Building Energy Retrofits Under Capital Constraints☆

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Abstract

Write the abstract last. 4 sentences. State the problem. Say why it's an interesting problem. Say what your solution achieves. Say what follows from your solution.

Keywords: Office building; energy retrofit; energy efficiency measures; simple payback; staging; integrative design; measure bundles; measure packages; energy simulation

1. Introduction

Governments and institutions are focusing on building energy efficiency as an area for sizable, cost-effective energy use reduction and greenhouse gas mitigation [1, 2]. Commercial buildings are important to consider, as they are capital intensive and long-lasting; the median lifetime is 70 years [3]. Without considerable efforts to retrofit the current building stock for energy efficiency, as much as 80% of 2005 thermal energy consumption can remain past 2050 [4]. Currently, while 86% of construction costs go to building renovation, little of that goes to significantly improve the energy efficiency of buildings [5]. Renovation rates are around 2.2%, with an 11% average energy savings [6]. This rate needs to grow several-fold, with average savings around 55%, to approach modest emission reduction targets and Architecture 2030 goals [6]. Few renovation projects in the U.S. have achieved this savings level, with one recent study

☆Fully documented methods available here.

identifying only 50 such projects, known as deep or advanced energy retrofits [7, 8].

Lack of access to capital, insufficient payback, and saving uncertainty are top barriers to making energy retrofits more prevalent [9, 10]. Most projects are funded with limited internal capital, sometimes with assistance from grants, rebates, and other incentives. These projects have tended towards individual lighting, controls, and HVAC equipment measures with reliable savings, as it can be very expensive to go through an extensive energy audit that may not significantly reduce the savings uncertainty. While this current practice of single measure ranking by simple-payback results in good financial payback on a per-measure basis, it doesn't take advantage of measure integration that can yield greater energy savings. Most notably, heating and cooling load reduction measures enable downsizing central mechanical equipment for significant replacement cost savings. This means that choosing measure with optimal payback individually may not yield the best retrofit decision overall.

Several studies have investigated and established methodologies for choosing energy retrofits, summarized by [11]. A subset of the retrofit literature considers the integrative aspect of measure selection. [12] show performance of measure packages under different decision criteria and the impact of uncertainty. This approach captures the interaction between retrofit measures. However, it is not always possible to implement measures at once. [13] demonstrate a process to implement measures in order depending on capital availability. This reduces financial risk exposure of a large retrofit project, and stays within an internal budget. Both approaches are needed. Extending the project timeline allows major equipment replacements that are already embedded in capital plans to be incorporated into a comprehensive retrofit package. This allows targeted load reductions to precede equipment replacement, and to properly account for the cost of waiting. There is a trade-off between sacrificing expected life of equipment by replacing it now with other measures, or waiting until end-of-life and forgoing possible energy savings from implementing measures sooner.

This paper establishes a methodology for evaluating energy retrofit packages under capital constraints, and demonstrates it through a case-study of an office building in Philadelphia, PA.

2. Methods

2 pages describing method 5 pages details the number of optimization options expands greatly; prior studies are cross-sectional, not longitudinal

2.1. Case Study

The case study is a commercial office building at the Philadelphia Navy Yard, shown in Figure 6. It was originally built as a barracks, and underwent major renovation in 1999 to become an office building. The building is about 75,000 ft2 (6,968 m2), of which about 60,000 ft2 (5,574 m2) is conditioned space, about 40,000ft2 (3,716 m2) of that office, spread over 3 stories and a conditioned basement. The Energy Utilization Index (EUI) in this study is referenced to conditioned floor area. The building exterior wall is 1.5ft (0.46m) thick brick, and has a window-to-wall ratio of 17%. Three Variable Air Volume (VAV) units with DX cooling serve the building. A gas boiler serves heating coils at each air handler and provides reheat for terminal boxes in each thermal zone. Gas hot water heaters provide service hot water.

Figure 1: Figure caption

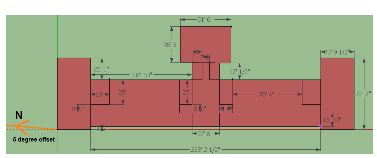

Figure 2: Figure caption

The building energy model uses the Openstudio[REF] modeling platform. The simplifications on the model are to assume an identical floor plan on each story, which is nearly the case in the building. The fenestration is modeled with a set window-to-wall ratio on each exterior wall, rather than modeling each window individually, to improve simulation speed with little accuracy loss on load calculations [14]. Mechanical equipment and lighting specifications are detailed from design drawings. Plug load is modeled with a set area density for office, conference, and lobby areas from sub-meter data, and equipment schedules were then adjusted to match the hourly plug load profile[15, 16]. Air infiltration is assumed to be a uniform, constant 0.2 ACHnat across the exterior enclosure [REF? used 189]. The model uses AMY weather data from the Philadelphia International Airport, located a few miles from the building site. A detailed summary of building instrumentation and calibration are available in [17, 18]. The model calibrates to 10-month hourly sub-metered energy data for heating, cooling, service hot water, fan, lighting, total building electric, and total building gas energy use. Plug load and miscellaneous electric use, including water systems pumps and elevators use, is assumed equal to the total building electrical energy use less all other metered electrical loads cooling, fans, and lighting. January 2012 data are not available, as sub-meter data was not installed until late January, and HVAC sub-meter data in December 2012 are not comparable, as the building underwent a major controls upgrade. The lack of data for these periods increases the uncertainty in heating energy use for model calibration, as nearly a fourth of annual heating degree days occurred in January. The calibration disregards anomalous service hot water use data in April and May, when water use spiked, coinciding with a construction period on the second floor. Table 4 shows coefficient of variation of the root square mean error (CVRSME) and normalized mean bias error (NMBE) calibration statistics for each end use following ASHRAE Guideline 14 [19]. The final model calibration adjusted solely building temperature setpoints to 71.51 F (21.90.6 C) for heating and 72.51.5 F (22.50.83 C) for cooling, to match observed variation in the deadband range for VAV temperature control.

	CVRSME	**NMBE**	**Months**
Calibration Target	15%	5%	All
All Electricity	6.1%	-0.6%	All
Plug Loads	5.9%	-2.1%	All
Lighting	4.9%	2.6%	All
Fans	9.3%	-1.2%	Omit December
Cooling	12.6%	3.6%	Omit December
All Gas	12.0%	2.3%	Omit December
Heating	12.6%	1.7%	Omit December
Service Hot Water	9.5%	2.3%	Omit April and May

Table 1: Table caption

3. Discussion

2 pages comparison to related work

compare to [12]

4. Conclusions

0.5 pages

5. LaTeX templates

5.1. Lists

- Bullet point one
- Bullet point two

1. Numbered list item one
2. Numbered list item two

Treatments	Response 1	Response 2
Treatment 1	0.0003262	0.562
Treatment 2	0.0015681	0.910
Treatment 3	0.0009271	0.296

Table 2: Table caption

5.2. Tables

5.3. Equations

$$e = mc^2 \tag{1}$$

Acknowledgements

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