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Deep Retrofit System Solution Assessment for Philadelphia Navy Yard Office Buildings

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ABSTRACT

Initial assessments of economically attractive integrated building energy system solutions that can substantially reduce energy consumption in two medium-sized office buildings in the Philadelphia Navy Yard are presented. These sites were selected because they are the current and future headquarters of the DOE Energy Efficient Buildings Hub (EEB HUB). Energy efficient retrofit solutions involving integrated building systems with 40-60% site- and source-energy reduction potential relative to selected baseline energy consumption configurations are identified. The scope of retrofit options explored and integrated involve the building envelope, lighting and HVAC systems as well as the related control systems, providing a spectrum of retrofit options that range from low-/no-cost options to relatively higher capital cost options that involve significant capital upgrades and facility renovations. The energy savings estimates are based on combining multiple energy conservation measures (ECMs) that are tailored to the building use type and climate conditions. Energy performance (energy savings potential) and economic impact (NPV, IRR, and simple payback) of these retrofit system solution recommendations are assessed for two office buildings – Building 101 and Building 661, at the Philadelphia Navy Yard. A suite of retrofit system packages is presented for each building with a range of initial investments and economic returns to assist the investment decision making process, by stakeholders such as the building owner and operator. Results of the cost benefit analyses will be presented in light of incentives for high performance office buildings in the Philadelphia ten-county region.

1. INTRODUCTION

The work presented was funded and performed under the Department of Energy's Energy Efficient Building Systems Regional Innovation Cluster Initiative. This effort focused on the objective to implement a process and tools for exploring and selecting system configurations resulting from functional integration of standard classes of equipment for energy efficient building retrofit solutions. Further, the goal was to identify integrated solutions spanning building envelope, HVAC, lighting and control system upgrades for a deep retrofit (i.e. ≥ 50% reduction in energy usage) for small to medium sized commercial buildings in the Philadelphia ten-county region.

The current work differs from conventional retrofit analysis methods by significantly reducing the level of effort required to obtain acceptable prediction accuracy on building energy and economic performance, and environmental footprint. Deployment of systems solutions, i.e. configurations composed from standard components and controls and optimized for a building, in a repeatable manner requires a paradigm shift from the existing design and delivery process, whereby configurations are assembled sequentially and involve time-consuming customization. Replicable system solutions can be accomplished by appreciating the fact that given a building type and an understanding of its usage and its micro-climate, energy conservation measures (ECMs) exist that can substantially reduce energy demand (for example, daylighting, solar absorption chillers and solar heating, dedicated systems for ventilation air management and space humidity control). These system-level solutions can be realized by a moderate number of system alternatives and hardware. The challenge is to automate the evaluation procedure. The first phase of this effort was conducted to rank ECM concepts and alternatives based on their individual predicted energy and thermal comfort performance. The ECMs were also ranked according to the levels of economic and physical effort required to implement each one in the building. Combinations of complementary ECMs were created to identify candidate system solutions and the predicted benefits that would accrue to that system choice in an upgrade retrofit of one or more existing buildings. Cost-benefit analysis of the selected individual and packaged ECMs allowed close to optimal selection of ECMs by trading energy cost performance against economic performance measured through

NPV and simple payback analyses. The goal of the project was a methodology and set of tools for rapid and accurate (relative to a much reduced set of input parameters compared to conventional energy analysis methods) evaluation of a broad range of integrated sub-system solutions, spanning building envelope, lighting, space conditions and other components, and district energy systems such as cooling/heating plants, on-site power generation and renewable systems. Two Philadelphia Navy Yard office buildings were selected as exemplar buildings to evaluate the accuracy and efficacy of the tool in comparison to typical building retrofit analyses.

2. METHODOLOGY

The current work utilized a methodology and toolset for energy and economic performance evaluation of integrated building energy systems developed under a Department of Defense (DOD) project (SERDP project EW-1709). The toolset automates the process of identification of ECMs and estimation of energy usage intensity (EUI) reduction (Ahuja *et al.*, 2011). The tool workflow is comprised of a three step process – establish energy use baseline, identify promising ECMs, and assemble integrated solutions. The toolset utilizes basic building attributes such as envelope, lighting, and HVAC equipment information, to estimate baseline site-energy and source-energy usage. The tool then estimates the reduction in energy usage which could be attributed to selected integrated system solutions including combinations of multiple ECMs that are tailored to the building use type and climate conditions. The methodology was applied to Building 101 and Building 661 (respectively the current and future EEB HUB headquarters at the Philadelphia Navy Yard) and results for the baseline and the expected reduction in site-energy, source-energy, and annual energy costs due to integrated solutions are reported herein.

The energy consumption of the baseline building and of the retrofit scenarios were calculated using a simplified building modeling program designed for this purpose. The model treats a building as a single thermal zone and performs an 8760-hour mass and energy balance calculation on the components of the building thermal loads. Heat gain or loss due to conduction through the building envelope was determined using the ASHRAE radiant time series method. HVAC system energy consumption was computed from the building hourly loads assuming that the HVAC equipment performance could be represented with seasonally averaged constant coefficients and the primary and the secondary HVAC loops were assumed to be in a quasi-steady-state, i.e. with negligible thermal mass with respect to system capacity. Additionally, capital cost models for the baseline and retrofit system configurations were developed from RSMeans (Mossman, 2010) and other publicly available cost data. An energy cost analysis suitable for computing simple payback, NPV, and IRR was also included by implementing a utility rate/energy resource cost component in the model that could make use of widely available local utility rate structure data as applied to the 8760-hour annual energy consumption results from the energy model. Surana *et al.* (2012) have reported the details of the energy analysis model.

3. BUILDING 101 ENERGY PERFORMANCE ANALYSIS

Building 101 is a 61,700 ft^2 gross area, 50 ft high office building. The building has three floors above grade with a partially below grade conditioned basement. A walkthrough audit of Building 101 was conducted in July 2011 to obtain the inputs required for the analysis. Desai *et al.* (2012) have reported the details of the analysis input parameters. Historical data of actual site-energy consumption of electricity and natural gas at the building level were also obtained during the audit. It should be noted that the level of effort for this audit was similar to a Level 1 ASHRAE audit (Deru *et al.*, 2011). Actual site-energy consumption was then compared with the computational estimates obtained from the modeling tool. Building 101 energy analysis results are presented in this section based on the three step process described previously.

3.1 Step 1 – Baseline / Actual Site-Energy Consumption for Building 101
Actual site-energy consumption of electricity, natural gas, and water for Building 101 are shown in Figure 1A. The respective costs of these utilities derived from recent energy bills are shown in Figure 1B. It is observed from Figure 1B that electricity is the dominant energy cost for Building 101. The meter readings and utility costs are for the whole building; sub-metering at the zone, usage-type, tenant, or floor level was not available. Figure 1C shows the comparison of actual data and model estimates for the annual site-energy consumption and the operating energy costs. It can be observed from Figure 1C that the toolkit estimates Building 101's annual site-EUI to be 80 kBTU/ft^2 compared with the actual EUI of 82 kBTU/ft^2. The annual operating energy cost for Building 101 is predicted

assuming constant occupancy. The cost function is based on the local rates and tariffs for electricity and natural gas in June 2011. Results from an external Energy Audit Report for Building 101 provided by Bohadel (2011) are also reported in Figure 1C. Figure 1C shows that after calibrating the Audit Tool with the plug and light loads, the site-EUI estimates match reasonably well. Annual source-energy consumption estimates for Building 101 based on actual site-energy usage information and Audit Tool estimates are shown in Figure 1D. These estimates were based on source-energy multipliers for energy sources provided by Deru and Torcellini (2007).

3.2 Step 2 – Energy Usage Reduction Potential for Building 101
The audit tool includes the capability to analyze the effects of several ECMs, in isolation and when integrated as a system. The ECMs were classified into two categories (basic and moderate) based on initial investment of the upgrade, potential barriers to implementation, and energy reduction potential. ECMs classified as basic are typically no-cost/low-cost and can be implemented with little disruption to building operations. Moderate ECMs require significant capital outlay and installation could measurably disrupt the operation of the building. A detailed list of the ECMs considered for analysis is reported by Desai *et al.* (2012). A Pareto plot for the site-energy use reduction potential due to implementation of the individual ECMs is shown in Figure 2. It should be noted that the energy use reduction estimates presented in Figure 2 are individual effects of the ECMs, implemented only one at a time.

3.3 Step 3 – Integrated System Solutions for Building 101
Two integrated solutions were designed based on promising ECMs selected from Figure 2. The two packages, referred to as "basic" and "moderate," will serve as illustrations of promising integrated solutions. Other alternative assemblies that provided similar whole building energy use reduction could have been selected but were not because they were inappropriate for the climate of the Philadelphia region or not adaptable to the specific design features of Building 101. The basic upgrade package is recommended to include three ECMs: daylight-based dimming, upgraded lighting and delamping, and weatherization. The moderate upgrade package is recommended to include four ECMs: all three ECMs from the basic upgrade package and hybrid ground source heat pump (GSHP).

In the basic package, lighting upgrades such as daylight dimming reduces lighting power by dimming the electrical lights while maintaining a constant illumination level at the work surface. Upgraded lighting uses more efficient and fewer lighting fixtures resulting in reduced illumination levels in the building. Weatherization seals the cracks and penetrations (for example, in windows and doors) in the exterior envelope to reduce infiltration.

In the moderate package, hybrid GSHP systems operate on the same principle as more conventional air-to-air heat pumps, except that they use the ground as a heat source or sink rather than the ambient outside air. An air-to-air heat pump sees its efficiency decline substantially in heating mode when the ambient air temperature drops below 30^oF. At 15^oF ambient temperature, the COP of an air-to-air heat pump is typically around unity, the same as electric resistance heating. Such units typically require supplemental heaters when the outside temperature is expected to spend significant time below 32^oF. Performance also degrades substantially in the cooling mode when the outdoor air temperature exceeds approximately 85^oF. In contrast, the deep ground temperature remains fairly constant at approximately 55^oF all year round so that a heat pump system using it as a heat source or sink will operate at or near design efficiency conditions most of the time. Typically, this means a maximum COP of 8 in cooling mode and 4 in heating mode compared with 3.5 and 2.5 for a typical air source heat pump, respectively. GSHP systems use a network of vertical wells or horizontal pipes filled with glycol or brine to exchange heat between the ground and the evaporator / condenser of the heat pump. As long as the annual total heating and cooling loads are reasonably well balanced the system will continue to operate at the design efficiency. However, if the loads are significantly unbalanced the deep ground will heat up (or cool down) over several annual cycles if the cooling load is higher (or lower) than the heating. Any excess cooling load can be offset with a supplemental cooling tower in series with the ground loop, while excess heating load can be offset with a solar hot water system or a fossil fuel boiler.

Estimated effects of the integrated solutions on energy usage and annual operating costs of Building 101 are shown in Figure 3. The corresponding operating cost reduction potential is shown in Figure 4. Percent saving potential estimates for site- and source-energy and annual operating costs are summarized in Figure 5. It can be observed from these results that substantial energy use and annual energy cost reduction potential exists for Building 101. Based on the investment strategy of the project, one of the system solutions presented in this report can be considered for detailed design.
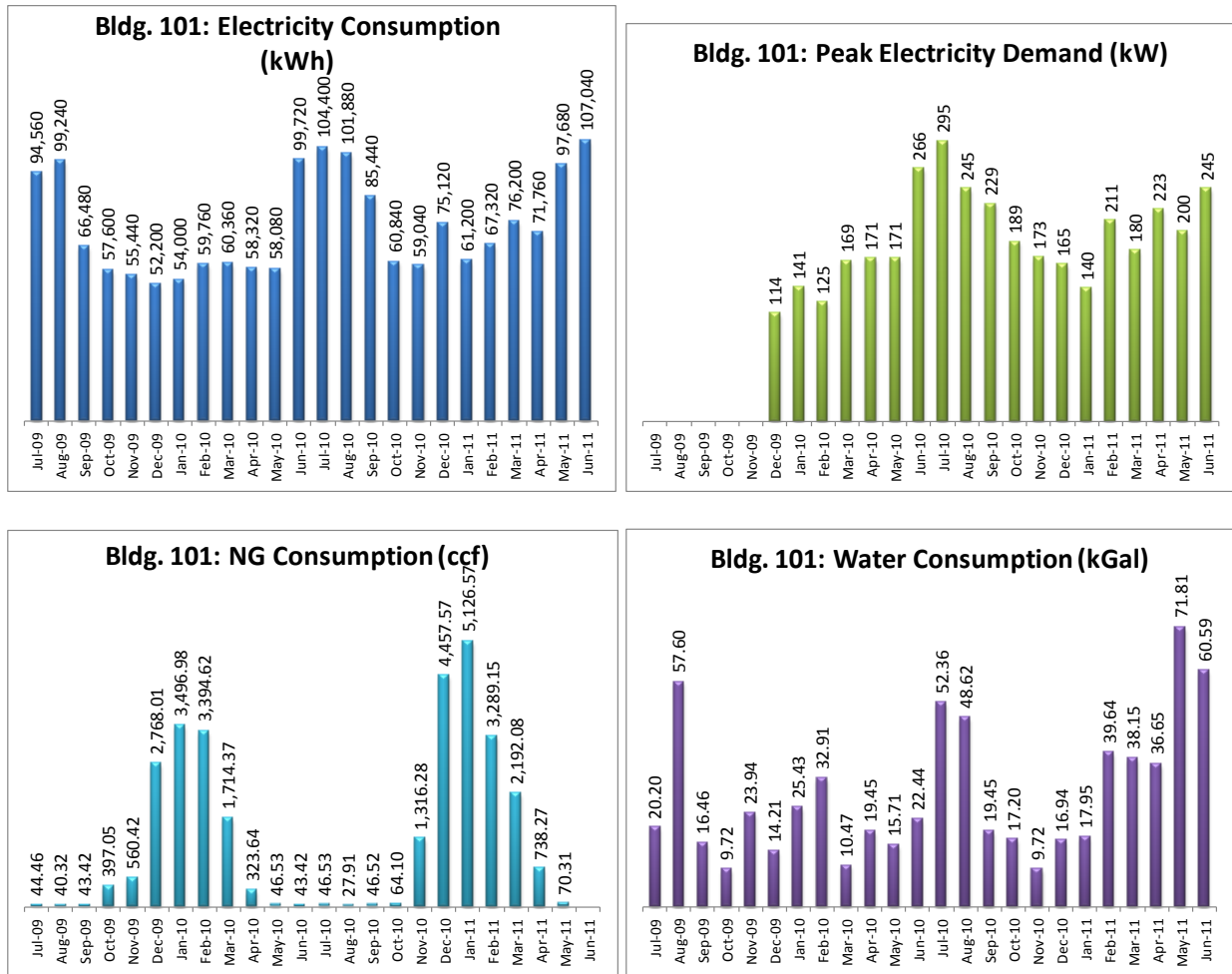
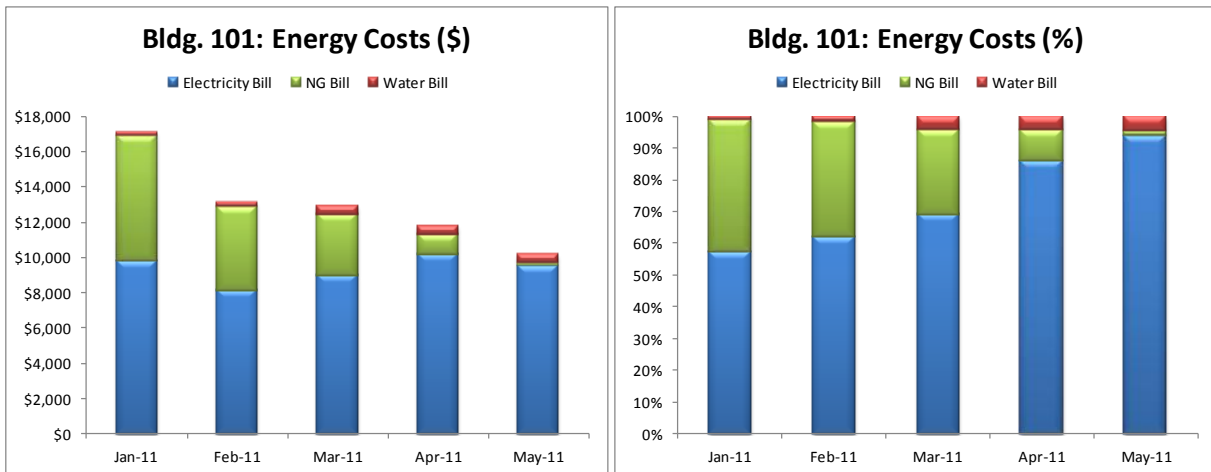**Figure 1A:** Actual site-energy consumption of Building 101.
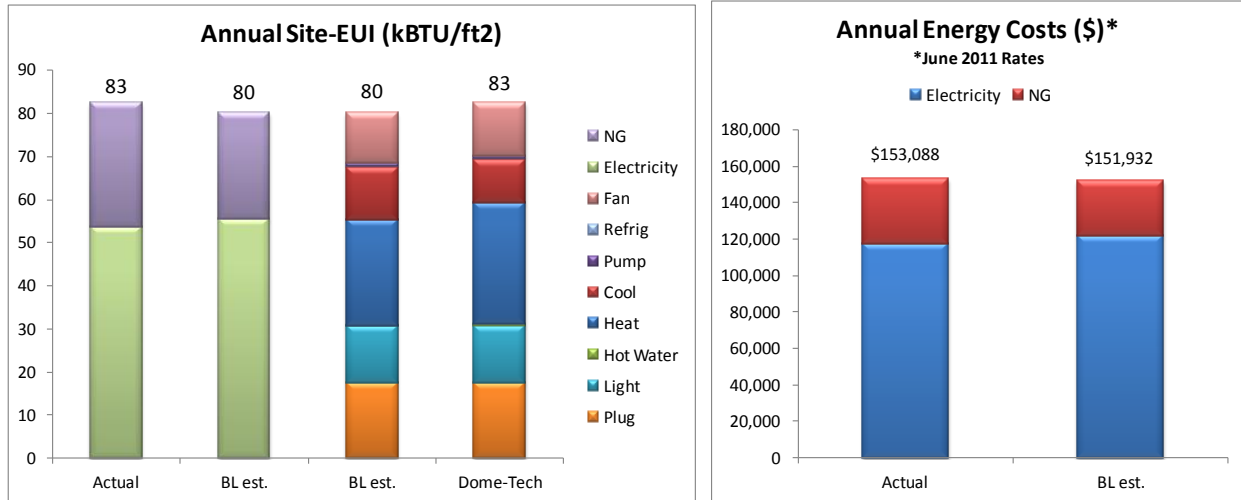

Figure 1B: Actual energy costs for Building 101.

Annual Site-EUI (kBTU/ft2)

Legend: NG, Electricity, Fan, Refrig, Pump, Cool, Heat, Hot Water, Light, Plug

Bars: Actual — 83; BL est. — 80; BL est. — 80; Dome-Tech — 83

Annual Energy Costs ($)*
*June 2011 Rates

Legend: Electricity, NG

Bars: Actual — $153,088; BL est. — $151,932

Figure 1C: Building 101 site-energy consumption and annual operating costs comparison.

Annual Source-EUI (kBTU/ft2)

Legend: NG, Electricity, Fan, Refrig, Plug, Light, Pump, Hot Water, Cool, Heat

Bars: Actual — 209; BL est. — 211; BL est. — 211

Source-Energy Factors

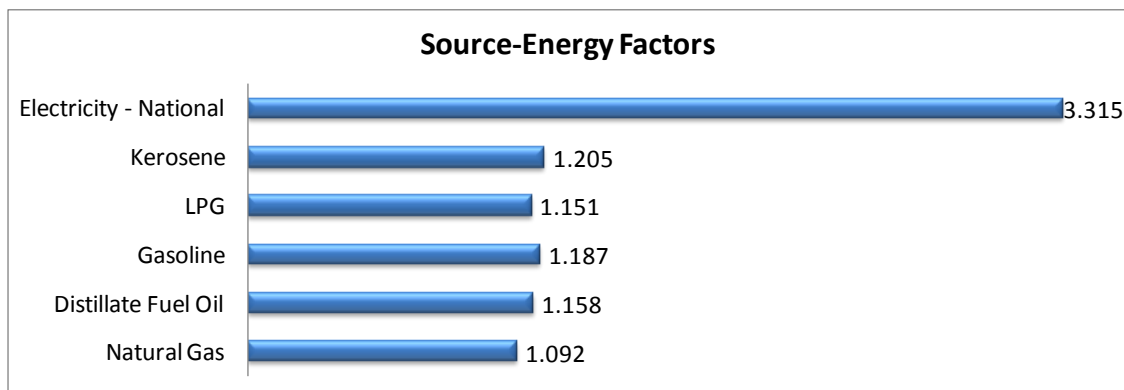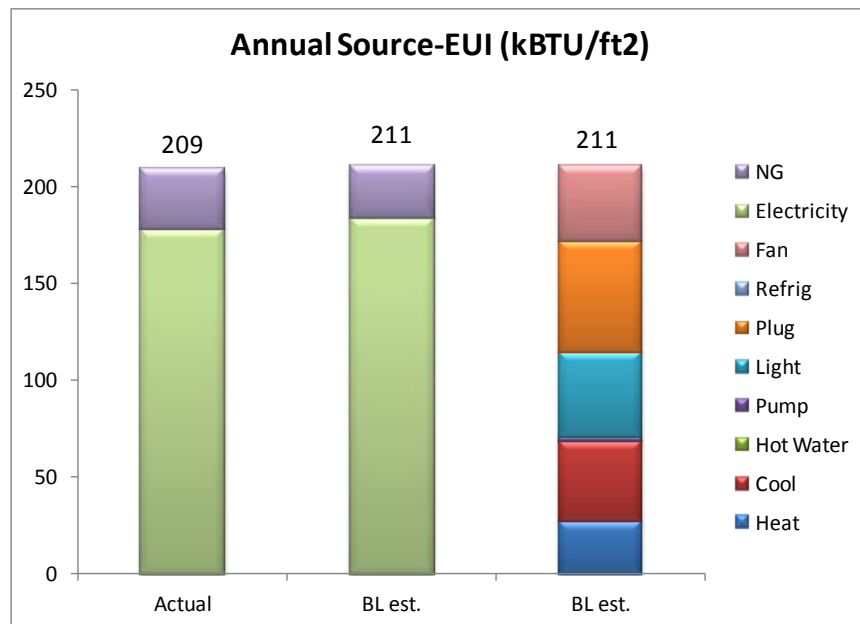|	
Electricity - National	3.315
Kerosene	1.205
LPG	1.151
Gasoline	1.187
Distillate Fuel Oil	1.158
Natural Gas	1.092

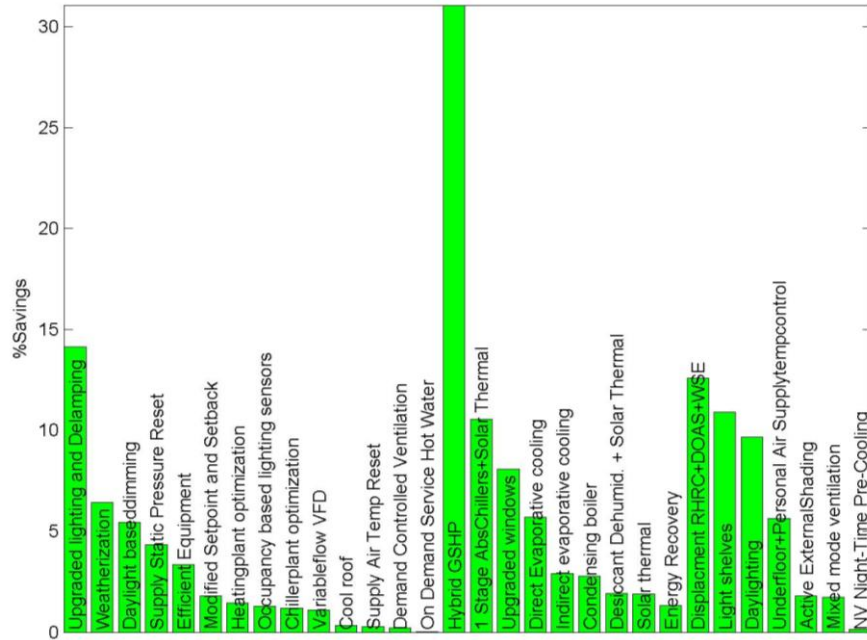**Figure 1D:** Building 101 source-energy consumption estimate comparison.

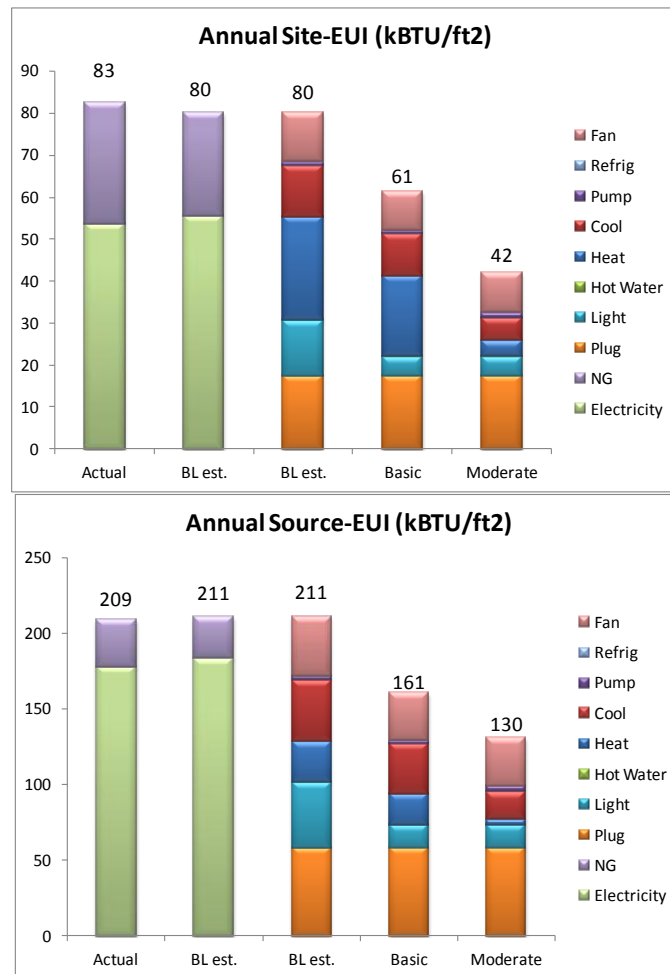**Figure 2:** Building 101 site-energy usage reduction estimates due to individual ECMs.

Figure 3: Integrated system solutions with site- and source-energy use reduction potential.
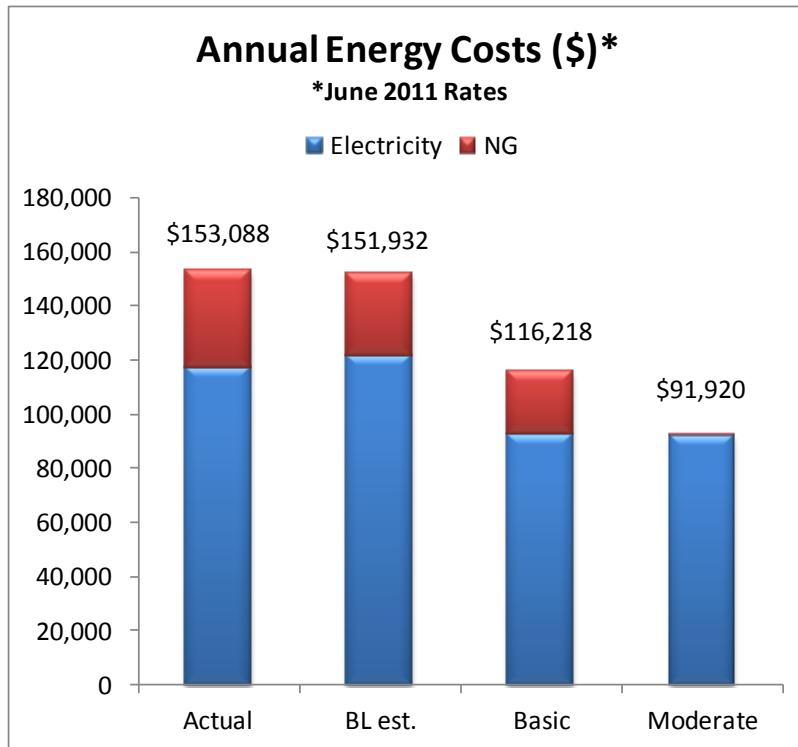
Figure 4: Integrated system solutions with annual operating cost reduction potential.
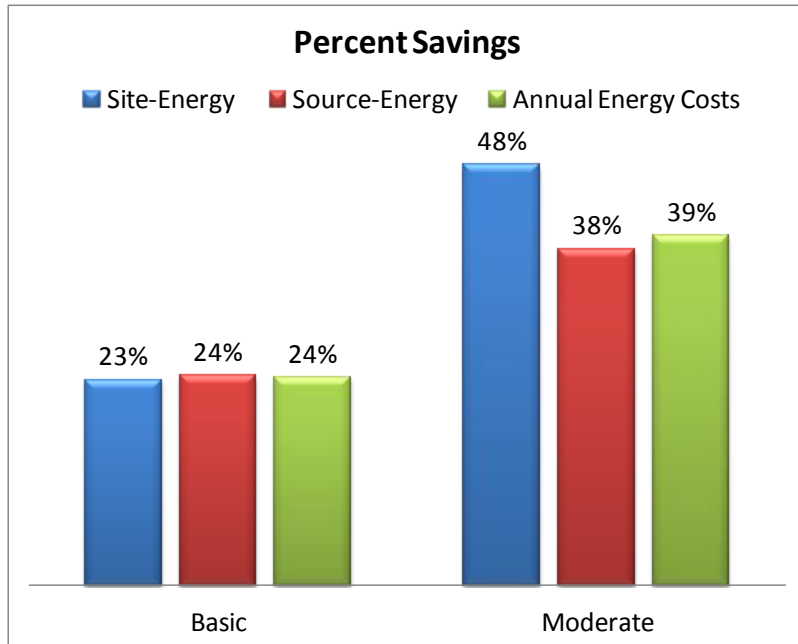

Figure 5: Site-energy, source-energy, and annual operating cost reduction potential due to integrated system solutions recommended for Building 101.

4. BUILDING 101 ECONOMIC PERFORMANCE ANALYSIS

Key economic indicators of retrofit investments including initial cost, energy cost savings, simple payback, IRR, and NPV are reported for the recommended basic and the moderate upgrade packages. ECM recommendations provided by an independent Level II audit are also reported for comparison (Figure 6).

The independent Level II audit results presented in Figure 1C and Figure 6 were based on a systematic energy audit process for analyzing a building's existing energy usage and identifying opportunities to conserve energy and achieve energy cost savings (Bohadel, 2011). The energy audit involved a site visit by engineering staff in October 2011 that included analysis of the building management system, air handling units, boiler and auxiliaries, and direct expansion cooling systems. Bohadel (2011) further states that the audit team primarily utilized the building management system to facilitate the identification of ECMs and assess a sample of existing equipment. A summary of the proposed ECMs along with the economic returns is provided in Figure 6. The independent audit report estimates that the combined effect of their proposed ten ECMs would result in 36% annual electricity savings, 38% annual natural gas savings, and 38% annual energy costs savings.

The Audit Tool initial cost estimates for the basic and the moderate upgrade package along with results provided by the external audit are presented in Figure 6. It can be observed from Figure 6 that initial investments of $271,594 and $404,954 are required for the basic and the moderate upgrade packages, respectively. These estimates, based on RSMeans data, are provided as initial assessments to aid the retrofit decision making process. A detailed cost-benefit analysis is recommended before financing, scheduling, and implementation decisions are made for retrofit solutions.

Based on the initial cost estimates and energy savings potential, annual cash flows for an investment period of 15 years starting in 2012 are calculated. These cash flow estimates assume 1% annual inflation and 4% discount rate recommended by DOE FEMP (Rushing *et al.*, 2011).

A summary of the economic return estimates for Building 101 is provided in Figure 7. Results are reported with and without incentives (assumed to be 50% of incremental initial costs). For the case without incentives, the positive NPV retrofit solutions with the basic and moderate upgrade packages are expected to result in approximately 11% and 13% IRR, with a corresponding simple payback period of 7.6 and 6.7 years, respectively. For the case with incentives, the positive NPV retrofit solutions with the basic and the moderate upgrade packages are expected to result in approximately 27% and 30% IRR, with a corresponding simple payback period of 3.8 and 3.4 years, respectively. The moderate upgrade package, with higher NPV, is recommended for Building 101. It should be noted that the effect of incentives on economic returns is demonstrated as academic illustrations. A detailed study of the design, availability, and timing of ECM initial cost incentives in the Philadelphia ten county region is recommended for informed retrofit decisions.

5. BUILDING 661 ENERGY AND ECONOMIC PERFORMANCE ANALYSIS

The reduced-order building modeling tool developed previously was also utilized to analyze the baseline energy consumption of Building 661 and potential solutions to deep retrofit for the planned building renovation. Building 661 is not occupied at the present time. Actual site-energy usage of this building is neither available nor representative of the future occupied building energy footprint. Energy Plus simulation results from analyses performed by researchers at Carnegie Mellon University (CMU) were used to create a baseline and to compare the Audit Tool based energy use estimates with the Energy Plus model results (Karaguzel and Lam, 2012).
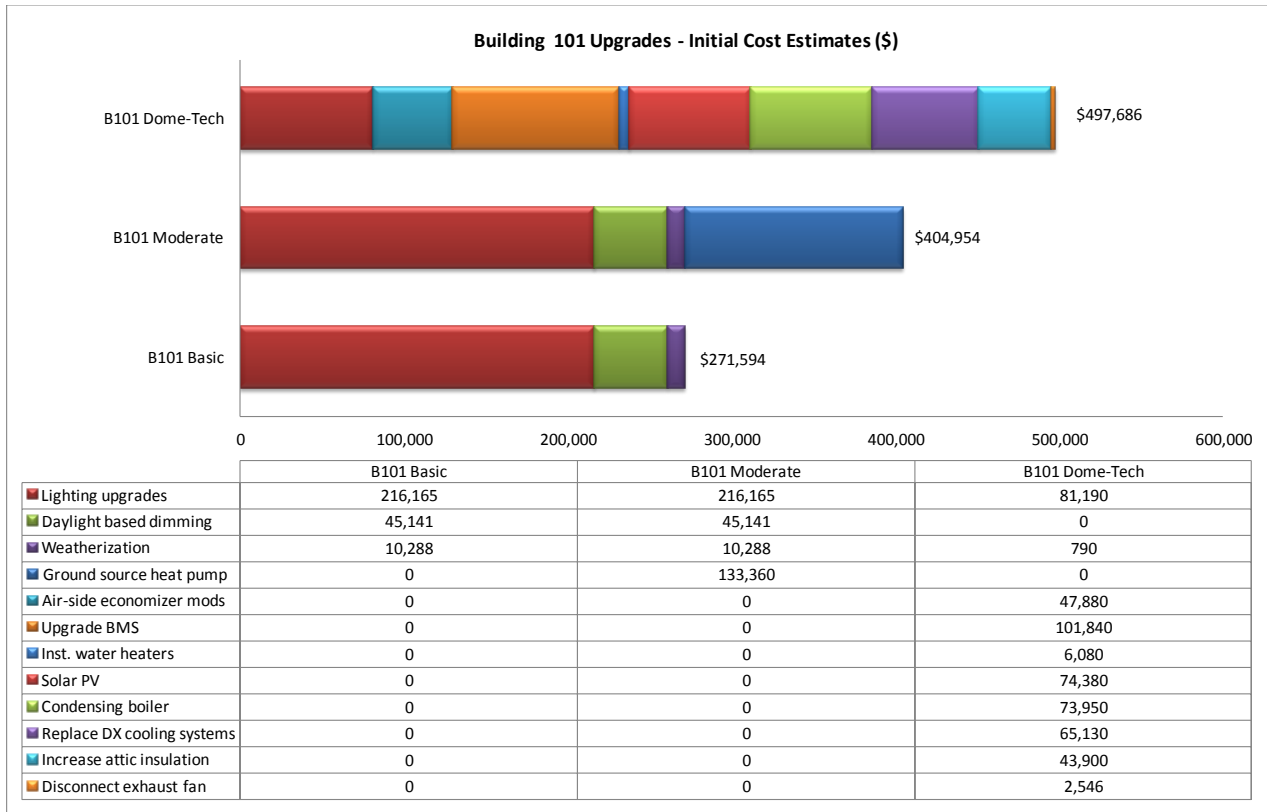
Figure 6: Initial cost estimates.

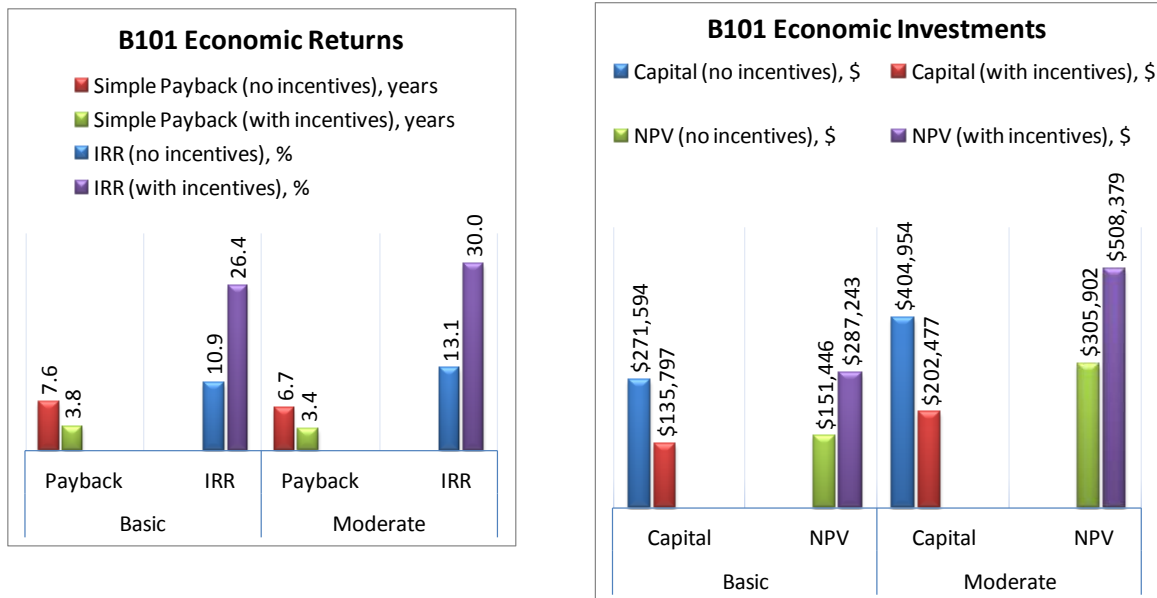|	B101 Basic	B101 Moderate	B101 Dome-Tech
Lighting upgrades	216,165	216,165	81,190
Daylight based dimming	45,141	45,141	0
Weatherization	10,288	10,288	790
Ground source heat pump	0	133,360	0
Air-side economizer mods	0	0	47,880
Upgrade BMS	0	0	101,840
Inst. water heaters	0	0	6,080
Solar PV	0	0	74,380
Condensing boiler	0	0	73,950
Replace DX cooling systems	0	0	65,130
Increase attic insulation	0	0	43,900
Disconnect exhaust fan	0	0	2,546

Figure 7: Summary of economic return estimates for Building 101.

Substantial site-energy, source-energy, and annual energy cost savings (40-60% relative to the baseline consumption) are estimated for Building 661 based on integrated solution recommendations. A prioritized list of three integrated solutions is provided based on different levels of capital investment requirements and renovation constraints. Key economic indicators of retrofit investments including initial cost, energy cost savings, simple payback, IRR, and NPV are also reported for the three upgrade packages. Desai *et al.* (2012) have reported the details of the analysis and the recommendations for Building 661 retrofit solutions.

6. CONCLUSIONS

Initial assessments of economically attractive retrofit solutions for Building 101 and Building 661 are provided. Substantial energy use reduction and cost savings were estimated based on integrated solution recommendations. A detailed cost-benefit and energy analysis was recommended before financing, scheduling, and implementation decisions are made for the recommended retrofit solutions. The solutions derived using the audit tool and the energy cost benefits were largely consistent with those provided by the convential building audit and analysis path while allowing a larger number of options to be considered and consuming less labor and computational resources.

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