

NYC CO-OP AND CONDOMINIUM BOARD GUIDE TO ENERGY EFFICIENCY
UPGRADES IN BUILDINGS

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Abstract

The purpose of this project is to help Better Buildings New York (BBNY), a non-profit organization focused on increasing energy efficiency and decreasing energy bills of NYC buildings, educate multifamily co-op and condo boards on energy efficiency upgrades and retrofits available for their buildings. The current market for these technologies and opportunities is vast, and at times, overwhelming. Various energy efficiency technologies exist with different costs, energy savings and impacts. Therefore, there was a need to create a medium for which these technologies and benefits could be communicated in a quick, non-technical, and easily understood manner.

BBNY's audience for this project is co-op and condo boards in multifamily apartment buildings. In these types of buildings, they are the decision-makers who are responsible for making renovation/retrofit choices. Therefore, this project focuses around the myriad of energy efficient technologies that are applicable to multifamily building environments, and how to convey this information to this type of audience. The research team used literature review, NYC building data sets, and Department of Energy modeling software (eQUEST) to vet a list of technologies BBNY was interested in presenting to board members. Each technology was researched to find information relating to five areas: capital costs, energy efficiency gains, payback periods, consistency of payback periods, and difficulty of installation. Once this information was collected, the team decided that there would be two main deliverables for the client.

The first deliverable is a full academic report that delves into the intricate methodology and technical analysis used to evaluate each technology. This report serves as a reference for understanding the various types of technologies available for multifamily retrofits, and a breakdown of their functionality. However, due to the background of the intended audience, the team wanted to create a way for the technologies to be easily understood and compared to one another.

Therefore, a second deliverable was developed with a ranking system to rate each of the technologies within the five previously defined areas. The ranking score used quantitative and qualitative information from the original research, and provided a way to compare the technologies against each other. The first part of the second deliverable is a condensed brochure that takes each technology and evaluates it on a single page, with a chart displaying the ranking score it received when compared to the whole list of technologies covered. The second part of the second deliverable is an MS Excel tool that offers a dynamic ranking system to provide a personalized list of technologies related to building attributes and user preference.

From these two deliverables, BBNY has the means to provide co-op and condo boards with guidance on energy efficient, retrofit technologies. The decision-makers in thousands of multifamily buildings now have a starting point to learn what technologies may be appropriate for further investigation. It is through these types of grassroots, information campaigns that energy efficiency gains and carbon footprint reductions in multifamily buildings can become a reality in New York City.

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EXECUTIVE SUMMARY

While most public discourse regarding building energy efficiency revolves around highly visible features like solar panels or green roofs, many other efficiency retrofit options have the potential to significantly reduce total annual energy consumption from buildings in the United States. For cities such as New York City, with high population density and strong demand for heating, cooling and lighting, residential energy use conservation can have meaningful environmental and monetary impacts. This report aims to provide co-op and condominium boards useful information about their own opportunities for energy and cost savings by making improvements to their buildings. Every type of energy efficiency technology has different costs, energy savings and payback periods. This report, along with its accompanying guide and Excel-based tool, provides co-op and condominium boards a starting point for considering energy efficiency improvements in their multifamily buildings.

INTRODUCTION

National discussions about energy are often filled with arguments about oil prices and energy independence. Meanwhile, energy consumption continues to grow within the built environment, contributing a large share to total energy needs. Buildings in the United States consume about 39 percent of total energy demand, which equates to 38 percent of the nation's carbon dioxide emissions, 49 percent of sulfur dioxide emissions, and 25 percent of nitrogen oxide emissions.ⁱ According to the US Energy Information Administration, residential homes and apartments consume 23 percent of the nation's energyⁱⁱ and represent the single largest consumer of electricity, at 39 percent of the nation's total demand.ⁱⁱⁱ

Energy consumption in New York City (NYC) buildings reveals even more staggering numbers. The city's built environment is responsible for 94 percent of its electricity consumption and 75 percent of its carbon footprint.^{iv} New York City buildings account for \$15 billion in energy costs every year. To address the energy challenges facing the city, the NYC government has upgraded energy standards in their building codes. The most recent example of this is the 2011 NYC Energy Conservation Codes, which are more stringent energy efficiency standards for building construction and remodeling. As part of PlaNYC, the Greener, Greater Buildings Plan aims to upgrade the city's largest buildings, resulting in an annual energy cost savings of \$700 million and the creation of almost 18,000 construction jobs.

As New York City pushes for energy efficiency and conservation in its buildings, it is critical that apartment buildings actively participate. Energy efficiency upgrades to apartment buildings save tenants money, reduce the city's carbon footprint, and ease the strain on the local utility grids. With many NYC multifamily apartment buildings under the direction of co-op or condominium boards, it is important they understand the energy efficiency opportunities in their buildings.

This report is presented as a learning tool for co-op and condominium boards in energy efficiency upgrades. With the introductory knowledge in this report and its accompanying guide, a residential building's board can begin to understand the energy efficiency retrofits possible in their building. The end goal being that they will be more informed about energy efficiency opportunities when speaking with building engineers and contractors. As the reader explores the technologies presented, remember that final decisions on energy efficiency retrofits should be made with official consultation of a building contractor expert. The purpose of these tools is to serve as a valuable resource when a board begins discussing energy conservation measures.

OBJECTIVES

Three main objectives were established for this project:

- (1) Explain how energy is consumed in multifamily buildings, and explore where inefficiencies exist.
- (2) Conduct a review of energy efficiency technologies in order to gain a general understanding of how energy could be saved through either retrofitting or applying new, advanced technologies. The analysis of each upgrade technology includes an examination of its feasibility and economical impact in reducing energy consumption.
- (3) Develop an easy-to-understand user guide and ranking tool to help the NYC co-op and condominium boards realize the potential aspects of improving energy efficiency in their buildings and encourage them to apply the most appropriate strategy.

METHODOLOGY

To accomplish the objectives listed above, the team created the following methodology to obtain the data and information necessary to deliver a comprehensive technology analysis:

PART 1: OBTAINING A SAMPLE

First, the team obtained a data set from the NYC Mayor's Office of Long Term Planning and Sustainability, which contained a listing of all buildings in New York City that currently employ No#6 fuel oil boilers.^v The data set not only provided estimated heating use (both fuel oil and millions of British Thermal Units (mmBTUs) per building), but also age, size, units and floors. From here, the team was able to filter the data to only co-op/condo buildings in Manhattan. This provided over 600 cases for this study. Although there are residential co-op and condominium buildings in New York who do not use boiler systems for heating, this was the most complete building sample data set the team could find that could estimate the range of sizes and heating needs of co-op/condo buildings in New York.

With this data set, the team generated summary statistics to find distributions for building size (square footage, units and floors) and energy consumption (mmBTUs). The team used STATA, a statistical software package, to determine the percentiles: 5th, 25th, 50th, 75th, and 95th. The intent of defining these categories was to understand the range of sizes for co-op and condominium buildings, as well as the estimated energy consumption for buildings of various sizes.

PART 2: TECHNOLOGY MODELING

Next, the team wanted to evaluate different technologies for efficiency gains and energy savings potential. A listing of technologies of interest was initially provided by the client, and ranged from small-scale adjustments to whole building retrofits. An early obstacle the team faced was how to estimate the impact of each technology on different building sizes. Some technologies, such as high-efficiency light bulbs or boilers, have relatively standard proportional efficiency gains across all building sizes. The team researched listed technologies through literature review and case studies, as discussed later in this methodology.

While some energy efficiency retrofits achieve comparable results in a wide range of buildings, energy efficiency gains from several other technologies depend on specific building characteristics. Since this project's scope was not a few specific buildings but an entire borough in New York City, the team decided that by taking some of the baseline characteristics of the sample introduced in Part 1, and inputting them into a building simulation model,

certain technologies could be isolated and changed to estimate efficiency gains from different technologies for different sizes of buildings. For this task, the team used the US Department of Energy's (DOE) building modeling system eQUEST. This system is a user-friendly version of a more in-depth DOE model, and is a widely recognized and respected building energy analysis program.^{vi} Originally developed in the late 1970's, it is used as a starting point for simulation tools and methods developed by ASHRAE (American Society of Heating, Refrigerating and Air Conditioning Engineers), NASA, US Postal Service and the electric and gas industry.^{vii}

The model calculates hourly building energy consumption data for an entire year, based on 47 different input points, including insulation, building envelope, windows, roofing, and HVAC system. From this information, eQUEST develops a model for a building based on building plans and user inputs. Then, alternative analyses are made by changing the model to include energy efficiency upgrades with specific technologies within the building. Finally, a side-by-side comparison is made for the energy use and savings based on these upgrades.

For this project, inputs into the model were based on several assumptions. Most of the 47 inputs were kept as their default settings within the eQUEST system, except for components of the building relevant to this analysis. For this modeling system, windows, insulation, and HVAC systems were evaluated. The baseline setting for all three of these inputs were changed based on the 1979 New York Building Energy Efficiency Code.^{viii} From here, different baseline runs were conducted based on the building size, as determined by the percentile breakdown in Part 1 of the Methodology.

Once these baseline runs were conducted (one for each of the five percentile groups), individual technologies were targeted for upgrades within each building. For insulation, windows and HVAC upgrades, the team used the 2007 New York Building Energy Efficiency Code standards, to demonstrate how these upgrades would impact building performance^{ix} (See Appendix 1 for eQUEST outputs). The reason 2011 standards were not used was due to how recently they were created, and the fact that they may not have impacted many buildings yet.

In total, 40 model runs were conducted in eQUEST. The resulting efficiency gains in each building from each technology were used as an estimate of potential energy efficiency percentage gains for adjusting a specific aspect of the building. These percentages were later used to determine rankings when comparing these technologies to each other.

PART 3: CASE STUDIES AND LITERATURE RESEARCH

Although the team used eQUEST for analyzing technology retrofits such as insulation, HVAC and windows, not all of the technologies could be modeled within this system. Therefore, case studies and independent research were used to evaluate the other technologies of this report: green roofs, solar installations, boiler systems, combined heat-power microturbines, water heaters, lighting, and building energy management systems. Each of these technologies was reviewed in the same way that the eQUEST data was reviewed, and is covered in Part 4 of the Methodology.

PART 4: TECHNOLOGY EVALUATION

To provide the co-op or condominium board with a ranking of available retrofit and technology options, the team performed systematic analysis of each of the technologies listed above (both modeled and researched), the results of which are detailed in the report. Each technology analysis includes the following factors:

- Current Efficiency Challenges (within the building)
- Description of Technology
- Advantages
- Disadvantages
- Savings Potential

Residential building boards can refer to each technology analysis by turning to its dedicated section in the report. The team used this five-pronged analytical structure to gather information to create a ranking system comparing the technologies to one another. This ranking system is employed within the MS Excel tool, discussed in Part 5 of this Methodology.

PART 5: TECHNOLOGY GUIDE AND RANKING TOOL FOR CO-OP AND CONDOMINIUM BOARDS

The final task was to provide an outreach guide and Excel tool that co-op and condominium boards could use to make informed decisions on energy efficiency improvements to their buildings. Before these tools could be made, there needed to be a way to compare one technology to another.

To make these comparisons, each technology was evaluated based upon the following factors:

- Cost Estimates for the Project
- Difficulty of Installation
- % Estimated Efficiency Gains
- Estimated Payback Periods
- Consistency of Payback

These five components are similar to the five areas described in Part 4 of the Methodology. However, the team was tasked at the beginning of the project to look at these five specific areas for a potential ranking system. As such, the literature review and model runs researched for the areas in Part 4 of this project were the source of information in part 5. From this foundation, a ranking system was developed to compare these technologies to each other.

Finally, the team created a brief user guide that synthesizes the information provided in this academic report and the ranking system developed. The guide provides a basic overview of each technology, and a comparison through ranking charts on each page. Accompanying this guide is an Excel-based ranking tool available through Better Buildings New York's website. The tool provides a tailored comparison based on the user's specific building characteristics and technology preference. An in-depth explanation of the ranking system and Excel tool can be found in Appendix 2 of this report.

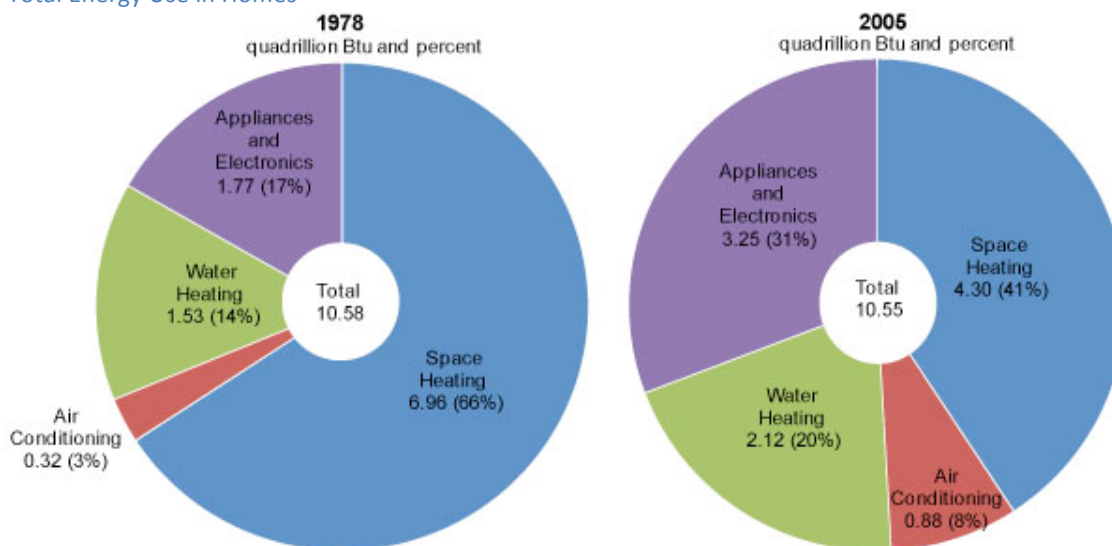
NOTE TO THE USER

It should be noted from the beginning that the research conducted for this report, user guide and tool only provide a broad overview of opportunities and options for technology retrofits. These rankings are intended to provide a starting point for co-op and condominium boards to begin their investigation of energy-efficiency options within their buildings. Professional evaluations and estimates should be considered before residential building boards take any serious action in their buildings.

ENERGY USE IN BUILDINGS: WHY ENERGY EFFICIENCY MATTERS

According to the US Energy Information Administration (EIA), the total energy use in homes actually decreased from 1978 to 2005. However, the energy consumption structure went through several changes: Energy consumed in appliances and electronics in 2005 increased to almost twice from the 1978 levels, while space heating decreased to 41% of the total energy consumption^x. Also, water heating and air conditioning both experienced small increases. In sum, given the changing energy consumption structure, there is a need to examine many potential pathways for energy conservation.

Figure 1: Total Energy Use in Homes



Source: U.S. Energy Information Administration, 1978 and 2005 Residential Energy Consumption Survey

The heating and cooling of a building depends on numerous variables, including construction, weather, engineering and physics. Simply put, building heating and cooling revolves around maintaining a desired indoor air temperature. Through physics, air temperature and moisture seek equilibrium between gradients. Because ambient air outside the building rarely matches the temperature desired inside, indoor air temperature tends to change in the direction of the outside, ambient air temperature. Thus, keeping the heated/cooled air inside the building (with proper ventilation) is the crux of the issue. Poor insulation, leaky windows and doors, as well as heat transfer through windows are examples of how air inside a building can escape, causing the building HVAC system to work harder to replace the lost air with the air of the desired indoor temperature. Therefore, many retrofit technologies help buildings retain their desired temperature more consistently and passively, thus lowering the amount of energy needed to actively heat and cool indoor spaces.

According to the DOE's Buildings Energy Data Book, 35% of multi-family residences' energy use goes towards heating and cooling, with 13% going towards lighting and 10% going towards water heating.^{xi} Combined, these four areas account for over 50% of a building's energy usage. The focus of this guide is to review technologies that have energy costs related to these areas of a building, and what technologies can be used to help reduce those costs.

TECHNOLOGY EVALUATIONS OF THE REPORT

As stated in the Methodology, the heart of this report is a broad overview of each of the technologies in the MS Excel ranking tool. Once the user inputs basic building characteristics and ranking preferences, the tool will return a recommended ranked list of technologies for co-op or condominium boards to explore. With this list, boards can revisit this document to investigate specific technologies of interest. Each of the technologies was evaluated under the following characteristics:

- Current Efficiency Challenges
- Description of Technology
- Advantages
- Disadvantages
- Savings Potential

LIGHTING

Current Efficiency Challenges

Traditional incandescent light bulbs consume a lot of energy in relation to the amount of light they produce. In fact, 90% of the energy in these bulbs is given off as heat^{xii}. Lighting accounts for 13% of residential energy consumption in the United States. New lighting standards beginning in 2012 will ensure that new lights sold in the U.S. consume 25-80% less energy than traditional, less efficient incandescent bulbs^{xiii}. Many types of incandescent, CFL and LED bulbs meet the new lighting standards^{xiv}. However, it is important to note that 22 types of traditional incandescent bulbs are exempt from these new standards^{xv} (see appendix for list). Installing newer, efficient light bulbs will immediately reduce building energy consumption. Also, new lighting technology lasts many times longer than traditional incandescent bulbs, translating into less frequent bulb replacement and lower maintenance costs^{xvi}.

Description of Technology

Incandescent: Incandescent lighting is the most common type of residential lighting^{xvii}. The bulbs operate without a ballast, light up instantly, provide a warm light, and can be dimmed^{xviii}. However, they operate inefficiently compared with other lighting options and have a short average operating life^{xix}. Incandescent lamps are cheap to purchase, but because of their short lifespan and inefficiency, they are expensive to operate^{xx}.

Standard Incandescent Lamps (or “A”-type): Standard incandescent lamps are the most common and least efficient available light source^{xxi}. The light comes from a coil of tungsten wire that glows when heated by electric current^{xxii}. Larger-wattage incandescent bulbs are proportionally more efficient than smaller-wattage bulbs (i.e. they produce more light per unit energy input), but depending on how much light is needed in a space, larger-wattage lamps may not be cost-effective^{xxiii}. Long-life incandescent bulbs are a variation of A-type bulbs^{xxiv}. They have thicker filaments, last longer than regular A-type bulbs, but are less efficient^{xxv}.

Energy-Saving Incandescent (or Halogen): Energy-saving incandescent, also known as halogen, lamps are a type of incandescent lighting that achieve better energy efficiency than standard incandescent A-type light bulbs^{xxvi}. Halogen lamps are filled with gas and have a coating to reflect heat^{xxvii}. The combination of filling and coating keep the filament hot (i.e. emitting light) while using less energy^{xxviii}. These lamps provide a very high quality light, but are much more expensive to buy than standard incandescent lamps^{xxix}. However, because of their more efficient energy use, the energy-saving incandescent lamps have lower operating costs than standard lamps^{xxx}.

Reflector Lamps (or Type “R”): Reflector lamps (Type R) spread and direct light over specific areas and are mainly used for floodlighting, spotlighting, and downlighting^{xxxii}. Reflector lamps consist of two types: parabolic aluminized (or Type PAR) and ellipsoidal (Type ER)^{xxxiii}. Parabolic aluminized lamps are used for outdoor floodlighting^{xxxiiii}.

Ellipsoidal lamps focus light beams in front of their enclosure and project light downward from recessed fixtures^{xxxiv}. Ellipsoidal reflectors are twice as energy efficient as parabolic reflectors when used in recessed fixtures^{xxxv}.

Fluorescent Lighting: Fluorescent lamps use 65-75% less energy than incandescent lamps and last about 10 times longer^{xxxvi}. These lamps illuminate when electric current is conducted through mercury and inert gases in a fluorescent tube^{xxxvii}. Fluorescent lamps require a ballast to control operating current and provide a high start-up voltage^{xxxviii}. Electronic ballasts are generally preferred over electromagnetic ballasts because they reduce flicker and operate more efficiently^{xxxix}. A special ballast is needed to dim fluorescent lamps^{xl}. There are two general types of fluorescent lamps: compact (CFL) and fluorescent tube^{xli}.

Compact Fluorescent Lamps: Compact fluorescent lamps (CFLs) can operate more efficiently than incandescent lamps while still using incandescent fixtures^{xlii}. Replacing incandescent bulbs with CFLs can save up to 75% of the initial lighting energy^{xliii}. Although CFLs cost 3-10 times more than comparable incandescent bulbs, their operating life is 6-15 times longer^{xliv}. Despite these efficiencies, CFLs still emit 80% of their energy as heat (compared to 90% for standard incandescent lamps)^{xlv}. The tubes will last about 10,000 hours, while an electronic ballast will last about 50,000 hours. Most currently available CFLs have electronic ballasts^{xlvi}. CFLs are designed to operate within a certain temperature range, below which reduced output could occur. Most models are for indoor use^{xlvii}. CFLs are most efficient and cost-effective in areas where lights are on for long periods of time^{xlviii}. Only a few CFL models can be dimmed^{xlix}.

Fluorescent Tube Lamps: Fluorescent tube lamps are second in popularity to standard incandescent lamps but operate more efficiently^l. Fluorescent tube lamps are identified as T5^{li}, T8 and T12^{lii}. “T” stands for “tubular” and the numbers thereafter represent a tube’s diameter in eighths of an inch^{liii}. For example, a T5 lamp is a tubular lamp with a diameter of 5/8”. Fluorescent tube lamps have a dedicated fixture with a built-in ballast^{liv}. The two most common types are 40-watt, 4-foot (1.2-meter) lamps and 75-watt, 8-foot (2.4-meter) lamps. T5 lamps are shorter than T8 and T12 lamps and therefore cannot be used to replace these larger lamps without changing sockets or ballasts^{lv}. Tubular fluorescent fixtures and lamps are used mainly for ambient lighting in large indoor areas^{lvi}.

LED Lighting: Light-emitting diodes (LEDs), previously used only as indicator lights for electronics, have grown into a major lighting technology and have begun expanding into residential lighting^{lvii}. LEDs are highly energy efficient and rapidly improving in economic competitiveness with other lighting types^{lviii}. LEDs last longer, are more durable, and offer better light quality than nearly any other type of lighting available^{lix}. Residential LEDs use at least 75% less energy and last up to 25 times longer than incandescent lighting^{lx}. LEDs are directional, near-monochromatic, and they emit almost no heat^{lxi}. Despite their advantages and their becoming less expensive, LEDs remain much more costly to purchase than alternative lighting types.

Occupancy Sensors: Occupancy sensors turn lights on and off by detecting a person's presence in a certain area. The technology is most effective in spaces where people frequently move in and out in unpredictable patterns, for instance restrooms, conference rooms and hallways^{lxii}. The two main technologies used for occupancy sensors are infrared and ultrasonic^{lxiii}. Infrared technology detects heat and motion, while ultrasonic detects sound^{lxiv}. More expensive occupancy sensors use a combination of the two technologies. Occupancy sensors for lighting in shared spaces could significantly reduce lighting energy use in those areas, though the overall impact on energy use depends heavily on the proportion of shared space to private rooms in the building. A more invasive lighting retrofit would include occupancy sensors in private apartments, which would increase the energy savings potential but also may be unattractive to residents, who would have less control as to when lights turned off in certain spaces.

Advantages

Replacing lamps requires little to no structural changes to the building, unless new lamps do not fit into the old lamp fixtures, e.g. when replacing T12 or T8 fluorescent tubes with T5. Replacing hallway, lobby and stairwell bulbs is not invasive to building residents, while replacing bulbs in apartment units is quick and minimally invasive. Payback periods are short and less variable for lighting retrofits compared to other building upgrades. New lighting

technology is more efficient and longer lasting than standard incandescent lamps, meaning less frequent bulb replacement.

Disadvantages

Installing lighting in apartment units is invasive to residents, albeit briefly. Residents must be made aware of the schedule for installing new lighting. Once the new lighting is installed, residents may require time to adjust to the new lighting source, e.g. CFLs may take several seconds to reach full illumination and may emit a different quality light than standard incandescent.

Savings Potential

Lighting retrofits reduce the amount of energy used to produce the same amount of light. Standard incandescent lamps lose almost all of their energy through heat. More efficient lighting technologies create less heat waste while producing equivalent illumination. Compared to standard incandescent lamps, energy-saving incandescent lamps save 25% on energy costs, while CFLs and LEDs save 75% (see Table 3 below).

Table 3: Lighting Comparisons

Comparisons between Traditional Incandescent and Energy-Efficient Light Bulbs				
	60W Traditional Incandescent	43W Energy-Saving Incandescent	15W CFL	12W LED
Energy \$ Saved (%)	–	~25%	~75%	~75-80%
Annual Energy Cost*	\$4.80	\$3.50	\$1.20	\$1.00
Bulb Life	1000 hours	1000 to 3000 hours	10,000 hours	25,000 hours

*Based on 2 hrs/day of usage, an electricity rate of 11 cents per kilowatt-hour, shown in U.S. dollars.

In addition, a study funded by the California Public Utilities Commission found the lifecycle cost-benefit ratios and net present values of replacing old T8 fluorescent tubes with newer, high-lumen T8 tubes, abbreviated as “HL” in the “replacement lamp” column (see Table 4 below)^{kv}. Benefit-cost ratios greater than one and net present values greater than 0 indicate that the cost of purchasing new, higher-efficiency fluorescent tubes for installation is justified by the benefits of the energy savings they bring about over their life span. As shown in the table, replacing old T8 fluorescent tubes with the new T8 tubes makes economic sense when viewing the retrofit over its lifespan.

Table 4: Lifecycle Costs and Benefits for Fluorescent Tube Replacements

Lamps	Baseline Lamp	Replacement Lamp	Lifecycle Benefit/Cost Ratio	Net Present Value \$/unit
2	32W F32T8 7XX	32W F32T8 8XX HL	2.7	20
2	F34T12CW or F34T12WW	32W F32T8 8XX HL	5.5	88
2	F40T127XX	32W F32T8 8XX HL	5.0	48

Source: California Energy Commission^{lxvi}

Finally, a case study of a 941-unit high-rise development in San Diego helps show the potential savings of lighting retrofits in high-rise apartment buildings. Retrofits for unit lighting incurred an initial cost of \$75,280 and an annual savings of around \$50,000, equating to a 1.5-year payback period^{lxvii}. These figures generate an estimated 10-year energy savings of over \$400,000.

INSULATION

Current Efficiency Challenges

Space heating and cooling represent the largest single share of energy consumption in U.S. buildings, at 38%^{lxviii}. The building envelope is responsible for containing heated or cooled air within the building. Any areas in the building envelope lacking proper sealant or insulation provide gaps for conditioned air to escape, reducing the building's energy efficiency and increasing average annual energy consumption. Also, a porous building envelope can reduce resident comfort through drafts and unstable indoor air humidity levels^{lxix}.

Description of Technology

According to the U.S. Department of Energy, the building envelope is defined as "the elements of a building that enclose conditioned spaces through which thermal energy may be transferred to or from the exterior or to or from unconditioned spaces."^{lxx} The Pacific Northwest National Laboratory sums up the building envelope as "the boundary separating the inside from the outside and through which heat is transferred^{lxxi}." The building envelope typically includes the roof, walls, windows, doors and foundation, but can also include the bottom floor if it is located above a breezeway or parking garage^{lxxii}.

Insulation materials are grouped into "light" and "heavy." Light insulation materials contain three categories: 1) mineral base, e.g. glass wool, rock wool, vermiculite, perlite, fiber-glass and expanded clay; 2) honeycombed plastic material, e.g. expanded polystyrene, extruded polystyrene and polyurethane; 3) vegetable-based insulators, e.g. cork, cellular wool, linen tow, cotton and coco fiber. Heavy insulation materials include: thick honeycombed terracotta bricks, cellular concrete building blocks, wood and hemp and lime walls^{lxxiii}. Please see Table 1 for a generalized ranked list of insulation materials in order of efficiency.

Table 1: Light insulation materials in decreasing order of efficiency^{lxxiv}

Insulation name	Insulation grouping
Polyurethane	Honeycombed plastic
Extruded polystyrene	Honeycombed plastic
Cork	Vegetable-based
Linen wool	Vegetable-based
Rock wool	Mineral base
Glass wool	Mineral base
Hemp wool	Vegetable-based
Expanded polystyrene	Honeycombed plastic
Hemp	Vegetable-based
Vermiculite	Mineral base
Hemp+Lime	Mineral + Vegetable-based

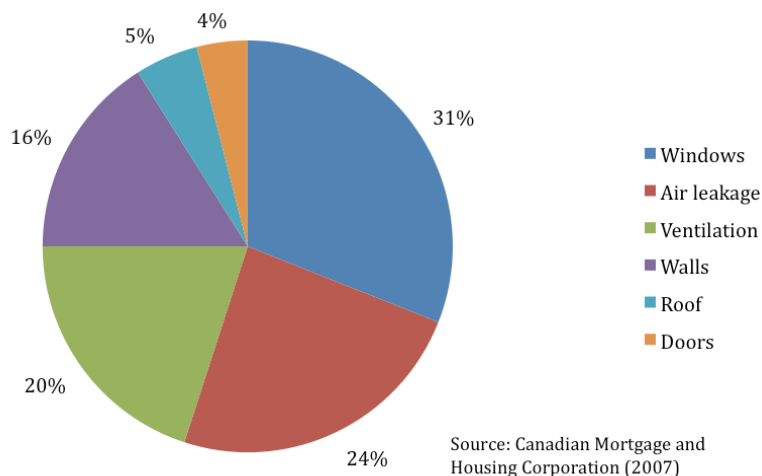
Source: International Energy Agency 2007

Advantages

EPA estimates that improving air sealing and insulation in individual homes can cut total household energy costs by 10%^{lxxv}. A Canadian study of air leakage control in existing multi-unit residential buildings indicates that air leakage alone represents 24% of space heating energy use^{lxxvi}. A case study of an air leakage control project in a 21-story apartment building in Ottawa, Canada demonstrated a 12% average energy savings with a 5.7 year payback period^{lxxvii}.

Because the building envelope is an umbrella term for components like the roof, windows, doors and foundation, building envelope inefficiencies can be addressed gradually over time, without necessarily requiring a large capital outlay. For instance, given financial or other constraints, a co-op or condominium board could choose to seal windows but not install new insulation. An air leakage audit would help the board decide which building envelope inefficiencies are most pressing.

Figure 7: Sources of Heat Loss in Multi-Unit Residential Buildings



Disadvantages

Interior building retrofit measures could be disruptive to residents. Replacing windows or caulking air leaks would require contractors to enter each residential unit for perhaps hours. Compared to a retrofit like lighting replacement, building envelope upgrades could prove more disturbing to residents. Also, depending on the

retrofit, the building may be under renovation for a long time.

Savings Potential

Two case studies conducted by the Canadian Mortgage and Housing Corporation point to significant annual energy reductions from retrofitting the building envelopes of high-rise apartment buildings, the retrofits in these cases dealing with air leakage control^{lxviii}. The first case study was in 1990 and concerns a 30-year old, 21-story, 240-unit, 154,000 square-foot apartment building in Ottawa, Canada. The structure of the building was cast-in-place concrete. The walls were insulated with 38 mm extruded polystyrene insulation and the exterior cladding was brick. An energy audit determined that air leakage accounted for 33% of the building's heat loss. Air leakage control measures consisted of the following.

- Sealing all shafts (top and bottom)
- Sealing exterior envelope leaks
- Sealing exterior doors
- Sealing exterior windows

Initial cost outlay (in 2012 USD) for the retrofit was about \$81,000 and the annual cost savings were around \$14,000. These retrofit measures resulted in a 12% annual energy savings with a payback period of 5.7 years. The conversion of 1990 Canadian Dollars to 2012 US Dollars does not account for potential changes in technology affordability during that time span.

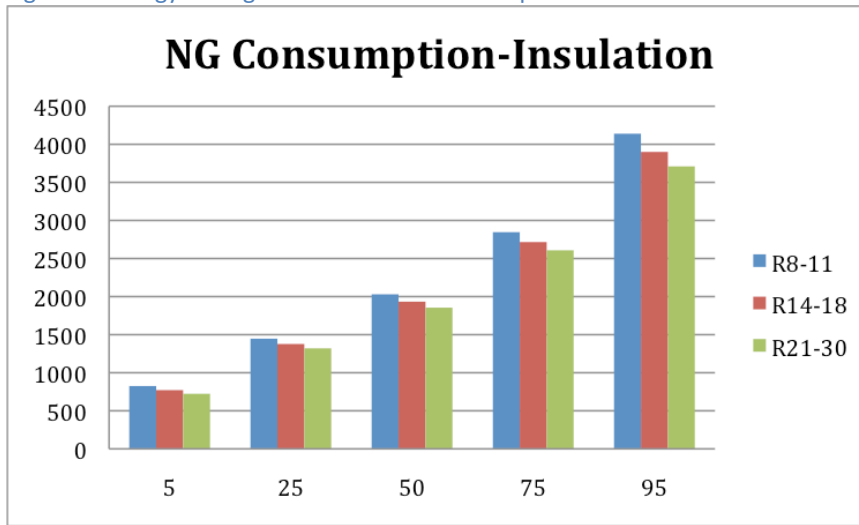
The second case study concerned a 10-story building with 95 condominiums and a total floor area of 106,000 square-feet. The building was heated with electric baseboard heaters and the corridor air was heated by natural gas. The interior walls of the building were brick insulated, and there was also 35mm of extruded polystyrene insulation. An energy audit determined that air leakage accounted for 34% of the building's heat loss. Air leakage control measures included:

- sealing all shafts (top and bottom)
- sealing penthouse mechanical room
- sealing exterior envelope leaks
- sealing exterior doors
- sealing exterior windows

Initial cost outlay (in 2012 USD) for the retrofit was approximately \$56,000 and the annual cost savings were around \$9,000. These retrofit measures resulted in a 12% annual energy savings with a payback period of 6.2 years. Again, the conversion of 1990 Canadian Dollars to 2012 US Dollars does not account for potential changes in technology affordability during that time span.

As R-value increases, natural gas consumption decreases, resulting in energy cost savings. For high-rise buildings, as building floor increases, natural gas consumption per square foot decreases, and energy savings increase. For all buildings, as building floor increases, energy savings per unit fluctuate around \$40/unit. This implies that the incentives for improving insulation won't be affected by building size. Compared to windows upgrades, the upfront cost for insulation is much cheaper, and has a shorter payback period as well. However, energy savings associated with insulation have limitations.

Figure 8: Energy Savings in Natural Gas Consumption Due to Insulation



WINDOWS

Current Efficiency Challenges

Windows are often overlooked when residential building boards consider energy efficiency upgrades. According to the Alliance to Save Energy, heating and cooling losses attributable to windows “account for 10 percent of building energy.”^{lxxxix} During both heating and cooling months, windows act as a break in a wall’s insulation surface, letting in cold during the winter and heat during the summer. When gauging the efficiency properties of windows, the industry standard is to use U-values instead of R-values, which are commonly used for insulation. These values are simple indicators of the non-solar heat flow of the window. The lower the U-value, the more efficient the window is at reducing temperature loss. Although there are other factors that gauge the effectiveness of window’s efficiency, this report uses U-value as the main performance indicator.

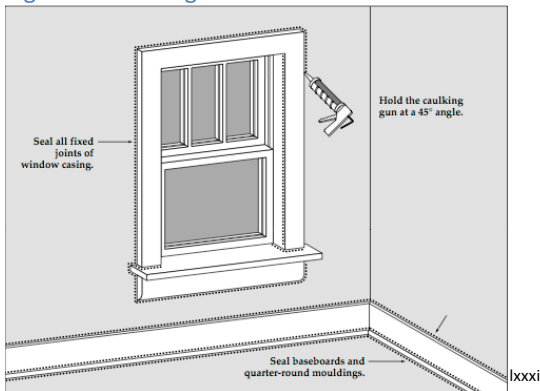
There are three different styles of window upgrades that could be considered. The low-hanging fruits are window caulking and weatherizing around the windows. The next level is retrofitting older windows. Finally, the most expensive and most energy-efficient option is to replace the entire fenestration.

WINDOW CAULKING AND WEATHER STRIPPING

Description of Technology

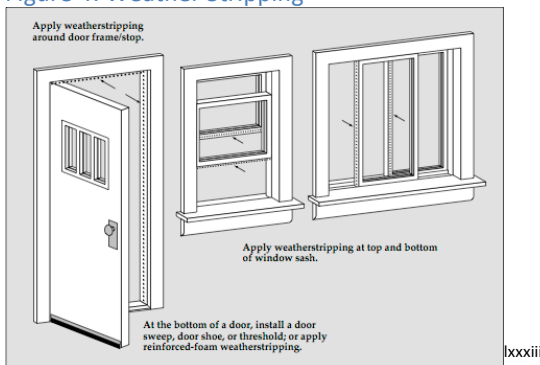
The first area of energy efficiency gains for windows come from sealing the cracks and holes that prevent the window from letting in ambient air. There are many ways of checking whether a window is leaking, from simply putting a hand around the edges to feel for a draft, or placing a piece of paper between the sill and the actual window, and upon pulling the paper, see if it comes out without tearing. Caulk is a substance that can form a seal between cracks in walls, doors, and windows (See Figure 3). The seal is usually less than a quarter-inch wide, and the substance of caulk can vary based on the needs of the user. DOE recommends Butyl Rubber for window sealings, as well as a few other caulk types, depending on the circumstances of the window.^{lxxx}

Figure 3: Caulking a Window



An alternative to caulking is purchasing strips of material that can fill the spaces around the windows. Unlike caulk, these materials are usually rolled or nailed into place, and can be much more visible than caulk (See Figure 4). Similar to caulk selection, the window framing, material and climate must be taken into consideration. Once again, the DOE website has a great chart that provides insight into the different types of weather stripping and the situations in which to apply it.^{lxxxii}

Figure 4: Weather Stripping



Advantages

Caulking and weather stripping could be done by tenants themselves (with careful instructions), or through the maintenance staff of a building. The US DOE has a website outlining the ways to apply caulk and weatherizing strips to windows.^{lxxxiv} The desired type of caulk depends on the window surface material, and the preferred quality of product, with respect to budget constraints. Due to the low cost and easy implementation of these tools, almost any building can move forward with these initiatives. The Landmark/Historic housing commission specifically states that weather stripping and caulking are ordinary maintenance measures not requiring a permit from the Commission.^{lxxxv}

Disadvantages

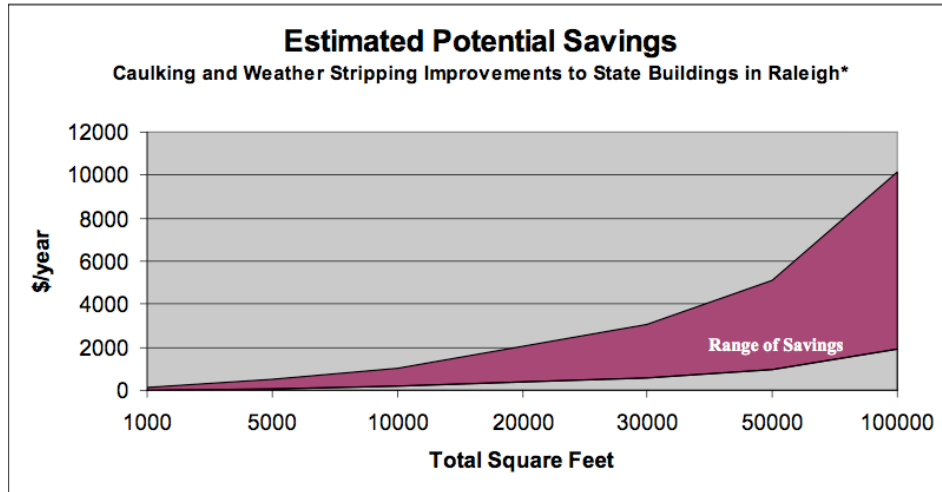
For caulking, it is important to select the right material, because some caulks are designed for specific surfaces. Applying the wrong caulk to the wrong surface can damage paint and/or the window itself. Also, this type of retrofit can require reapplication if the windows are used often. Caulking should be done during spring or summer months, when warmer weather and higher humidity allow caulk to dry more gradually than in the colder, drier winter months.

Weatherstripping can be difficult to install since it needs to be aligned perfectly with the cracks. Some materials wear easily, while others require hammers, saws and nails to install and secure. It is also a visible retrofit, which may not be aesthetically pleasing to the tenants.^{lxxxvi}

Savings Potential

The DOE states that these technologies usually pay back in about one year's time.^{lxxxvii} Costs depend on the local stores within the area. A quick search of Lowes Home Improvement website shows that it costs about \$10 for two windows worth of weather stripping. A tube of caulk is even cheaper, ranging around \$2-\$5, but will use a half-cartridge per window.^{lxxxviii}

Figure 5: Estimated Potential Savings for Caulking and Weather Stripping Improvements



*The above estimates are based on a NIST study of air infiltration rates in two buildings using the actual total energy cost of \$1.59/sf for state-owned facilities in Raleigh, NC.

lxxxix

INTERIOR STORM WINDOWS

Description of Technology

A more advanced form of retrofitting is to add a new component to the old window. One option is for interior storm windows. These windows offer greater convenience than exterior storm windows. Storm windows, in general, are an added layer of glass fitted over the existing window from either the outside or inside of the building. The extra layer of glass provides a barrier to help reduce ambient air infiltration from outside the building to the conditioned air inside. Storm windows are especially attractive for apartment buildings because they can be installed from the inside. The drawback, however, is that they are not as efficient as replacing old windows with new windows with a lower U-value.^{xc}

Advantages

The interior storm windows are capable of being put up from inside the building, and are not a permanent retrofit. They are also several times cheaper than replacing an entire window unit. Finally, Landmark/Historic housing commission exempts this retrofit from needing a permit.^{xcii}

Disadvantages

Interior storm windows can be difficult to install because of the exact fit necessary, possibly requiring the expertise of a contractor. They also can take away from the aesthetically pleasing nature of a window, because of the added window layer. Interior storm windows also make it difficult to easily open and close the windows.

Savings Potential

According to some "Do-It-Yourself" interior storm window websites, an average size interior storm window costs under \$55.^{xcii}, excluding labor costs of around \$25.00 - \$50.00 per window. In most cases, the savings recover the cost of the windows in 18-24 months.^{xciii} Other sites claim these installations can save about 30% on heating and air conditioning bills.^{xciv}

WINDOW COATINGS AND FILMS

Description of Technology

The efficiency of a glass window can be altered not only by replacing the window, but also by adding a coating or film to the window. Some of these coatings, called "low-emissivity" or "low-e," can dramatically lower the window's U-value, and thus increase its efficiency greatly. These films can also reduce the amount of solar heat gain (SHG) into the room, reducing cooling needs, or increase the heat gain and reduce heating needs. SHG is another metric used to define window efficiencies. For New York, the DOE Energy Star recommends mostly higher SHG values, usually 0.35 or above (from a scale of 0 to 1).^{xcv} The SHG value is another factor to take into consideration when looking at this retrofit.

Advantages

The installation difficulty of window coatings and films vary from product to product. Some are relatively easy to apply, and cheap to purchase, and can be easily peeled off. However, some films may require a professional installation, and adhesive properties may make it difficult to remove. Solar window film is sold in home improvement stores and it comes packaged in small rolls that can cover one or two windows. The cost, as of 2011, ranges from \$20 to \$50 per roll.^{xcvi} Regarding landmark buildings, window films are not listed under the categories requiring a permit.^{xcvii} However, because the aesthetics of the actual glass may be altered, the building may want to check their specific circumstances if considered a Landmark/Historic building before moving forward.

Disadvantages

Special care should be taken to select the proper coating or film for a given climate. Putting the wrong type of film on the window can have a reverse effect for the heat-loss/heat-gain desired impacts. In some cases, the film darkens the window so much that lights have to be turned on to see in the room. Older-technology films are characterized by being able to absorb heat from the sun and not letting it in the room. The problem is that the film heats up and, when applied to a single pane of glass or the inner pane of a double pane window, most of the heat is still sent to the interior of the building, increasing room temperature beyond the desired level. Furthermore, warranties for windows may be voided when altering the windows with a film, because when the film gets hot, it heats the glass and makes it expand, stressing the glass. Therefore, before pursuing this option, check to see if the warranty will be voided by applying the coating or film.^{xcviii}

Savings Potential

According to some window film manufactures, an average film will save around 30-50% in heating and/or cooling costs.^{xcix, c}

REPLACING OLD WINDOWS WITH NEW WINDOWS

Description of Technology

The greatest gains in energy efficiency in windows will normally come from replacing old windows with new, more efficient models. For comparison, most single pane glass windows will have a U-value near 1.0.^{ci} An Energy Star window for the New York region is required to have a U-value of 0.32.^{cii} For this section, eQUEST model runs were used to gauge the efficiencies in various size buildings based solely on changing the windows from a U-value of about 1.03, to 0.55, and then to 0.21. The U-value of .55 represents a moderate efficiency upgrade, with .21 indicating a top-of-the-line upgrade.^{ciii}

Advantages

The most obvious advantage is the incredible gains in efficiency these windows provide, reflected by reducing the building's heating and cooling needs. By upgrading the windows, the building's HVAC system should have to work significantly less, therefore lowering heating and cooling bills.

Disadvantages

Replacing entire windows in a building is more invasive and more capital intensive than window upgrade options

covered earlier in the report. Additionally, the Landmark Preservation Commission has stricter standards on what can be done on a designated building. The following are examples of the types of work that require a permit from the Commission:

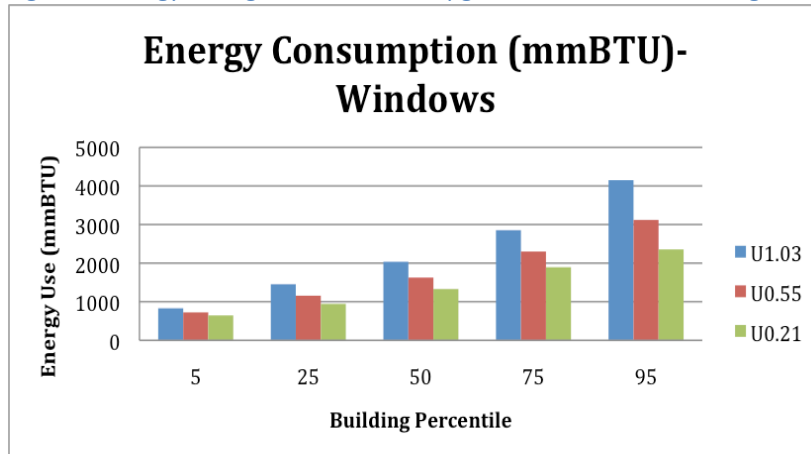
- installing new window sash or frames;
- installing exterior storm windows and exterior storm window frames;
- installing or removing exterior shutters;
- installing window awnings;
- repairing or altering window enframements;
- installing or removing exterior security window grilles or bars;
- changing the shape or design of window openings;
- blocking in existing windows or creating new ones^{civ}

Any new window installment in a designated landmark/historic building will require a permit from the city.

Savings Potential

The Environmental Defense Fund sums it up as follows: “Double-glazed windows transmit less than half the heat of single-glazed windows; any single-glazed window can be replaced and will pay for itself in eight to twelve years.”^{cv} Compared to other window upgrades, replacing windows will be the most expensive option. However, the eQUEST modeling provides a look at the efficiency gains by changing a single technology. In this case, by upgrading the U-value of the windows, moving from a single-pane to double-paned glass, and decreasing the U-value by half each time, model results show energy efficiency gains from 30-50%.

Figure 6: Energy Savings from Window Upgrades in eQUEST Modeling



Average mmbTU provides a snapshot of a building’s heating needs. eQUEST provided the efficiency gains that these types of windows could experience in different size buildings, and heating requirements were taken from the initial data provided. By taking the efficiency gains from the windows and applying it to the current heating demand of these buildings, an estimate of potential heating savings was determined.

Compared to other upgrades, window replacement results in high cost savings, but at the expense of high the upfront costs. There is a trade-off between operation savings and upfront cost, and therefore the feasibility of window replacement as a retrofit option depends on the available budget of a property.

WATER HEATERS

Current Efficiency Challenges

A building's water is typically heated by electricity or natural gas. The choice of fuel then determines whether the building has an electric resistance or atmospheric natural gas tank system.^{cvi} While some recently retrofitted residential buildings may have individual hot water tanks for each unit, larger and older buildings have a central hot water system in place. Propane and heating oil are other common fuel sources for water heaters. Storage systems are historically the most common form of hot water systems. In storage systems, heat is transferred from a burner or coil to the water within the tank. The system typically runs constantly in order to keep the water in the tank at a stable hot temperature, even when the hot water is not being used. The size of the tank depends on the amount of demand in the building, but regardless, energy is lost for continuous heating of the water in a storage system. For example, for the entire US residential stock of hot water heaters in 2005, electric storage systems were rated to be 88% efficient with their energy use while gas-fired storage systems were rated to be only 56% efficient.^{cvi} The subsequent energy losses for these systems can be substantial for a building. There are a variety of upgrade options for water heating systems. These technologies are described below, including their advantages and disadvantages for different building types.

TANKLESS WATER HEATERS

Description of Technology

Tankless water heaters provide hot water only as it is demanded. Water is heated, either with a gas burner or electric element, and is delivered as a constant supply. Heat loss is effectively avoided because of the instantaneous nature of the system; however, the flow rate of hot water can decrease as demand increases.^{cvi}

Advantages

Tankless water heaters require less total energy than storage systems. These systems work well in smaller buildings with more compact floor plans and therefore shorter distribution distances.^{cix} These systems can use electricity, gas, propane or solar as their source of fuel. For this analysis, however, the team looked specifically at the most ubiquitous tankless heaters on the market: Natural Gas (NG).

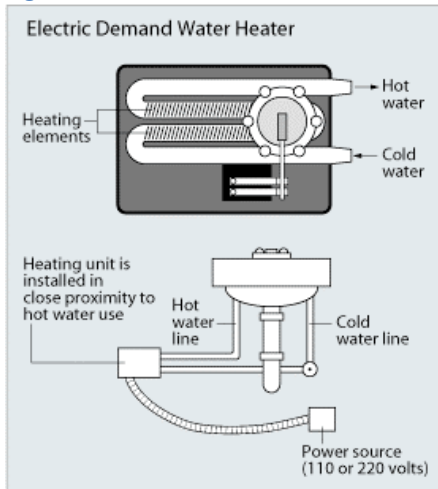
Disadvantages

Tankless water heater systems can have higher upfront and installation costs than the typical storage system, however the maintenance costs can be lower because less equipment is involved in the system. Finding hot water systems that can be installed as a retrofit can be a challenge, however, as most systems are often designed with new construction in mind.^{cx} The amount of hot water demanded can also be a disadvantage for a tankless system since the rate of flow of hot water is limited.

Savings Potential

Tankless water heaters only work when hot water is needed; therefore, they do not produce the standby energy losses associated with storage water heaters. According to DOE, tankless water heaters are on average 24%–34% more energy efficient than conventional storage water heaters, and can be more efficient for homes that have a larger demand of hot water.^{cx} In addition, tankless water heaters last twice as long as their conventional counterparts, which helps to even out the life cycle cost. However, tankless water heaters cost much more than conventional water heaters, and federal tax credit for tankless water heaters expired at the end of year 2011.

Figure 9: Tankless or Demand Water Heater



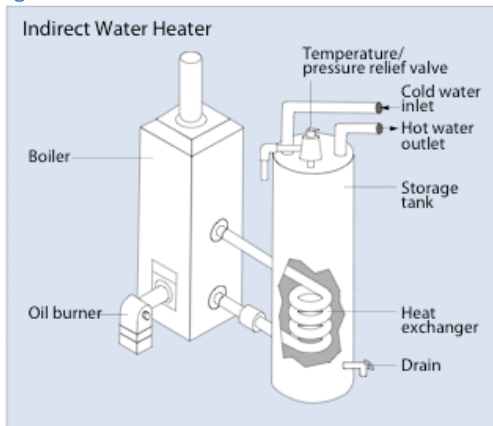
(Source: U.S Department of Energy-Energy Efficiency & Renewable Energy: http://www.energysavers.gov/your_home/water_heating/index.cfm/mytopic=12820)

INDIRECT WATER HEATERS

Description of Technology

Indirect water heater systems use boiler systems already installed in a building. Water used in the boiler is passed through a heat exchanger into a hot water storage tank.

Figure 10: Indirect Water Heater



Advantages

Indirect water heater systems achieve similar energy savings as tankless water heaters since additional energy is not required to keep the tank at a constant temperature. The costs for installation and maintenance are often less than the costs for tankless water heaters since much of the system is already in place with the boiler.^{cxii} In conjunction with a high-efficiency boiler and a well-insulated water storage tank, the overall energy savings from an indirect water heater system are of the greatest of the water heating system options.^{cxiii}

Disadvantages

An indirect water heater system does require the use of a boiler or, less typically, a furnace. The upfront costs are low as long as this system is already installed in the building.

Savings Potential

Indirect water heaters use a heat exchanger installed in a main furnace or boiler to heat water flowing through it when a hot water faucet is turned on. Indirect water heaters also provide hot water only on demand, and therefore avoid the standby energy losses. According to American Council for an Energy-Efficient Economy (ACEEE), an indirect water heater is an ideal option because it not only eliminates the standby energy losses, but also costs much less than tankless water heaters. ACEEE suggests to select indirect water heaters with a combined appliance efficiency rating (CAE) of at least 0.85 to achieve optimal savings^{cxiv}. In addition, indirect water heaters work more efficiently in colder climates like New York City's when the heating system is used regularly, making it a good choice for multi-family residential buildings in NYC.

SOLAR WATER HEATERS

Description of Technology

Solar water heaters displace at least some of the conventional energy—electricity, natural gas, or oil—used to typically heat a building's water. There are multiple types of solar water heaters, the most common containing a solar collector and storage tank(s)^{cxv}. Solar water heater systems often use one of three types of solar collectors—flat plate, integral collector-storage, and evacuated-tube—and have either active or passive design. Active solar water heating can have either direct or indirect circulation systems. Direct systems circulate water through the solar collector while indirect systems use a heat-transfer fluid that moves the heat from the collector to the water. These indirect systems are best in colder climates where freezing is frequent^{cxvi}. Passive solar systems utilize the natural tendencies of water to flow when heated and are best suited to warmer climates. In some colder climates, a different fluid can be used within a passive system in order to protect from freezing hazards^{cxvii}.

Advantages

The source of energy for solar water heaters is free and can be fairly predictable, even if intermittent.

Disadvantages

Solar hot water systems often require backup systems to account for cloudy days. The overall effectiveness of these systems also depends heavily on the number of days of sun for the specific location. In New York City, the average annual amount of solar radiation is 3kWh/m²/day whereas the Southwest region of the US receives an average annual amount of 6kWh/m²/day.^{cxviii} The solar potential considerations needed for a Photovoltaic (PV) system are also critical when planning a solar water heating system (See the Solar section below). Additionally, it is often recommended to install backup systems, so that demand can still be met on cloudy days and peak usage times.

Savings Potential

Solar water heaters usually have a slightly higher purchase price compared with conventional water heaters, but yield great potential energy savings. According to DOE, installing a solar water heater can reduce approximately 50% to 80% of energy consumed on water heating^{cxix}. Also, based on Energy Star's calculation, solar water heaters could potentially save \$190 to \$250 annually for an average American home, and multi-family residential buildings will have even greater savings^{cx}.

The federal government offers a tax credit of 30% of a solar water heater's cost, with no upper limit, making the payback period even more acceptable. Solar water heaters also have a longer life expectancy than conventional gas or electric storage water heaters. In addition, since sun light is free, it reduces the risk brought by energy price fluctuation.

BUILDING MANAGEMENT SYSTEMS

Current Efficiency Challenges

For many older buildings, including multi-family residential structures, a lack of energy consumption transparency can be a major problem. In order to identify and fix a building's inefficiencies, its energy consumption patterns must be understood. Without quality usage information, tenants are disconnected from the impact that their behavior has on their energy consumption and therefore are not properly incentivized to change. Some of the worst cases of this disconnect occur in multi-family buildings that are monitored by one utility meter. In this case, there is almost no incentive for a tenant to monitor and reduce their energy use because they are not individually responsible for the associated energy costs. Also, without proper building knowledge, it can be very difficult to pinpoint energy inefficiencies.

EMS AND SUBMETERING

Description of Technology

Building management systems (BMS) present an opportunity to realize a detailed understanding of energy usage within a building, thus influencing consumptive behavior. Industrial operations and facility managers have used BMS and energy management systems (EMS) from companies like Johnson Controls and Cisco to identify and fix inefficiencies in production processes and operations, and this idea is spreading to the residential sector. Homes can now install energy monitoring systems that display usage rates so that the user can identify and fix over-consumptive behaviors. With the movement to smart metering and other innovative technologies, a BMS system can coordinate with electric utilities and implement demand-management techniques, potentially easing pressure on the local electric grid and saving money in energy costs. As NYSERDA has identified, with regard to BMS, the switch to sub-metering is one of the best opportunities for NYC multi-family.^{cxix}

Sub-metering measures the utility usage in an individual home, rather than measuring and recording only the usage of the entire building. As the NYC Department of Housing Preservation and Development describes, sub-metering essentially bills the individual apartment for its energy use, rather than including the charges in monthly rent.^{cxix} This simple concept of "pay-for-what-you-use" breaks the common disconnect between tenant and energy consumption, as tenants become directly aware of the finances involved with energy usage.

Advantages

Sub-metering impacts one of the most important pieces of residential energy efficiency: consumer behavior. Instead of every homeowner paying an equal share of the whole building's utility bill, each apartment pays for its direct utility usage. NYSERDA cites how sub-metering opens the opportunity for utilizing smart meter technologies in multi-family buildings. This combination will continue to help individual consumers identify the time of day that electricity is cheapest, supporting conservation during peak load times.^{cxix} One of the sub-meter industry's leading companies, E-mon, describes how tenants often support sub-metering because they are given more control of their energy usage and are not financially responsible for other apartments' consumption.^{cxix}

There are a variety of incentive programs that NYC multi-family buildings can use to help implement sub-metering and BMS technologies. NYSERDA's Electric Reduction in Master-Metered Multifamily Buildings Program (ERMMB) provides eligible buildings with rebate incentives for certain sub-metering components and other energy efficiency appliances.^{cxix} Con Edison also runs an incentive program through the Association for Energy Affordability, which offers incentives for energy management systems for buildings whose heating fuel bill comes from Con Edison.^{cxix}

Disadvantages

As with many large-scale retrofits, sub-metering and building/energy management systems can be rather capital intensive. Because of the capital involved, not all buildings are best fits for these systems. Calculations by Con Edison suggest that the threshold size of 15 units for a multifamily building upgrading to an energy management system, with any size below 15 units experiencing onerously high payback periods.^{cxix} Further obstacles for

multifamily buildings are the eligibility requirements for the Con Edison and NYSERDA incentive programs. Interested co-op or condominium boards should contact directly the individual programs to learn more about the eligibility of their building.

Savings Potential

As with all energy efficiency upgrades, energy and financial savings are specific to each building. Sub-metering could vary in realized savings, because the savings are often driven by consumer reaction. Understanding this, NYSERDA cites that many buildings can realize energy savings of up to 20 percent with sub-metering.^{cxxviii}

Meanwhile a study by Con Edison shows a 61-unit Manhattan multifamily building experiencing a 1.6-year payback on their energy management system, once the incentives are taken into account. By July 2011, the Con Edison program had installed 11 energy management systems, citing an overall energy savings of 10-15 percent. Additionally, E-mon cites an urban multifamily project in Pittsburgh, PA that witnessed a monthly savings of \$16,000, equating to a payback period of just seven months.^{cxxix}

HEATING, VENTILATION AND AIR CONDITIONING (HVAC) SYSTEM

Current Efficiency Challenges

In the United States, heating, ventilation and air conditioning (HVAC) systems are a great source of energy consumption. According to the Residential Energy Consumption Survey prepared by Energy Information Agency (EIA), air conditioners are installed in about 82% apartment buildings in the United States^{cxxx}, and contribute to more than 50% of the energy consumption in multifamily residential buildings.

Description of Technology

In the northeast region, including New York City, space heating consumes more energy than cooling due to the specific weather pattern. New York City lies in cooling zone 2 and heating zone 2, requiring approximately 935 cooling hours and 3784 heating degree-days per year. Therefore, an average NYC home needs about four times more heating than cooling over a calendar year. In general, natural gas remains the most common fuel for heating. According to the EIA, about 49% of American homes use natural gas as the main fuel source for space heating^{cxxxi}.

The energy efficiency of HVAC systems is represented by Energy Efficiency Ratio (EER) or Seasonal Energy Efficiency Ratio (SEER), as established by the Department of Energy. The required SEER value of 10, established in 1987, was later improved to a SEER value requirement of 13 in 2006^{cxxxii}. This is approximately a 30% of energy savings. The SEER value could be converted to coefficient of performance (COP), generally used for heating, and Energy Efficiency Ratio (EER), generally used for cooling. Newer HVAC equipment usually has a higher SEER value, which represents a better energy performance.

Advantages

Actively switching to new HVAC systems brings significant energy savings, and the payback period is usually acceptable for multi-family residential buildings. Any building that hasn't replaced their HVAC in the past six to eight years will most likely have a SEER 10 rated system, and could see efficiency gains of 30% by switching to a SEER 13 model.

Besides retrofitting the HVAC system, there are passive opportunities for co-op or condominium boards to improve their buildings' HVAC efficiency. This includes working on the building envelope and windows to ensure that the conditioned air is not escaping outside, or the outside air is coming in. These actions will allow the buildings HVAC system to achieve a desired temperature with less energy.

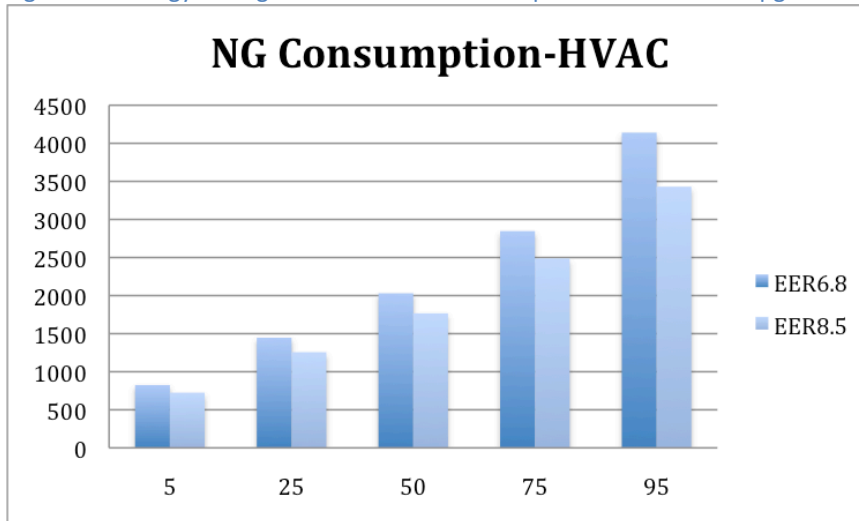
Disadvantages

There are high capital costs for new HVAC systems, especially as they increase in size. Therefore, this retrofit's feasibility depends on the available budget of the co-op or condominium board. In addition, if a building is a Landmark/Historic, there must be a permit before any HVAC upgrades can be pursued.

Savings Potential

As EER and COP values increase within an HVAC system, the buildings energy consumption needs decrease. By using eQUEST, two scenarios were run to compare increasing the buildings HVAC system from an EER 6.8 to an EER 8.5 (not Seasonal), which is a 25% increase in efficiency. The model results were a 20-30% increase in energy efficiency within the building, which if compared with a move from SEER 10 to a SEER 13, similar results would be seen. However, due to the high capital costs of this technology, the payback periods may be quite long. According to a Lawrence Berkeley National Laboratory Study, an average payback period for an upgraded HVAC system can be around 8 years.^{cxxxiii}

Figure 11: Energy Savings in Natural Gas Consumption Due to HVAC Upgrade



SOLAR

Current Efficiency Challenges

Using solar energy to improve a building's energy efficiency is a popular and sometimes economically viable project. Potential solar projects include flat-plate photovoltaic panels, concentrating photovoltaic systems and solar hot water heaters.

PHOTOVOLTAIC (PV)

Description of Technology

Photovoltaic (PV) solar cells directly convert the energy from sunlight to electricity^{cxxxiv}. Creating a fully functional PV system requires multiple solar arrays comprised of individual PV cells^{cxxxv}. It is important to note that PV systems are composed of many other parts in addition to individual solar cells. PV systems produce direct current electricity, which must be converted to alternating current in order for it to be used in a typical residential setting^{cxxxvi}.

Flat-Plate PV systems are some of the most common solar systems^{cxxxvii} and can be utilized in a variety of ways. A flat-plate PV system can be fixed in one position or can be outfitted to follow the motion of the sun^{cxxxviii}. One of the advantages of flat-plate systems is their ability to create electricity even on cloudy days, as these systems harness some of the energy in diffuse sunlight^{cxxxix}.

Concentrating systems use lenses to capture and focus the sun’s energy onto a smaller area: the PV cell. These systems use less solar cell material than flat-rate systems and more of less expensive materials. However, they require tracking mechanisms and precise control systems to maximize their efficiency.^{cxl}

Advantages

Essentially, any building could create its own electricity from PV systems. However, there are many critical factors determining whether or not a building would benefit from PV installation. While some PV systems produce power from diffuse sunlight, solar cells reach much higher efficiencies when they have more direct, concentrated sunlight^{cxli}. The solar potential of a building or location is usually a good place to start when considering PV systems. There are many “solar maps” available on the internet that can serve as a starting point, including National Renewable Energy Laboratory^{cxlii} and the New York City Solar Map^{cxliii}, created by the New York City Solar City America Partnership to show existing solar systems and solar potential for rooftops in the five boroughs.

Disadvantages

Solar PV systems are expensive. There are many federal, state, and local incentive programs reducing the cost of solar installations, but the initial capital cost can be too high for some buildings. In addition to cost barriers, PV systems are complicated engineering products, and can require costly additional mechanical systems (e.g. sun-tracking mechanisms) in order to reach their full potential.

Savings Potential

The financial savings and payback scenarios associated with PV systems are dependent on many factors including system size, cell efficiency, and even weather. To reduce the high capital cost with PV systems, NYSERDA offers a \$1.50/watt rebate program (1 kW system would equate to \$1,500 rebate), with a \$10,500 limit.^{cxliv} Additionally, the federal government offers a 30 percent tax credit for PV systems.^{cxlv} For electricity cost savings, any electricity produced by the PV system offsets the energy typically taken from the grid and charged to the building. Essentially—using the average kWh price for NYC from October 2010-October 2011—the PV system saves the building 19.7 cents per generated kWh.^{cxlvi}

SOLAR HOT-WATER – SEE WATER HEATER SECTION

GREEN AND WHITE ROOFS

Current Efficiency Challenges

Roof space accounts for a large share of all impervious surfaces in NYC, with roofs comprising 28 percent of the city’s impervious space. A building’s roof can have a major impact on the thermal comfort of a building, and—as in the case of the urban heat island effect—surrounding buildings as well. On hot summer days, dark and non-reflective roofs absorb the sun’s thermal energy and can become 90° F hotter than the ambient air.^{cxlvii} This excess heat can, in turn, raise the air temperature of the floors closest to the roof, requiring more energy to regulate the indoor temperature. As the roof materials re-radiate this heat back into the surrounding air, the local temperature can be raised. This phenomenon is known as the Urban Heat Island Effect, and can result in the need for higher energy demand as the need to cool indoor air increases.^{cxlviii} In addition to these energy concerns, the heat absorbed by the dark materials can cause warping and structural damage to a roof. As a final note, it is important to consider the storm water runoff implications of an impervious roof. Without proper storm water management on roofs, excess runoff can help contribute to sewer overflows.^{cxlix}

GREEN ROOFS

Description of Technology

Sometimes also referred to as “planted roofs,” green roofs consist of a soil and vegetative layer on the top of a building, creating a small living environment on what would typically be a solid, impervious surface. The US

Department of Energy (DOE) describes two categories of green roofs—extensive and intensive. Intensive green roofs consist of more diverse plants and require much more soil, which will often require higher structural support. Extensive green roofs use a shallower soil base and smaller plants such as succulents. The DOE suggests that extensive green roofs are often more environmentally effective than intensive green roofs^{cl}.

Advantages

Green roofs address many building inefficiencies, with a particular emphasis on energy efficiency and storm water management. In terms of energy, green roofs provide benefits on both an individual building and city-wide scale. For an individual building, green roofs drastically reduce the heat absorbed by a typical impervious surface. The roof essentially creates an additional thermal barrier, which helps avoid an increase in indoor temperature, thus reducing the need for energy-intensive air conditioning. This new thermal barrier can also serve as heat-trapping insulation during cold months by limiting the amount of heat escaping from the top of the building, thus reducing the demand for additional heating. However, green roofs should not be considered a substitute for standard insulation.^{cli} At the city level, green roofs help lower the urban heat island effect, as they absorb the sun's energy rather than re-radiating it back into the surrounding air. This lower urban heat island effect reduces the energy demand for air conditioning across the city in the hot summer months. Green roofs are highly touted for their storm water management capabilities. Instead of water rushing off impervious roofs, green roofs allow rainwater to infiltrate the soil and be released in a more natural time frame, reducing stress on the city's sewer system and water treatment facilities.

Disadvantages

Introducing a green roof to an existing building can be a capital and time-intensive project, with initial EPA estimates ranging from \$10/ft² to \$25/ft², although the agency anticipates the cost to decrease as the industry grows.^{clii} In addition to up-front capital costs, the EPA suggests considering maintenance costs, which can range from \$0.75 to \$1.50 per square foot, when analyzing the benefits and costs of a green roof.^{cliii} Even with the interest and capital available, not every building can support a green roof. The DOE recognizes other barriers to the implementation of green roofs including a lack of consistent industry design standards and strategies, varying maintenance requirements, and a fear of leaks. Lastly, the DOE suggests that the energy benefits are likely higher for low-rise buildings^{cliv}.

Furthermore, Landmark/Historic buildings will once again have to apply for permits for any changes to their roofs, including green roofs.

Savings Potential

The NYC government has implemented a tax abatement program for new green roofs, which covers \$4.50/ft² of green roof coverage, or a maximum of \$100,000.^{clv} The energy savings of green roofs vary widely and depend on a variety of factors including building size and climate. Savings from a green roof in NYC multifamily buildings can be individually modeled with the help of an industry expert; however, there are some reference studies of NYC buildings installing green roofs. The NYC Department of Design and Construction reports energy savings for a green roof ranging from \$0.05 to \$0.10 per square foot.^{clvi} Meanwhile a study published by NYSERDA showed that a modeled green roof on the Gratz Industries building in NYC could see up to \$1,846 in annual energy cost savings. This same report, however, noted that based on installation costs, the payback period for the modeled green roof may exceed the useful life range of the building.^{clvii}

WHITE ROOFS

Description of Technology

Cool roofs, or "White roofs," use a lightly colored reflective coating to reflect solar radiation back away from the building and urban area. Not only does this coating have a high reflectivity rating, but also a high emissivity rating, which means that energy absorbed by the material is quickly re-radiated back into the surroundings^{clviii}. In contrast to green roofs, cool roofs do not act as their own thermal barrier during the colder winter months. If a building is

losing heat through its roof during the heating season, additional efficiency measures such as insulation may be needed in addition to a white roof. Cool roof materials and colors vary, with a white coating often described as the “coolest.”^{clix} According to the DOE, there are close to 3,000 Energy Star compliant cool roof options.

Advantages

A large energy *inefficiency* in many buildings is the dark-colored, heat-absorbing roof. During summer months, a dark roof will absorb an immense amount of solar energy, which heats the indoor air, requiring more air conditioning. A building with a cool roof will see a drop in indoor air temperature during summer months, requiring less energy and money to run the air conditioning equipment. The NYC Department of Design and Construction (DDC) found the temperature of a white-coated roof to be about 30° F cooler than a base, dark-colored roof.^{clx} Meanwhile the NYC CoolRoofs program lists a variety of other benefits associated with cool roofs, including extended roof life due to a lack of temperature extremes and a lowering of the urban heat island effect.^{clxi}

Disadvantages

Cool roof materials and installation typically cost more than standard dark roofs. A 2006 study cited by the EPA suggests that a cool roof coating will cost between \$0.75 and \$1.50 per square foot, while a cool roof single-ply membrane could range between \$1.50 and \$3.00.^{clxii} While reducing cooling costs in the summer, some cool roofs have resulted in slightly higher heating costs in the winter. However, the NYC CoolRoofs program has found that the savings gains on cooling costs often outweigh the small increase in heating costs.^{clxiii}

Savings Potential

Energy and financial savings are very site- and building-specific, meaning savings can vary significantly from building to building. The NYC DDC estimated cool roof payback periods using 2004 energy rates, and found that existing buildings with low insulation experienced the most savings. The report found that an old existing building switching from a dark-membrane coated roof to a white-membrane coated roof could realize payback in approximately 5 years.^{clxiv} For a more individual evaluation, the US DOE has created an introductory Cool Roof Calculator for building specific calculations.^{clxv}

BOILERS

Current Efficiency Challenges

Residential buildings often use either a furnace or boiler system for heating. A furnace heats air, which is then distributed throughout the building using air ducts. Boilers, on the other hand, heat water and distribute either hot water or steam through a system of pipes and radiators. Steam boilers operate at a higher temperature and less efficiently than hot water boilers. The efficiency of a boiler is measured using a calculation of its annual fuel utilization efficiency (AFUE). An AFUE calculation shows the ratio of the heat output of the boiler compared to the total fuel, or energy, consumed to produce that heat output. If a boiler has an AFUE of 80%, then 80% of the fuel input is distributed as heat while 20% is lost in the process. An AFUE calculation does not consider heat loss from distribution throughout the building, which can sometimes be up to an additional 35%, depending on the system design. There are both gas-fired and electric boilers. An all-electric boiler has an inherently better efficiency rating than a gas-fired boiler, but efficiency gains are present for both systems.^{clxvi}

RETROFITTING THE BOILER

Description of Technology

The most common retrofit to an existing gas-fired boiler is the addition of a vent damper. A vent damper decreases heat loss to the chimney. Steam boilers achieve more efficiency gains with dampers than hot water boilers, which operate at higher temperatures. Also, larger systems achieve greater efficiency gains than smaller systems. Installing an intermittent ignition device can also increase a boiler’s efficiency, rather than having a constantly

running pilot light.^{clxvii} Installing programmable thermostats can also improve the system's efficiency. Lastly, a large portion of the heat loss can occur in the distribution of the heat throughout the building. Upgrading and insulating air ducts or steam pipes can reduce the amount of heat lost in the building.

Advantages

Many of these upgrades are smaller projects that can be done over time, greatly reducing initial capital costs of the project. Efficiency gains can be made in incremental steps with these upgrades, rather than an all-or-nothing installation of a new system.

Disadvantages

The costs for retrofitting a system could cost more than replacing it. Full calculations should be made and all short- and long-term costs considered before pursuing a retrofit option for the boiler system.^{clxviii} Specifically, an intermittent ignition light can be expensive and require expertise to install.^{clxix}

REPLACING THE BOILER

Description of Technology

Older boiler systems often have an AFUE between 50% and 70% whereas new boilers have an AFUE of at least 80%. ENERGY STAR® boilers have an AFUE rating of at least 85%. These new boilers achieve greater efficiency through improvements such as electronic ignition (instead of a constantly running pilot light), new combustion technologies for greater output of the same fuel input, and sealed combustion that "uses outside air to fuel the burner, reducing drafts and improving safety."^{clxxx}

Advantages

Upgrading the boiler system can achieve greater efficiency gains for a longer time span for the building. The total costs for replacing an old boiler system often are less than continuous retrofits over time.

Disadvantages

The upfront capital costs can be high, since replacing such a large system in the building is a large project and cannot be done in incremental steps like retrofit options can.

Savings Potential

With an estimate of the capital costs for installing a new boiler, the savings and rate of return can be calculated using the table below. The table gives potential dollars saved for different upgrade scenarios. The savings depends highly upon the fuel costs for the system and the rate of return depends mostly on the size and cost of the new system. Perhaps unlike some other upgrades, the savings in energy and costs from a boiler upgrade are real.

Table 2: Potential Savings with New Efficient Boiler System

		AFUE of New System			
		80%	85%	90%	95%
AFUE of Existing System	50%	\$37.50	\$41.24	\$44.24	\$47.36
	55%	\$31.20	\$35.29	\$38.88	\$42.10
	60%	\$25.00	\$29.41	\$33.33	\$37.80
	65%	\$18.75	\$23.52	\$27.77	\$31.57
	70%	\$12.50	\$17.64	\$22.22	\$26.32
	75%	\$6.50	\$11.76	\$16.66	\$21.10
	80%		\$5.88	\$11.11	\$15.80
	85%			\$5.55	\$10.50

Source: ACEEE: Heating, <http://www.aceee.org/consumer/heating> and US DOE: http://www.energysavers.gov/your_home/space_heating_cooling/index.cfm/mytopic=12530

COMBINED HEAT AND POWER MICROTURBINES

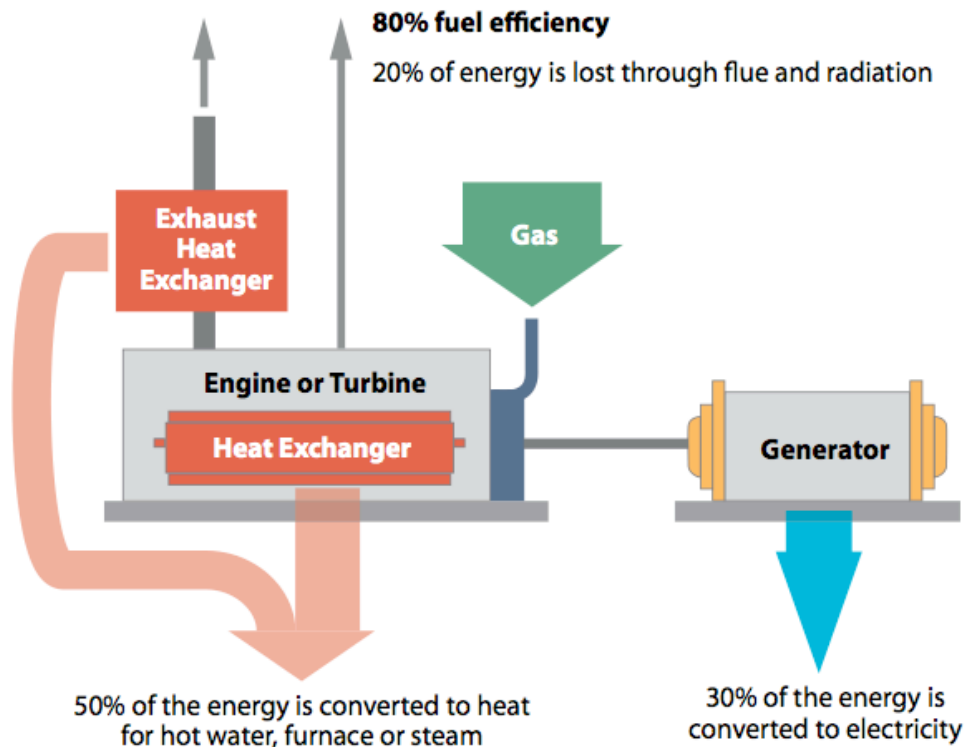
Current Efficiency Challenges

Electricity generation and transmission are not 100% efficient. Turbines creating electricity can only capture a portion of the energy stored in a fuel source. Much of the energy in the fuel source is lost to waste heat escaping the turbine system. Further, the actual transmission of the electricity through power lines results in lost energy. In addition, the proportion of New York households using fuel oil for home heating is almost four times the national average. In response to dirty fuel oil contributing to the city's air pollution, the NYC government has called for the phase out of many of the dirtiest fuel oils. Combined Heat and Power systems address both the electric and heating problems, as these systems produce electricity on-site, capture the waste heat from the electricity production, and use the waste heat to help heat the building, reducing the need for heating fuels.

Description of Technology

Combined Heat and Power (CHP) systems use a microturbine and a fuel source to generate on-site electricity and capture the excess heat to distribute throughout the building.^{clxxi} Typical natural gas-powered turbine systems are about 15-45% efficient in capturing the energy in the fuel source. Much of the energy is lost to waste heat, however a CHP system is designed to capture waste heat and direct it to heating a hot water or furnace system, resulting in a CHP system that can reach 80% efficiency.^{clxxii} The NYC Department of Buildings (DOB) provides a useful diagram (see Figure 2) in their guide to natural gas powered CHP systems:

Figure 2: Combined Heat and Power System



Source: http://www.nyc.gov/html/dob/downloads/pdf/combined_heat_and_power_systems.pdf

Advantages

CHP microturbines can offer a wide variety of benefits to a building. Using waste heat from the generation process can drastically reduce the demand for heating fuel in building, saving money and emissions from boilers. CHP systems often use natural gas as their primary fuel, which is a cleaner alternative to heating oil boilers and electricity from coal. In addition to the single building benefits, the on-site electricity generation lessens the load demand on the main power grid, which can also increase efficiency and reduce emissions on the state-scale.

Disadvantages

CHP systems can be a very capital-intensive investment and are not appropriate for all buildings. The NYC DOB suggests that CHP systems work best in buildings with electric bills of at least \$100,000 per year and with minimum energy usage rates meeting the minimum output of the CHP system. Additionally, CHP installation requires a number of government and utility approvals, as well as a connection to a natural gas source. Given these complexities, it is highly recommended to consult with a mechanical engineer who specializes in CHP systems. The NYC DOB provides a starting guide to CHP systems, and the link can be found in the below *Resources* section.

Savings Potential

The savings potential for a CHP system will vary greatly building to building. A trained consultant with CHP experience would be able to offer savings estimates after a thorough building evaluation. A case study presented by the New York State Energy Research and Development Authority (NYSERDA) predicts that an NYC hotel will save \$80,000 in annual electricity costs with the installation of two CHP systems.^{clxxiii}

GUIDE/STEPS FOR CO-OP AND CONDOMINIUM BOARDS

In addition to this report, the project team has developed a brief user guide that synthesizes the information provided here into an easier-to-read format. The guide also provides a basic comparison of these technologies against each other through ranking charts on each page of a review. Accompanying this guide is an Excel-based ranking tool available through Better Buildings New York's website. The tool provides an even more in-depth ranking system that takes into account the users building characteristics and technology preferences. These two guides (the condensed brief and the Excel tool) can all be referenced back to this all-encompassing document here, as this report acts as the foundation of all the research presented.

CONCLUSION

Energy efficiency presents an incredible opportunity for positive local, regional, and global impacts. While building residents save money, regional strain on the electrical system is relaxed, and global pollutant emissions are lowered. Whatever the motivation, energy efficiency should be viewed as an enormous opportunity to upgrade a building. New York City is leading the charge for energy efficient buildings, and residential co-ops and condominiums have the opportunity to be at the forefront of this movement.

This report aims to simplify the large and confusing energy efficiency market by congregating and condensing existing industry knowledge. Energy efficiency upgrades can be burdensome and intimidating to those without formal building science training. With this long-form report, along with user-friendly guide and Excel-ranking tool deliverables, the goal of this project is to educate co-op and condominium boards on the energy efficiency options for their buildings.

Co-op and condominium boards are encouraged to use this full-length academic report as a supplemental resource to their decision process. After reading through the condensed guide and exploring the personal Excel tool, co-op or condominium boards are encouraged to use this long-form report to learn further details about the energy efficiency technologies that interest them.

As described previously, this report is not a final decision tool. It is the project team's hope that co-op and condominium boards will use these products to understand potential energy efficiency upgrades for their building. This report should serve as a resource for co-op and condominium boards as they speak with industry professionals about the best retrofit options for their buildings.

For further information, please contact Better Buildings New York at info@betterbuildingsny.org

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1. EQUEST

As discussed in the Methodology, there were three technologies vetted using eQUEST: Insulation, Windows and HVAC. The basic size of each of the five types of buildings used in the model runs were based on the spread of data used from the NYC Mayor's Office of Long Term Planning and Sustainability (See Figure 1). The baseline runs were based off the 1979 New York Building Energy Efficiency Code.

Appendix Figure 1: Building Size Inputs in eQUEST

Percentile	Floors	Total Units	Buildingsqft
5th	6	29	55,883
25th	11	53	77,967
50th	14	78	116,824
75th	16	120	177,975
95th	21	350	384,336

The rest of this appendix reviews some of the data collected from eQUEST based on the technology upgrades performed.

For insulation, the baseline R-values used were R-8 to R-11. A second round of model runs were conducted, and the building insulation in each of the five original baseline runs was upgraded to R-14 to R-18. Finally, one last round of insulation upgrades were run, with r-values of R-21 to R-30. The results are seen in Image 2 below.

Appendix Figure 2: eQUEST Insulation Output

Percentile	R-Value	% Decrease in heating needs
5th	R8-11	Baseline
	R14-18	-6%
	R21-30	-12%
25th	R8-11	Baseline
	R14-18	-5%
	R21-30	-9%
50th	R8-11	Baseline
	R14-18	-5%
	R21-30	-9%
75th	R8-11	Baseline
	R14-18	-5%
	R21-30	-8%
95th	R8-11	Baseline
	R14-18	-6%
	R21-30	-10%

For windows, u-values were used. The original windows for each of the five baselines were a u-factor of around 1 with a single pane glass window. To upgrade these runs, double paned glass was used, with a decreasing u-factor of around u-.55 first, and then u-.25 as the most efficient run.

Appendix Figure 3: eQUEST Windows Output

Percentile	U-Factor	% Decrease in Gas Consumption
5th	1.02-1.04	Baseline
	0.55	-21%
	0.24-0.25	-23%
25th	1.02-1.04	Baseline
	0.55	-22%
	0.24-0.25	-24%
50th	1.02-1.04	Baseline
	0.55	-22%
	0.24-0.25	-24%
75th	1.02-1.04	Baseline
	0.55	-30%
	0.24-0.25	-40%
95th	1.02-1.04	Baseline
	0.55	-9%
	0.24-0.25	-19%

For HVAC systems, the Energy Efficiency Ratio (EER) and Coefficient of Performance (COP) were altered to reflect the 1979 code standard and the 2007 code standard. These numbers reflect the efficiency of a unit, and are increased to indicate a more efficient unit has been installed.

Appendix Figure 4: eQUEST HVAC Outputs

Percentile	EER	COP	% Decrease in heating needs
5th	6.8	0.668	Baseline
	8.5	0.806	-12%
25th	6.8	0.668	Baseline
	8.5	0.806	-13%
50th	6.8	0.668	Baseline
	8.5	0.806	-13%
75th	6.8	0.668	Baseline
	8.5	0.806	-13%
95th	6.8	0.668	Baseline
	8.5	0.806	-17%

2. RANKING SYSTEM AND TOOL

Appendix 2 focuses on an overview of the Microsoft Excel Tool’s interface, and the five areas of the ranking system (including how the scores were assigned in each area). The first section will be an overview of the layout of the tool, and how it functions. Then, by using one technology as an example, each of the five ranking areas within the tool will be described in detail.

OVERVIEW

The Microsoft Excel Tool (hereafter “the Tool”) is comprised of several spreadsheets, denoted by tabs along the bottom of the document. The first tab entitled "Inputs" is the initial page the user will see upon opening, and will be the only page they will need to look at for the purpose of ranking technologies. All subsequent tabs labeled with a technology are the calculations that were used for ranking each technology, and can be hidden if necessary. The very last tab entitled “Ranking System” contains the ranking scales used for each of the five categories.

The first tab “Inputs” (see Image 1) is the user interface component of the Tool. The overall idea of this sheet is that the user would open it and fill-in two parts: Part 1 is the characteristics of their building, and Part 2 is their importance ranking of the five areas we vetted each technology. After they fill in this information, they click "Run Analysis" button to get a ranking of technologies in the grayed out area, called Part 3. The sheet has two macros on it (the two buttons), so macros will have to be enabled to use the "Run Analysis" and "Reset" button.

Image 1: "Inputs" Tab on the first page of the Tool

BetterBuildingsNY

This technology ranking tool is intended to give a quick overview of the technologies that should be investigated for your building. Fill out the yellow boxes in Part 1 and Part 2 of this sheet, and click the "Run Analysis" button to see your results in Part 3. The higher the score, the better the technology fits your building characteristics and Ranking Importance criteria.

Part 1: Building Inputs	Part 2: Ranking Importance Criteria*		Part 3: Results
Landmark/Historic Building? <input type="text" value="Yes"/>	Efficiency <input type="text" value="3"/>	Run Analysis	Rankings
# of Units in Building <input type="text" value="78"/>	Capital Costs <input type="text" value="3"/>		Raw Score
# of Windows per Unit <input type="text" value="3"/>	Installation Difficulty <input type="text" value="3"/>	Reset	Technology
Total Square Footage of Building <input type="text" value="116,000"/>	Payback Periods <input type="text" value="3"/>		
Building Footprint (length in ft) <input type="text" value="40"/>	Reliability of Gains <input type="text" value="3"/>		
Building Footprint (width in ft) <input type="text" value="50"/>	*Select a score of 1 through 5 for each of the five ranking categories. 5 means extreme importance, and 1 means little importance. A number can be used more than once, but the more variation, the better the results.		
Last time HVAC was replaced <input type="text" value="Pre-2006"/>			
Current Water Heating System <input type="text" value="Natural Gas"/>			
Centralized Water Heating System? <input type="text" value="Yes"/>			

For Part 1, building inputs should be filled out to the best of the user’s ability. If any inputs are unknown and left blank, the technologies depending on that input will automatically be weighted at the bottom. Other technologies, because of building applicability, may also be automatically weighted towards the bottom in Part 3. An example of this is if the user does not know the building footprint, and leaves those inputs blank, then Green and White Roofs will be ranked at the bottom. Another example is with Submetering. If there are less than 15 units in the building, the research in this report has shown that it is uneconomical for those buildings to pursue that type of system. Therefore, if the user inputs less than 15 in the “# of Units in Building” box, then the Submetering will go to zero.

For Part 2, the “Ranking Importance Criteria” was created to assign different weights for the five categories each technology was evaluated by: Efficiency, Capital Costs, Installation Difficulty, Payback Periods, and Reliability of Gains. Each of these five areas is given a ranking of one (1) to five (5). Five means of great importance, and one means of little importance. A number can be used more than once. How these weights are incorporated into the actual ranking will be discussed later, but the main reason this was included in the tool was to allow the user to define their priorities for the technologies they are looking for. These preferences are taken into consideration with the ranking scores, and tailor the results even further to the specific user.

Finally, after Part 1 and 2 have been filled out, the user clicks the “Run Analysis” macro button. This aggregates the total ranking score for each technology, and lists them from highest to lowest in the grayed out area (Part 3). The intent of this output is to provide the user with an idea of the technologies they should be looking at based on their building characteristics and preference criteria.

Now that the user interface has been explained, the remaining sections of this appendix will go over each of the five ranking areas, and how they were calculated. This will all be done with an example technology: Window Film. Image 2 below shows all five ranking areas for one technology. The following five sections will go through the methodology used for each area.

Image 2: Window Film Ranking Calculations

	Window Film
<u>Efficiency</u>	
Efficiency Ranking of Technology	3
Importance Weight	60%
Weighted Subtotal	1.8
<u>Difficulty of Installation</u>	
Difficulty of Installation (historic permit needed)	No
Difficulty of Installation Ranking (part 1)	4
Difficulty of Installation (Weight for Permit) (part 2)	0
Subtotal	4
Importance Weighting	60%
Weighted Subtotal	2.4
<u>Costs</u>	
Estimated Cost for Actual Product (\$)	\$50
Estimated Cost Per Unit (\$)	\$150
Estimate Cost Rankings	4
Importance Weighting	60%
Weighted Subtotal	2.4
<u>Payback Periods</u>	
Payback Periods Ranking	3
Importance Weighting	60%
Weighted Subtotal	1.8
<u>Certainty of Paypack Periods</u>	
Certainty of Paypack Periods Rankings	3
Importance Weighting	60%
Weighted Subtotal	1.8
Total Ranking Scores	10.2

EFFICIENCY

The first gray box in Image 2 (above) is associated with the “percent of energy efficiency” gains associated with the type of technology. “Percent energy efficiency gains” was defined as how much the technology increases the efficiency of the desired activity. With the example of Window Films, the research indicated that by adding certain types of window films, the windows become efficient, reducing the heating or cooling needs of a room by around 30%.

A scale of one to five was then used to provide an initial score for that technology is this category. The scoring chart for efficiency is displayed in Image 3.

Image 3: Energy Efficiency Ranking Guide

Ranking	% Energy Efficiency Gain
1	1-10
2	11-20
3	21-30
4	31-40
5	41+

In the case of Window Films, because the research found that it was around 30%, a score of three (3) was assigned to this technology in this category.

Image 4: Energy Efficiency Ranking Score for Window Films

Efficiency	
Efficiency Ranking of Technology	3
Importance Weight	60%
Weighted Subtotal	1.8

The “Importance Weight” is where Part 2 of the initial “Inputs” page relates. Each of the five areas of the Tool was given a score of one to five, as discussed in the Overview section of this appendix. In this example, the user ranked all five areas the same, giving them a three out of five. Three divided by five equals 0.6, or 60%. This percentage is multiplied by the efficiency ranking score of the technology to get a weighted subtotal (3 x 0.6=1.8). Each of the five sections gets a weighted subtotal, with the final score of the technology being the summation of all five subtotals.

DIFFICULTY OF INSTALLATION

The second gray box in Image 2 (above) is associated with the “Difficulty of Installation” for the technology. The first line in this box is a simple “Yes”/ “No” binary variable that asks whether the technology needs a permit if it is being applied in a landmark/historic building. This answer will come into play in the second part of this section.

The second line of this section (Part 1) assigns a ranking for the difficulty of installing this technology. The higher the score, the less costly, time consuming and invasive the technology is considered (invasive meaning having to actually enter a resident’s unit). For Window Films, a score of four (4) was awarded. This is because some films can be a “Do-It-Yourself” (a five), while others may require the maintenance manager of the building to come into the apartment and apply it (a four).

Image 5: Difficulty of Installation Ranking Guide (Part 1)

Ranking	Difficulty of Installation
1	Contractor and invasive
2	Contractor, non-invasive
3	Maintenance manager and invasive
4	Maintenance manager and non-invasive
5	DIY

The third line in this section (Part 2) adjusts the value to the Part 1 score based on whether the building being run in the model is historic or not. By using a logic statement in Excel, a one is subtracted from the score in this section if the building the user lives in is historic/landmark, *and* the technology being evaluated needs a permit for historic/landmark buildings. If both answers are “yes” (one depending on the user’s input on the first page, and the other already set behind the scenes), then one point is subtracted from the score given in Part 1. If either the building or the technology is a “no”, then a zero is subtracted, unchanging the original score.

Image 6: Difficulty of Installation Ranking Guide (Part 2)

Score Adjustment	
-1	Building and Tech meet permit requirement
0	Non-Landmark/Tech doesn't need permit

The final step is to take the Importance Weight given to this section and multiply the subtotal, to get the weighted subtotal. As seen in Image 7 below, Window Films are excluded from needing a permit in historic/landmark buildings, the Part 1 ranking is a four, and the Part 2 ranking is zero because the technology does not need a permit, for a subtotal of four. Finally, the four is multiplied by the Importance Weight to get a Weighted Subtotal of 2.4.

Image 7: Difficulty of Installation Ranking Score for Window Films

Difficulty of Installation	
Difficulty of Installation (historic permit needed)	No
Difficulty of Installation Ranking (part 1)	4
Difficulty of Installation (Weight for Permit) (part 2)	0
Subtotal	4
Importance Weighting	60%
Weighted Subtotal	2.4

COST ESTIMATES

The third gray box in Image 2 is associated with the estimated capital costs per unit of the technology. This is the upfront money needed to purchase the technology, and does not take into account installation, operation and maintenance, or available tax credits/incentives from the city, state or federal government. To make cost comparisons equal across technologies, there had to be a similar scale used to compare them. Therefore, a “per unit” measure was used for all technologies.

Image 8: Cost Estimate Ranking Guide

Ranking	Cost Estimates Per Unit
1	\$2000+
2	\$1,000-\$2,000
3	\$500-\$1,000
4	\$100-\$500
5	\$10-\$100

For smaller technologies, like Window Films, the cost of one film can be about \$50. Multiplied by the number of average windows per unit, a cost per unit is determined. A logic statement is used in the Excel sheet for the row “Estimated Cost Rankings” to adjust the ranking as the number of windows in an average apartment increase or decrease. For the example used here, three windows are estimated for each unit, making the total cost per unit ($\$50 \times 3 = \150), giving this technology a score of four (4). However, if there were 10 windows in an average unit, the cost would ($\$50 \times 10$) \$500 per unit, and the score would drop to a three (3).

Image 9: Cost Estimates Per Unit Ranking Score for Window Films

Costs	
Estimated Cost for Actual Product (\$)	\$50
Estimated Cost Per Unit (\$)	\$150
Estimate Cost Rankings	4
Importance Weighting	60%
Weighted Subtotal	2.4

Larger technologies, like HVAC systems, that have a single, large price tag, have an overall cost estimated by the size of the building square footage. This large sum is then divided by the total number of units entered by the user, and a per unit cost is estimated. Depending on where per unit cost range ends up dictates the ranking (see Image 8).

Once again, the final step is to take the Importance Weight given to this section and multiply the subtotal, to get the weighted subtotal.

PAYBACK PERIODS

The fourth gray box in Image 2 is associated with the estimated payback period for the technology. This is defined as when the savings from the technology will have paid back the upfront capital costs. Evaluating payback periods were a bit more subjective than the previous three criteria. This is due to the fact that payback periods are heavily contingent on specific building performance, and it is difficult to provide exact numbers for each technology. Therefore, for this Tool, there were ranges used to break up the different spans of payback periods. As with every other ranking area, the higher the score, the quicker the payback period. Based on the research conducted by the team, anything that is able to payback within a year or two is considered to be an excellent return on investment. As the years increased in chunks of three or four, the rankings decreased.

Image 10: Payback Period Ranking Guide

Ranking	Payback Periods
1	12+ years
2	10-12 years
3	6-9 years
4	3-5 years
5	1-2 years

For Window Films, the research indicated from case studies and producers of this technology that the payback period should be in the 2-6 year range. Therefore, a score of four (4) was given to Window Films. Once again, the final step is to take the Importance Weight given to this section and multiply the subtotal, to get the weighted subtotal.

Image 11: Payback Period Ranking Score for Window Films

Payback Periods	
Payback Periods Ranking	4
Importance Weighting	60%
Weighted Subtotal	2.4

CERTAINTY OF PAYBACKS

The fifth and final gray box in Image 2 is associated with the certainty of the payback periods for the technology. This final ranking criterion was also extremely subjective, and based on how uncertain the literature review and model outputs were for the technology. For technologies that had a small range for estimated payback periods, their certainty score was high. Light bulbs, for example, are a technology that has a high certainty for payback period because of their engineered efficiency, and the fact that they are not contingent on other components of the building. HVAC, on the other hand, has literature and model data indicating payback periods ranging from a few years to over a decade. That's because even with an efficient HVAC system, and leaky building envelope can make any gains in efficiency negligible. When it comes to a technology that has a large range of years for payback, it indicates that payback and efficiency gains may be variable, and therefore a lower score is given to the technology.

Image 12: Certainty of Payback Period Ranking Guide

Ranking	Certainty of Payback Periods
1	Quite Variable
2	Variable
3	Pretty steady
4	Quite reliable
5	Extremely reliable

For Window Films, the research seemed to suggest that because of the lower costs, and the fact that they are retrofitting a portion of the building envelope, the payback periods are pretty steady. Therefore, a ranking of three (3) was given. When incorporating the Importance Weight, the last weighted subtotal is calculated.

Image 13: Certainty of Payback Period Ranking Score for Window Films

Certainty of Paypack Periods	
Certainty of Paypack Periods Rankings	3
Importance Weighting	60%
Weighted Subtotal	1.8

CONCLUSION

After each of the subtotals has been calculated, they are summed, and an Overall Score is found for that technology. For Window Film, based on median building characteristics from the data and an equal preference across all five ranking areas, a score of 10.2 is given (see Image 2, last row). Remember that as the inputs of the building change in Part 1, as well as the "Importance Ranking Criteria" in Part 2, the numbers and scores for each technology will change as well. This score would be compared against all the other calculated scores of technologies in the tool, and presented to the user in Part 3 of the "Inputs" tab after they click the "Run Analysis" button.

This tool is not intended to be the deciding factor for a board. Rather, it is a starting point to help a board understand what technologies may be best for them to investigate, based on building characteristics and their preferences on technology attributes.

REFERENCES

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- ⁱ Whole Building Design, “Optimize Energy Use,” accessed March 2012, http://www.wbdg.org/design/minimize_consumption.php.
- ⁱⁱ U.S. Energy Information Administration, “Use of Energy in the United States,” accessed March 2012, http://www.eia.gov/energyexplained/index.cfm?page=us_energy_use.
- ⁱⁱⁱ U.S. Energy Information Administration, “Use of Electricity,” accessed March 2012, http://www.eia.gov/energyexplained/index.cfm?page=electricity_use.
- ^{iv} The City of New York, “PlaNYC: A Greener, Greater New York,” updated April 2011, 168-169.
- ^v The City of New York, “NYC Open Data”, search results last accessed March 2012, <http://nycopendata.socrata.com/browse?q=%236%20oil&sortBy=relevance>.
- ^{vi} James J. Hirsch & Associates, “eQuest Introductory Tutorial,” version 3.64, last accessed March 2012 at http://doe2.com/download/equest/eQ-v3-64_Introductory-Tutorial.pdf, p15.
- ^{vii} Ibid.
- ^{viii} State of New York: State Energy Office, “State Energy Conservation Construction Code,” Printed January 1, 1979.
- ^{ix} New York State Department of State, “Energy Conservation Construction Code of New York State,” August 2007, <http://publicecodes.citation.com/st/ny/st/b1200v07/index.htm>.
- ^x U.S. Energy Information Administration, “Share of energy used by appliances and consumer electronics increases in U.S. homes,” Residential Energy Consumption Surveys (RECS), released March 2011, <http://www.eia.doe.gov/consumption/residential/reports/electronics.cfm>.
- ^{xi} U.S. Department of Energy, “Buildings Energy Data Book: 1.2.5: 2010 Buildings Energy End-Use Expenditure Splits, by Fuel Type,” accessed February 2012, <http://buildingsdatabook.eren.doe.gov/ChapterIntro1.aspx>.
- ^{xii} U.S. Department of Energy: Energy Savers, “Lighting Choices,” last accessed March 2012, http://www.energysavers.gov/your_home/lighting_daylighting/index.cfm/mytopic=11975.
- ^{xiii} U.S. Department of Energy: Energy Savers, “New Lighting Standards,” last accessed March 2012, http://www.energysavers.gov/your_home/lighting_daylighting/index.cfm/mytopic=11977.
- ^{xiv} Ibid.
- ^{xv} U.S. Department of Energy: Energy Savers, “Lighting Choices Exemptions,” last accessed March 2012, http://www.energysavers.gov/your_home/lighting_daylighting/index.cfm/mytopic=11978#exempt.
- ^{xvi} Ibid.
- ^{xvii} U.S. Department of Energy: Energy Basics, “Incandescent Lighting,” last accessed March 2012, <http://www.eere.energy.gov/basics/buildings/incandescent.html#sil>.
- ^{xviii} Ibid.
- ^{xix} Ibid.
- ^{xx} Ibid.
- ^{xxi} Ibid.

^{xxii} Ibid.

^{xxiii} Ibid.

^{xxiv} Ibid.

^{xxv} Ibid.

^{xxvi} Ibid.

^{xxvii} Ibid.

^{xxviii} Ibid.

^{xxix} Ibid.

^{xxx} Ibid.

^{xxxi} Ibid.

^{xxxii} Ibid.

^{xxxiii} Ibid.

^{xxxiv} Ibid.

^{xxxv} Ibid.

^{xxxvi} U.S. Department of Energy: Energy Basics, “Fluorescent Lighting,” last accessed March 2012, <http://www.eere.energy.gov/basics/buildings/fluorescent.html>.

^{xxxvii} Ibid.

^{xxxviii} Ibid.

^{xxxix} Ibid.

^{xl} Ibid.

^{xli} Ibid.

^{xlii} Ibid.

^{xliii} Ibid.

^{xliv} Ibid.

^{xliv} U.S. Department of Energy: Energy Basics, “LED Lighting,” last accessed March 2012, http://www.energysavers.gov/your_home/lighting_daylighting/index.cfm/mytopic=12031.

^{xlvi} U.S. Department of Energy: Energy Basics, “Fluorescent Lighting.”

^{xlvii} Ibid.

^{xlviii} Ibid.

^{xliv} Ibid.

ⁱ Ibid.

ⁱⁱ Rennselaer Polytechnic Institute Lighting Research Center, "T5 Fluorescent Systems," last accessed March 2012, <http://www.lrc.rpi.edu/programs/nlpi/lightingAnswers/lat5/pc1.asp>.

ⁱⁱⁱ U.S. Department of Energy: Energy Basics, "Fluorescent Lighting."

ⁱⁱⁱⁱ Rennselaer Polytechnic Institute Lighting Research Center, "T5 Fluorescent Systems."

^{liv} U.S. Department of Energy: Energy Basics, "Fluorescent Lighting."

^{lv} Rennselaer Polytechnic Institute Lighting Research Center, "T5 Fluorescent Systems."

^{lvi} U.S. Department of Energy: Energy Basics, "Fluorescent Lighting."

^{lvii} Rennselaer Polytechnic Institute Lighting Research Center, "LEDs," last accessed March 2012, <http://www.lrc.rpi.edu/researchAreas/leds.asp>.

^{lviii} U.S. Department of Energy: Energy Basics, "LED Lighting."

^{lix} Ibid.

^{lx} Ibid.

^{lxi} Ibid.

^{lxii} Energy Star, "Automatically Control Lighting," last accessed March 2012, http://www.energystar.gov/index.cfm?c=business.EPA_BUM_CH6_Lighting#S_6_7.

^{lxiii} U.S. Department of Energy: Energy Savers, "Lighting Occupancy Sensor Controls," last accessed March 2012, http://www.energysavers.gov/your_home/lighting_daylighting/index.cfm/mytopic=12210.

^{lxiv} Ibid.

^{lxv} Katie Ackerly and Steven Nadel, American Council for an Energy-Efficient Economy, "Analysis of Standards Options for Fluorescent Tubes," January 2008, http://www.energy.ca.gov/appliances/2008rulemaking/documents/2008-02-01_documents/CASE_studies/Analysis_of_Standards_Options_for_Fluorescent_Tubes.pdf.

^{lxvi} Ibid.

^{lxvii} Clark Energy Group, Case Studies, last accessed March 2012, http://www.clarkenergygroup.com/docs/CEG_CaseStudies.pdf.

^{lxviii} U.S. Department of Energy, "Buildings Energy Data Book: 1.1.5: 2010 Buildings Sector Energy Consumption," accessed February 2012 http://buildingsdatabook.eren.doe.gov/docs/xls_pdf/1.1.5.pdf.

^{lxix} Canada Mortgage and Housing Corporation, "Air Leakage Control Manual for Existing Multi-Unit Residential Buildings, December 2007, <http://www.cmhc-schl.gc.ca/odpub/pdf/65847.pdf>.

^{lxx} Department of Energy, U.S. Code §434.201, page 553, <http://www.gpo.gov/fdsys/pkg/CFR-2011-title10-vol3/pdf/CFR-2011-title10-vol3-sec434-201.pdf>.

^{lxxi} Pacific Northwest National Laboratory Resource Center, "Building Envelope," last accessed March 2012, <http://resourcecenter.pnl.gov/cocoon/morf/ResourceCenter/article/114>.

^{lxxii} Canada Mortgage and Housing Corporation, "Air Leakage Control Manual for Existing Multi-Unit Residential Buildings."

^{lxxiii} International Energy Agency, "Financing Energy Efficient Homes: Existing Policy Responses to Financial Barriers," February 2007, <http://www.iea.org/papers/2007/FinancialBarrierBuilding.pdf>.

^{lxxiv} Ibid.

^{lxxv} Energy Star, "Methodology for Estimated Energy Savings from Cost-Effective Air Sealing and Insulating, last accessed March 2012 at http://www.energystar.gov/index.cfm?c=home_sealing.hm_improvement_methodology.

^{lxxvi} Canada Mortgage and Housing Corporation, "Air Leakage Control Manual for Existing Multi-Unit Residential Buildings."

^{lxxvii} Ibid.

^{lxxviii} Ibid.

^{lxxix} Alliance to Save Energy, "DOE Program Expands Market for Highly Efficient Windows," August 2010, <http://ase.org/efficiencynews/doe-program-expands-market-highly-efficient-windows>.

^{lxxx} U.S. Department of Energy: Energy Savers, "Caulking," last accessed March 2012, http://www.energysavers.gov/your_home/insulation_airsealing/index.cfm/mytopic=11270.

^{lxxxi} Window Caulking Image, last accessed March 2012, <http://ltgovernors.com/wp-content/uploads/2009/11/caulk-window-sealant.png>.

^{lxxxii} U.S. Department of Energy: Energy Savers, "Weatherstripping," last accessed March 2012, http://www.energysavers.gov/your_home/insulation_airsealing/index.cfm/mytopic=11280.

^{lxxxiii} GreenSpace Construction, Weatherstripping Image, last accessed March 2012, <http://greenlightconstruct.squarespace.com/caulking-and-weatherstripping/>.

^{lxxxiv} U.S. Department of Energy: Energy Savers, "Caulking."

^{lxxxv} New York City Landmarks Preservation Commission, "Guidelines and Materials Checklists for Performing Work on Landmarked Buildings," August 2005, 29, last accessed March 2012, <http://www.nyc.gov/html/lpc/downloads/pdf/pubs/workguide.pdf>.

^{lxxxvi} U.S. Department of Energy: Energy Savers, "Weatherstripping."

^{lxxxvii} U.S. Department of Energy: Energy Savers, "Caulking and Weatherstripping," last accessed March 2012, http://www.energysavers.gov/your_home/insulation_airsealing/index.cfm/mytopic=11260.

^{lxxxviii} Lowe's, "Window Weather Stripping," last accessed March 2012, <http://www.lowes.com/SearchCatalogDisplay?Ntt=window+weather+stripping&storeId=10151&N=0&langId=1&catalogId=10051&rpp=24>.

^{lxxxix} The North Carolina Division of Environment Assistance and Outreach, "Energy Efficiency," last accessed March 2012, <http://portal.ncdenr.org/web/deao/ea/energy-efficiency>.

^{xc} U.S. Department of Energy: Energy Savers, "Storm Windows," last accessed March 2012, http://www.energysavers.gov/your_home/windows_doors_skylights/index.cfm/mytopic=13490.

^{xci} New York City Landmarks Preservation Commission, "Guidelines and Materials Checklists for Performing Work on Landmarked Buildings," August 2005, 29.

^{xcii} Window Saver Company, Interior Storm Windows, last accessed March 2012, <http://www.windowssaver.com/>.

^{xciii} The Plastic Factory, "Defender Interior Insulating Windows," last accessed March 2012, <http://www.defenderinsulatingwindows.com/faq/>.

^{xciv} Window Saver Company, "Interior Storm Windows," last accessed January 2012, <http://www.windowssaver.com/index.html>

^{xcv} Energy Star, “Energy Star Windows,” last accessed March 2012,
http://www.energystar.gov/index.cfm?c=windows_doors.pr_anat_window.

^{xcvi} Carole Oldroyd, Demand Media, “Pros & Cons of Solar Film for Home Windows,” accessed March 2012 at National Geographic, <http://greenliving.nationalgeographic.com/pros-cons-solar-film-home-windows-2276.html>.

^{xcvii} New York City Landmarks Preservation Commission, “Guidelines and Materials Checklists for Performing Work on Landmarked Buildings,” August 2005, 29.

^{xcviii} Florida Solar Energy Center, “About Window Films,” last accessed March 2012,
<http://www.fsec.ucf.edu/en/consumer/buildings/homes/windows/films.htm>.

^{xcix} Llumar EnerLogic, last accessed March 2012, http://www.llumarenerlogic.com/pdf/LLumar_EnerLogic_Commercial_LR.pdf.

^c 3M, Window Films, last accessed March 2012,
http://solutions.3m.com/wps/portal/3M/en_US/Window_Film/Solutions/Markets-Products/Residential/.

^{ci} Whole Building Design, “Windows and Glazing,” last updated June 2010, last accessed on February 2012,
<http://www.wbdg.org/resources/windows.php>.

^{cii} Energy Star, “Energy Star Windows-Performance Criteria,” last accessed on March 2012 at
http://www.energystar.gov/index.cfm?c=windows_doors.pr_anat_window

^{ciii} Ibid.

^{civ} New York City Landmarks Preservation Commission, “Guidelines and Materials Checklists for Performing Work on Landmarked Buildings,” August 2005, 29.

^{cv} Environmental Defense Fund, “Dirty Heating Oil in New York City,” updated January 2011,
<http://www.edf.org/health/report/dirty-heating-oil-new-york-city>.

^{cvi} American Council for an Energy-Efficient Economy, “Water Heating,” last accessed March 2012 at
<http://www.aceee.org/consumer/water-heating>.

^{cvii} U.S. Department of Energy, “2010 Buildings Energy Data Book,” March 2011, p5-17.

^{cviii} U.S. Department of Energy: Energy Savers, “Demand (Tankless or Instantaneous) Water Heaters,” last accessed March 2012 at http://www.energysavers.gov/your_home/water_heating/index.cfm/mytopic=12820.

^{cix} ACEEE, “Water Heating.”

^{cx} U.S. Department of Energy: Energy Savers, “Tankless Coil and Indirect Water Heaters,” last accessed February 2012 at http://www.energysavers.gov/your_home/water_heating/index.cfm/mytopic=13020.

^{cxii} U.S. Department of Energy: Energy Savers, “Estimating a Storage, Demand, or Heat Pump Water Heater’s Costs,” last accessed March 2012 at http://www.energysavers.gov/your_home/water_heating/index.cfm/mytopic=13010.

^{cxii} ACEEE, “Water Heating.”

^{cxiii} U.S. Department of Energy: Energy Savers, “Tankless Coil and Indirect Water Heaters.”

^{cxiv} ACEEE, “Water Heating.”

^{cxv} U.S. Department of Energy: Energy Basics, “Solar Water Heaters,” last accessed March 2012 at
http://www.eere.energy.gov/basics/buildings/water_heaters_solar.html#%2020%20October%202011.

^{cxvi} Ibid.

^{cxvii} *Ibid.*

^{cxviii} Natinal Renewable Energy Lab, "U.S. Solar Radiation Resource Maps," http://rredc.nrel.gov/solar/old_data/nsrdb/1961-1990/redbook/atlas/Table.html.

^{cxix} U.S. Department of Energy: Energy Savers, "The Economics of a Solar Water Heater," last accessed March 2012 at http://www.energysavers.gov/your_home/water_heating/index.cfm/mytopic=12860.

^{cxx} Energy Star, "Solar Water Heaters," last accessed March 2012 at http://www.energystar.gov/index.cfm?c=solar_wheat.pr_savings_benefits.

^{cxxi} New York State Energy Research and Development Authority, "Electric Reduction in Master Metered Buildings Program," last accessed March 2012 at <http://www.nysersda.ny.gov/en/Page-Sections/Multifamily-Performance-Program/Existing-Buildings/~media/Files/EERP/Multifamily%20Homes/Existing%20Buildings/ermm-app-overview.ashx>.

^{cxxii} New York City Department of Housing Preservation and Development, "Frequently Asked Questions: Sub-Metering Utilities for Enhanced Section 8 Participants," last accessed March 2012 at <http://www.nyc.gov/html/hpd/downloads/pdf/Sub-metering-tenants-update.pdf>.

^{cxxiii} New York State Energy Research and Development Authority, "Electric Reduction in Master Metered Buildings Program."

^{cxxiv} Energy Monitoring Products, "Multifamily and Apartment Metering Applications," last accessed March 2012 at <http://www.emon.com/multifamily.html>.

^{cxxv} New York State Energy Research and Development Authority, "Electric Reduction in Master Metered Buildings Program."

^{cxxvi} Association for Energy Affordability, "Con Edison Multi-Family Energy Efficiency Program," last accessed March 2012 at http://www.aeanyc.org/site/c.dhJJTOzFoH/b.6239865/k.5F24/Con_Edison_MultiFamily_Energy_Efficiency_Program_Frequently_Asked_Questions.htm.

^{cxxvii} Con Edison, "Con Edison Energy Efficiency Programs July 2011," last accessed February 2012 at http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/con_edison_ee.pdf

^{cxxviii} New York State Energy Research and Development Authority, "Electric Reduction in Master Metered Buildings Program."

^{cxxix} Energy Monitoring Products, "E-Mon Submetering Article-Park Plaza Condominium Submetering," last accessed March 2012 at http://www.emon.com/story_parkplaza.html.

^{cxxxx} U.S. Energy Information Administration, "Residential Energy Consumption Survey – Analysis and Projections: Air Conditioning," last accessed March 2012 at http://205.254.135.7/consumption/residential/reports/air_conditioning09.cfm.

^{cxxxi} U.S. Energy Information Administration, "Residential Energy Consumption Survey – Analysis and Projections: First Results," last accessed March 2012 at <http://205.254.135.7/consumption/residential/reports/2009overview.cfm>.

^{cxxxii} Environmental and Energy Study Institute, "Air Conditioner Efficiency Standards," last accessed March 2012 at <http://www.eesi.org/fact-sheet-air-conditioner-efficiency-standards-seer>.

^{cxxxiii} Lawrence Berkley National Laboratory, "Life-cycle Cost and Payback Period Analysis for Commercial Unitary Air Conditioners," last accessed April 2012 at http://efficiency.lbl.gov/drupal/files/ees/Lifecycle%20cost%20and%20Payback%20Period%20Analysis%20for%20Commercial%20Unitary%20Air%20Conditioners_LBNL-54244.pdf

^{cxxxiv} U.S. Department of Energy: Energy Basics, "Photovoltaics," last accessed March 2012 at http://www.eere.energy.gov/basics/renewable_energy/photovoltaics.html.

-
- ^{cxxxv} U.S. Department of Energy: Energy Basics, “Photovoltaic Cells,” last accessed March 2012 at http://www.eere.energy.gov/basics/renewable_energy/pv_cells.html.
- ^{cxxxvi} U.S. Department of Energy: Energy Basics, “Photovoltaic Systems,” last accessed March 2012 at http://www.eere.energy.gov/basics/renewable_energy/pv_systems.html.
- ^{cxxxvii} *Ibid.*
- ^{cxxxviii} U.S. Department of Energy: Energy Basics, “Flat-Plate Photovoltaic Systems,” last accessed March 2012 at http://www.eere.energy.gov/basics/renewable_energy/flat_plate_pv_systems.html.
- ^{cxxxix} *Ibid.*
- ^{cxli} U.S. Department of Energy: Energy Basics, “Concentrator Photovoltaic Systems,” last accessed March 2012 at http://www.eere.energy.gov/basics/renewable_energy/concentrator_pv_systems.html.
- ^{cxlii} *Ibid.*
- ^{cxliii} National Renewable Energy Laboratory, “Solar Maps,” last accessed on April 2012, <http://www.nrel.gov/gis/solar.html>
- ^{cxliiii} New York City Solar America City Partnership, “New York City Solar Map,” last accessed on April 2012, <http://nycsolarmap.org/>
- ^{cxliiv} North Carolina State University: Database of State Incentives for Renewables and Efficiency, “New York NYSERDA PV Incentive Program,” last accessed March 2012 at http://www.dsireusa.org/incentives/incentive.cfm?Incentive_Code=NY10F&re=1&ee=1.
- ^{cxli v} North Carolina State University: Database of State Incentives for Renewables and Efficiency, “Federal Residential Renewable Energy Tax Credit,” last accessed March 2012 at http://www.dsireusa.org/incentives/incentive.cfm?Incentive_Code=US37F.
- ^{cxli vi} U.S. Department of Labor: Bureau of Labor Statistics, “Average Energy Prices in New York-Northern New Jersey-February 2012,” last accessed March 2012 at <http://bls.gov/ro2/avgengny.pdf>.
- ^{cxli vii} New York City Department of Design and Construction, “DDC Cool and Green Roofing Manual,” June 2007, p2.1.
- ^{cxli viii} *Ibid.*
- ^{cxli ix} “DDC Cool and Green Roofing Manual,” p2.6.
- ^{cl} U.S. Department of Energy, Energy Efficiency and Renewable Energy, “Federal Technology Alert: Green Roofs: DOE/EE-0298,” last accessed March 2012 at http://www1.eere.energy.gov/femp/pdfs/fta_green_roofs.pdf.
- ^{cli} U.S. Environmental Protection Agency, “Reducing Urban Heat Islands: Compendium of Strategies – Green Roofs,” p5, last accessed March 2012 at <http://www.epa.gov/heatisd/resources/pdf/GreenRoofsCompendium.pdf>.
- ^{cli i} U.S. Environmental Protection Agency, “Reducing Urban Heat Islands: Compendium of Strategies – Green Roofs,” p10.
- ^{cli ii} *Ibid.*
- ^{cli v} U.S. Department of Energy, Energy Efficiency and Renewable Energy, “Federal Technology Alert: Green Roofs: DOE/EE-0298.”
- ^{cli v} New York State Department of Taxation and Finance, “Green Roof Properties in New York City,” last modified January 2012, last accessed April 2012 at http://www.tax.ny.gov/research/property/assess/manuals/vol4/pt2/sec4_06/sec499_bbb.htm
- ^{cli vi} “DDC Cool and Green Roofing Manual,” p3.4.

-
- clvii New York State Energy Research and Development Authority, "Green Roof Thermal and Stormwater Management Performance: The Gratz Building Case Study, New York City," December 2010, last accessed March 2012 at http://www.nyseda.ny.gov/~media/Files/Publications/Research/Other%20Technical%20Reports/09-05-gratz-green-roof.ashx?sc_database=web.
- clviii The City of New York, "Cool Roofs: How Cool Roofs Work," last accessed March 2012 at <http://www.nyc.gov/html/coolroofs/html/how/how.shtml>.
- clix U.S. Department of Energy, "Guide to Cool Roofs," last accessed March 2012 at http://www.energysavers.gov/pdfs/guide_to_cool_roofs.pdf.
- clx "DDC Cool and Green Roofing Manual," p29.
- clxi The City of New York, "Cool Roofs: How Cool Roofs Work."
- clxii U.S. Environmental Protection Agency, "Reducing Urban Heat Islands: Compendium of Strategies – Green Roofs," p12.
- clxiii The City of New York, "Cool Roofs: How Cool Roofs Work: FAQs," last accessed March 2012 at <http://www.nyc.gov/html/coolroofs/html/about/faq.shtml>.
- clxiv New York City Department of Design and Construction, "DDC Cool & Green Roofing Manual," June 2007, accessed January 2012 at http://www.nyc.gov/html/ddc/downloads/pdf/cool_green_roof_man.pdf
- clxv US Department of Energy, "Roof Savings Calculator," accessed December 2011 at <http://www.roofcalc.com/>
- clxvi U.S. Department of Energy, "Energy Savers: Furnaces and Boilers," accessed February 2012 at http://www.energysavers.gov/your_home/space_heating_cooling/index.cfm/mytopic=12530.
- clxvii U.S. Department of Energy, "Energy Savers: Gas-Fired Boilers and Furnaces," accessed February 2012, at http://www.energysavers.gov/your_home/space_heating_cooling/index.cfm/mytopic=12550.
- clxviii U.S. Department of Energy, "Energy Savers: Furnaces and Boilers."
- clxix U.S. Department of Energy, "Energy Savers: Gas-Fired Boilers and Furnaces."
- clxx U.S. Department of Energy, "Boilers: Energy Star," accessed February 2012 at http://www.energystar.gov/index.cfm?fuseaction=find_a_product.showProductGroup&pgw_code=BO.
- clxxi The City of New York, Department of Buildings, "Microturbines," last accessed March 2012 at <http://www.nyc.gov/html/dob/html/sustainability/microturbine.shtml>.
- clxxii New York City Department of Buildings, "Installing Natural Gas-fueled Combined Heat and Power (CHP) Systems," December 2010, accessed at http://www.nyc.gov/html/dob/downloads/pdf/combined_heat_and_power_systems.pdf.
- clxxiii New York State Energy Research and Development Authority, "Microturbine/CHP Demonstration," last accessed March 2012 at <http://www.nyseda.ny.gov/en/Page-Sections/Research-and-Development/Microturbine-CHP-Project.aspx>.