Tall Building Deep Retrofits: Are We Making the Progress Needed, Or That We Think We Are?

Byron Stigge, Level Infrastructure
Richard Yancey, Building Energy Exchange
Adam Hinge, Sustainable Energy Partnerships

ABSTRACT

The path to zero-carbon is clear for new buildings and single-family homes, but tall existing buildings remain stubbornly difficult to retrofit cost-effectively. Tall buildings, particularly in northern regions, struggle with technical and economic hurdles such as high winter morning peak demands and relatively cheap natural gas prices. Many tall existing building retrofit projects are announced with dramatic predicted energy savings and carbon reduction, but there is less evidence about how these projects are performing post-retrofit, both on the energy/carbon performance and the capital cost of the retrofit and building operating cost reduction.

This paper presents energy performance data from energy retrofits in high-rise office and multifamily buildings based on results from a wide-ranging survey of tall existing building retrofits in northern climate cities over the past four years. The results include 32 buildings from 6 countries with metered pre- and post-retrofit whole building energy consumption data. Pre- and post- retrofit energy use intensity (EUI), greenhouse gas emissions intensity (GHGI), and percent savings is presented for all retrofit projects. The survey found that getting deep reductions, particularly in tall multifamily buildings is a real challenge, mostly because of challenging project economics to meet owner capital return requirements. A technical solutions summary captures the trends and the most common strategies for decarbonizing existing buildings. Finally, an analysis of what drives these decarbonization retrofits provides an interesting summary of the various retrofit motivations, approaches, and triggers.

Introduction

Cities around the US have been adopting ambitious policies to reduce energy use and resulting carbon emissions from buildings, both for new construction and the large stock of existing buildings. These policies are yielding significant results, driving new construction designs to all electric buildings and retrofits of smaller existing buildings. Achieving dramatic reductions from tall existing buildings remains a challenge, particularly in northern US cities where winters are quite cold and the existing buildings have heating systems designed around steam or high temperature hot water heating distribution. In these cases, retrofitting more advanced heating distribution can require giving up precious space in existing spaces and be prohibitively expensive.

New York City (NYC) has both some of the most ambitious climate policies aimed toward existing buildings, but also a lot of tall, older buildings that are extremely challenging to easily retrofit to low carbon solutions. Tall buildings dominate NYC's iconic skyline. NYC has both the largest stock of office space in the US and a wide mix of tall multifamily residential buildings. While many of these buildings were built in the first half of the 20th century before attention was paid to energy efficiency, there are also hundreds of newer high-rise residential towers throughout the city.

Both NYC and New York State (NYS) have ambitious climate policies, the most significant being adopted in 2019. NYC's Climate Mobilization Act (Local Law 97 of 2019, or LL97) set long term carbon intensity limits for all buildings over 25,000 square feet (SF) that ratchet down over time. LL97 was one of the first of a growing number of Building Performance Standards established in cities and states to drive regular, incremental performance improvement over time in existing buildings. The first LL97 compliance period began in 2024 having limits that impacted less than a quarter of existing buildings. Limits reduce significantly for the second compliance period (2030-2034), requiring most buildings to reduce emissions. There are some buildings that may need to cut emissions by more than half relative to what they emitted in 2018.

A few months after passage of NYC's Climate Mobilization Act, the NYS Legislature passed the Climate Leadership and Community Protection Act (CLCPA) that established targets for a 100% renewable electric grid by 2040 and 40% statewide emissions reductions by 2030. This promise for a low carbon electricity grid sent the signal for large buildings in NYC to move away from fossil fuels and towards electric sources for heating and hot water as a principal way to reduce carbon emissions to comply with LL97.

Building owners impacted by NYC LL97 expressed concerns about finding cost-effective solution sets for tall buildings that would need to meet extremely ambitious GHG intensity targets starting in 2030. They questioned whether there were case studies of high-rise buildings, with measured performance data, showing how NYC could achieve the targets. NYS launched a process to develop a Carbon Neutral Buildings Roadmap that identified very tall buildings as "difficult-to-electrify buildings" (NYSERDA 2022). To attempt to answer these questions, a wide-ranging survey of tall existing building retrofits in northern climates has been conducted.

Methodology and Process

The project team put out requests to dozens of experts seeking deep retrofit case studies of buildings over 15 stories, with the requirement that any case study must include both pre- and post-retrofit whole building measured performance. Buildings could be from geographically diverse locations but must have a climate comparable to that of NYC. The authors sought buildings that had measured savings of at least 20%, but ideally with savings greater than 30%.

The team initially sought case studies for any type of tall building, but after reviewing available data on the projects that met our criteria, decided to initially focus on tall office buildings. Data collection for the office buildings began in 2019, and results for tall office deep retrofits were published in 2020 (BE-Ex 2020). Because the largest portion of buildings that would be impacted by LL97 are large multifamily buildings, a second, more challenging search began for deep multifamily retrofits in 2023. Again, we reached out to dozens of experts around the world.

For all of the case studies profiled, the authors collected measured post-retrofit energy consumption by fuel source that allowed the GHG intensity of the building to be calculated (in all cases using NYC emissions conversion factors as prescribed in LL97 rules, as this project intended to show the feasibility of meeting LL97 limits).

18 Office Deep Retrofit Profiles

In 2020 the research team endeavored to identify buildings which had completed a retrofit and could demonstrate 20% Site EUI savings based on metered data. The search included the team's contacts from around the world and included over 100 individuals, organizations, and publications. The search extended over 6 months and resulted in 18 projects which fit the criteria outlined above.

Office Retrofits: Characteristics of Buildings Selected

The selected buildings cover a wide range of size, location, ownership, and retrofit approach, demonstrating there are many ways to deliver deep energy retrofits, and all types of office buildings can qualify.

Three projects in international locations demonstrated a different approach and cultural norms than typical practices in the US. Many more deep energy retrofits were identified in international locations, but obtaining whole building energy data for both pre- and post-retrofit conditions proved very challenging due to privacy laws in Europe and Australia. Eight projects from around the US, but in a similar climate zone to New York, expanded the breadth of retrofit approaches and technologies for office buildings. And seven tall buildings in New York City showed the strategies for deep retrofits applied regionally and were relevant to local energy and carbon reduction which were the target for this research.

Half of the projects (9 of 18) were classified as a 'Repositioning' or 'Major Tenant Turnover' meaning a significant amount of renovation work was happening to the building and the energy efficiency investments were integral to the work or a minor portion of the total project budget. The other half were classified as 'Incremental' projects which upgraded boilers, windows, radiator valves, insulation, or other singular components when those components reached the end of their useful life. Three of the Incremental projects were investments with the sole purpose of energy efficiency and had investment paybacks justified by reduced energy costs.

Table 1. Office Retrofits: Buildings Selected for Profiles

#	Building Name	Location	Floors (#)	Area (SF)	Occupancy Type	Year(s) Renovated	Retrofit Approach
1	United Nations HQ	New York, NY	39	805,000	Owner-occupied	2008 – 2015	Repositioning
2	Byron Rogers Federal Bldg.	Denver, CO	18	494,000	Owner-occupied	2012 – 2014	Repositioning
3	1177 West Hastings Street	Vancouver, BC	26	307,000	Multi-tenant	2007 – present	Tenant Turnover, Incremental
4	Kyoto Station	Kyoto, Japan	15	2,520,000	Multi-tenant	2016	Energy Only Retrofit
5	560 Lexington	New York, NY	23	329,000	Multi-tenant	2010 – present	Incremental Improvements
6	Five Manhattan West	New York, NY	15	1,700,000	Multi-tenant	2015 – 2017	Repositioning
7	NEC Headquarters	Tokyo, Japan	43	1,560,000	Owner-occupied	2010 – present	Incremental Improvements
8	District Center	Washington, DC	12	908,000	Multi-tenant	2017 – 2018	Repositioning

9	Millennium Building	Washington, DC	12	240,000	Multi-tenant	2012 – present	Incremental Improvements
10	Empire State Building	New York, NY	102	2,850,000	Multi-tenant	2010 – present	Repositioning, Tenant Turnover
11	222 South Riverside Plaza	Chicago, IL	35	1,237,000	Multi-tenant	2012, 2015 – 2018	Repositioning
12	One Battery Park Plaza	New York, NY	35	860,000	Multi-tenant	2010 – present	Incremental Improvements
13	125 Maiden Lane	New York, NY	17	316,000	Multi-tenant	2011 – 2014	Energy Only Retrofit
14	1001 Penn-sylvania Ave	Washington, DC	14	836,000	Multi-tenant	2010 – present	Energy Only, Incremental
15	Sun Life Assurance	Chicago, IL	10	140,000	Multi-tenant	2010 – 2012	Major Tenant Turnover
16	801 Grand	Des Moines, IA	44	920,000	50% /50% Owner/Tenant	2013 – 2016	Major Tenant Turnover
17	Transport for London (TfL) Palestra Bldg.	London, UK	12	404,000	Single-tenant	2010 – present	Tenant Turnover, Incremental
18	330 West 34th Street	New York, NY	18	720,000	Multi-tenant	2016	Repositioning, Tenant Turn.

A summary of the 18 retrofit projects with pre-retrofit and post-retrofit data demonstrating at least a 20% Site EUI reduction. *Source*: BE-Ex 2020.

Office Retrofits: Metered Energy Savings Data

Whole building, Site EUI savings ranged from 17% to 56% in the set of selected buildings. The highest percentage savings came from buildings with higher pre-retrofit EUI in the upper end of the 100-200 kBtu/sf range. The 330 W 34th St building with only 17% savings was included in the profile set even though it did not reach the 20% savings threshold because it demonstrated significant savings on an already low EUI building (48 kBtu/sf to 40 kBtu/sf).

Post-retrofit GHGI (as calculated using NYC LL97 carbon factors) ranged from 3.1 kg CO_2/sf to 8.6 kg CO_2/sf. For reference, NYC LL97 GHGI limits for office buildings are 4.5 kg CO_2/sf from 2024-2029 and 2.7 kg CO_2/sf from 2030-2034. This means all but one project would be in compliance with LL97 until 2029 and none of the projects, after the deep energy retrofit with energy savings from 17%-56%, would be in compliance in 2030 and beyond.

Table 2. 18 Office Retrofits – Pre & Post Retrofit Site Energy Use Intensity (EUI) and Post-Retrofit Greenhouse Gas Emissions Intensity (GHGI)

#	Building Name	Site EUI (kBtu/sf)			GHGI* [kg CO2/sf]
		pre-retrofit	post-retrofit	% reduction	
1	United Nations Headquarters	213	93	56%	6.1
2	Byron Rogers Federal Building	94	42	55%	3.4
3	1177 West Hastings Street	162	80	50%	5.7
4	Kyoto Station Mixed Use	222	119	46%	8.6
5	560 Lexington Avenue	90	52	45%	3.9
6	Five Manhattan West	73	42	42%	3.1
7	NEC Headquarters	94	57	40%	4.1
8	District Center	60	38	36%	3.2

9	Millennium Building	73	47	36%	3.9
10	Empire State Building	122	79	35%	5.5
11	222 South Riverside Plaza	116	76	35%	5.6
12	One Battery Park Plaza	145	99	33%	6.4
13	125 Maiden Lane	76	52	31%	4
14	1001 Pennsylvania Avenue	71	50	29%	4.2
15	Sun Life Assurance	113	81	28%	6.1
16	801 Grand	96	70	27%	5.8
17	TfL Palestra Building	147	113	23%	7.2
18	330 West 34th Street	48	40	17%	3.3

*GHGI calculated for all buildings using the 2024-2029 GHG emissions conversion coefficients for all energy sources including electricity and district thermal energy specified in LL97 for New York City – therefore, not representative of actual GHGI for any buildings located outside New York City

Office Retrofits: Case Study Profile Example

Selected projects received a one-page spread showing all of the research data and retrofit aspects in a clear and concise way as shown in Figure 1 below. The left side of the spread states the facts and figures of the building characteristics such as size, location, ownership, occupancy. The right side of the spread lists the energy efficiency measures deployed on the project categorized by system type.

Key aspects of retrofit data collected turned out to be 'Retrofit Approach' and 'Retrofit Motivation'. These became important as interviews were conducted and themes began to emerge. Retrofit Approach came out of the attempt to group projects and find common themes. Some projects were typical energy efficiency projects with the sole purpose of reducing energy consumption, energy cost, GHG emissions, or some combination of the three. These were characterized as 'Energy Only' projects. Other projects evolved over many years or even decades as individual pieces of equipment or building components failed or reached the end of their useful life. These were characterized as 'Incremental' projects. Some deep retrofits were a component of a larger project like a major repositioning, major tenant turnover, or a gut renovation and were characterized as 'Repositioning'.

When design teams and owners were asked 'why did you do this project?' a wide variety of answers emerged. Most of the Energy Only retrofit approach projects did the project with the primary purpose of reducing energy use and energy cost.

Seeing the wide variety of retrofit approaches and retrofit motivations was revealing to the research team as they broke down conventional thinking about energy retrofits. Often when an 'energy efficiency retrofit' project is considered in the abstract it is thought of as an Energy Only project and with the primary motivation of Energy Savings. In reality Energy Only projects account for a minority of deep energy retrofits in this research survey. More often energy efficiency retrofits are delivered at major investment milestones in the life of a building when tenants, systems, owners or even the physical structure of the building changes. Coupling energy efficiency with other major non-energy related investments can make more financial, logistical, and operational sense.

A written description of the project background, design process, and notable aspects of energy savings followed. To the extent possible any economic information obtained was also included in the write-up as some profiles utilized incentives, low-interest financing, or had notably high or low energy costs. Each project had unique lessons learned which provided some of the most meaningful insights of the research. For example, the NEC HQ building in Tokyo maintained a running list of potential EEMs for over a decade implementing a few EEMs each year and adding new EEM possibilities each year as technologies and economics evolved over time. Five Manhattan West was an obsolete office building acquired by a large property owner in New York City. The repositioning of the asset centered on 'creating value' which included many aspects of interior design, overall aesthetics, occupant comfort, energy efficiency, controllability, health, and branding.

6.
Five Manhattan West

Retrofit Approach

- Repositioning
- Major tenant turnover
- Energy-only retrofit
- Incremental improvements

Retrofit Motivation

- ESG commitments
- Energy cost savings
- Property value enhancement
- Compliance or penalty avoidance

Key Figures

Pre-Retrofit Site EUI 73 kBtu/sf
Post-Retrofit Site EUI 42 kBtu/sf
% Energy Reduction 42%

Post-Retrofit GHGI 3.1 kg CO_2/sf
(using NYC LL97 factors)

Location
New York, New York

Owner
Brookfield Properties

Floor area
1,700,000 sf

Number of stories
15

Year built
1968

Year renovated
2015 – 2017

Occupancy
Multi-tenant

Retrofit Background

In 2011, Brookfield acquired this property with the strategy to give it a high-profile, wide-ranging retrofit. In 2017, Brookfield completed a comprehensive $350 million redevelopment program which included a recladding of the exterior curtain wall with insulated, low-iron, low-emissivity floor-to-ceiling glass, along with a full lobby renovation, elevator modernization and robust new infrastructure.

Description of Retrofit

The single-most notable ECM at this building was the façade reclad / new curtain wall with insulated, low-iron, low-emissivity floor-to-ceiling glass. However, all mechanical systems were replaced or refurbished as well, including the cooling tower. All equipment was fitted with variable frequency drives and hooked up to a new BMS. All new lighting was installed in public areas of the building, and all new tenant spaces resulted in new lighting throughout the entire building.

Power over Ethernet (PoE) lighting was installed in a few places, but there were two main challenges with this approach — first, generally engineers aren't very fluid with the technology, and second, laborers prefer not to do this low-voltage work.

Metered Energy Savings and Other Benefits

Over the course of the renovation and re-occupancy the building went from an EUI around 70 kBtu/sf to 42 kBtu/sf, a savings of 43% over the 3-4 year period.

Economic Considerations

The overall renovation of the building was aimed at repositioning the property and energy efficiency was a subcomponent to the broad package of building modernization. Thus separating out the costs for energy efficiency was not a useful exercise. The façade reclad, a major cost of the renovation, was primarily done to provide better light and views for potential tenants, though it also offered improved comfort and energy savings. Other ECMs were packaged with the major HVAC system replacement and delivered much of the energy savings.

Key Lessons Learned

When thinking about a major repositioning project to create value in commercial real estate assets, energy efficiency should be part of the overall value proposition along with aesthetics, occupant comfort, controllability, health, and branding.

22 High Rise / Low Carbon

A complete facade reclad and mechanical system upgrades comprehensively repositioned this building creating enhanced property value, higher asset value, and substantial energy savings.

Site EUI
kBtu/sf
energy source
electric
steam
42%
Energy Reduction
73
42
2013
2017

GHGI (using NYC LL97 factors)
kg CO_2/sf
3.1
4.5
NYC LL97 2030 Limit
2017

Energy Conservation Measures Overview

lighting
All new code compliant lighting

cooling
Cooling tower replacement
New DX units throughout property

heating
Perimeter Fin Tube, Steam to Hot Water Exchangers & Fan Steam Coil

ventilation
Direct Exchange Package Unit

envelope
Facade complete recladding

plug loads

hot water
Local electric hot water heaters
Retail steam hot water heaters

other
BMS installed on majority of equipment
Regenerative Drives on Modernized Elevators

High Rise / Low Carbon 23

Figure 1. Sample of an office retrofit profile spread containing building data, project description, metered energy data, project photos, and EEMs implemented. Source: BE-Ex 2020.

Office Retrofits: Technology Solutions Summary

The energy efficiency measures utilized in the selected office retrofit projects are summarized in Table 3 below showing the variety of EEMs implemented across all projects, to glean trends from the overall data set. 17 of the 18 projects utilized a lighting retrofit and all 18 optimized a component of the office building's cooling systems. Considering lighting and cooling represent the largest energy consumption end-uses in office buildings, this trend represented the best opportunity for energy efficiency in office building retrofits. Beyond lighting and cooling the other end uses of heating, ventilation, envelope, plug loads, and hot water were utilized as unique aspects arose in each building. Fewer overall trends were identified for these end uses and these end uses did not represent a majority of energy savings for the retrofits.

Table 3. Technical Solutions Matrix - Summary of EEMs deployed in selected tall office building retrofits

System	ECM Description	1. United Nations HQ	2. Byron Rogers Federal	3. 1177 West Hastings	4. Kyoto Station	5. 560 Lexington Avenue	6. Five Manhattan West	7. NEC Headquarters	8. District Center	9. Millennium Building	10. Empire State Bldg	11. 220 South Riverside	12. One Battery Park	13. 125 Maiden Lane	14. 1001 Pennsylvania Ave	15. Sun Life Assurance	16. 801 Grand	17. TfL Palestra Bldg	18. 330 West 34th Street
Lighting	Reduced lighting power density	●	●	●	●	●	●	●	●	●	●	●	●		●	●	●		●
	Daylight sensors and controls	●	●	●		●			●		●							●	
	Occupancy sensors	●	●	●				●							●				●
	Reduced lighting schedules			●				●									●		
Cooling	Cooling plant replacement upgrade	●	●	●	●	●	●	●		●	●				●	●		●	●
	VFDs on motors: pumps, fans, etc.		●	●	●	●	●					●	●	●	●	●	●		
	Reduced schedules, setpoint temps			●				●		●			●						
	Other innovative cooling ECMs	●	●		●			●		●		●			●	●		●	
Heating	Boiler plant replacement or upgrade		●	●	●			●						●		●		●	
	Distribution system improvements			●			●	●		●	●	●				●			
Ventilation	AHU replacement or upgrade						●			●	●	●		●		●	●		
	Demand control ventilation	●			●					●	●				●	●			
	Outside air economizer		●	●													●	●	●
Envelope	Façade reclad, window replacement	●	●				●				●		●		●				●
	Air tightness improvements			●													●		
	Additional insulation		●	●							●				●	●			
Plug Loads	Energy Star appliances, computers										●								●
	Cloud-based computing (no servers)			●															●
	Other plug load ECMs			●					●	●									
Hot Water	Hot water heater replacement		●		●													●	
	Electrify hot water generation			●			●									●			●
	Other hot water ECMs									●	●								
Other	Upgraded or new BMS and controls	●	●	●	●	●	●		●	●	●	●	●	●	●	●		●	
	Regenerative drive elevators		●	●		●	●					●	●		●				●
	On-site renewables		●		●														
	Other ECMs			●	●			●		●	●							●	

14 Multifamily Deep Retrofit Profiles

In 2023 the authors shifted focus from office building retrofits to multifamily residential buildings. Again, the search was for tall buildings in a climate similar to New York City which had completed a retrofit and could demonstrate 20% Site EUI savings based on metered data. The search included the team's contacts from around the world and included over 100 individuals, organizations, and publications. The search extended over 9 months and resulted in only 14 projects which fit the criteria outlined in the methodology section above.

Multifamily Retrofits: Characteristics of Buildings Selected

The selected buildings cover a wide range of size, location, ownership, affordability mix, and retrofit approach demonstrating there are many ways to deliver deep energy retrofits and all types of multifamily buildings are candidates for deep retrofits.

Once again 5 of the 14 projects were identified in international locations and demonstrated a slightly different approach to retrofitting residential towers than typical practices in the US. As with the office retrofit research, many more deep energy retrofit projects were identified in international locations, but obtaining whole building energy data proved very challenging due to privacy laws in Europe and Australia particularly for the residential sector. 3 of the 14 projects were located around the US, but in a similar climate zone to New York. The remaining 6 tall residential buildings in New York City showcased strategies for deep retrofits in the target area.

The aspect of affordable housing, or buildings with some units receiving some type of subsidy for income restricted tenants, turned out to be a key aspect in this sector. Surprisingly only 3 buildings were completely market rate, while 7 were completely 'affordable', and the remaining 4 had a mix of market rate and income restricted units. Most of the buildings with affordable units received funding, grants, or significant financial incentives for the capital costs for retrofits. The market rate buildings in this compendium financed the investments through private capital sources with minimal public incentives or funding.

More projects (9 of 14) were classified as a 'Major Renovation' meaning a significant amount of renovation work was happening to the building and the energy efficiency investments were integral to the work or a minor portion of the total project budget. The other 5 were classified as 'Incremental' or 'System Replacement' projects which upgraded boilers, windows, radiator valves, insulation, or other singular components when those components reached the end of their useful life.

Table 4. Multifamily Retrofits: Buildings Selected for Profiles

#	Building Name	Location	Floors (#)	Units	Ownership	Affordability	Retrofit Approach
1	Ken Soble Tower	Hamilton, ON	17	146	Rental	Affordable	Major Renovation
2	French Apartments	Manhattan, NY	13	174	Rental	Affordable	Major Renovation
3	Int'l Tailoring Bldg	Manhattan, NY	13	173	Coop	Market Rate	System Replacement
4	Wilmcote House	Portsmouth, UK	11	111	Rental	Affordable	Major Renovation
5	Valla Torg	Stockholm, SWE	14	302	Rental	Affordable	Major Renovation
6	172 E 4th St	Manhattan, NY	12	102	Coop	Market Rate	Incremental
7	Rivermark Apts	Cambridge, MA	20	300	Rental	70% Afford	Major Renovation
8	340 On The Park	Chicago, IL	64	343	Condo	Market Rate	Incremental
9	Putnam Square	Cambridge, MA	13	94	Rental	Affordable	Major Renovation

10	Polyclinic Apts	Manhattan, NY	10	151	Rental	Affordable	Major Renovation
11	Gateway Plaza	Manhattan, NY	34	1,700	Rental	15% Afford	Incremental
12	Moulins de la Pte	Paris, FRA	14	41	Condo	Affordable	Major Renovation
13	Roosevelt Landing	Rosevelt Isl, NY	20	1,003	Rental	25% Afford	Major Renovation
14	Bellmont Towers	Vancouver, BC	13	37	Condo	Market Rate	System Replacement

A summary of the 14 multifamily residential retrofit projects with pre-retrofit and post-retrofit data demonstrating at least a 20% Site EUI reduction. *Source*: BE-Ex 2024.

Multifamily Retrofits: Metered Energy Savings Data

Whole building, Site EUI savings ranged from 17% to 66% in the set of selected residential buildings. The highest percentage savings came from buildings with higher pre-retrofit EUI in the upper end of the 100-130 kBtu/sf range. The Roosevelt Landing and Belmont Towers buildings with only 17% savings were included in the profile set even though they did not reach the 20% savings threshold because they demonstrated unique technical or implementation approaches, namely a cogeneration plant, and an envelope-only retrofit.

Post-retrofit GHGI (as calculated using NYC LL97 carbon factors as discussed earlier) ranged from 0.6 kg CO2/sf to 5.0 kg CO2/sf. For reference, NYC LL97 GHGI limits for multifamily buildings are 6.8 kg CO2/sf from 2024-2029 and 3.3 kg CO2/sf from 2030-2034. This means all buildings would be in compliance with NYC LL97 until 2029 and all but one of the projects would be very close to the 2030-2034 limits after a deep energy retrofit.

Table 5. Multifamily Retrofits – Pre & Post Retrofit Site Energy Use Intensity (EUI) and Post-Retrofit Greenhouse Gas Emissions Intensity (GHGI)

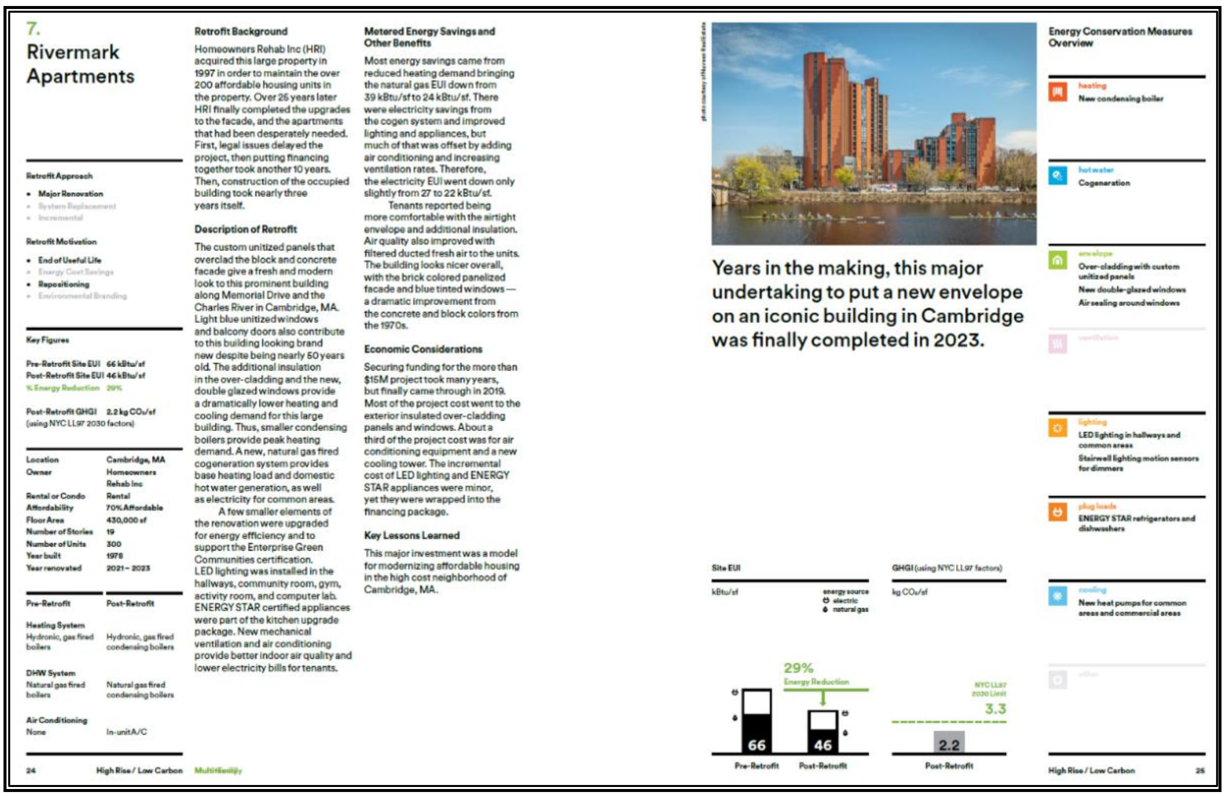
#	Building Name	Site EUI (kBtu/sf)			GHGI* [kg CO2/sf]
		pre-retrofit	**post-retrofit**	**% reduction**	
1	Ken Soble Tower	100	34	66%	1.5
2	French Apartments	131	60	54%	3.5
3	Int'l Tailoring Bldg	96	51	47%	2.4
4	Wilmcote House	30	19	37%	0.8
5	Valla Torg	63	40	37%	1.9
6	172 E 4th St	62	42	32%	2.1
7	Rivermark Apts	66	46	30%	2.2
8	340 On The Park	81	58	28%	2.5
9	Putnam Square	100	73	27%	3.7
10	Polyclinic Apts	125	98	22%	5.0
11	Gateway Plaza	58	46	21%	2.1
12	Moulins de la Pte	78	63	19%	3.0
13	Roosevelt Landing	98	81	17%	3.6
14	Bellmont Towers	71	59	17%	2.8

*GHGI calculated for all buildings using the 2030-2034 GHG emissions conversion coefficients for all energy sources including electricity and district thermal energy specified in LL97 for New York City – therefore, not representative of actual GHGI for any buildings located outside New York City.

Multifamily Retrofits: Case Study Profile Example

Similar to the Office Retrofit Profiles, each selected multifamily project received a one-page spread showing all of the research data and retrofit aspects in a clear and concise way. Multifamily residential projects had similar categories of 'Retrofit Approach' including Major Renovation, System Replacement, and Incremental. 'Retrofit Motivation' for the residential projects was most commonly End of Useful Life as many 40- to 60-year old residential buildings have boilers, radiators, windows, and lights that have not been replaced since they were built. 4 projects underwent a Repositioning which motivated a variety of building-wide improvements including energy system, envelope, lobby, and apartment unit upgrades (Valla Torg, Rivermark Apartments, Putnam Square, Belmont Towers). About half of the projects stated part of their motivation was to reduce energy costs.

Three projects were classic 'Incremental' projects which slowly improved building systems for over a decade or more (172 4th St., 340 on the Park, Gateway Plaza). These projects strategically invested in building systems at point of system failure such as serious boiler issues, or chronically leaky windows. Projects were financed out of capital reserves which had been built up for just such an occasion.



7.
Rivermark Apartments

Retrofit Approach
- Major Renovation
- System Replacement
- Incremental

Retrofit Motivation
- End of Useful Life
- Energy Cost Savings
- Repositioning
- Environmental Branding

Key Figures

Pre-Retrofit Site EUI 66 kBtu/sf
Post-Retrofit Site EUI 46 kBtu/sf
% Energy Reduction 29%

Post-Retrofit GHGI 2.2 kg CO_2/sf
(using NYC LL97 2030 factors)

Location	Cambridge, MA
Owner	Homeowners Rehab Inc
Rental or Condo	Rental
Affordability	70% Affordable
Floor Area	430,000 sf
Number of Stories	19
Number of Units	300
Year built	1978
Year renovated	2021 – 2023

	Pre-Retrofit	Post-Retrofit
Heating System	Hydronic, gas fired boilers	Hydronic, gas fired condensing boilers
DHW System	Natural gas fired boilers	Natural gas fired condensing boilers
Air Conditioning	None	In-unit A/C

24 High Rise / Low Carbon Multifamily

Retrofit Background

Homeowners Rehab Inc (HRI) acquired this large property in 1997 in order to maintain the over 200 affordable housing units in the property. Over 25 years later HRI finally completed the upgrades to the facade, and the apartments that had been desperately needed. First, legal issues delayed the project, then putting financing together took another 10 years. Then, construction of the occupied building took nearly three years itself.

Description of Retrofit

The custom unitized panels that overclad the block and concrete facade give a fresh and modern look to this prominent building along Memorial Drive and the Charles River in Cambridge, MA. Light blue unitized windows and balcony doors also contribute to this building looking brand new despite being nearly 50 years old. The additional insulation in the over-cladding and the new, double glazed windows provide a dramatically lower heating and cooling demand for this large building. Thus, smaller condensing boilers provide peak heating demand. A new, natural gas fired cogeneration system provides base heating load and domestic hot water generation, as well as electricity for common areas.

A few smaller elements of the renovation were upgraded for energy efficiency and to support the Enterprise Green Communities certification. LED lighting was installed in the hallways, community room, gym, activity room, and computer lab. ENERGY STAR certified appliances were part of the kitchen upgrade package. New mechanical ventilation and air conditioning provide better indoor air quality and lower electricity bills for tenants.

Metered Energy Savings and Other Benefits

Most energy savings came from reduced heating demand bringing the natural gas EUI down from 39 kBtu/sf to 24 kBtu/sf. There were electricity savings from the cogen system and improved lighting and appliances, but much of that was offset by adding air conditioning and increasing ventilation rates. Therefore, the electricity EUI went down only slightly from 27 to 22 kBtu/sf.

Tenants reported being more comfortable with the airtight envelope and additional insulation. Air quality also improved with filtered ducted fresh air to the units. The building looks nicer overall, with the brick colored panelized facade and blue tinted windows — a dramatic improvement from the concrete and block colors from the 1970s.

Economic Considerations

Securing funding for the more than $15M project took many years, but finally came through in 2019. Most of the project cost went to the exterior insulated over-cladding panels and windows. About a third of the project cost was for air conditioning equipment and a new cooling tower. The incremental cost of LED lighting and ENERGY STAR appliances were minor, yet they were wrapped into the financing package.

Key Lessons Learned

This major investment was a model for modernizing affordable housing in the high cost neighborhood of Cambridge, MA.

Years in the making, this major undertaking to put a new envelope on an iconic building in Cambridge was finally completed in 2023.

Site EUI
kBtu/sf
energy source
electric
natural gas
29% Energy Reduction
66 Pre-Retrofit
46 Post-Retrofit

GHGI (using NYC LL97 factors)
kg CO_2/sf
NYC LL97 2030 Limit 3.3
2.2 Post-Retrofit

Energy Conservation Measures Overview

heating
New condensing boiler

hot water
Cogeneration

envelope
Over-cladding with custom unitized panels
New double-glazed windows
Air sealing around windows

ventilation

lighting
LED lighting in hallways and common areas
Stairwell lighting motion sensors for dimmers

plug loads
ENERGY STAR refrigerators and dishwashers

cooling
New heat pumps for common areas and commercial areas

other

High Rise / Low Carbon 25

Figure 2. Sample of a multifamily retrofit profile spread containing building data, project description, metered energy data, project photos, and EEMs implemented. *Source*: BE-Ex 2024.

Multifamily Retrofits: Technology Solutions Summary

The energy efficiency measures utilized in the selected multifamily retrofit projects are summarized in Table 6 below to see the variety of EEMs implemented across all projects and to glean trends from the overall data set. Ten of the 14 projects replaced or significantly upgraded central boiler plant equipment and these EEMs contributed the bulk of the energy savings in their respective retrofit projects. Also common were hot water boiler replacements or hot water distribution efficiencies. As expected, envelope work was involved in all but three projects as the aging residential building stock represented in this compendium was due for significant window repair or replacement, and air sealing. Beyond heating, hot water, and envelope the other end uses of cooling, lighting, and plug loads were utilized as unique aspects arose in each building. Lighting improvements were common, but not significant in overall EUI savings contributions.

Table 6. Technical Solutions Matrix - Summary of EEMs deployed in selected tall multifamily building retrofits

System	**ECM Description**	**1. Ken Soble Tower**	**2. French Apartments**	**3. Int'l Tailoring Bldg**	**4. Wilmcote House**	**5. Valla Torg**	**6. 172 E 4th St**	**7. Rivermark Apts**	**8. 340 On The Park**	**9. Putnam Square**	**10. Polyclinic Apts**	**11. Gateway Plaza**	**12. Moulins de la Pte**	**13. Roosevelt Landing**	**14. Bellmont Towers**
Heating	Boiler replacement		●	●			●	●		●					
	Boiler control improvements		●							●	●		●		
	Steam riser balancing or TRVs		●							●	●		●		
	Electrification of space heating	●		●	●							●			
Hot Water	Hot water boiler replacement	●	●	●	●							●		●	
	High efficiency water fixtures		●								●			●	
	DHW distribution improvements	●	●		●	●					●	●	●		
	Air source heat pump for DHW			●		●						●			
Envelope	Window replacement	●			●	●	●	●		●		●	●		●
	Air sealing around windows	●	●		●	●	●	●		●		●	●	●	●
	Over-cladding or exterior insulation	●			●	●		●					●	●	●
	Add'l thermal barrier on interior		●			●									
Ventilation	Air sealing ductwork		●				●				●	●			
	Heat recovery on exhaust air ERVs	●		●	●	●							●		
	Reduced night ventilation schedule		●						●		●		●	●	
	Motion sensors on toilet exhaust		●												
Lighting	LED lamps in common areas	●	●		●	●	●	●	●	●	●	●		●	
	Motion sensors / smart lighting	●						●							
Plug Loads	ENERGY STAR appliances	●						●		●					
	Gas to electric cooking	●													
	Heat pump dryers	●													
Cooling	Building-wide central chillers			●					●						
	VRF air conditioning common areas	●	●					●		●					
	Ceiling fans	●													
Other	Photovoltaics on rooftop					●									
	Instant DHW or Cogen for DHW							●	●						
	EV charging stations								●						

Findings

Office

The authors identified several common motivational factors amongst the case study projects. These included key opportunities that can trigger a retrofit project; opportunities to efficiently expand a project's scope; and the important role of tenant space operation to a building's overall GHG emissions.

The first major finding was that building-wide renovations provide a unique opportunity for deep energy savings. Energy efficiency can be a strategic addition to major renovation projects, providing some of the deepest savings while significantly contributing to the overall property value creation. The deepest savings found were in retrofits that were aligned with planned major capital investments, such as the replacement of primary system equipment at the end of useful life, or holistic building renovations. Owners reported that the energy efficiency improvements positively impacted prospective tenants' perception of a building's quality, thus significantly contributing to attracting desirable tenants. Most of these major renovation type projects did not separate the costs (and overheads) for necessary capital investments versus energy efficiency measures (Byron Rogers, Five Manhattan West, Empire State Building).

Secondly, office tenant spaces present strategic and essential savings opportunities. Tenant vacancy, turnover, or repositioning tends to be a time of reinvestment, and substantial energy savings can be found in addressing tenant spaces which are a key component of a carbon mitigation plan. Office tenant equipment and behavior drive many buildings' energy consuming systems, but finding a time to implement deep energy savings while tenants are occupying a space is the major challenge. 4 projects in this compendium, Sun Life Assurance, 125 Maiden Lane, Kyoto Station, and 222 South Riverside, did complete retrofits while tenants remained in place, but the energy savings opportunities were limited and implementation was significantly more challenging on these projects. Retrofit projects where tenants remain in their spaces have the advantage of utilizing existing monthly energy consumption data, interval data, peak demand data, or other uniquely useful information to aid retrofit design optimization, such as calibrating energy models, right-sizing equipment, and much more. Measured performance is hard to find, but vitally important to verify results: 'If you don't measure it, you can't manage it and you can't fix it.'

Real-time energy management systems (R-TEMS) were another common finding in office retrofits. Building operating engineers were able to identify patterns of inefficiencies and opportunities for savings in their building systems themselves without major capital investment or engineering designers' involvement. Continual tweaking of lighting, cooling, and ventilation systems, with the help of constant feedback from an EMS, over time, resulted in appreciable energy savings at the Millennium Building, TfL Palestra, and 1001 Pennsylvania for example.

For more conventional retrofit projects the authors found a comprehensive design and planning process to be a necessary component of creating a retrofit project that actually achieves predicted results at predicted costs. The design process for most deep energy retrofits in this compendium included energy modelling, multiple rounds of cost-benefit analysis, coordination with contractors, and tenant engagement that took longer and cost more than a simple, code compliant, business-as-usual design approach. Owners and designers of deep energy retrofits continually impressed the importance of setting out adequate time and budget for the design team to study options and design creative, yet practical, solutions.

Although there are 18 buildings in this compendium that range in location, height, technical solutions, occupancy type, implementation approach, EUI, GHGI, and other factors, the search process to find these sites was extensive. The authors were surprised with the challenge to identify even 18 case studies of high-rise office buildings with metered energy data both before and after a retrofit that resulted in more than 25% energy savings. Benchmarking laws (including public disclosure) were critical to providing pre- and post-retrofit metered energy consumption data. Despite many press announcements and articles for tall building retrofits projecting deep savings, it was hard to verify actual savings after implementation. There are likely more effective deep retrofit projects in Europe, however whole-building energy data was hard to find due to a variety of factors including limited collection of tenant energy use by owners, privacy laws and norms, and other factors. Plenty of low rise (4-8 stories) examples in more mild climates with low EUI, low GHGI, publicly available metered data, and deep savings over 25% are available. A compendium of this typology could be large and wide-ranging.

Multifamily

It was even more difficult to find tall residential buildings that had completed a deep retrofit than it was to find office building retrofits. The authors reached out to dozens of industry leaders, researched over 60 potential case studies for nearly a year, but found most typical retrofits showed less than 20% savings or were low-rise residential.

Nevertheless, general trends for the sector did emerge. Older, tall residential buildings tend to have simple heating and ventilation systems with limited controls making fine tuning and optimization difficult. Renovating occupied residential buildings adds significant complexity. Condo and Coop Boards tend not to be building industry professionals. Residential building owners and managers have a limited ability to afford professional consultants which is at odds with the buildings' more complex decision-making process. Major owners reported that achieving more than 20% in savings was unusual.

Similar to office buildings, most residential retrofits were not part of a long-term capital plan, rather they were a reaction to building systems at the end of useful life requiring immediate or urgent attention. A common retrofit approach was for a building to undergo major changes such as a gut renovation, window replacements, or building HVAC systems replacements during a repositioning and major re-investment project. Other deep retrofits occurred over many years when systems failed or imminently required replacement. In both approaches there was a consistent lack of planning for long term decarbonization or capital investment.

Deep retrofits tend to be invasive and require major system replacements which is very challenging to do in an occupied building. 9 of the 14 projects were 'Major Renovations' in which tenants moved out or the building turned over completely. The 5 'Incremental' or 'System Replacement' projects showed it is much easier to renovate an empty building or back of house base building systems.

Residential deep retrofits completed prior to 2023 were mostly boiler replacements and facade improvements. New high efficiency boilers, air sealing, and high-performance windows were the big impact measures for most of the case studies in this report. The fact that there were only 2 partial electrification projects in this compendium showed electrification is in an early stage in the residential retrofit sector. That said, the authors identified many electrification conversions in design and construction indicating a similar report undertaken a few years from now may well produce significantly different results.

Electrification is key to deep decarbonization, but the economics of electrification need to evolve before we see conversions at scale. The low cost of natural gas and the high cost of electricity in most large cities makes the economics of electrification of space heating and hot water very challenging. Currently the cost of installing heat pumps in occupied apartments is much higher than replacing an existing gas fired boiler. Although boilers require periodic replacement, steam radiators and hydronic heating distribution systems do not have an 'end of useful life', or a natural point where a capital investment could be supplemented making a pathway to a conversion.

Issues Common to Both Office and Multifamily Projects

It was extremely challenging to find projects with measured pre- and post-retrofit whole building measured energy performance. Outside of the US, whole building measured performance in larger, multi-tenant buildings is generally not available due to data privacy laws that prevent building owners from being able to access tenant energy consumption.

We found that an important driver for availability of energy data was in US cities that have benchmarking and transparency laws, where annual whole building energy consumption needs to be publicly reported. The cities with these policies provided the best source of projects with comprehensive, longitudinal energy performance for both office and multifamily projects.

The authors were surprised at how difficult it was to find deep retrofit case study projects with measured whole building energy performance. There were hundreds of case studies throughout the literature touting dramatic projected energy savings from deep retrofits, but very few projects where principals involved with the projects could provide measured savings along with details of the completed retrofit.

Verified post-retrofit data is scarce. Validated, metered, whole-building energy data is what makes this compendium unique, but proved to be one of the biggest challenges in finding case studies. Lack of data collection, and data inconsistencies persist. The cost and effort required to gather, validate, and analyze whole building energy use for residential buildings is expensive and few owners can justify the cost. Outside of the US/North America, whole building energy data including tenant usage is very hard to get, often due to privacy laws.

Differences between the Two Building Typologies

The typical fuel mix for energy use in tall office and multifamily buildings in heating climates is very different, particularly for NYC where a significant portion of the building stock was built prior to the 1960s. In general, the majority (often around 70%) of multifamily building energy use is fossil (natural gas or oil) for space and water heating loads, with a smaller percentage electricity consumption for appliances, plug loads and air-conditioning.

Office building energy use is quite different, with air conditioning and other electrical equipment loads dominating energy use. With significant internal loads and gains from occupants, there is much lower space heating load, and generally very low domestic hot water use. As a result, the fuel mix is reversed, with most office buildings having only 30-40% (or less) fossil fuel use.

With CLCPA's requirement to convert the electric grid to renewable energy, resulting in lower emissions per kWh consumed by 2030 and beyond, office buildings do not need to reduce as much as residential buildings, where the fossil fuel use GHG intensity is not getting smaller over time.

While it was relatively easy to compile 18 office retrofit profiles with at least 20% energy reduction (with most complying, or near compliance post retrofit, with the LL97 2030 limit) we were quite surprised how difficult it was to find that number of case studies in the multifamily sector. While we would regularly hear from several experts about a given project having deep savings, after repeated prodding of those experts they could not provide post-retrofit energy data, or in many cases the measured data did not result in the expected savings.

In discussions with major multifamily portfolio owners (including some of the most environmentally aware owners) about deep retrofits, they remarked that getting to 30% reduction in a large building is extremely challenging, and that even 20% energy reduction can be difficult. One driver of more shallow retrofits of multifamily buildings is that these buildings rarely empty out, with only a couple of apartment units vacant at any given time. As most existing buildings rely on a central boiler or legacy heating and water heating system that serves all tenants, it is extremely difficult to do any major system replacement that may involve changing or modifying heating distribution systems within tenant spaces.

In addition, tenants make nearly all decisions about energy use within their apartment unit without any control by the owner, so there are not many opportunities to reduce tenant loads. As a result, multifamily retrofits generally only do relatively minor improvements to existing systems.

For office buildings, we were frustrated by the lack of transparency by a few single tenant buildings that had done high profile retrofits promising an open process of information sharing including websites dedicated to documenting the retrofit, but then were not willing to share post-retrofit measured performance. This is likely due to the performance gap between predicted and actual performance but does not help in understanding how high profile retrofits are really performing.

Conclusion

As cities and States across the country, and around the globe, adopt and begin to implement aggressive building performance standards (BPS) a new approach to designing, retrofitting and operating buildings –especially existing buildings– must emerge. With their dominant use of onsite fossil fuel for heating and hot water, reducing emissions is especially challenging for tall residential buildings in cold climates.

The focus of BPS's, such as NYC's LL97, on carbon intensity has shifted the motivation of building owners and the energy professional that serve them from an emphasis on energy cost reduction with a fast payback or relatively high rate of return, to looking at longer term carbon reductions that, in many cases, are not cost effective unless done as part of a longer term decarbonization plan that takes into account the end of life of major energy using systems, as well as other "building life-cycle events," such as change of major tenants in an office building, or re-positioning of an office or multifamily building.

While the authors found more examples of fuel-switching from fossil to electric systems in office buildings, in surveying experts in 2023 and 2024 we only found two multifamily electrification projects that had a year of post-retrofit energy use. With laws in place like LL97 that are sending policy signals for big carbon reductions by 2030, that is changing, and we expect to see many more case studies of electrification retrofits that are currently in construction.

The reality of current energy prices, however, is that it is extremely difficult to make a business case for converting an existing large multifamily building with steam or high-temperature hot water distribution to an electric heat pump solution – the capital cost can be extremely high and often result in higher operating cost to the owner and or tenant. In addition, electrifying existing multifamily buildings usually results in shifting heating and hot water energy costs from the owner to the tenants; this is a major policy barrier for most affordable housing.

A critical factor in developing a comprehensive decarbonization plan is to strategically align the technical solutions with the asset plan, optimizing packages of retrofit measures and interventions over time to best align with the building's financial and business plan as well as its existing conditions. This retrofit approach, called Strategic Decarbonization Planning (SDP), has been successfully developed in tall building deep retrofit pilots supported by NYSERDA's Empire Building Challenge. These case studies, as well as many related resources, have been gathered on Retrofitplaybook.org. SDP is also centered in a new guide, jointly developed by ASHRAE, USGBC, and NYSERDA.

However, it is important to recognize that a building's optimized roadmap to zero emissions may not align with a given BPS's compliance cycles. For example, a strict adherence to meet the stipulated reductions every five years may force improvements that are not optimally sequenced for maximum carbon reduction at minimum cost. Therefore, as BPS policies continue to evolve, it is important to consider alternative compliance pathways (ACP) that still can achieve policy goals, while allowing for the economic and technical realities found in this report. ACP's can still require the implementation of a long-term plan to reduce or eliminate carbon emission over time but also allow for one that is correctly tailored to a specific building's needs, even if out of sync with some BPS GHG limitation schedules.

Successful implementation of BPS policies, like LL97, will require a new "business as usual" in the real estate sector. A paradigm shift toward strategic planning promises to provide a key tool to realizing a viable path to net zero carbon for existing buildings. However, this market transformation will require a commensurate expansion of support and resources, both technical and financial, to help building stakeholders create flexible long-term plans that are responsive to their building's existing technical and financial conditions. This knowledge gap, and subsequent need, is especially acute in existing multifamily buildings, particularly cooperatives and condominiums, which typically have less sophisticated management.

References

Building Energy Exchange (BE-Ex) 2020. High Rise | Low Carbon: Office Deep Retrofit Profiles. Building Energy Exchange, Level Agency for Infrastructure, and Sustainable Energy Partnerships. August 2020. https://be-exchange.org/wp-content/uploads/2020/10/beex_highrise_lowcarbonreport_102920rt.pdf

Building Energy Exchange (BE-Ex) 2024. High Rise | Low Carbon: Multifamily Deep Retrofit Profiles. Building Energy Exchange, Level Agency for Infrastructure, and Sustainable Energy Partnerships. October 2024. https://be-exchange.org/wp-content/uploads/2024/10/beex_HRLCmultifamily_report_1024hmupdates.pdf

New York State Energy Research & Development Authority (NYSERDA) 2022. The Future of Buildings: New York's Carbon Neutral Buildings Roadmap. December 2022. https://www.nyserda.ny.gov/-/media/Project/Nyserda/Files/Programs/Carbon-Neutral-Buildings/carbon-neutral-buildings-roadmap.pdf