service hot water usage, refrigeration power density) and associated time varying schedules

While several of these attributes can be determined during a Level 1 or 2 audit, other parameters can be filled from standard sources like ASHRAE Handbook (American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc , 2008), and a report by NREL (Griffith et al. 2008) on estimating model parameters from CBECS data. For weather data we used 30 year average available in TMY3 files (Wilcox and Marion, 2008) for 1024 weather station locations, although this can be customized to a specific weather file for validation purposes. In several instances building data required for energy performance modeling may not be available. In order to estimate the missing building information, we use the CBECS 2003 database, which is relatively richer in the reported building attributes. For a given building we find the closest CBECS building match based on climate zone, usage and size. Relevant data from the closest match in CBECS is then used to supply the missing attributes. We used this procedure to fill in the missing building attributes in the DoD RPAD, see section 4.1.

3. MODELING FRAMEWORK

3.1 Building Load and Energy Performance Model

The energy consumption of a building in the baseline configuration or with upgraded retrofit options and systems is calculated using a simplified modeling program designed for this purpose. The model treats a building as a single thermal zone and performs an 8760-hour energy balance calculation on the components of the building thermal loads. Heat gain or loss due to conduction through the building envelope is determined using the ASHRAE radiant time series method. HVAC system energy consumption is computed from the building hourly loads assuming that the HVAC equipment performance can be represented with constant coefficients and the primary and secondary HVAC loops are assumed to be quasi-steady (further details can be found in (Narayanan et al, 2012)).

3.2 Energy Conservation Measures

We now describe various low energy design principles, or ECMs which were modeled in the tool. These measures are categorized based on their functions: Lighting and equipment, Envelope, HVAC terminal side, and HVAC supply side (see Table 1). The approach to modeling these measures vary from simple changes in building model parameters (e.g. COP, envelope thermal properties, set points etc.) based on engineering judgments to physics based models. A unique aspect of our approach compared to standard audit methods is that the interactions of the selected ECMs with each other is captured to a level of detail which is consistent with the fidelity of energy performance and thermal load model described in the previous section (further details can be found in (Narayanan et al, 2012)).

3.3 Assembling Retrofit Systems and Packages

In order to achieve desired reduction in energy consumption for a given building, typically several retrofit ECMs need to be applied in conjunction, leading to a packaged retrofit system solution. While the best (e.g. in terms of minimum economic cost leading to desired energy savings) packages solution will vary across buildings, one can pre-assemble packages which are expected to give similar performance across a "class" of buildings. For example, one can consider usage and/or climate adaptive packages which are tailored to give best performance for a class (or cluster) of buildings with similar usage and/or within a similar climate zone. Alternatively, packages can be constructed with consideration to the cost (in terms of payback) and complexity (in terms of the extent of building infrastructure modification involved), as described qualitatively below:

- **Basic Upgrade Package:** Involves retrofit measures that typically have a quick (<2years) payback requiring minimal building/system modification and minimal disruption to ongoing building operations.
- **Moderate Upgrade Package:** Involves retrofit measures with longer (~5 years) payback requiring considerable modifications to equipment and envelope and some disruption to building operations.
- **Major Upgrade Package:** Involves retrofit measures with much longer payback and require significant modifications or replacements to equipment and envelope and major disruption of building operations.

Table 1 illustrates the ECMs within groups having increasing cost and complexity. While assembling the packages, ECMs which are incompatible with each other or provide similar functionality should be eliminated in the same package. For example, direct evaporative cooling, desiccant dehumidification, and energy recovery should not be used together under most circumstances, since they negatively affect each other's performance. Similarly, displacement ventilation (DV) with radiant heating/cooling is functionally similar to under floor ventilation; therefore these ECMS should not be considered in same package. Based on these considerations, 10 standard packages were defined that are progressively more expensive, complex and disruptive to implement: 1 Basic, 3 Moderate and 6 Major. Note that a moderate upgrade package includes all the ECMs in the basic package, and similarly a major package includes ECMs from both moderate and basic package.

Table 1: Energy conservation measures, and their characterization

Retrofit Type	Basic	Moderate	Major
Lighting and Equipment	Light Scheduling, Occupancy Based Lighting Sensors, Daylight Based Dimming, Upgraded Lighting/Delamping, Efficient Equipment		Light Shelves, Day Lighting (Solar Tubes, Sky Light)
Envelope	Weatherization, Cool Roof	Upgraded Windows, Increased Insulation	Active External Shading, Green Roof
HVAC Supply Side	Airside Economizer, Fan Assisted Pre-cooling, Modified Set point and Set back, Supply Air Temperature Reset, Supply Static Pressure Reset, Water Side Economizer, Demand Control Ventilation,		Displacement Ventilation with Radiant Heating and Cooling, Underfloor Air Ventilation (UFAD) with Personal Supply Temperature Control, Mixed Mode ventilation, Natural Ventilation for Night Time Pre-cooling
HVAC Terminal Side	CAV to VAV, VAV and Control Retrofit, Chiller Plant Optimization, Heating Plant Optimization, On Demand Service Hot Water, Condensing Boiler Dedicated Outside Air System	Indirect Evaporative Cooling, Direct Evaporative Cooling, Hybrid Ground Source Heat Pump, Solar Thermal, , Dessicant Dehumdification, Energy Recovery, Solar Waste Heat Absorption Chiller	

4. RESULTS

In this section, we describe the application of DRAT on two types of case studies: DoD RPAD portfolio retrofit analysis and specific DoD building retrofit analysis. For the first use case we use the CBECS database to fill in the missing building attributes in the RPAD and compute the baseline energy use for each building in the RPAD. We then cluster the RPAD by CBECS primary usage categories, and ASHRAE climate zones. For each cluster we select a representative building based on energy usage, square footage, number of floors and average envelope properties. We then screen energy efficient retrofit options for each of these representative buildings and estimate potential energy savings. We then extrapolate the energy savings potential to the portfolio level. For the second use case, DRAT is applied to 6 existing DoD buildings for which detailed building information was made available from a level 2 audit. For each building we first establish the DRAT baseline and compare it to metered or simulated data from a detailed whole building simulation (e.g. EnergyPlus , TRNSYS), apply the ECM analysis, and assemble system packages that result in 40% or higher energy savings.

4.1 DoD RPAD Analysis

The U.S. DoD Real Property Database (RPAD) consists of 247,205 building with a total of 1.72 Billion ft^2. The following building attributes are available in this database:

- Location: property unique identity number, city, state, zipcode
- Usage: building description, operational status, current use
- Building characteristics: total area, number of floors above grade, floors below grade, construction type and construction material

To estimate the missing information in the RPAD for energy modeling, we mapped missing data from CBECS. Before applying the mapping, we pruned the RPAD, as follows:

- Buildings smaller than 300 ft^2 and with CBECS primary usage type="Other", which constitute around 12% of the DoD RPAD, were removed.
- Buildings with identical attributes were removed, which reduced the database to 161,988 unique buildings.

99.98% of DoD buildings in the pruned RPAD were found to be matched to buildings in the CBECS database. For subsequent energy modeling and retrofit analysis, we used this augmented DoD RPAD.

DoD Energy Consumption Stock Characteristics

For each building in the DoD database, we compute the site energy consumption. Table 2 shows that the total model based site energy consumption estimate is 135,580 billion Btu for the 1.72 billion GSF US DoD RPAD, resulting in an average EUI of 78.7 kBtu/GSF-yr. The table also shows the reported worldwide DoD area, site energy and EUI obtained from the US DoD Annual Energy Management Report, 2009. Using this source, the US DoD reported site energy use and EUI are estimated at 186,932 billion Btu and 108.6 kBtu/GSF-yr, respectively, underestimating the total US DoD site Btu by nearly 30%. Given that key parameters for the DoD RPAD buildings were estimated from CBECS database, and the simplifying assumptions of the energy model, this discrepancy seems reasonable. Moreover, further analysis suggests that adding moderately to the level of detail in the simulation will significantly improve accuracy (see later). Figure 1 shows the breakdown of site energy consumption for the DoD RPAD based on the building usage. The top two building usage sectors are lodging and office. Also shown is the distribution of buildings by EUI in the lodging and office sectors, and the median EUI

Table 2: Comparison of estimated DoD total and average EUI with that reported across all DoD stock.

	GSF (Billion)	Site Btu (Billion)	Avg. EUI (Btu/GSF)
Worldwide	1.93	209,789	108,560
US (Estimated)	1.72	186,932	108,560
Model Results	1.72	135,580	78,736

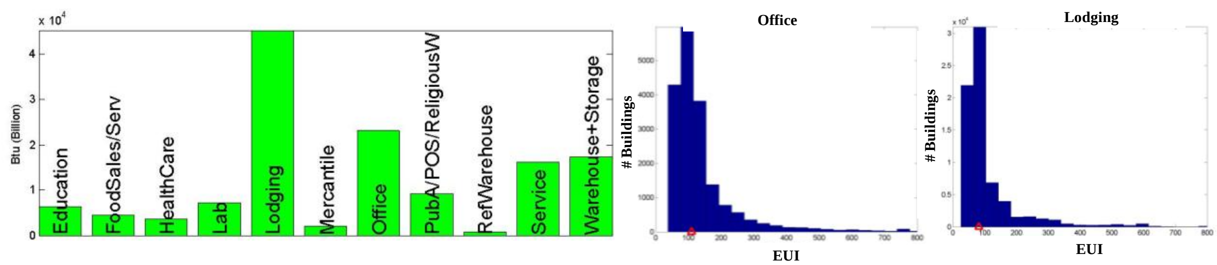
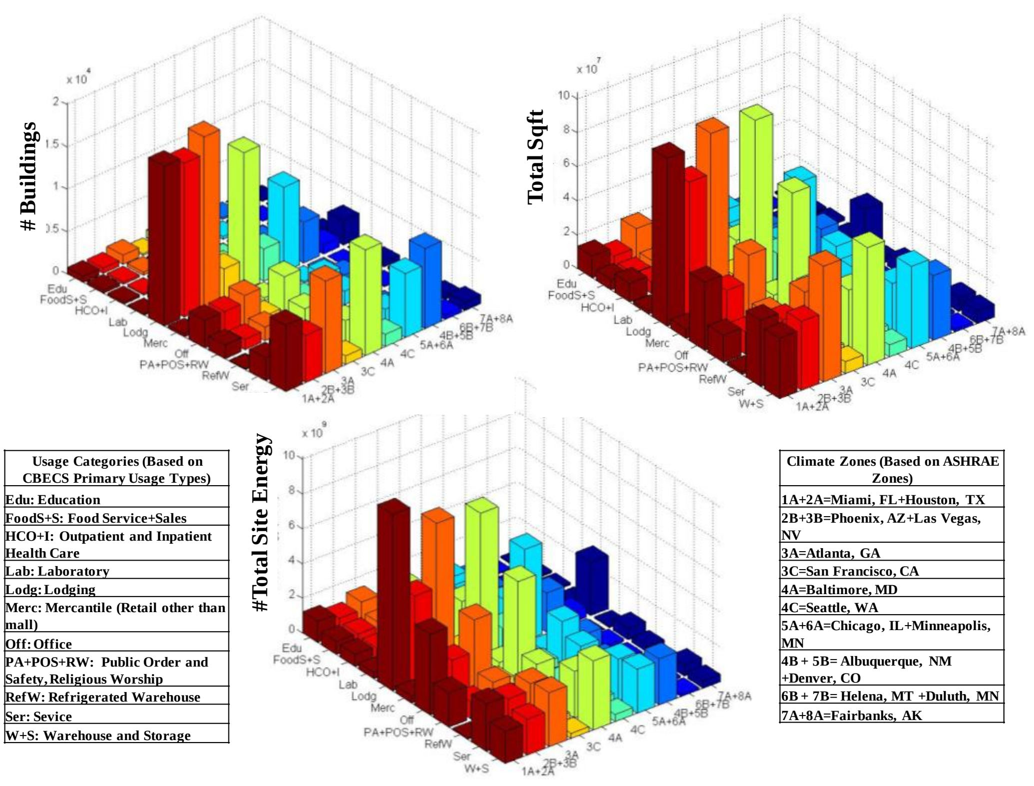


Figure 1: DoD Site energy (Btu Billions) based on building usage. Healthcare category includes outpatient and inpatient services, and Pub/POS/RelW includes public assembly, public order and safety, and religious worship. EUI distribution for top two DOD usage sectors: office and lodging. The red triangle is the median EUI for each sector.

Composition of Median EUI Building

Buildings representative of each use type and climate were obtained by clustering the energy analysis results for the DoD RPAD based on CBECS primary usage types, and ASHRAE climate zones. There are 110 “bins” in which to cluster the results, based on 10 climate zones and 11 building use types. Figure 2 shows the aggregate number of buildings, area and site energy use for each of the 110 bins. The procedure for selecting the representative (or median) building in each cluster is as follows. We first select a feature vector, for each building in the cluster, which comprises of following attributes: energy use, square footage, number of floors and average envelope properties. The average envelope property is the area weighted average conductance of the roof, walls and fenestration features. This feature vector is then normalized in each dimension by the maximum value attained by the attributes (i.e. energy use, square footage, number of floors and average envelope properties) in the cluster. A weighted mean is then computed. Finally, the closest building to the computed weighted mean is determined and is taken to be the representative building for the cluster. Table 3 shows the EUI of the representative building in each cluster. The percent EUI variability within a cluster from its median, across all clusters was found to be no more than 37%. The last two columns in Table 3 compare the model based DoD median EUI with the estimated CBECS EUI (estimated from the reported site energy consumption in the CBECS database) across different usage categories.



Usage Categories (Based on CBECS Primary Usage Types)
Edu: Education
FoodS+S: Food Service+Sales
HCO+I: Outpatient and Inpatient Health Care
Lab: Laboratory
Lodg: Lodging
Merc: Mercantile (Retail other than mall)
Off: Office
PA+POS+RW: Public Order and Safety, Religious Worship
RefW: Refrigerated Warehouse
Ser: Sevice
W+S: Warehouse and Storage

Climate Zones (Based on ASHRAE Zones)
1A+2A=Miami, FL+Houston, TX
2B+3B=Phoenix, AZ+Las Vegas, NV
3A=Atlanta, GA
3C=San Francisco, CA
4A=Baltimore, MD
4C=Seattle, WA
5A+6A=Chicago, IL+Minneapolis, MN
4B + 5B= Albuquerque, NM +Denver, CO
6B + 7B= Helena, MT +Duluth, MN
7A+8A=Fairbanks, AK

Figure 2: Clustering based on usage and climate zones, showing site energy consumption in different clusters.

Energy Efficient Concept Screening

Figure 3 shows the savings from a few individually applied ECM's for DoD representative buildings in each cluster. As expected, certain measures are more effective for specific climates, e.g. relatively higher effectiveness for weatherization and insulation in cold climates. Figure 4 shows site energy savings with three assembled systems: basic package, moderate package, and major package. Figure 5 summarizes the implications for DoD stock, extrapolated from representative building savings. Here we assume that within each cluster, different buildings will exhibit similar savings as that of the representative building, since they are subjected to similar thermal loads. Based on this, we can estimate the fraction of the stock space (in sqft) for which savings will be greater than a given threshold. Thus, the way to interpret this table is: due to upgraded lighting, 48% of DoD space can save more than 10% (which is the chosen threshold). Similarly, one can estimate that: 98% DoD space can save more than 20% with basic package, 97% DoD space can save more than 40% with moderate package, and 63% DoD space can save more than 60% with the major package.

Table 3: Energy Use Intensity (EUI) of Median Building (kBtu/ft^2)

Median EUI (KBtu/Sqft)	Miami, Houston	Phoenix, Las Vegas	Atlanta	San Francisco	Baltimore	Seattle	Chicago, Minneapolis	Albuquerque, Denver	Helena, Duluth	Fairbanks	Average EUI by Usage	CBECS Average EUI
	1A+2A	2B+3B	3A	3C	4A	4C	5A+6A	4B + 5B	6B+7B	7A+8A		
Education	88.9	91.1	103.8	72.0	72.5	46.0	85.4	78.5	108.5	99.5	**76.7**	**85.1**
Food Service + Sales	140.0	138.8	138.1	309.1	144.7	271.7	156.3	150.0	147.5	158.9	**136.2**	**294.5**
Health Care (Outpatient), Health Care (Inpatient)	81.2	84.8	73.9	64.9	71.0	151.9	99.8	84.1	105.4	90.2	**71.6**	**193.7**
Laboratory	245.2	175.4	157.2	155.8	129.7	110.1	129.6	117.9	329.5	172.5	**115.3**	**283.8**
Lodging	70.2	68.7	76.3	65.0	97.0	93.3	95.3	122.9	122.0	106.4	**86.1**	**94.2**
Mercantile (Retail other than mall)	97.9	101.2	80.9	82.8	90.7	86.3	90.4	115.5	140.5	105.4	**76.7**	**115.1**
Office	132.9	111.7	110.3	125.0	96.5	126.1	97.5	108.9	111.9	128.5	**89.8**	**93.6**
Public Assembly, Public Order and Safety, Religious Worship	87.9	78.2	84.1	68.0	71.8	58.5	82.2	76.7	74.0	125.2	**79.8**	**74.8**
Refrigerated Warehouse	49.2	85.2	37.2	29.9	116.3	0.0	64.3	96.7	0.0	0.0	**42.5**	**117.6**
Service	71.4	75.0	66.8	61.9	83.5	80.2	88.7	82.2	86.8	97.5	**71.11**	**84.1**
Warehouse and Storage	86.2	95.7	53.9	74.3	79.6	115.5	78.1	93.7	132.0	90.9	**53.79**	**33.6**

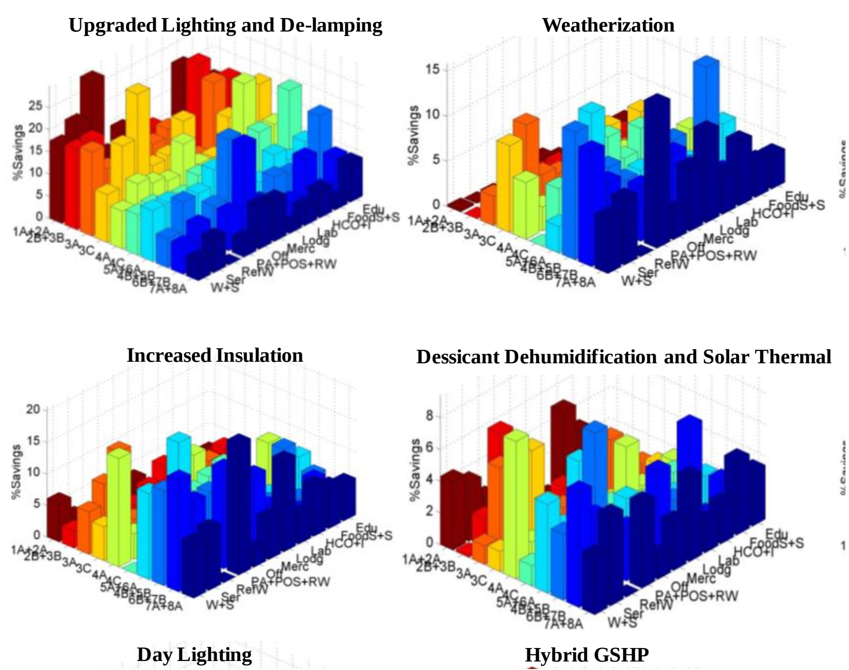


Figure 3: Site Energy Savings due to few selected ECMs for the median DoD building for each climate zone and building use category.

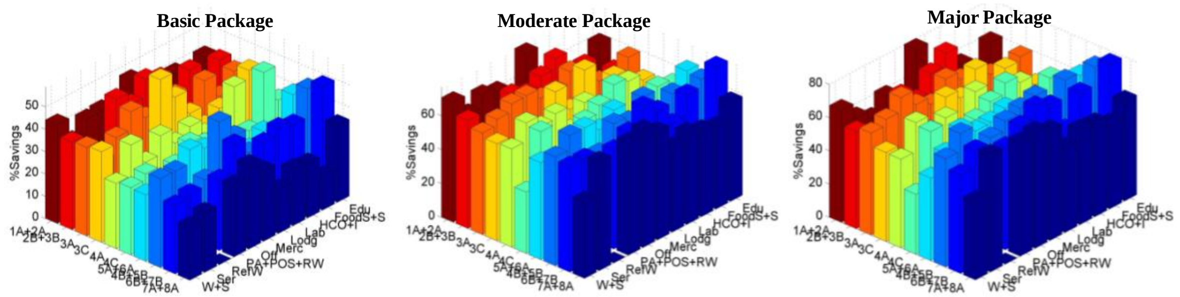


Figure 4: Site Energy Savings from different package applications for the median DoD buildings for each climate zone and building use category.

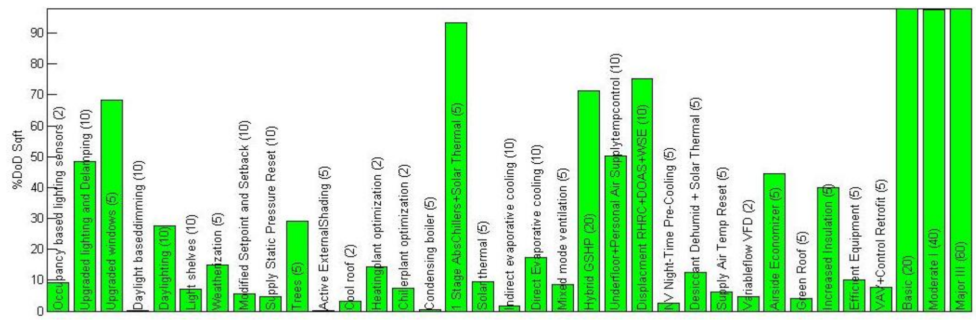


Figure 5: Extrapolation of energy savings for DOD portfolio based on savings for the median EUI buildings. The numbers in brackets indicate the chosen threshold (i.e % savings) for that ECM.

4.2 DoD Specific Buildings Analysis

In this section we discuss the application of DRAT to specific DoD buildings at multiple sites around the US: Naval Station Great Lakes (IL), Ft. Carson (CO), Ft. Bragg (NC) and Ventura Naval Base (CA). With the availability of more detailed information for these buildings (collected during Level 2 audits), there was no need to extrapolate the data from CBECS database for establishing the baseline EUI and ECM analysis. Figure 6 below shows the comparison of estimated EUI based on DRAT with either metered data (Drill Hall, Bldg26 and Ventura) or simulation results from high fidelity tools like TRNSYS (Ft Carson and Ft Bragg). The DRAT EUI estimates are within 10-15% of the metered values. We then applied the ECM analysis and identified climate-adaptive system packages with a potential for 40% or more energy savings for each of these buildings. We describe in detail the results of this analysis for Building 1225 at Ft. Carson and then list the identified packages and resulting savings for the other buildings.

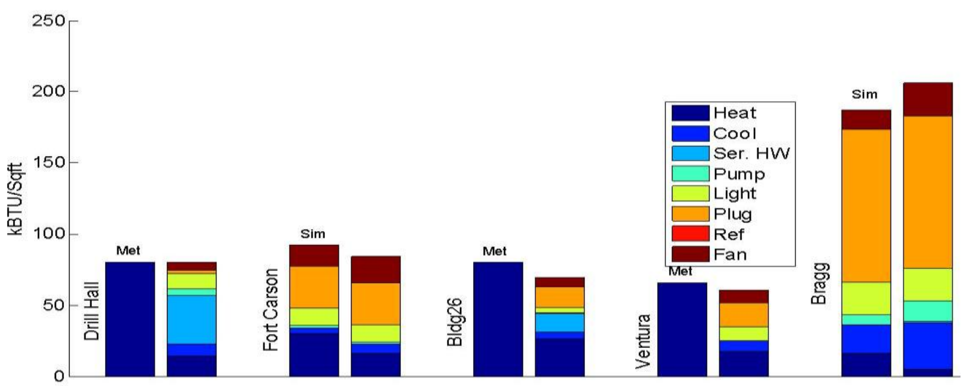
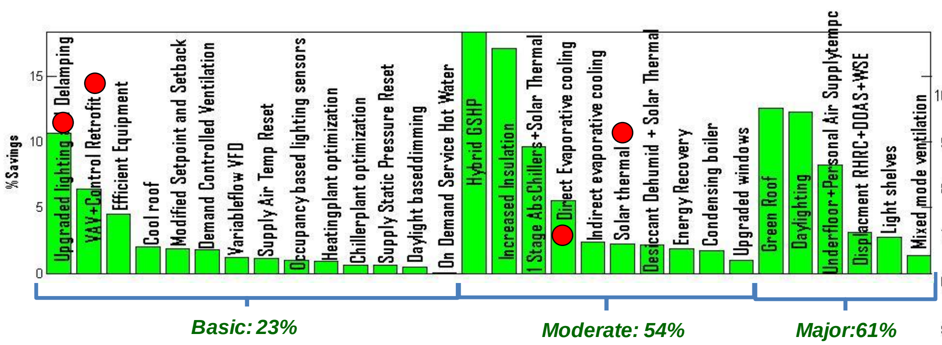
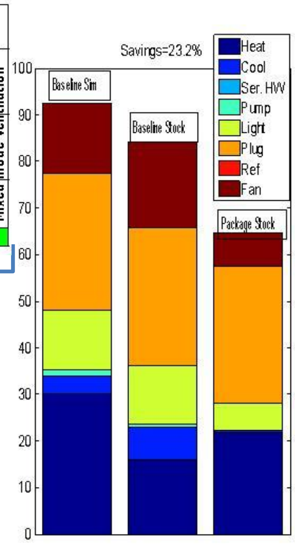


Figure 6: Comparison of EUI for different DOD facilities

Building 1225 is a single-story office building constructed in late 1980's with a total floor area of 18630 sqft. The building is mixed use office type and is heavily used with estimated peak occupancy of around 150. The building is open only on weekdays with total 45 operating hours. The glazing fraction is very low around 4%, and the wall and roof construction material are brick and metal deck, respectively. A single central fan room contains two constant volume multi-zone units. Controls are pneumatic converted to DDC with the pneumatic actuators and zone controls still in place. Gas-fired boilers in the building provide the primary heating, and chilled water from a chiller plant provides cooling. Lighting is primarily T8 32W fluorescent. Figure 7 shows the site energy saving reduction from applying different ECM's. The basic, moderate and major package on an average saves 23%, 54% and 61%, respectively. A package comprising *Upgraded lighting, VAV control retrofit, Direct evaporative cooling and Solar thermal* was chosen for this building, believed to be best suited to the CO climate and building usage. Figure 7 on right shows the site energy saving of 23.3% with this assembled package.

Table in Figure 7 shows the component-by-component breakdown of the energy reduction resulting from packaged system as predicted by DRAT. For comparison, also shown in the right columns, are predictions based on a TRNSYS model. As can be seen the two models predict very similar overall energy savings, however at an individual end use level, there are differences. Except for the heating energy, the general trend is similar. In the TRNSYS model, the baseline total annual heating energy consumption is 590.8 GJ compared to 314.8 GJ in the DRAT model. The bulk of this difference is likely due to the single zone assumption in the DRAT, the implications of which were previously discussed. The trend in heating consumption from baseline to advanced system is also different, with the DRAT model showing an increase in heating energy of 110 GJ annually versus an annual reduction in heating energy of 140 GJ for the TRNSYS model. In the DRAT results, the total reduction in fan and lighting energy is 360 GJ. Assuming half of this reduction can be ascribed to the heating season, we should expect heating energy to increase by about 180 GJ. The actual increase is 110 GJ, with the difference being offset primarily by heat gained from the solar thermal system. In the TRNSYS model, the fan and lighting annual energy consumption reduction totals approximately 210GJ, of which we can ascribe about 110 GJ to the heating season. This would increase heating energy to approximately 700 GJ but for a contribution from solar thermal of 250 GJ. This results in a real heating energy reduction to 448 GJ of heating energy annually.





	Stock Baseline (GJ)	Stock Adv	Stock %Energy Reduction	TRNSYS Baseline (GJ)	TRNSYS Adv	TRNSYS % Energy Reduction
Heating	314.8	425.3	35.1%	590.8	448.4	-24%
Cooling	135.0	9.2	-93.1%	74.7	39.7	-46.9%
Pump	11.8	3.4	-70.1%	28.1	6.3	-78%
Fan	361.1	140.0	-61.2%	294.0	185.8	-36.8%
Lighting	249.2	110.7	-55.1%	249.2	141.9	-43%
Plug	580.5	580.5	0%	580.5	580.5	0%
EUI	84	64.5	-23.2%	92.4	71.4	-22.8%

Figure 7: Site energy savings for different ECM's for Building 1225. ECMs marked with red circles are used to assemble a package whose savings is shown in stacked bar graph on the right. Comparison of energy savings broken by end use type based on DRAT and TRNSYS model is shown in the table.

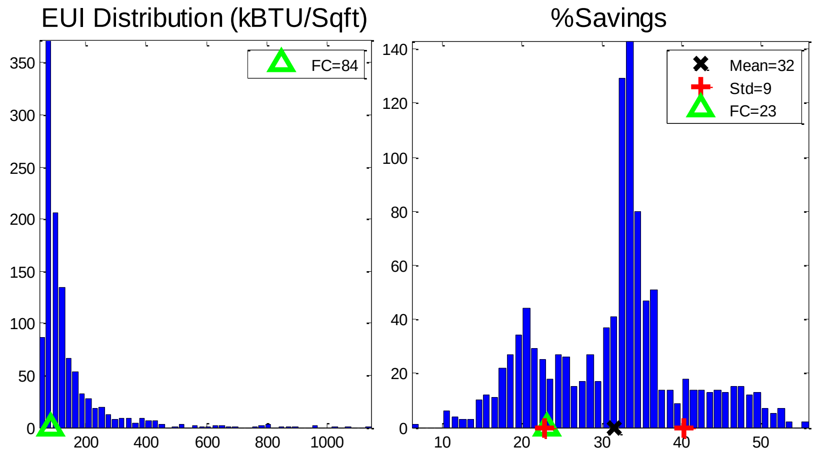


Figure 8: On left is EUI distribution in the cluster (Office, 5B) to which Fort Carson building belongs. On right is the distribution of site energy savings resulting from packaged system chosen for Building 1225 at Ft. Carson.

Figure 8 shows the site EUI distribution for all DOD facilities (in RPAD) in the Office, 5B cluster, see section 4.1 for definition of clusters, to which the Ft. Carson building belongs. Note that the mean EUI of the cluster is very close to the nominal EUI value of 84 KBTU/sqft of Building 1225. Also shown are distribution of energy savings in the cluster which results from applying assembled package chosen for Building 1225. The average savings are around 32% with a standard deviation of 9%, and the savings of 23% estimated for Ft. Carson building falls in the one-sigma range. These results show that buildings with similar usage and in a similar climate zone can exhibit similar trend in energy savings for a system of climate adaptive ECMs, suggesting that the extrapolation of savings based on appropriately chosen representative buildings to a portfolio of buildings can yield statistically meaningful conclusions. Energy savings analysis was performed for other buildings shown in Figure 6. Figure 9 shows the site energy savings: 46% for Drill Hall at Great Lakes (system includes *On demand service hot water, Demand controlled ventilation, Solar thermal, Increased Insulation, Day-lighting and Displacement ventilation with radiant heating and cooling)*, 48% for building at Ventura Base (integrating *Weatherization, Upgraded lighting and delamping, Modified setpoints/setbacks, Hybrid GSHP, Upgraded windows and Day lighting)*, 49% for Building 26 at Great Lakes (integrating *Efficient equipment, Modified set-point and set –back, Hybrid GSHP, Solar thermal and Upgraded windows)*, 31% for building at Ft. Bragg (integrating *VAV control, Efficient equipment, Supply air temperature reset, Chiller plant optimization, VFD, Hybrid GSHP and Day lighting)*.

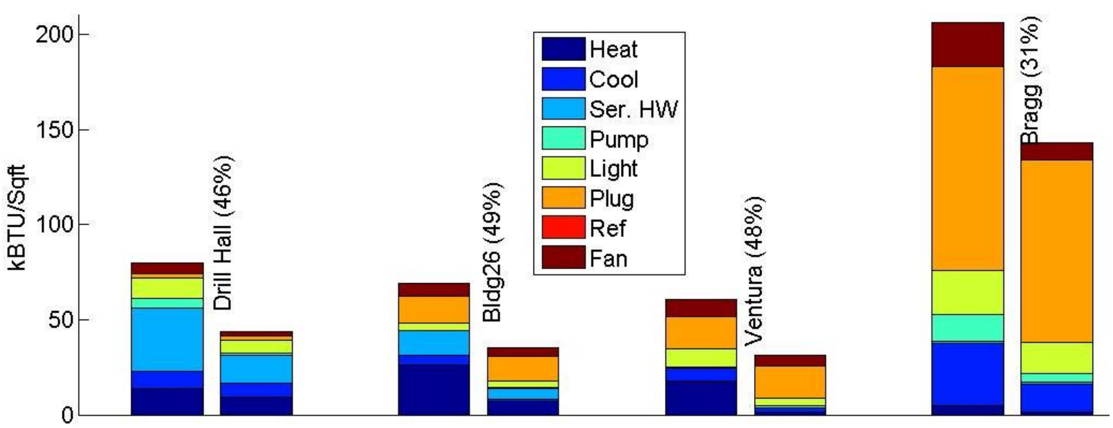


Figure 9: Site energy savings for some of DOD facilities.

5. CONCLUSIONS

Efficient energy modeling and screening of energy efficient retrofit system solutions within existing building(s) is demonstrated for DoD installations using a rapidly executable methodology and tools. Multiple DoD installation buildings were analyzed further where detailed system and validation data was available. The tool also has an automated capability for rapid uncertainty and sensitivity analysis to bound the energy performance estimates provided, subject to variability in the model input parameters; due to limitations of space the capability and results are not reported here. The results show the benefits and potential for substantially improving the energy efficient retrofit assessment procedure currently practiced in the industry. In the future, we plan to further validate the models within the tool using monthly and annual energy consumption data from installations across additional usage and climatic categories. The tool will also be augmented with first and lifecycle cost models; whereas now the present tool enables energy related operating cost and source energy analysis. This will enable energy and economic benefit tradeoff analysis for selecting appropriate energy conservation measures and retrofit systems.

NOMENCLATURE

The nomenclature should be located at the end of the text using the following format:

Sqft	square footage	(sqft)
S	set of buildings	(-)

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