Deep energy retrofit of commercial buildings: a key pathway toward low-carbon cities

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Energy efficiency of commercial buildings is a fundamental part of the solution for developing low-carbon cities worldwide. Existing commercial buildings consume significant energy, as well as presenting great requirements and opportunities for energy-efficient retrofits. This article introduces an approach to commercial building retrofits that achieve large energy savings with attractive economics. A case study is used to illustrate the procedure of conducting deep retrofits of large commercial buildings. The article also presents a 'pilot-to-portfolio' approach that can amplify outcomes of single building retrofit to buildings within the same portfolio.

The commercial and residential buildings sector accounts for approximately one-fifth of the world's total delivered energy consumption, which is expected to continue coming in large part from fossil fuels (over 80%) [101]. In developed countries such as the USA, this value can reach up to 40%, with approximately equal shares attributed to commercial and residential buildings [102]. Commercial building energy use is predicted to expand by 0.9 and 2.7% per year from 2007 to 2035 for developed and developing countries, respectively [103]. Thus, energy efficiency of commercial buildings is becoming a fundamental strategy in mitigating GHG emissions in communities, cities and countries worldwide.

McKinsey & Company and the National Academy of Sciences estimate that the USA can reduce 28% of the commercial and residential building energy consumption in a cost-effective manner by 2020 and 32% by 2030, respectively [1,2]. Capturing this opportunity will require, in part, fundamental changes in the way buildings are renovated and newly constructed.

Approximately 86% of current building construction expenditures are for the renovation of existing buildings and the remainder is for new construction. An estimated 14 billion m^2 of existing buildings (~50% of the entire building stock in the USA) will need to be renovated over the next 30 years [3]. These renovations include end-of-life equipment and component replacements, tenant improvements and upgrades for market repositioning. Currently, over 2 billion m^2 out of a total of the total 7 billion m^2 of US commercial building space (or ~30%) are due for renovation and are therefore ideal for a **deep energy retrofit**, or an **integrative design** project to dramatically increase building energy efficiency at good economics. At a range of zero (or negative) to US$500 per square meter investment (incremental to the original cost of renovation) for each project, deep energy retrofits represent a multi-billion dollar market opportunity.

Existing commercial building stock is currently being retrofitted at a rate of approximately 2.2% per year. These retrofits typically reduce the energy consumption per building to 11% below the 2003 national average [103]. At this rate, half of the existing building stock will be retrofitted by 2030, with a cumulative carbon emissions savings of 13.5 million metric tons (Mt) (an 8% reduction). By contrast, the American Society of Heating, Refrigerating, and Air-Conditioning Engineers, the international organization of building engineers that sets US building codes, has signed on to 2030 challenge goals calling for the reduction of 179 Mt of carbon by 2030 through existing building retrofits.

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Key terms

Deep energy retrofit: A retrofit to increase building energy efficiency that uses integrative design to improve the economics of efficiency and achieve bigger energy savings at equal or lower cost, driving much larger savings (more than 50%) than conventional, isolated energy retrofits.

Integrative design: A highly collaborative and iterative design process for resource efficiency in which whole-systems thinking is employed to create multiple benefits from single expenditures, often justifying much larger resource savings than what is typically achieved.

Net present value: The sum of expenditures and savings cash flows that are discounted over some time period in order to account for the time–value of money.

Energy efficiency measure: An isolated building renovation project to increase energy efficiency.

This article introduces the approach and the key principles of deep energy retrofits, which are commercial building retrofits that achieve the energy savings necessary to create low-carbon cities and meet societal goals. A case study is employed to illustrate the procedure of conducting a deep retrofit for large commercial buildings. The paper further presents a 'pilot-to-portfolio' approach that can potentially amplify outcomes of a single building deep energy retrofit to more buildings within the same portfolio to further improve the economics of efficiency.

Differences between deep & conventional retrofits

A deep energy retrofit is the process that yields buildings that save at least 50% annual energy costs (compared with the average energy use of similar-type buildings [104]) with an attractive **net present value** (NPV). Deep retrofits are most economical when applied to buildings with overall poor efficiency performance and with multiple building systems (e.g., windows, cooling equipment and lighting) nearing their end of useful life. A deep energy retrofit will result in integrated construction projects strategically implemented over perhaps several years to upgrade the building envelope (exterior walls, windows and roof) for thermal and electrical load reduction, and to replace at least 50% of lighting, and heating, ventilating and air-conditioning (HVAC) equipment. A conventional retrofit will achieve 15–25% energy savings and thus will give attractive financial returns. It will result in isolated construction projects to upgrade HVAC components and/or lighting, and may include retro-commissioning (or 'tuning up' the operation of the existing building equipment). Figure 1 presents the typical retrofit process used in the Building Owners and Managers Association International (BOMA) and the Clinton Climate Initiative model, which is part of the BOMA Energy Performance Contract toolkit released in 2009 [105]. Essentially, this process can be summarized into four main steps:

- Qualification: determine overall viability of a project;
- Discovery: determine which **energy efficiency measures** (EEMs) to confidently recommend to client;
- Verification: increase the accuracy of capital, operation, and energy-cost savings estimates;
- Implementation: construct EEMs and verify the savings.

The deep energy retrofit process can be summarized in a similar way. The process differentiators that enable deeper savings exist throughout the entire retrofit process. Examples of such process differentiators include:

- A continuously collaborative team;
- The advantage of a highly informed and motivated client;
- The existence of a fully budgeted 'baseline' capital improvement plan (to enable piggybacking on planned equipment and infrastructure upgrades);
- The more extensive and integrated investigation of potential energy efficiency measures;
- The development of the theoretical minimum energy use or stretched technical potential;
- The evaluation of opportunities in tenant spaces;
- The establishment of a sophisticated yet digestible business case to compel the owner to push for deeper energy savings.

Case demonstration of the deep retrofit process: Federal office building

Brief description of the federal office building

The Federal Office Building (FOB), just under 50,000 m^2 and located in the heart of a large metropolitan area in the USA, is pursuing impressive sustainability targets above and beyond federal requirements with the goal of being an example for other building retrofits nationwide. Built in the mid-20th century, this high-rise federal building is held to a multitude of government mandates, codes and standards. Not only must the building comply with the government's NetZero goals of the future, but as a historic building it is required to reflect respectfully on its past and preserve architectural elements characteristic of the era in which it was built. The FOB is pursuing leadership in energy and environmental design for new construction platinum certification, which will require full participation of its tenants – all government agencies. The design team is hopeful that this project will serve as an example for other similar federal and private high-rise buildings across the country.

Deep retrofit process

Qualification

A charrette was conducted in the early stages of design to clarify objectives and identify goals, involving owners, tenants, architects, engineers and other consultants. The design team discussed the various federal

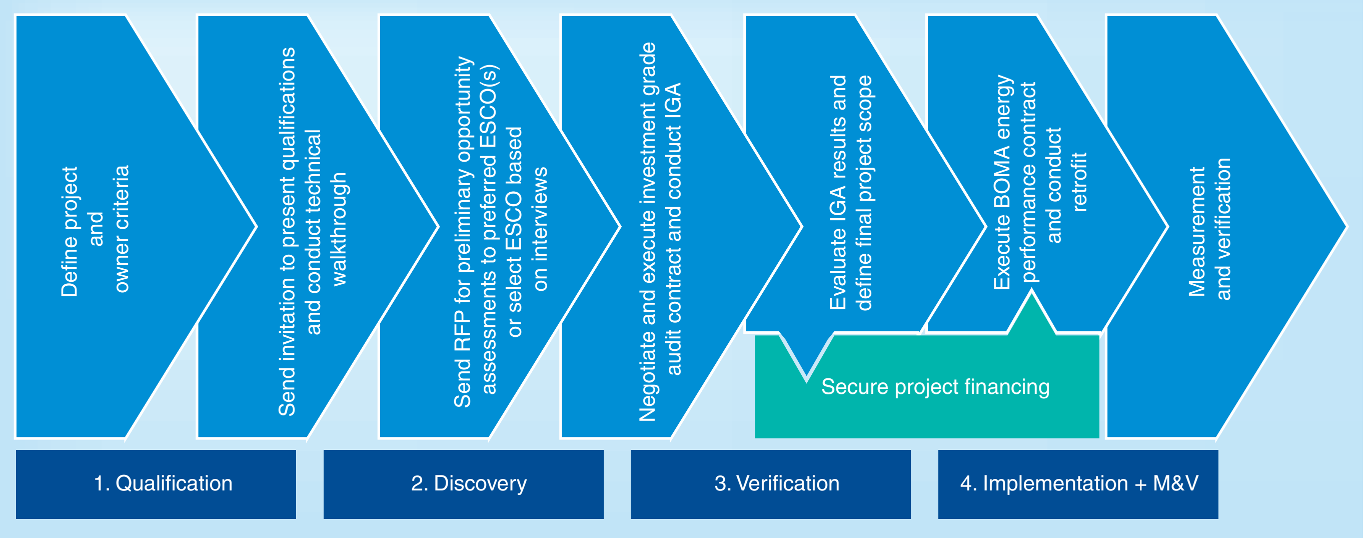

Figure 1. BOMA Internatinoal and the Clinton Climate Initiative project development process.
BOMA: Building Owners and Managers Association; ESCOs: Energy service companies; IGA: Investment grade audit; M&V: Measurement and verification RFP: Request for proposal.
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requirements and mandates with which the project is required to comply, and settled on a scheme that would significantly exceed code and mandate requirements. With an energy use intensity target of 85.2 $kWh/m^{2\text{-year}}$ (27 $kBtu/ft^{2\text{-year}}$) and a target energy reduction of 50% below AHSRAE Standard 90.1 2004, this building will be 10–15 years ahead of schedule towards reaching 2030 NetZero goals, and it will be one of the most efficient office buildings in the USA.

Discovery

Opportunities to implement EEMs are abundant, but existing conditions provide barriers to their implementation and optimization. In particular, the building orientation presents significant heating, cooling and day lighting challenges. The FOB is oriented almost 45° off of the North–South axis, meaning the two longer sides of its rectangular footprint face Northeast and Southwest. As a result, the sunny side of the building is generally hot while the other side in shadow is generally cool. This is not ideal for uniformity in thermal heat gain and loss throughout the building. Rather than considering this a disadvantage, the design team proposes a solution in which heat from the warm side of the building is reclaimed and used to heat the cool side of the building, and vice versa, using water to transfer the heat. In combination with a large thermal storage tank, an active chilled beam system – a relatively emerging technological solution in the USA, and effective zoning strategies, this system will dramatically reduce energy use by essentially allowing the building to heat and cool itself. The decision to install a chilled beam system stems mainly from the fact that it is more efficient and space-effective to distribute pipes of warm and cold water rather than large ducts of conditioned air. In addition, the thermal set-point ranges of hot and cold water are less extreme than is required with other HVAC systems, which conserves energy in the base building mechanical systems.

The windows in the FOB must serve a variety of purposes: they must maintain the same color and character of the original building windows, which are considered historic; they must block excessive solar heat gain; provide superior insulation; allow plenty of daylight into the space; and block out infrared and ultraviolet rays. Determining a window specification that optimizes all of these factors is critical to meeting project goals for energy use, visual and thermal comfort, and historic preservation. The proposed solution involves replacing the existing double-pane insulated window units with two sets of triple-pane insulated window units with a large air gap (owing to the geometry of the existing window box). The design team's goal for glass performance is a U-value of 0.625 (W/m^2-K). The visible light transmission coefficient and shading coefficient are being refined to maximize daylight and minimize heat gain. A different visible light transmission coefficient will be specified for the Northeast and Southwest facades of the building to maximize the amount of daylight that is allowed to infiltrate the space.

Tenant participation is a significant consideration in the design process. The nature of the work conducted by many building tenants precludes the ability for open office workspace in most of the building. This forced the design team to develop floor plans consisting mostly of private offices, enclosed workrooms and conference rooms. Inherently, this limits the amount of the floor plan that receives usable day lighting and maintains a connection to the outdoors with line-of-site views. In addition, budget constraints prevent the tenants from being able to purchase new, highly efficient office equipment such as copy machines, printers and laptop computers. Most of the tenants plan on moving in furniture that they already own, rather than purchasing new furniture. This limits the design team's control over materiality and surface reflectances of the tenant space, meaning that more lighting may be required since dark surfaces absorb more light than lighter surfaces.

A comprehensive Tenant Sustainability Design Guide will, thus, be beneficial and is currently under development for use as a tool to help inform tenant design decisions. It is intended to aid the tenants in understanding the project's sustainability goals and the fact that tenant participation is critical for the FOB to achieve these goals. The guidelines will serve as both an educational tool and a roadmap for the tenants to make the most sustainable choices in their space for optimized performance and comfort. As a subset to the Guide, the design team is developing a building standard for plug loads and occupant behavior (including items and topics such as ENERGY STAR® rated equipment, smart power strips, and employee education regarding efficient equipment operation). Plug loads account for approximately 30% of the existing building's energy use today. Eventually this plug load energy use will be cut in half as equipment is replaced and upgraded.

Other EEMs scheduled for implementation include:

- Innovative lighting technologies such as light-emitting diodes and other solid state lighting systems;
- Addressable lighting controls for daylight harvesting (dimming) and occupancy control;
- Flat plate solar thermal panel system sized to provide 100% of the building's domestic hot water load;
- Monitoring and controls such as building automation system and sub-metering of electricity and chilled water use on a tenant level.

Verification

Two main modeling tools are utilized to help inform the design of the FOB: energy modeling and life cycle cost analysis (LCCA). Packages of EEMs are evaluated for energy performance and cost–effectiveness, rather than individual measures.

In order to retrofit the FOB for energy efficiency, energy modeling tools that are capable of calculating the total energy and cost savings from EEMs must be utilized. Working through this process enables the design team to analyze multiple options to optimize the retrofit design, taking into consideration its specific climate zone and building type. Whole building energy modeling using eQUEST® software provides a method for analyzing the interactive effects of EEMs on an hourly basis. The FOB energy model provides in particular:

- Accurate calculation of energy and cost savings to justify the additional capital investment or design time that may be required to implement the EEMs;
- A method to quickly compare various alternatives and optimize the building design for maximum load reduction and energy efficiency;
- Assessment of energy codes and green building standards with which the FOB retrofit project must comply.

The main intent of the LCCA is twofold. First, it will help the owner and the design team to understand the life cycle costs from construction, ownership, operation and maintenance of each design strategy. Second, it will help tenants and the design team to make informed decisions when choosing between strategies to get the best long-term value. Long-term value is realized through a retrofit that is cost effective, achieves an improved work environment, and meets or exceeds aggressive federal sustainability goals. The design team evaluates the costs of entire packages of integrated measures using an Excel-based tool that was built in-house. With the support of the owner and the tenants, this approach enables the analysis to best capture the savings or costs related to the interactions between design strategies, as they would actually perform in operation. Throughout the design process, results from the LCCA and energy model dynamically help inform and guide design decisions. Figure 2 shows the comparison of predicted energy savings over existing building performance between the optimized solution (chilled beams) and the base case solution (a variable air volume system). In addition to the reasons described previously in this text, the chilled beam system saves energy over the variable air volume system.

Implementation

All of the above methodologies and technologies are currently under further evaluation and development for the FOB project. Currently, the design team is in the early stages of design. Construction will not be completed for several years. As the project evolves, the design team will continue to develop and refine EEMs, specifications, assumptions and cost considerations to ensure that project sustainability goals are met in a cost-effective way. Measures will be selected for inclusion in the final design by weighing relevant initial and operating cost criteria as well as energy savings criteria. The FOB's second life is beginning – a life that will honor its historic past through preservation of aesthetic elements, while paving the way to its future as a modern sustainable building that will serve as a guiding example for other retrofits to follow.

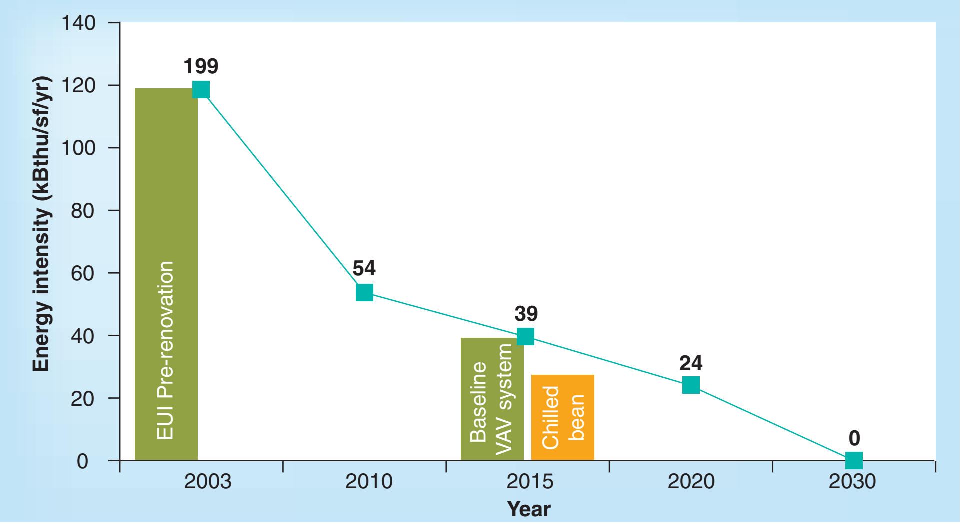

Figure 2. Comparison of predicted energy savings over existing building performance between the optimized solution (chilled beams) and the base case solution (VAV system – the business-as-usual case) [1kBTU/ft$^{2\text{-year}}$ = 2.93 kWh/m$^{2\text{-year}}$].
EUI: Energy use intensity; VAV: Variable air volume.

Deep retrofit amplification: 'pilot-to-portfolio' approach

Not only can deep energy retrofits reduce energy cost in a single building, but also in an entire real-estate portfolio. A deep energy retrofit can be used as a tool for portfolio-scale energy reduction by uncovering integrated EEMs (as opposed to simpler and isolated efficiency measures) and providing other lessons. This approach should be taken as part of a strategic portfolio plan to reduce energy. The Northwest Energy Efficiency Alliance and others provide recommendations and guidance on creating a strategic real-estate portfolio energy management plan [4,106].

Key elements of the pilot to portfolio approach are grouping very similar buildings together and conducting a pilot deep energy retrofit of the typical buildings. The more similar the typical buildings are to the group of buildings it represents, the more informative the findings will be and the less analysis that will be required in the future. To create groups of similar buildings, one should sort all the buildings in the portfolio by factors such as:

- Building age;
- Building function;
- Building size and shape;
- HVAC system type;
- Climate and microclimate.

One typical building from the group of similar buildings should then be selected for the pilot retrofit. The deep pilot retrofit of the typical building will address the following questions for all the buildings in the portfolio.

▪ Which groups of integrated EEMs were particularly cost effective?

The pilot retrofit team will identify the specifications, capital cost and return on investment for one or more groups of integrated EEMs. This information will be critical as one plans a larger investment across the rest of the portfolio.

▪ Which groups of integrated EEMs will require further design work in order to be replicated?

A subset of the total identified EEMs may require tailoring to specific buildings. It will be important to indicate in your portfolio plan which measures will require this extra design work. For instance, an EEM that links the heating controls to the lighting occupancy sensors may not require electrical design work since the wiring is similar across the portfolio of buildings. Conversely, replicating an EEM to install skylights may require some lighting design work to ensure the correct placement for optimal light distribution.

▪ What building systems or components can be eliminated or combined with others?

If it genuinely goes deep, the pilot retrofit should identify opportunities to downsize heating, cooling, electrical and lighting systems. The designer should explain the basic concepts and technologies used to downsize or combine the systems. With this information, designers of the retrofits of other buildings in the portfolio can streamline their analysis.

▪ Which implementation team members were particularly creative or integrative?

The deep energy pilot retrofit can also be a proving ground for the team charged with reducing energy across the portfolio. Look for talented people who are not afraid to be unconventional and who want to go beyond incremental energy savings.

Key term

Integrated EEMs: Individual building renovation projects that capture synergies with each other and existing building systems to increase energy efficiency and improve economics.

- **What corporate or institutional policies helped or hindered implementation of EEMs?**

In many cases, people in a corporation or institution may not realize that their policies can hinder or encourage efficiency. A thorough examination of a single building as provided by a deep energy retrofit can reveal institutional impediments and enablers.

Conclusion

This article presents the principle and process of performing deep retrofits to reduce total energy use of a commercial building. The pilot retrofit can produce valuable inputs that will enable deeper energy cost savings for building stocks within the same portfolio. The study shows that the deep retrofit and pilot-to-portfolio approach is better than the conventional retrofit effort. The former approach can provide a much longer menu of energy efficiency options that building owners can choose depending on their financial situations and other considerations. It delivers a well-designed and well-integrated energy efficiency measure package with aggressive energy-reduction goals. The pilot-to-portfolio approach enables wide population and replication of produced efficiency measures throughout similar building stocks with minimum cost [107].

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Financial & competing interests disclosure

The authors have no relevant affiliations or financial involvement with any organization or entity with a financial interest in or financial conflict with the subject matter or materials discussed in the manuscript. This includes employment, consultancies, honoraria, stock ownership or options, expert testimony, grants or patents received or pending, or royalties. No writing assistance was utilized in the production of this manuscript.

Executive summary

Introduction

- Energy efficiency in buildings is a large and profitable opportunity to reduce GHG emissions.
- However, fundamental changes in the way buildings are renovated are required in order to capture the opportunity.
- Deep energy retrofits applied to individual buildings and portfolios are a clear pathway.

Differences between deep & conventional retrofits

- A deep energy retrofit uses integrative design to save 50% of the building energy consumption with attractive economics.
- A conventional energy retrofit saves only 15–25% with similar economics.

Case demonstration of the deep retrofit process: federal office building

- A case study was presented that demonstrates a viable pathway towards the net-zero energy building goal in 2030.

Deep retrofit amplification: 'pilot-to-portfolio' approach

- Deep energy retrofits can inform a strategic portfolio plan for reducing energy across a real estate portfolio.
- Outcomes from a pilot project to retrofit one typical building can be amplified across the portfolio for improved economics of efficiency.

Future perspective

- One in three US commercial buildings are old, failing and offer a window of opportunity for a deep energy retrofit. Over the next 10 years, building retrofits will be one of the fastest growing fields that are critical to significantly reducing global carbon emissions, especially in developed countries where the majority of the building construction expenditures are for the renovation of existing buildings.

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■■ **This website is completely devoted to explaining the principles of deep retrofits, detailing the deep retrofit process, and providing useful tools.**