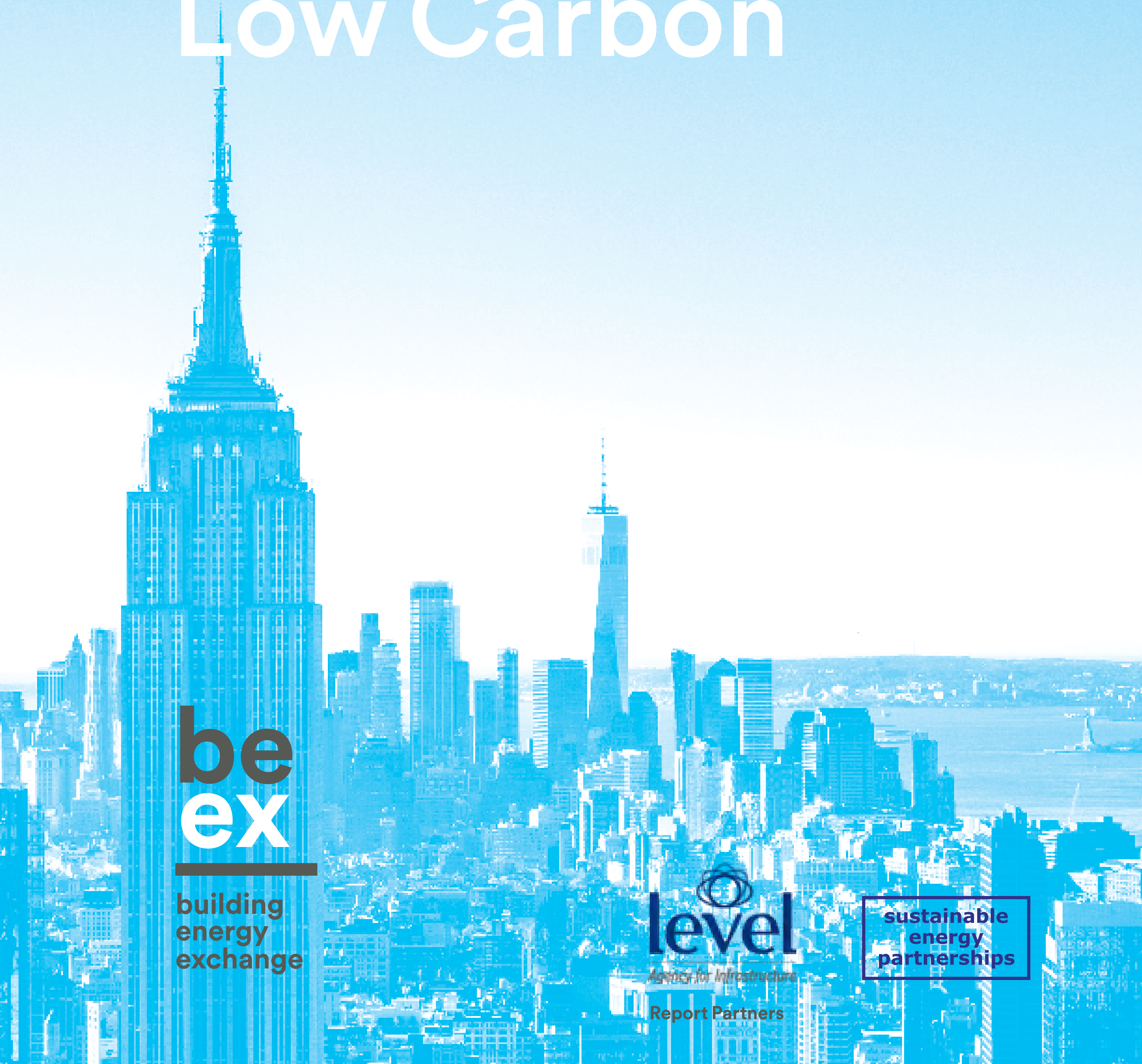
report summary

Office Deep Retrofit Profiles

High Rise / Low Carbon



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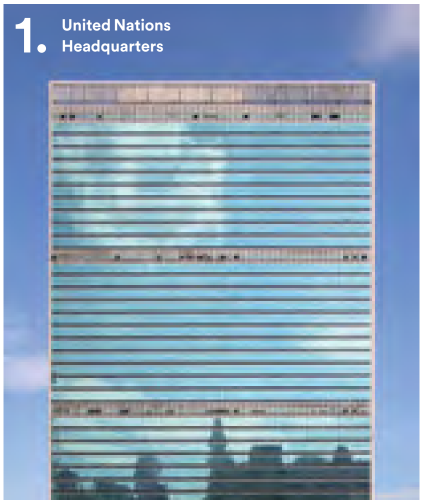
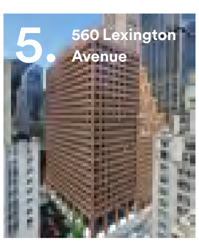

1. United Nations Headquarters


2. Byron Rogers Federal Building


3. 1177 West Hastings Street


4. Kyoto Station Mixed Use


5. 560 Lexington Avenue


6. Five Manhattan West

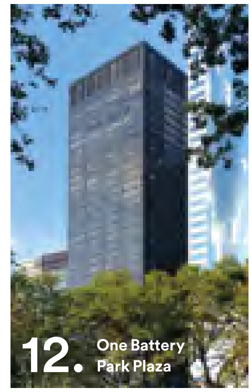

7. NEC Headquarters


8. District Center


9. Millennium Building

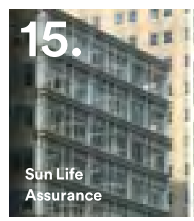

10. Empire State Building

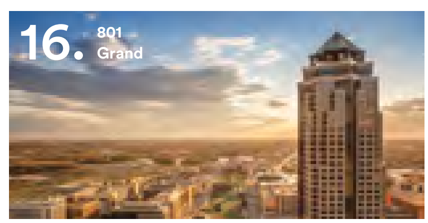

11. 222 South Riverside Plaza

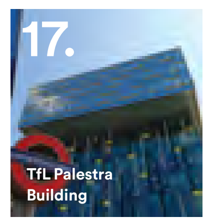

12. One Battery Park Plaza

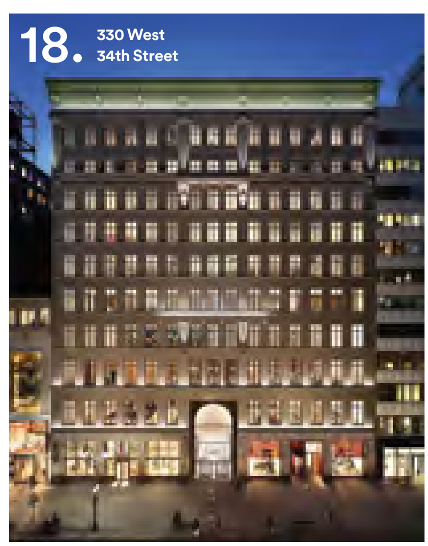

13. 125 Maiden Lane


14. 1001 Pennsylvania Avenue


15. Sun Life Assurance


16. 801 Grand


17. TfL Palestra Building


18. 330 West 34th Street

contents

This is an abbreviated version of a full length report, which can be found on the report project page: https://be-exchange.org/report/hi-rise-low-carbon/

Faded sections have been omitted from this abridged version.

executive summary

New York's iconic skyline is dominated by commercial high-rise office buildings. One of the engines of its economy and the home to many of the world's leading corporate headquarters, these buildings are a foundational part of New York City's identity.

These same skyscrapers also have a fundamental role in achieving our City and State's climate action goals. This survey provides a diverse set of relevant deep energy retrofit case studies, from around the globe, which demonstrate how high-rise office buildings can achieve low carbon emission targets.

With the passage of the Climate Mobilization Act's (CMA) Local Law 97 (LL97), in April, 2019, the City's groundbreaking legislation to curb carbon emissions, many questions have arisen about the ability to transform New York's existing skyline into high performing buildings with dramatically lower carbon emissions — especially our high-rise office buildings. This research team conducted a global search for deep energy retrofits of high-rise office buildings that achieved LL97's aggressive carbon emission limits, and asked, what can we learn from them? The compendium explores key questions, including: what energy savings are achievable; what buildings systems were upgraded; what technology was deployed; what were the obstacles and opportunities; what factors motivated the project; and what are the key lessons learned?

This study's benchmark was to find deep retrofit projects of existing high-rise office buildings that resulted in annual operational carbon emissions at or below the LL97's 2030 carbon caps.[0]
To provide the most relevant examples, the authors chose to limit the examples to projects in a climate

Key Findings

- **Major building-wide renovation projects provide an effective vehicle for deep energy savings**
  Energy efficiency can be a strategic addition to major renovation projects, providing for some of the deepest savings while also significantly contributing to the overall property value creation.

- **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 — a key component of a carbon mitigation plan.
  Tenant in place energy efficiency retrofits can be challenging, but highly effective.

- **Planning and analysis are foundational to a cost-effective deep retrofit**
  A comprehensive design and planning process is a necessary component of creating an effective deep retrofit that achieves predicted results at effective costs.

- **Only measured performance confers successful retrofit savings**
  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.'

- **Changing context: The look forward may be different than the look back**
  Carbon will become a new performance metric, influencing ROI economics, technology choices, and retrofit project motivations, costs and benefits.

zone similar to New York, and, most importantly, only to include projects that had measured and verifiable pre- and post-retrofit energy data. This last requirement often proved the most challenging.

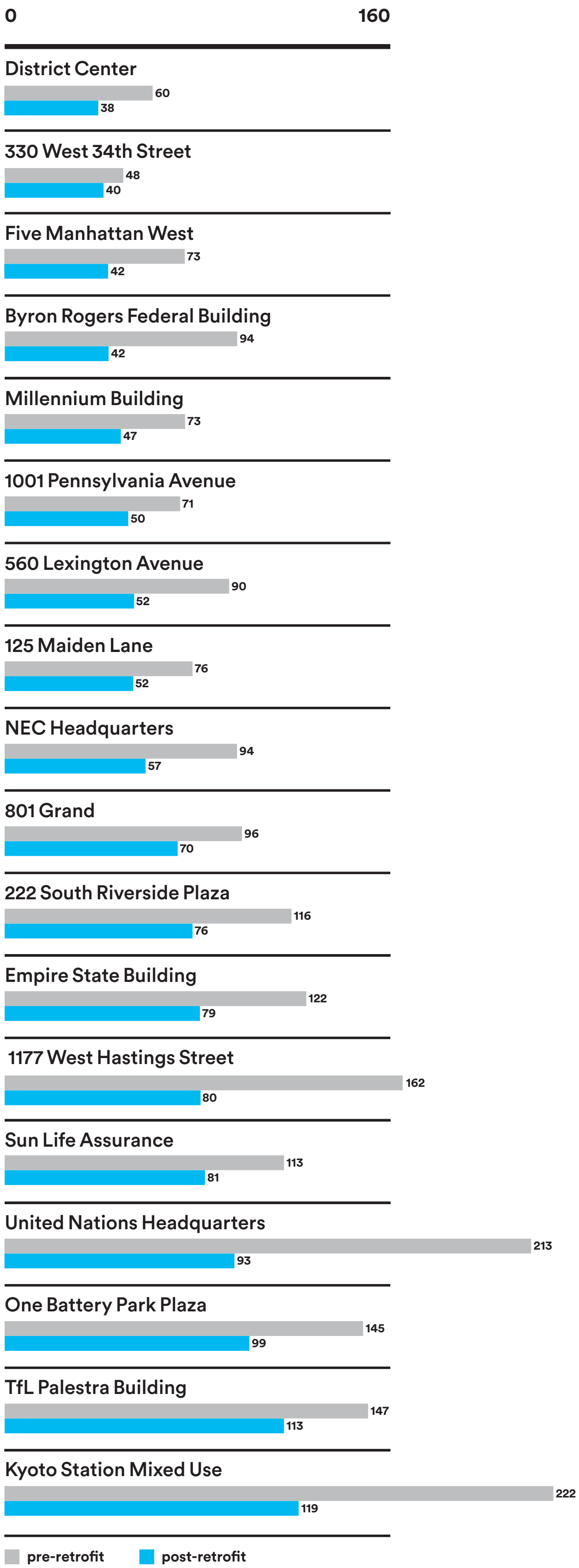
Nonetheless, this survey profiles eighteen projects that undertook a deep retrofit that resulted in often dramatic energy reduction. A complete facade reclad, a Midtown tenant repositioning, a Chicago upgrade and densification, a midwestern energy model calibration, a Japanese climate policy demonstration project, the comprehensive repositioning of NYC's most iconic tower, and many more, this diverse set of retrofit projects was able to achieve an average of a 36% reduction in their site energy intensity, with several projects cutting their energy use in half. Additionally, it is worth noting that all these projects occurred prior to, and, therefore, in the absence of, the recent aggressive climate legislation, demonstrating that low carbon high-rise office retrofits are, indeed, possible.

These profiles represent a variety of building sizes, typologies, ages, and ownership structures. Some projects were complete 'gut renovations' of empty buildings, others were incremental upgrades while the building's tenants remained in place. As detailed in the report's Technical Solutions Matrix, almost all the projects included energy efficiency upgrades to their lighting systems and controls, both favored and cost effective retrofit savings opportunities; and most

Site EUI [kBtu/sf]

Post-Retrofit EUI Low to High

The bar graphs below show pre- and post-retrofit metered Site EUI for each building, ordered by lowest to highest post-retrofit Site EUI.

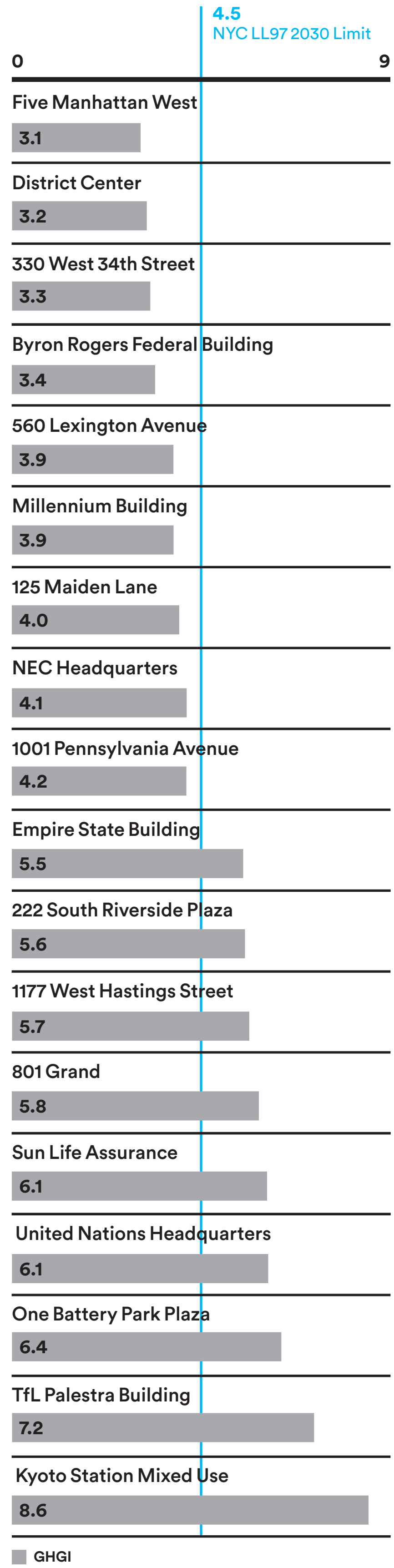


found significant carbon reductions from recommissioning, upgrading, or completely replacing their cooling systems. Each retrofit had various motivating factors, noted in the Summary List of Building Profiles, including complete repositioning of the property, to strategic upgrades during tenant turnover or equipment end-of-life. Whether driven by a corporate Environmental, Social, and Governance (ESG) commitment, reduced operating costs, or to attract new tenants with increased comfort and quality, all the projects included a planned, intentional, and tactical deployment of energy efficiency, suffused throughout the project.

As the urgency of the global climate crisis mounts, many jurisdictions are looking to New York City's LL97 and New York State's Climate Leadership and Community Preservation Act for precedent. These aggressive laws steer a pathway to a carbon neutral economy and building sector by mid-century, and it is imperative that they succeed. This survey provides several glimmers, clues, and concrete models as to how New York's commercial high-rise office buildings can appreciably contribute to achieving these essential climate goals.

Post-Retrofit GHGI [kg CO_2/sf]
(using NYC LL97 factors)
Low to High

The bar graphs below show post-retrofit GHGI, ordered from lowest to highest.



0 For buildings outside of NYC, the authors estimated the project's CO_2 emissions using LL97's stated carbon coefficients for the 2030 target year.

key findings

Major building-wide renovation projects provide an effective vehicle for deep energy savings

Energy efficiency can be a strategic addition to major renovation projects, providing for some of the deepest savings while also 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.
- Projects did not separate the costs (and overheads) for necessary capital investments versus energy efficiency measures (Byron Rogers, Five Manhattan West, Empire State Building).*
- A few case studies did set aside an incremental budget for 'beyond compliance' measures, where benefits outweigh costs.
- There is potential for façade replacement, during full renovation and repositioning, that makes financial sense.

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 — a key component of a carbon mitigation plan.

- Tenant equipment and behavior drives many building energy consuming systems
    - Lighting retrofits were present in nearly every case study and are more often selected and controlled by tenants
    - After-hour demands for HVAC systems
    - Occupant density
    - Cloud computing vs. on-site data centers
    - Computers, appliances, other plug loads 'unregulated' by energy code, but can be significant contributors to EUI and GHGI
- That said, the timing of this research occurred during the COVID-19 pandemic and many owners reported large office buildings without a significant drop in energy use despite being mostly unoccupied. This observation needs further study and has not yet been fully researched.
- Lease covenants, though, can reduce some tenant energy savings potential as some leases require HVAC schedules, temperature setpoints, fresh air delivery, and other factors that dictate energy consumption, regardless of actual use or occupancy.

Tenant-in-place energy efficiency retrofits can be challenging, but highly effective.

- If tenants remain in place during an energy retrofit and the building must continue to function, then energy savings opportunities are limited and significantly more challenging, yet still possible, as seen in Sun Life Assurance, 125 Maiden Lane, and 222 South Riverside.*
- By installing and monitoring real-time energy management systems (EMS), building engineers were able to identify patterns of inefficiencies and operational stray in their building systems. Continual tweaking of these systems, with the help of constant feedback from EMS, over time, resulted in appreciable energy savings at the Millennium Building, TfL Palestra, and 1001 Pennsylvania.*

* see full report

Planning and analysis are foundational to a cost-effective deep retrofit

A comprehensive design and planning process is a necessary component of creating an effective deep retrofit that achieves predicted results at effective 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.
- 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 (801 Grand, Kyoto Station, 222 South Riverside).*
- Importance of maintenance and follow through — retro-commissioning, and continuous system optimization after ECM implementation.

Only measured performance confers successful retrofit savings

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.'

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 went far and wide to identify even this many 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) are critical to understanding actual post-retrofit performance
- 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%. A compendium of this typology could be large and wide-ranging
- Measured performance will be required for owners and operations to understand the potential impacts of LL97, and proactively avoid potential penalties.

Changing context: The look forward may be different than the look back

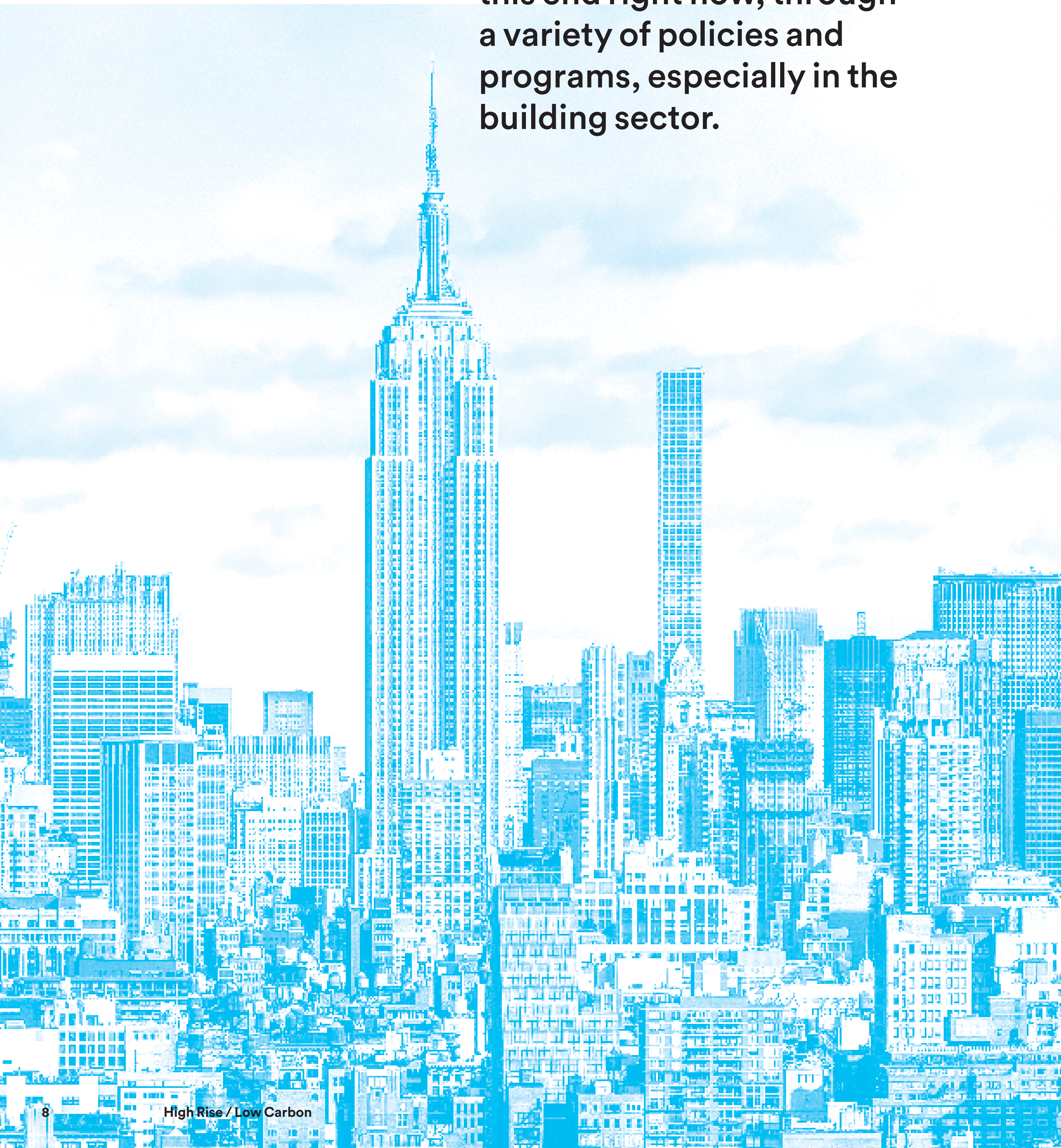
Carbon will become a new performance metric, influencing ROI economics, technology choices, and retrofit project motivations, costs and benefits.

These profiles are all retrofits with lessons learned looking backward. The projects represent technologies, motivations, and market conditions of the last 10 years, while the drivers for change will certainly be different in the upcoming 10 years and beyond. This new context means:

- New regulatory compliance requirements, and the potential impact of monetary fines, could significantly influence behavior, project scopes and even a project's return on investment (ROI).
- The future carbon intensity of the electric grid will influence the choice of building systems, technologies, and source energy.
- The demand for office space in the post-COVID world could shift occupancies, density, and tenant requirements; and pandemic mitigation measures are already influencing major building system modifications, including ventilation, as well as spatial requirements.
- A successful carbon trading option could impact a project's ROI, as well as introduce new incentives for exemplary efficiency projects.
- Other unforeseen changes will continue to change the decision making process of owners and tenants of office buildings.

introduction and background

Mitigating climate change is a priority for New York State, and a tremendous amount of effort is being made to this end right now, through a variety of policies and programs, especially in the building sector.



The State's Reforming the Energy Vision (REV) comprehensive energy strategy helps consumers make more informed energy choices, develops new energy products and services, and protects the environment while creating new jobs and economic opportunity throughout the State. The 2019 Climate Leadership and Community Protection Act (Climate Act, or CLCPA) establishes targets of a 100% renewable electric grid by 2040, a 40% state-wide greenhouse gas (GHG) emissions reduction by 2030, and an 85% state-wide GHG emissions reduction by 2050. The RetrofitNY program was established to mobilize the building industry to innovate and implement energy savings projects. NYSERDA is developing a Carbon Neutral Buildings Roadmap that supports increasing building energy efficiency, decarbonizing onsite energy services, utilizing clean energy from a variety of sources, and supporting real-time response to grid conditions. Finally, the Empire Building Challenge launched in 2020 will demonstrate scalable and replicable low carbon retrofit approaches for high-rise commercial and multifamily buildings across the state.

As the state's and the nation's largest municipality, New York City is also taking bold steps to mitigate climate change and reduce building-sourced GHG emissions. The City's 2009 Greener Greater Buildings Plan (GGBP) included Local Law 84 and Local Law 87, which required building energy benchmarking and building energy audits and retrocommissioning, respectively. Local Law 32, the Energy Stretch Code, mandates aggressive performance targets in the energy code, increasing every few years. And, Local Law 97, of 2019 , the cornerstone of the 2019 Climate Mobilization Act (CMA), sets GHG Intensity (kg CO_2/sf) limits for buildings with non-trivial penalties for non-compliance. The first compliance period of LL97 is from 2024-2029, and the second compliance period is from 2030-2034. Many owners are currently weighing the cost of retrofits versus the cost of penalties, and the technical viability of achieving the mandated deep energy retrofits in LL97 is a concern to many building owners and tenants.

New York City's 2009 Greener Greater Buildings Plan points out that the city's built square footage is highly concentrated in less than two percent of its properties — 15,000 properties over 50,000 square feet, which account for almost half of NYC's built square footage — and that 48% of New York City's total energy use comes from these properties. In order to meet the climate mitigation goals of the State and City, building owners will need to reduce their energy use and carbon emissions, especially high-rise building owners. However, while it has been widely demonstrated that it is possible to achieve very low-emission and even no net-emission, smaller buildings, in high-rise buildings, particularly in regions like that of New York, with cold winters and high heating demand, there is less experience and knowledge of achieving very low-emission large buildings.

A fair question is raised then, which is, just how feasible are deep energy retrofits of large commercial buildings? There is skepticism as to whether, specifically, the level of Greenhouse Gas Intensity (GHGI) reductions mandated by LL97 can feasibly be achieved for all buildings which are currently over the limits. High-rise commercial buildings have unique physical and economic constraints, and most existing tall, commercial buildings are currently well over the LL97 GHGI limit set for 2030. There are many well-known case studies showing the projected energy-use savings of high-rise buildings — for instance, case studies of projected savings for the Empire State Building, the UN Secretariat Building, and the Deutsche Bank Headquarters towers in Frankfurt, Germany — but even the industry casts doubt on the accuracy of modeled energy use predication — see *The World's Greenest Buildings: Promise Versus Performance in Sustainable Design* by Yudelson and Meyer, and Sidewalk Lab's *Energy Use and the Performance Gap* report.

It was somewhat discouraging to learn how difficult it was to find post-retrofit energy (or carbon) performance on high-rise building retrofits. There have been many announcements about deep retrofit projects, but we were disappointed to learn that very few of these had measured performance data publicly available to be included in this compendium.

Despite significant outreach to a variety of experts around the world, we found that the most reliable post-retrofit, whole-building energy data came from U.S. cities with mandatory building energy benchmarking with public disclosure. A number of good candidate projects were identified by experts in Europe, but owners either did not have, or were not willing to share, post-retrofit performance data. One issue is privacy; with stricter privacy protections in Europe, owners often do not have access to tenant energy consumption.

This report aims to provide a compendium that documents the proven capability of the market to deliver energy and carbon savings via high-rise commercial building retrofits. We document 18 case studies of deep energy retrofits of high-rise office buildings with metered pre- and post-retrofit energy data, presenting common technical solutions among these building retrofits.

summary list of building profiles

	Building	Location	# of Stories	Floor Area (sf)	Occupancy Type
1.	United Nations Headquarters	New York, NY	39	805,000	Owner-occupied
2.	Byron Rogers Federal Building	Denver, CO	18	494,000	Owner-occupied
3.	1177 West Hastings Street	Vancouver, BC	26	307,000	Multi-tenant
4.	Kyoto Station Mixed Use	Kyoto, Japan	15	2,520,000	Multi-tenant
5.	560 Lexington Avenue	New York, NY	23	329,000	Multi-tenant
6.	Five Manhattan West	New York, NY	15	1,700,000	Multi-tenant
7.	NEC Headquarters	Tokyo, Japan	43	1,560,000	Owner-occupied
8.	District Center	Washington, DC	12	908,000	Multi-tenant
9.	Millennium Building	Washington, DC	12	240,000	Multi-tenant
10.	Empire State Building	New York, NY	102	2,850,000	Multi-tenant
11.	222 South Riverside Plaza	Chicago, IL	35	1,237,000	Multi-tenant
12.	One Battery Park Plaza	New York, NY	35	860,000	Multi-tenant
13.	125 Maiden Lane	New York, NY	17	316,000	Multi-tenant
14.	1001 Pennsylvania Avenue	Washington, DC	14	836,000	Multi-tenant
15.	Sun Life Assurance	Chicago, IL	10	140,000	Multi-tenant
16.	801 Grand	Des Moines, IA	44	920,000	50% Owner 50% Tenant
17.	TfL Palestra Building	London, UK	12	404,000	Single-tenant
18.	330 West 34th Street	New York, NY	18	720,000	Multi-tenant

Year(s) Renovated	Retrofit Approach	Site EUI (kBtu/sf)			GHGI using NYC LL97 factors [kg CO_2/sf]
		pre-retrofit	post-retrofit	% reduction	
2008 – 2015	Repositioning	213	93	56%	6.1
2012 – 2014	Repositioning	94	42	55%	3.4
2007 – present	Tenant Turnover, Incremental	162	80	50%	5.7
2016	Energy Only Retrofit	222	119	46%	8.6
2010 – present	Incremental Improvements	90	52	45%	3.9
2015 – 2017	Repositioning	73	42	42%	3.1
2010 – present	Incremental Improvements	94	57	40%	4.1
2017 – 2018	Repositioning	60	38	36%	3.2
2012 – present	Incremental Improvements	73	47	36%	3.9
2010 – present	Repositioning, Tenant Turnover	122	79	35%	5.5
2012 and 2015 – 2018	Repositioning	116	76	35%	5.6
2010 – present	Incremental Improvements	145	99	33%	6.4
2011 – 2014	Energy Only Retrofit	76	52	31%	4.0
2010 – present	Energy Only, Incremental	71	50	29%	4.2
2010 – 2012	Major Tenant Turnover	113	81	28%	6.1
2013 – 2016	Major Tenant Turnover	96	70	27%	5.8
2010 – present	Tenant Turnover, Incremental	147	113	23%	7.2
2016	Repositioning, Tenant Turnover	48	40	17%	3.3

technical solutions matrix

Category	Solution	1. UN HQ	2. Byron Rogers Federal Building	3. 1177 West Hastings Street	4. Kyoto Station Mixed Use	5. 560 Lexington	6. Five Manhattan West
lighting	Reduced lighting power density	●	●	●	●	●	●
	Daylight sensors and controls	●	●	●	○	●	○
	Occupancy sensors	●	●	●	○	○	○
	Reduced lighting schedules	○	○	●	○	○	○
cooling	Cooling plant replacement or upgrade	●	●	●	●	●	●
	VFDs on motors for pumps, fans, etc.	○	●	●	●	●	●
	Reduced schedules and 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 or window replacement	●	●	○	○	○	●
	Air tightness improvements	○	○	●	○	○	○
	Additional insulation	○	●	●	○	○	○
plug loads	Energy Star appliances, new computers	○	○	○	○	○	○
	Cloud-based computing (no servers)	○	○	●	○	○	○
	Other plug load ECMs	○	○	●	○	○	○
hot water	Hot water heater replacement	○	●	○	●	○	○
	Electrification of hot water generation	○	○	●	○	○	●
	Other hot water ECMs	○	○	○	○	○	○
other	Upgraded or new BMS and controls	●	●	●	●	●	●
	Regenerative drive elevators	○	●	●	○	●	●
	On-site renewables	○	●	○	●	○	○
	Other ECMs	○	○	●	●	○	○

	7. NEC HQ	8. District Center	9. Millennium Building	10. Empire State Building	11. 222 South Riverside Plaza	12. One Battery Park Plaza	13. 125 Maiden Lane	14. 1001 Pennsylvania	15. Sun Life Assurance	16. 801 Grand	17. TfL Palestra Building	18. 330 West 34th Street
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solutions summary

lighting

Reduced lighting power density

Most buildings in this survey included some form of lighting fixtures or lamp replacements which included LED lighting, T5 or T8 lamps, task lighting, or dimmable ballasts. New technologies for lamps and fixtures provide higher efficacy which allows an overall reduction in energy use with better light temperature and increased lumens. New codes limiting lighting power density require many of these lighting ECMs.

- **All new code compliant lighting**
- **Lower lighting power density in tenant spaces**
- **LED lighting upgrades in parking garage, stairwells, and restrooms**
- **Lighting upgrade to T-8. T-5 and LED fixtures on floors with new tenant fit outs**
- **Continuous dimming high-efficiency LED lighting**
- **Task lighting**
- **Base building lighting retrofit with LED bulbs and occupancy sensors**
- **Tenant spaces lighting replaced to meet NYC Energy Efficiency Code**
- **Lighting override controls**

Daylight sensors, dimming, active blinds

This group of ECMs includes a variety of strategies to reduce energy consumption through the harnessing of natural daylight to replace overhead powered lighting including: light shelves, reflective ceilings, daylight sensors, daylight dimming, or daylight switching. Active blinds are included here as some reflect light up to ceilings though some are controlled to reduce solar gain rather than reduce lighting energy.

- **Natural daylighting**
- **Motorized blinds with app control**
- **Daylight dimming, occupancy/ vacancy sensors and controls**
- **Daylight sensors and controls**
- **Active blinds**

Occupancy sensors

Another common lighting ECM included motion sensors to monitor occupancy and switch off lighting in unoccupied spaces. More advanced examples in this compendium included occupancy sensors networked to BMS to directly control overhead lighting, temperature setpoints, and ventilation. Simple examples of occupancy controls were direct switches of lighting in stairwells or parking areas.

- **Occupancy sensors**
- **Occupancy-based lighting controls**
- **Occupancy sensors in stairwells**

Reduced lighting schedules

A couple buildings implemented the no-cost control ECM of simply reducing the number of hours overhead lights were on. This required lighting controlled by a BMS which is more common in large, tall office buildings than other building typologies.

- **Reduced lighting schedules**

cooling

Cooling plant replacement or upgrade

Nearly as frequent as the lighting replacement ECM, most buildings in this survey conducted some type of improvement to primary cooling plant equipment. Examples of cooling plant replacement with new high efficiency equipment included: variable speed screw chillers, turbo chillers with VFDs, or high-efficiency magnetic bearing chiller, heat recovery heat pump, or new DX units. Lower-cost solutions included replacing chilled water and condenser water pumps or replacing cooling towers at the end of their useful life.

- **Chiller plant retrofit**
- **High-efficiency magnetic bearing chiller**
- **New variable speed screw chiller**
- **Chiller upgrade to Turbo Chillers with VFD**
- **Heat Recovery Heat Pump**
- **Well water based water source heat pump**
- **New DX units throughout property**
- **Retro-commissioning of existing absorption chiller**
- **New chilled water and condenser water pumps**
- **Cooling tower replacement**
- **Cooling tower refurbishment**
- **Chilled beams**
- **Air and waterside economizers**
- **Constant volume induction converted to active chilled beams and VAV**

VFDs on motors in AHUs, cooling towers, pumps

Replacing old constant speed motors with variable frequency drive motors and associated controls allows pumps to reduce their electrical draw for non-peak operational conditions and reducing energy consumption. Common motors for VFD replacement included water pump motors, air handling fan motors, chillers, and dx units.

- **VFDs added to chillers and chilled water pumps**
- **Refurbished DX units with new motors and VFD**
- **Replace river water pumps and convert to VFDs**
- **VFD on condenser water**
- **VFDs on air handlers and pumps**

Reduced setpoint temps and schedules

Most tall office buildings have some form of BMS which allows fine-grained control of many setpoints related to cooling energy efficiency. Many of the buildings in this compendium found no-cost energy savings through reducing cooling setpoints and refining operating schedules. A number of owners included overtime charges for HVAC use which discouraged cooling energy consumption. Other control-related cooling

ECMs included increased deadband, adjustments to chilled water supply temperatures, chiller lockout schedule adjustments, and increased outdoor air free cooling.

- **Setpoint temperatures reduced**
- **Increase deadband for VAV units**
- **Adjust free cooling OA and chilled water temperatures**
- **Chiller lockout schedule and settings**

Other innovative cooling ECMs

Cooling systems had the widest variety of innovative and unique energy efficiency solutions that were customized to the specific conditions of the mechanical cooling systems in the buildings in this study. The following ECMs were unique to only one or two buildings so are listed here for brevity: chilled beams, river water heat rejection upgrades, plate-and-frame heat exchanger for free cooling, damper seals on smoke dampers, retro-commissioning of existing absorption chiller, relocate servers to optimal location for cooling, VRF system for lobby and lower level tenants, air and waterside economizers, and VAV terminals to replace constant volume induction units.

- **Pipes for river water heat rejection upgraded**
- **Tenants charged for overtime HVAC use**
- **Damper seals on the smoke evacuation dampers**
- **Relocate servers to optimal location for cooling**
- **VRF system for lobby and lower level tenants**

heating

Boiler plant replacement or upgrade

This ECM included replacement of primary boilers often at the end of their useful life. There were a couple conversions from district steam to natural gas for primary heating source and a couple examples of natural gas fired combined heat and power (CHP) plant installations or improvements. Energy savings were achieved through higher conversion efficiency boilers and improved controls.

- **Boiler replacements with new high efficiency condensing boilers**
- **High-efficiency condensing boilers and thermal storage tank**
- **Replaced old steam-to-water conversion for perimeter heating to new natural gas condensing boilers**
- **Natural gas cogen for hot water**
- **Steam to natural gas boiler conversion**
- **RCx of gas CCHP to optimize use of low temperature hot water**
- **Heat recovery plant utilizing waste heat via chiller heat mode**
- **Air-source heat pumps**

Distribution system improvements

For steam and hot water heating distribution systems this category included insulation of distribution hot water or steam pipes, replacement of valves, and new perimeter units. For air-based heating systems improvements included VFDs on AHUs, increased airflow control through dampers, and insulating ductwork.

- **Steam or hot water distribution pipe insulation**
- **Advanced steam controls and PRV upgrades**
- **New actuators, VFD motors, steam trap replacement**
- **Perimeter Fin Tube, Steam to Hot Water Exchangers & Fan Steam Coil**
- **Upgrade all internal controls to VAV boxes in ceilings throughout each floor**
- **Air ducts insulated**

ventilation

Air handling system replacement or upgrade

A wide variety of energy efficiency measures dealt with air handling equipment. Often AHUs were replaced if older existing equipment was past its useful life. Many ECMs dealt with retrofitting new controls and VFDs on AHU fan motors and often converting constant volume systems to VAV systems. Other central system measures included isolation dampers and conversion to displacement ventilation,

- **New VAV AHUs**
- **Total air distribution system converted to VAV**
- **Displacement ventilation**
- **Air distribution upgrades (overhead, hybrid overhead, perimeter fan coil, and chilled beam)**
- **VFDs on all supply and return/exhaust fans**
- **AHU controls upgraded**
- **VFDs on new air handlers with fan array**
- **AHU VFDs and static pressure reduction**
- **Floor isolation dampers**
- **VFDs set to auto mode and confirm speed settings**

Demand control ventilation

Reducing fresh air demand supply to unoccupied spaces was another common energy conservation measure in the retrofits in this study. This included either an occupancy sensor or CO_2 sensor and controls to reduce outside air supply volumes.

- **Demand control ventilation and CO_2 sensors**
- **Reduced ventilation nights and weekends**
- **Fresh air controls with presence detectors enabling shutdown when areas are unoccupied**
- **Carbon Monoxide control on garage ventilation**

Outside air economizer

Free cooling from 100% outside air or increased supply of outside air during shoulder seasons provided some energy savings, particularly in all-air systems.

- **Dedicated outside air system with heat recovery**
- **Free cooling coils in each DX unit**
- **Plate-and-frame heat exchanger for free cooling**
- **New dampers and controls for air economizers on all AHUs**

envelope

Façade recladding or window replacement

A few buildings in this study undertook a complete facade replacement if the building envelope was past its useful life or significantly out of date. Other more modest approaches included simply replacing windows or a selection of windows with products with higher insulation values, solar performance, and air tightness.

- **Facade complete recladding**
- **High-performance window replacement**
- **Window refurbishment and coatings**
- **Original glazed curtain wall, double-hung windows replaced with high performing, super-insulating windows**
- **Selective replacement of some windows from single-pane to double-pane**

Air tightness improvements

A simple low-cost measure for buildings with older facades was to reduce air leakage through weather stripping, caulking, gaskets, and other retrofit measures that kept windows in place.

- **Weather stripping replaced and new gaskets installed**
- **Passive stack effect mitigation**
- **Façade air tightness caulking for the entire tower**

Additional insulation

On complete facade recladding or roof replacement projects, a low-cost ECM was to increase insulation on exterior walls and roof surfaces. This included bringing insulation values up to code or even beyond code.

- **Super-insulated walls and roof with continuous air barrier**
- **Radiative barrier**
- **Additional insulation on exterior walls**
- **Additional insulation on roof and below grade level**

plug loads

Energy Star appliances

Some owners and tenants initiated policies or lease clauses requiring Energy Star appliances or appliances that comply with NYC Energy Efficiency Code.

- **New Energy Star appliances**
- **Appliances and plug loads in tenant spaces compliant with NYC Energy Efficiency Code**

No data servers in building

A major energy user within tenant spaces has been data servers and increased computation needs over the past decades. But with the rise of cloud computing and remote servers, that energy consumption has been moved to remote locations outside the footprint of some buildings in this study.

- **No data servers in building — all cloud computing**
- **Cloud computing to limit data center space and energy use**
- **Majority of tenant servers moved to the cloud**

Other plug load ECMs

Other creative approaches to reducing energy consumption from plug loads included monitoring systems, plug load reduction studies, design guidelines for plug loads, and Green Leadership programs.

- **Plug load reduction study and advanced power strips installed on select tenant floors**
- **Remote, app-driven control for tenants**
- **High Performance Design Guidelines require efficient controlled tenant equipment**
- **Green Leadership team partners with tenant services team to purchase from SMART suppliers that provide Energy Star appliances and computers for new tenants and for existing tenants on replacement cycles**

hot water

Hot water heater replacement

A few buildings in the study found energy savings through replacement of old, inefficient hot water heaters to new high efficiency condensing boilers. Some fuel switching from district steam to natural gas was also identified, though that may have had more of a positive impact on energy cost than on energy or carbon intensity.

- **High-efficiency condensing boilers**
- **Natural gas cogen for hotel HW**
- **New DHW tanks and heat exchangers to optimize low temp hot water from CCHP**
- **Retail steam hot water heaters**

Electrification of hot water generation

Interestingly a number of buildings elected to shift from central hot water generation and storage to point-of-use hot water heaters. For office buildings with low demand for hot water this reduced heat loss during storage and distribution which can be substantial for high peak, low volume buildings like tall office buildings.

- **New electric domestic hot water tanks**
- **Local electric hot water heaters**
- **Electrical point of use hot water heaters for hand washing and low-flow fixtures**

Other hot water ECMs

Some innovative ideas implemented for hot water generation included condensate heat recovery and hot water heater setpoint temperature schedule optimization.

- **Condensate heat recovery**
- **Adjust schedule on hot water heater that serves bathrooms, fitness center, and kitchens**

other ecms

Upgraded or new control system

Control technologies have advanced so much in the past decades that nearly all buildings in this study found energy savings through installing a completely new building management system or upgrading an existing BMS. With increased controllability energy savings can be achieved through reducing airflows, setpoints, lighting, and other systems during unoccupied or favorable weather conditions.

- **New BMS installed on majority of equipment**
- **Upgrade of existing BMS programming and modernized controls**
- **Conversion of pneumatic controls to DDC**
- **Supervisory Control Management System (SCMS)**
- **Cloud-based building energy management system (EMS), some more advanced than others, with the most advanced offering real-time energy management (RTEM) capabilities**
- **Tenant Energy Management Software and Engagement Program**
- **BAS system upgraded and integrated with ventilation system and river pump system**

Renewable energy

Due to the limited roof space availability only a few of the tall office buildings in this study utilized on-site renewable energy generation technologies such as solar photovoltaic or solar hot water panels.

- **Solar thermal domestic hot water**
- **Rooftop solar PV**
- **Solar hot water for hotel hot water**

Regenerative elevators

Tall buildings' elevator demands inherently add a small percentage of base building energy consumption to all tall buildings compared to low-rise buildings. But regenerative drive motors and destination dispatch can reduce elevator energy consumption at a small premium when elevators are replaced at the end of their useful life or during a building-wide repositioning.

- **Regenerative drives on modernized elevators**
- **Destination-dispatch regenerative drive elevators**

Other ECMs

Some ECMs did not fall into typical categories or were uniquely suited to a single property, but should still be highlighted as potential ECMs. These included: replacement of domestic water pumps, continual audits and optimization of various schedules and controls, green roofs, submetering, and Demand Response Programs.

- **Replaced domestic water pumps**
- **Continual audit of BMS settings to align HVAC schedules with lease requirements**
- **Seasonal audits to adjust BMS setpoints for weather changes**
- **Night Audits to ensure lights are off, sensors are working, equipment is only being used as needed, etc.**
- **Demand Response Program**
- **Roof and ground floor vegetation**
- **Native plant species green roof**
- **Submetering of electrical loads, lighting, plug load, mechanical equipment, and emergency generator**
- **Integration with mobile app and dashboard with occupancy, DLH, and temperature and humidity sensors**

Glossary of Terms and Abbreviations

AHU	Air handling unit
BAS	Building automation system
BMS	Building management system
CAV	Constant air volume
CCHP	Combined cooling, heating, and power system
CHP	Combined heat and power
CO	Carbon monoxide
DCV	Demand control ventilation
DDC	Direct digital control
DHW	Domestic hot water
DX unit	Direct expansion air conditioning unit
ECM	Energy conservation measure
EMS	Energy management system
ERV	Energy recovery ventilation
ESCO	Energy service company
ESG	Environment, social, governance
EUI	Energy use intensity
GHGI	Greenhouse gas intensity
HRV	Heat recovery ventilation
HW	Hot water
LEDs	Light-emitting diode lights
M&V	Measurement & verification
MESA	Managed energy services agreement
OA	Outdoor air
PRV	Pressure reducing valves
RCx	Retrocommissioning
RTEM	Real-time energy management system
SCMS	Supervisory control management system
Solar PV	Solar photovoltaic system
VAV	Variable air volume
VFD	Variable frequency drive

conclusions and path forward

New York City's LL97 sets ambitious GHG emissions targets, and a large number of its high rises are over the limits and will require significant reductions, particularly to reach the 2030 limits. Many questions have arisen about the ability to transform New York's existing skyline into high performing buildings with dramatically lower carbon emissions — especially high-rise office buildings.

This survey profiles a diverse set of eighteen projects that undertook a deep retrofit resulting in significant energy reduction — an average of a 37% reduction in their site energy intensity. Even though the projects occurred prior to recent aggressive City and State climate legislation, these case studies demonstrate that it's possible to implement a deep retrofit that meets or betters the aggressive 2030 emissions limits of LL97, sometimes even by a substantial amount.

As noted earlier, we identified several key findings in this report that bear repeating:

- **Major building-wide renovation projects provide an effective vehicle for deep energy savings**
  Energy efficiency can be a strategic addition to major renovation projects, providing for some of the deepest savings while also significantly contributing to the overall property value creation.
- **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 — a key component of a carbon mitigation plan.

  Tenant in place energy efficiency retrofits can be challenging, but highly effective.
- **Planning and analysis are foundational to a cost-effective deep retrofit**
  A comprehensive design and planning process is a necessary component of creating an effective deep retrofit that achieves predicted results at effective costs.
- **Only measured performance confers successful retrofit savings**

  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.'
- **Changing context: The look forward may be different than the look back**

  Carbon will become a new performance metric, influencing ROI economics, technology choices, and retrofit project motivations, costs and benefits.

The Path Forward

Building retrofits have many motivations, and are often complicated, multiyear projects. Nonetheless, they are an essential part of achieving our city and state's climate goals. This report identifies several central issues as part of the path forward to help accelerate and scale high-rise office deep retrofit projects.

A Critical Opportunity: Tenant turnovers and leases

Substantial energy and emissions reductions can be found in addressing tenant spaces. Virtually all of the non-owner-occupied building projects took advantage of lease changes, or a building repositioning to attract a new or different kind of tenant, to make major changes within tenant spaces (or the building systems serving those spaces). These tenant-related retrofits often realized significant savings.

Key points that were observed in the case study projects:

- Tenant equipment and behavior drives many building energy consuming systems
- Lighting retrofits were present in nearly every case study and are more often selected and controlled by tenants
- Equipment can be changed or improved that allow for more efficient delivery of after-hour demands for HVAC systems, providing the comfort conditions only where needed instead of throughout the whole space
- Occupant density drives energy consumption; there has been a major recent trend for space "densification," resulting in much higher energy use intensity in a given space (though likely to reverse in the near term due to COVID health concerns). Efficient tenant space design can dramatically reduce the energy and emissions growth from densification in many cases
- Cloud computing vs. on-site data centers is an increasingly important opportunity. Moving data centers out of tenant spaces into the cloud has been demonstrated to result in quite significant savings, and off-site cloud servers typically operate much more efficiently
- Many tenant energy loads, including computers, appliances, and other plug loads 'unregulated' by energy code, can be significant contributors to EUI and GHGI; effective tenant space design and engagement can reduce these loads significantly.

The bottom line: to meet NYC LL97's emissions limits, there will need to be much more effort from building owners and their tenants to collaborate on energy reductions, or they will need to sort out contractually how to split fines if the building is over the limits.

Looking Forward: Carbon will be the new metric

This report includes only high-rise, deep retrofit projects that have already been completed and have at least a full year of post-retrofit energy performance data (in many cases, several years of post-retrofit data). These profiles are all retrofits with lessons learned looking backward at technologies, motivations, and market conditions of the last 10 years, while the drivers for change will certainly be different in future decades.

Looking ahead to retrofits being planned and implemented now, there is a new regulatory paradigm that is shifting to measured energy and carbon performance. New York City's Local Law 97 of 2019, the centerpiece of the City's world leading Climate Mobilization Act, establishes GHG Intensity limits starting in 2024, and getting dramatically more stringent in 2030 and beyond, with very significant financial penalties when those limits are exceeded. Other building performance standards adopted in leading jurisdictions in the US and other countries are also driving new attention to measured building performance.

Regulatory compliance with these new carbon emissions limits, including the changing carbon intensity of the electric grid, compels building owners to look very differently at building retrofits. With carbon as the metric, a different set of technologies must be considered.

Faced with significant penalties if a building does not meet stringent emission limits, owners will be much more focused on improved energy and carbon performance, and reducing GHG emissions. Instead of just considering projected energy savings from modeling, there are likely to be new contractual models that deliver carbon savings to avoid the penalties. There is also the potential for monetization of GHG reductions with the trading system envisioned in LL97 — the legislation requires a study and implementation plan for a trading system that would allow for some buildings to purchase "emissions reductions credits" from other buildings, where they can be delivered at a lower cost. This system could provide a new revenue stream for the most forward thinking owners who can execute lower cost retrofits that perform below their respective LL97 limits, thus providing a monetizable carbon credit.

A carbon metric results in major changes looking forward:

- Carbon reductions will be a different lens to look through than energy cost
- Expectations of a very clean electric grid can dramatically influence heating decarbonization decisions
- Building ROI considerations and retrofit economics will change:
  - Project paybacks shorten when large potential penalties are taken into account

- There may be new potential revenue streams from trading when buildings can be made to operate under the emissions limits

New Initiatives: Scaling change

In order to better understand how to deliver very low-carbon high-rise buildings, a number of planning efforts are now underway:

The NY State Empire Building Challenge ■ As announced in Governor Cuomo's 2020 State of the State, NYSERDA is launching the Empire Building Challenge, which plans to leverage $50 million in State funds to create public-private partnerships with leading real estate owners, occupants, and solution providers to:

- Develop and demonstrate low-carbon retrofit approaches that can be replicated across the State's existing high-rise commercial office and multifamily buildings.
- Recruit best-in-class equipment manufacturers, solution providers, and other businesses to invest in business development, innovation, and product development to overcome the barriers preventing existing high-rise buildings in NYS from achieving carbon neutrality.
- Establish New York City as a hub for successful retrofits that create jobs and local economic development while reducing greenhouse gas emissions.

Carbon Neutral Buildings Roadmap ■ NYSERDA is also leading development of a Carbon Neutral Buildings Roadmap to chart the course for the buildings sector to reach carbon neutrality by 2050, as required by the NY State Climate Leadership and Community Protection Act (CLCPA). Some building typologies have an easier path to carbon neutrality, and it is widely acknowledged that high-rise buildings present some of the most vexing challenges. Documenting more, and deeper, retrofits, like those identified in this report, will help guide what is possible as part of that statewide roadmap.

Building Electrification Roadmap ■ To reach carbon neutrality it is necessary to phase out burning fossil fuel and begin a massive shift to electric heat and other end uses currently served by on site fuel combustion (or use of fossil driven district energy systems like the ConEd district steam system). In order to understand the more near term challenges to converting from traditional fossil fuel based heating and hot water systems, NYSERDA, in collaboration with the NY State Department of Public Service, is preparing a Statewide Building Electrification Roadmap that will identify challenges and barriers to building electrification in the near term, to chart the course for the building sector to reach carbon neutrality.

Closing

As this report is being finalized, in the summer of 2020, the landscape is very different from when it began. Demand for office space in the post-COVID world, and other unforeseen changes, will dramatically influence the decision-making process of owners and tenants of office buildings.

Additionally, the timing of this research occurred during the COVID-19 pandemic and many owners reported large office buildings without a significant drop in energy use despite being mostly unoccupied. This observation has not yet been fully researched and needs further study.

While this study has intentionally focused specifically on high-rise office buildings, a similar survey is needed to understand successful deep retrofits of high-rise multifamily buildings. Given the prevalence of large, high-rise multifamily buildings covered by LL97, and the many NYC stakeholders considering how to bring them down to the new GHG intensity limits, a similar global review of high-rise residential buildings would provide for an understanding of current practice and document what is working.

Finally, in the course of this research, the authors identified a number of "buildings to watch" (see left), where a promising deep retrofit project is underway but not yet complete, or not yet fully occupied with a year of measured energy data. A follow up to this survey, in two to three years, which includes several retrofits resulting from LL97 early actions, as well as key high potential projects outside of NYC, would be essential to better understand how the state of the retrofit market is evolving and the levers that can continue to accelerate and scale its progress.

Buildings to Watch

New York, New York:
Citigroup Headquarters
1333 Broadway
Empire State Building "2.0"
1100 Avenue of the Americas
660 5th Avenue
Rockefeller Center
1270 Avenue of the Americas
825 3rd Avenue
75 Rockefeller Plaza

Indianapolis, Indiana:
99 High Street

Boston, Massachusetts:
Regions Tower

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