

High Rise | Low Carbon; Office Deep Retrofit Profiles

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ABSTRACT

This paper summarizes an international survey of high performing deep retrofit projects in large commercial office buildings, creating a collection of case studies with post retrofit performance metrics, and an “inventory of retrofit solutions,” which highlights equipment and systems deployed.

It has been widely demonstrated that it is possible to get to very low energy/carbon (and even carbon neutral) buildings in smaller buildings, but in high rise buildings, particularly in regions like New York with cold winters and high heating demand, there is less knowledge or experience in achieving very low energy large buildings. Demonstrating successful deep retrofits of this critical typology is pivotal to the success of most all the progressive carbon reduction policies being implemented in cities around the world.

There have been several high-profile high rise “deep” energy retrofit projects with projected energy savings greater than 25%, including the Empire State Building and UN Headquarters building in New York City, the Deutsche Bank Headquarters building in Frankfurt Germany, and a variety of high rise multifamily buildings around Canada. However, the measured post-retrofit performance results of these projects, particularly documenting the post-retrofit energy and carbon, has never been compiled and compared in any useful way to understand the state of the market. Also missing is a companion comparison of what retrofit measures were undertaken in each project alongside what systems and equipment were deployed.

This paper examines compelling deep retrofit projects that have measured results and includes a high-level summary matrix ‘inventory’ of solutions, which itemizes the various systems, building components, and equipment deployed, sorted by type.

Introduction

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 and economy. These same skyscrapers also have a fundamental role in achieving our City and State’s climate action goals.

With the passage of the Climate Mobilization Act’s (CMA) Local Law 97 (LL97), in April, 2019, New York 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. LL97 establishes GHG Intensity limits for large buildings starting in 2024, and getting dramatically more stringent in 2030 and beyond, with very significant financial penalties when those limits are exceeded.

Some industry practitioners have questioned the feasibility of achieving the GHG limits, particularly for tall buildings, and questioned whether there are examples of buildings that have reached the limits.

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 survey explored 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?

The survey findings provide 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.

Building Profiles – Survey Findings

This paper's goal 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.¹ To provide the most relevant examples, the authors chose to limit the examples to projects in a climate zone somewhat similar to New York (including both significant heating and cooling loads), 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 paper profiles eighteen projects that undertook a deep retrofit resulting in often dramatic energy reduction. Table 1 provides a summary of the eighteen buildings.

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 New York City's most iconic tower, and many more, this diverse set of retrofit projects was able to achieve an average of a 37% reduction in their site energy intensity, with several projects cutting their energy use in half (see Figure 1 and Table 2). Additionally, it is worth noting that there has been some skepticism and questions expressed by many in the real estate community regarding the technical and financial feasibility of achieving the deep retrofit targets of New York's recent carbon emission law, LL97; however, all these projects occurred prior to, and, therefore, in the absence of, the legal penalties and motivations of the recent aggressive climate legislation, demonstrating that low carbon high-rise office retrofits are, indeed, possible.

¹ For buildings outside of NYC, the authors estimated the project's CO₂ emissions using LL97's stated carbon conversion coefficients for all energy sources including electricity and district energy for the 2030 target year.

Table 1. Eighteen Case Study Buildings:

#	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 Pennsylvania 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.

This diverse case study set represents 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 paper’s Technical Solutions Matrix (Table 3), almost all the projects included energy efficiency upgrades to their lighting systems and controls, both favored and cost-effective retrofit savings opportunities; and most found significant carbon reductions from recommissioning, upgrading, or completely replacing their cooling systems. Each retrofit had various motivating factors, summarized in the Key Findings section, including complete repositioning of the property, to strategic upgrades when a tenant turned over, or at the end of life of a major piece of equipment

or building system. 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.

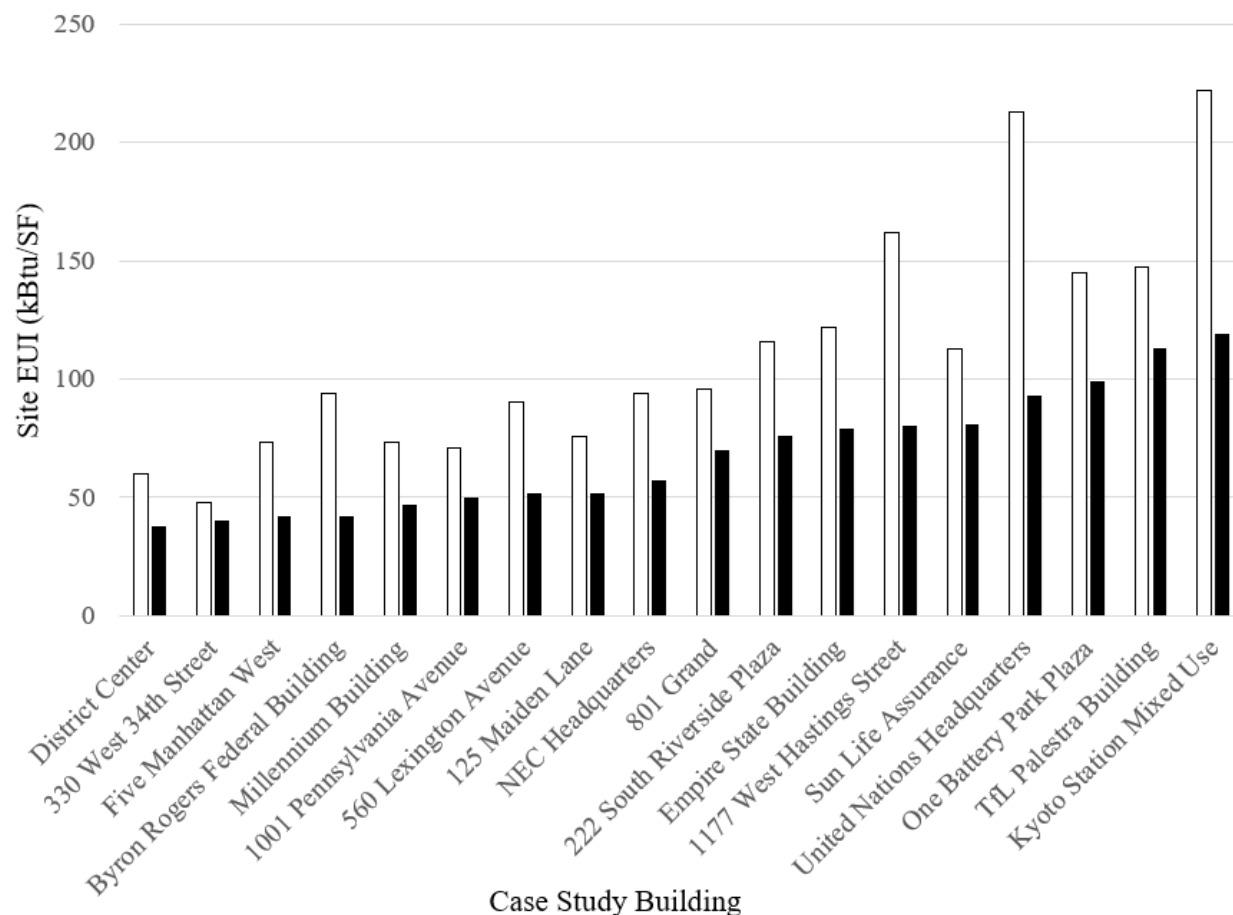


Figure 1. Pre-retrofit (white bars) and Post-retrofit (black bars) Site Energy Use Intensity (EUI) for eighteen case study buildings. *Source:* Primary sourced pre & post retrofit EUI data by authors through research and interviews (see Table 2 and BE-Ex 2020)

Note: More details about the case studies are presented in a full report that describes the overall project in depth. (BE-Ex 2020).

As the urgency of the global climate crisis mounts, many jurisdictions are looking to New York City's LL97 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 paper 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.

Table 2. Eighteen Case Study Buildings – Pre & Post Retrofit Site Energy Use Intensity (EUI):

#	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 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

Solutions Summary

One goal for the survey was to understand the technical solutions that drove the deep energy reductions, and what were the most common energy conservation measures (ECMs) that were found in a large number of the case study buildings. A summary of the measures is shown in the Technical Solutions Matrix (Table 3), with more detail about the measures following the table.

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.
- 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.

Table 3. Technical Solutions Matrix - Summary of Energy Conservation Measure (ECM) Deployed:

System	ECM Description	1. United Nations HQ	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. 220 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 34 th 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			•	•			•		•	•							•	

- 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.

- 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.

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.
- 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.
- 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
- 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

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.

- 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.

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.
- 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 CO2 sensor and controls to reduce outside air supply volumes.
- 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.

Envelope

- Facade 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.
- 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.
- 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.

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.
- 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.
- 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.

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

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.
- 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.
- 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.
- 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.
- Fuel Switching: It is worth noting that none of the retrofits selected for this paper included fuel switching for space heating. Two buildings did include fuel switching from natural gas/oil to electric driven air source heat pump for domestic hot water generation. This was a minor component to the retrofits for office buildings and had a complex impact on Site EUI and thus was not addressed due to the space limitations of the paper.

Key Findings

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. Some of the key themes include:

Major building-wide renovations 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 drive many buildings' 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 is often bluntly deployed, turning on entire floors or systems for comparatively light need or use. More targeted and tailored after-hours designs can be an effective savings tool.
- Occupant density can have a profound effect on energy intensity, and should be considered in any mitigation planning.
- Cloud computing, where feasible, versus on-site data centers, is an effective energy savings option, removing the load from the building itself, and transferring it off site, to an often more efficiently configured and designed location.
- Computers, appliances, other plug loads 'unregulated' by energy code, but can be significant contributors to EUI and Green House Gas Intensity (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.

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.

The Path Forward

Building retrofits have many motivations, and are often complicated, multiyear projects. Nonetheless, they are an essential part of achieving New York city and state's climate goals. This paper identifies several central issues as part of the path forward to help accelerate and scale high-rise office deep retrofit projects, as outlined in the Key Findings section. Additionally, three areas warrant note: tenant turn-over, carbon as a metric, and building electrification.

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.

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

Building Electrification

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 Con Edison district steam system). In order to understand the more near term challenges to converting from traditional fossil fuel based heating and hot water systems, New York State Energy Research & Development Authority (NYSERDA), in collaboration with the New York 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.

Conclusion

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 emission 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 paper 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 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.

Looking ahead to retrofits being planned and implemented now, there is a new regulatory paradigm that is shifting to measured energy and carbon performance. Also, 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.

In conclusion, it is worth noting that 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 paper 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.

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