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Achieving Deep Energy Savings in Existing Buildings through Integrated Design

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ABSTRACT HEADING

Commercial buildings consume a large amount of energy – 35% of the nation's electricity, and 13% of the nation's natural gas. And the majority of this existing commercial building stock will still exist over 20 years from now. Such a large stock of existing buildings presents a good opportunity for decreasing our national energy demand through energy retrofits. This paper will present key concepts for cost-effective retrofit projects with deep energy savings (45% and above) in existing buildings. Achieving deep savings typically requires an integrated design process, where all building systems and assemblies are evaluated in a holistic manner. With this process, for example, HVAC equipment replacement measures are evaluated in consideration of load reduction measures. The paper will present examples and considerations related to the integrated design process. The upfront cost of a deep retrofit project may be difficult to justify on the basis of energy savings alone. However, the business case is much easier to make when planned upgrades and equipment replacements are taken into account. The paper will present methods and considerations related to planning for retrofit projects, and evaluating and ranking deep retrofit options. The Department of Energy has recognized the energy savings potential in existing commercial buildings, and has recently published two Advanced Energy Retrofit Guides that target methods for achieving various levels of energy reduction in existing buildings. The guides address the office and retail building sectors. As representative examples of content included in each of the guides, the paper will include technical details from the guides related to specific energy reduction measures. The general project planning considerations presented in the guides are applicable nationwide, while the energy and cost savings estimates for recommended energy efficiency measures have been developed based on energy simulations and cost estimates tailored to five distinct climate zones. The results of these analyses are presented for individual retrofit measures, as well as a package of recommended measures for three project types: operations and maintenance measures implemented through the existing building commissioning process, standard retrofits, and deep retrofits. The paper will present these measures and packages, to show examples of retrofits that can be implemented in existing commercial buildings to achieve various levels of cost-effective energy reduction.

INTRODUCTION

Industry leaders have long recognized the role that energy retrofits can play in reducing operating costs and increasing asset value. Opportunities for improved energy performance exist in nearly every building. These opportunities come in many forms, including improved operational and maintenance practices, equipment retrofits, occupant behavioral changes, and building envelope modifications, to name just a few. Over the life of a building, different opportunities will be available at different times, depending on the changing usage of a building, remaining life of the equipment and assemblies, and availability of improved technologies in the market.

While the opportunities for energy improvements in existing buildings are significant, the process of identifying,

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analyzing, and implementing those improvements is not always straightforward. This paper presents key concepts for cost-effective retrofit projects with deep energy savings (45% and above) in existing buildings.

TYPES OF RETROFIT PROJECTS

Retrofit projects can be categorized into three types of projects: (1) Operations and maintenance (O&M) improvements implemented through the existing building commissioning (EBCx) process, (2) standard retrofits, and (3) deep retrofits. Energy savings typically increase in magnitude as you move from EBCx to deep retrofit. Regardless of the approach, after implementing retrofits, it's important to verify that the systems are installed properly and operating correctly in order to achieve the maximum energy savings potential of the retrofit. (Liu 2011a, Liu 2011b)

Significant energy savings can often be achieved with minimal risk and capital outlay by improving building operations and restructuring maintenance procedures, which is a key component of EBCx. EBCx is a quality-oriented process for investigating and optimizing the performance of a facility and its systems to meet the current needs of the facility. Research has shown 16% median energy savings among hundreds of EBCx projects across the country (Mills 2009).

Standard retrofit measures provide cost-effective and low-risk efficiency upgrade options for building owners who are limited to making incremental capital upgrades to their building. They are often conducted as like-for-like retrofits, meaning that the new equipment has same capacity as old equipment, but with higher energy efficiency. Standard retrofits are often implemented in a staged process, with one retrofit implemented after another. The sequencing of standard retrofit measures is important, as the impact of some retrofits may have an impact on other systems. For example, a lighting retrofit may reduce the cooling load on the HVAC system, which could allow for downsizing the cooling system. Accounting for these interactions may yield greater savings than just like-for-like retrofits.

A deep retrofit is a building energy retrofit approach that uses an integrated design process to improve the economics of efficiency and achieve much larger energy savings than conventional energy retrofits. A deep retrofit project provides an opportunity for a building owner to reduce energy consumption significantly beyond the savings from O&M and standard retrofit measures. In deep retrofit projects, all systems are evaluated concurrently, as an overall system, and the project may involve the simultaneous retrofit of multiple systems. While deep retrofits can achieve deep energy savings, they may require a larger upfront investment and may have longer payback periods than O&M or standard retrofit measures. They are usually conducted as part of a major building remodel.

KEY CONCEPTS FOR DEEP RETROFITS

Deep retrofit projects combine many O&M and capital retrofit measures in an integrated whole-building design process to achieve energy savings of 45% or more from a building's current usage. The integrated design process enables a deep retrofit project to achieve more than just a simple sum of the O&M and retrofit measures. Since these projects affect multiple building systems and assemblies (e.g., envelope, lighting, and HVAC), the retrofit of each system and assembly should be designed in close consideration of the other retrofits for maximum benefits to be realized. For a deep retrofit project that is a major building remodel, the design process can look similar to that of a new construction project.

Deep retrofit projects are rarely conducted on their own for the sole purpose of energy savings. Typically, they are considered and implemented in conjunction with other needed work at a facility that is being performed for non-energy reasons, such as major envelope upgrades, equipment at the end of its life and in need of replacement, or major occupancy changes. Deep retrofit projects are most cost-effective when piggybacked on other major work happening in the facility.

INTEGRATED DESIGN PROCESS

The integrated design approach to energy retrofits focuses on the simultaneous or staged retrofit of multiple building systems, with a package of measures of varying complexities and financial benefits. For example, a building owner may complete a lighting retrofit at the same time as increasing the amount of roof insulation and replacing the HVAC system.

The integrated approach is well-suited to building owners who either have ambitious energy savings goals to be met in a short period of time, or have the opportunity to install deep retrofit measures due to planned changes in a building's systems, such as those that occur when a building is repurposed or undergoes a major renovation. From a financial perspective, implementing multiple measures simultaneously has two distinct benefits:

1. The overall economics of the project are often improved. Cumulative project costs can be reduced compared to the staged approach (implementing retrofits one after the other), due to efficiencies from installing multiple measures at once. Lifecycle benefits may be increased, as energy savings begin at a high level rather than increasing over time as retrofits are gradually implemented.
2. The integrated approach allows for the optimization of equipment sizes when multiple building systems and assemblies are replaced. For example, if lighting and HVAC systems are replaced, the HVAC system designer can take into account the reduced cooling load from the lighting retrofit, resulting in a smaller cooling system. Though this can also occur in the staged approach, the integrated approach is generally more conducive to identifying such opportunities.

The integrated design approach typically involves architects, design engineers, and potentially commissioning providers working together as part of an integrated design process, where the various design disciplines coordinate closely to design and specify systems and assemblies that will meet the owner's needs as well as result in minimal energy use (Energy Design Resources 2002). Retrofit systems are designed in concert, rather than as a sum of individual parts, and the final design is evaluated using lifecycle economics. The design team develops multiple retrofit options, and ranks these options against energy reduction goals, cost constraints, and other goals and considerations before deciding on a final design with the Owner.

The integrated design of lighting, envelope, HVAC, and plug load systems calls for a design team with special capabilities. Chief among these capabilities is that of open communication among team members. To foster open communication, the integrated design process uses a different team structure than a traditional design process. It is more of a team-based approach, with more collaboration between the various disciplines than the hierarchical owner-architect-engineer organization found in the traditional design process. (ASHRAE 2011)

Investing in greater efficiency and load reduction can significantly reduce costs through downsizing, or even eliminating, HVAC systems. This is a key feature of deep retrofits, but it cannot be achieved without thoughtful, integrated design. The following, step by step approach for designing a deep retrofit project will lead to maximum benefits:

1. Define the needs and services required by the building occupants in a current facility requirements document. Start from the desired outcomes. This means identifying a purpose, such as cooling, instead of going directly to a solution, such as chillers.
2. Understand the existing building structure and systems. What needs are not being met? Why not?
3. Understand the scope and costs of planned or needed renovations. What systems or components require replacement or renovation for non-energy reasons? What costs and interruptions to service or occupancy do those renovations entail?
4. Reduce loads. Select measures to reduce loads:
    - First, through passive means such as increased insulation
    - Then, by specifying the most efficient non-HVAC equipment and fixtures
5. Select appropriate and efficient HVAC systems. After reducing loads as much as possible, consider what HVAC system types and sizes are most appropriate to handle the reduced loads.
6. Find synergies between systems and measures. Find opportunities to recover and reuse energy waste streams. This exercise will often identify multiple benefits that arise from a single expenditure.

7. Optimize controls. After the most appropriate and efficient technologies have been selected, the focus should shift to optimizing the control strategies for the HVAC, lighting, and plug load systems.
8. Realize the intended design. Conduct initial and ongoing commissioning to ensure continued realization of the intended design and its benefits.

For deep retrofits, it's important that the design team consider the building's various systems and components as an integrated system. Members of the project team must coordinate to minimize the expected energy usage of the building and meet the owner's specific design goals. Because of the complex interaction between systems, a whole-building energy modeling software program is often required for the integrated approach.

PLANNING FOR DEEP RETROFIT PROJECTS

The upfront cost of a deep retrofit project may be difficult to justify on the basis of energy and maintenance cost savings alone. The business case is much easier to make when planned upgrades and the avoided costs of equipment and assembly replacements are taken into account. Many building upgrades occur throughout the life of a building, and these planned capital improvements represent opportunities to perform a cost-effective deep retrofit. Table 1 shows examples of key opportunities for embarking on a deep retrofit project.

Table 1. Opportunities in a Building's Life to Perform a Deep Retrofit

Building Event	Opportunity
End (or near end) of life major equipment replacement	Major equipment replacements provide an opportunity to also address the envelope and other building systems. After reducing thermal and electrical loads, the marginal cost of replacing the major equipment with smaller equipment, or no equipment at all, can be negative.
Roof, window and siding replacement	Planned roof, window and siding replacements provide opportunities for significant improvements in daylighting and envelope thermal performance at small incremental costs. These improvements in turn allow for reduced artificial lighting and a smaller HVAC system.
Major occupancy change	A major occupancy change presents a prime opportunity for a deep retrofit. Owners may be able to leverage tenant investment in the fit out. Also, major retrofits are best done when the space is vacant, before the new tenants move in.
Building greening	A desire to achieve green building or energy certification may require significant work on the building and its systems, which may then make a deep retrofit economical.

When building owners are aware of these opportunities, they can engage the integrated design process and make a planned component replacement grow into a deep retrofit. In some cases, the opportunity is obvious. For example, if the roof must be replaced, insulation can be added to the new roof. But other opportunities are less straightforward. For instance, if a building's roof needs replacement in five years but the boiler is slated for replacement now, it probably makes most economic sense to move that roof replacement up, and add insulation to reduce the heating load and the size and cost of the boiler. This latter example highlights how a basic understanding of the deep retrofit process can help building owners reap greater rewards from their investments.

Another major consideration is the deep retrofit project's impact on the building occupants during the construction phase. If the building will be occupied during the project, this will limit the types of measures that can be considered. For example, a complete replacement of the building envelope is not a realistic option if the building will remain occupied during construction.

Once motivated to embark on a deep retrofit project, building owners need to develop a project-specific business case that will ensure that the project meets long-term cost-effectiveness requirements. There are many financial analysis methods available, including simple payback, net present value, internal rate of return, and life cycle cost, to name a few. When reviewing the deep retrofit options developed by the design team, it's important to evaluate the financial impacts in a consistent and appropriate manner. A project can initially appear to be unattractive when viewed through the lens of simple payback period, while a more complete economic analysis such as net present value reveals it to be a profitable investment. Life-cycle cost analysis is more effective at identifying the best project option, once the costs and benefits of each alternative are carefully analyzed and expressed in present value terms.

When performing the financial analysis for deep retrofit options, the incremental costs and benefits should be used, comparing the costs and benefits of the options to the costs and benefits related to just a newer version of the current equipment. Also, programs such as utility on-bill financing, utility incentive programs, and tax relief can be an effective way to reduce a project's total cost. These should be factored into the estimated costs of deep retrofit options when evaluating alternatives.

EXAMPLE DEEP RETROFIT PACKAGES

Example deep retrofit measure packages for office and retail buildings are provided in the Advanced Energy Retrofit Guides ("guides") available from the U.S. Department of Energy (DOE) (Liu 2011a, Liu 2011b). The energy savings and financial performance of the packages, which include a mix of measures, are analyzed for a representative retail and office building (Deru 2011) in five primary climate regions in the U.S.: hot & humid, hot & dry, marine, cold, and very cold.

There are a number of O&M and capital retrofit measures that could be included as part of a deep retrofit package, depending on the goals of the project and the outcomes of the integrated design process. The measures included in the guides' deep retrofit packages, shown in Tables 2 and 4, are representative examples of deep retrofit projects with a bundle of capital and O&M measures. They may not be applicable to some retail and office buildings, and there may be other measures that are applicable but aren't included in the list. The measures listed in these packages are applicable to a reference building that has characteristics similar to most standalone retail buildings and large office buildings in the U.S. of pre-1980 construction. (Deru 2011)

In the guides, the analysis of the deep retrofit packages assumes that O&M measures are implemented first, as part of an EBCx process, followed by the deep retrofit measures. This is estimated to result in savings of over 45% of site energy usage in the reference buildings, as shown in Tables 3 and 5, based on an analysis of the measures in the packages using EnergyPlus, a building energy simulation software program. Each climate zone shows significant energy savings, with slight variations between the climate zones. The analysis accounts for interactive effects between building systems and measures.

The estimated financial metrics associated with the deep retrofit packages in each climate zone are shown in Tables 3 and 5. These metrics include implementation of the measures shown in Tables 2 and 4. The costs and savings shown in these tables are incremental costs and savings for the retrofit measures, since it is assumed that the equipment is at the end of its useful life and is in need of replacement. The incremental costs and savings are based on the difference between similar standard efficiency equipment and an energy efficient option. Full costs were assumed for measures that only added functionality to the existing system.

Retail

The measures included in the 24,695 ft² (2,294 m²) retail building's deep retrofit packages in the guide are shown in Table 2 (Liu 2011a). The measures range from the addition of simple controls functionality (re-circuit and schedule lighting system), to significant changes to the building's systems (replace HVAC system). Most of the measures relate to the building's lighting system, since this is the end use that uses the greatest amount of energy for the retail building. The technical details related to the measures included in the deep retrofit packages can be found in the guide (Liu 2011a).

Two of the measures listed in Table 2 apply to a specific type of HVAC system commonly found in standalone retail buildings: single-zone packaged rooftop units. While this is probably the most common type of HVAC system found in existing standalone retail buildings, these two HVAC measures may not apply to other HVAC system types. However, the concepts can be applied to other HVAC system types: increase the efficiency of the existing system's cooling and heating sections, and utilize energy recovery.

Table 2. Retail Deep Retrofit Package Measures

System	Measure Description	Climate Zone
Lighting, Envelope, HVAC, Service Hot Water	O&M measures: Calibrate exterior lighting photocells, reduce envelope leakage, replace worn out weather stripping at exterior doors, clean cooling and heating coils and comb heat exchanger fins, revise air filtration system, add equipment lockouts based on outside air temperature, reprogram HVAC timeclocks to minimize run time, optimize outdoor air damper control, repair airside economizer, increase deadband between heating and cooling setpoints, replace plumbing fixture faucets with low flow faucets with sensor control.	All
Lighting	• Add daylight harvesting • Re-circuit and schedule lighting system by end use • Retrofit interior fixtures to reduce lighting power density by 58% • Install skylights and daylight harvesting • Retrofit exterior fixtures to reduce lighting power density, and add exterior lighting control	All
Envelope	Add roof insulation	Hot & Humid
HVAC	• Replace RTUs with higher efficiency units • Remove heat from front entry	All
HVAC	Replace HVAC system with a dedicated outdoor air system	Marine, Cold, Very cold

As shown in Table 3, the deep retrofit packages have a five-to-six year payback and positive net present value, making them a cost-effective method of achieving significant energy savings.

Table 3. Retail Deep Retrofit Savings and Financial Analysis

	Site Energy Use Intensity (EUI), kBtu/sf/yr (kWh/m²/yr)		Site EUI Reduction	Financial Analysis			
	Baseline	Post-Deep Retrofit		Total Package Cost	Total Annual Savings	Simple Payback, years	Net Present Value
Hot & Humid	107 (338)	44 (139)	59%	$161,000	$27,800	5.8	$4,860
Hot & Dry	103 (325)	47 (148)	54%	$129,000	$25,300	5.1	$37,800
Marine	90 (284)	38 (120)	58%	$124,000	$22,600	5.5	$19,900
Cold	100 (315)	43 (136)	57%	$139,000	$29,600	4.7	$61,300
Very Cold	102 (322)	46 (145)	55%	$130,000	$24,400	5.3	$30,400
Average	100 (315)	44 (139)	56%	$137,000	$25,900	5.3	$30,900

Office

The measures included in the 200,000 ft² (18,581 m²)office building's deep retrofit packages in the guide are shown in Table 4 (Liu 2011b). The measures range from the addition of simple controls functionality (occupancy sensor control of lighting), to significant changes to the building's HVAC systems (replace boilers and convert cooling plant pumping system). Most of the measures relate to the building's HVAC system, since this is the system with the greatest opportunity for optimization. The technical details related to the measures included in the deep retrofit packages can be found in the guide (Liu 2011b).

The measures were also chosen based on their impact on the tenants. The reference building is a multi-tenant commercial office building, whose owner likely cannot afford to ask the tenants to leave for a few years during the remodel. The measures included in the deep retrofit packages listed in Table 4 were selected based on this constraint.

Some of the measures listed in Table 4 apply to a specific type of HVAC system commonly found in large multi-tenant commercial office buildings: a multi-zone VAV air system with a water-cooled chilled water plant and a heating water system. These HVAC measures may not directly apply to other HVAC system types. However, the concepts can be applied to other HVAC system types: add functionality to adjust the system operating parameters during part load operation to realize energy savings and extended equipment life.

Table 4. Office Deep Retrofit Package Measures

System	Measure Description	Climate Zone
Lighting, Envelope, HVAC	O&M measures: Reduce envelope leakage, revise air filtration system, calibrate air and water sensors, re-enable supply air temperature setpoint reset, reduce HVAC equipment runtime, close outside air damper during unoccupied periods, reduce economizer damper leakage (except Hot & Humid), shut down cooling plant when there's no cooling load.	All
Lighting	• Retrofit interior fixtures to reduce lighting power density by 11% • Install occupancy sensors to control interior lighting • Add daylight harvesting • Retrofit exterior fixtures to reduce lighting power density, and add exterior lighting control	All
Envelope	Add roof insulation	All, except Hot & Humid
HVAC	• Widen zone temperature deadband, add conference room standby control (upgrade to DDC zone control) • Lower VAV box minimum flow setpoints, reset duct static pressure (upgrade to DDC zone control) • Add demand-controlled ventilation • Replace supply fan motor and VFD	All
HVAC	• Shut down heating plant when there's no heating load • Increase efficiency of condenser water pumping system • Change cooling plant pumping system to variable primary • Add a VFD to one chiller	Hot & Humid, Hot & Dry
HVAC	Increase efficiency of condenser water system	Hot & Dry
HVAC	Replace boilers and change heating plant pumping system to variable flow primary	Marine, Cold, Very cold

As shown in Table 5, the deep retrofit packages have a five-to-six year payback and positive net present value, making them a cost-effective method of achieving significant energy savings.

Table 5. Office Deep Retrofit Savings and Financial Analysis

	Site Energy Use Intensity (EUI), kBtu/sf/yr (kWh/m²/yr)		Site EUI Reduction	Financial Analysis			
	Baseline	Post-Deep Retrofit		Total Package Cost	Total Annual Savings	Simple Payback, years	Net Present Value
Hot & Humid	88 (278)	48 (151)	45%	$697,000	$117,000	6.0	$227,000
Hot & Dry	97 (306)	46 (145)	52%	$890,000	$161,000	5.5	$422,000
Marine	94 (297)	44 (139)	53%	$918,000	$162,000	5.7	$369,000
Cold	86 (271)	44 (139)	48%	$885,000	$153,000	5.8	$302,000
Very Cold	91 (287)	47 (148)	49%	$837,000	$137,000	6.1	$211,000
Average	91 (287)	46 (145)	50%	$845,000	$146,000	5.8	$306,000

CONCLUSION

Existing office and retail buildings consume 17% and 13% of total commercial building energy use respectively, the top two energy use of any sector, and these buildings contain ample opportunity for energy improvements. The majority of existing office and retail buildings were built before 1980, and the equipment in those buildings is inefficient when compared to newer technologies. Deep retrofit projects are a cost-effective opportunity for substantially reducing energy usage, through the implementation of a package of O&M and capital measures identified with an integrated design process.

ADDITIONAL INFORMATION

The U.S. Department of Energy's (DOE) *Advanced Energy Retrofit Guides* present general project planning guidance as well as financial payback metrics for energy efficiency measures. Emphasis is put on actionable information, practical methodologies, diverse case studies, and objective evaluations of promising retrofit measures. The guides are available through the DOE's Office of Energy Efficiency and Renewable Energy (EERE) at http://tinyurl.com/DOE-EERE.

Rocky Mountain Institute's *RetroFit Depot* (www.retrofitdepot.org) offers case studies, free energy modeling tools and a step-by-step overview of the deep retrofit process to help owners and energy service practitioners pursue deep retrofits.

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REFERENCES

ASHRAE. (2011). *Advanced Energy Design Guide for Small and Medium Office Buildings*. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta, GA.

Deru, M., et al. (2011). *U.S. Department of Energy Commercial Reference Building Models of the National Building Stock*. National Renewable Energy Laboratory, Golden, CO.

Energy Design Resources (2002). *Design Brief: Integrated Building Design*. California Public Utilities Commission.

Liu, G., et al. (2011a). *Advanced Energy Retrofit Guide for Retail Buildings*. Pacific Northwest National Laboratory, Richland, WA.

Liu, G., et al. (2011b). *Advanced Energy Retrofit Guide for Office Buildings*. Pacific Northwest National Laboratory, Richland, WA.

Mills, E. (2009). *Building Commissioning: A Golden Opportunity for Reducing Energy Costs and Greenhouse Gas Emissions*. Lawrence Berkeley National Laboratory, Berkeley, CA.