ARUP

Office to Residential Conversions: The Carbon Story

Foreword

John Mandyck
Chief Executive Officer
Urban Green Council

It seems so simple. In New York City, we have excess office space and not enough residential space. Why not convert those office buildings to homes? The answer, of course, is much more complicated, with zoning and economic hurdles to clear.

But lost in the conversation has been the carbon benefit of conversions. Now, thanks to this new research report from Arup, one big question is answered: how will these conversions save carbon and benefit the environment? Arup has comprehensively examined the proposed eligible population of NYC office buildings to determine both embodied and operational carbon savings from conversion versus new residential construction. This research is an important element to inform public discussion.

Urban Green Council thanks Arup for contributing to New York's body of knowledge with new data to drive decisions.

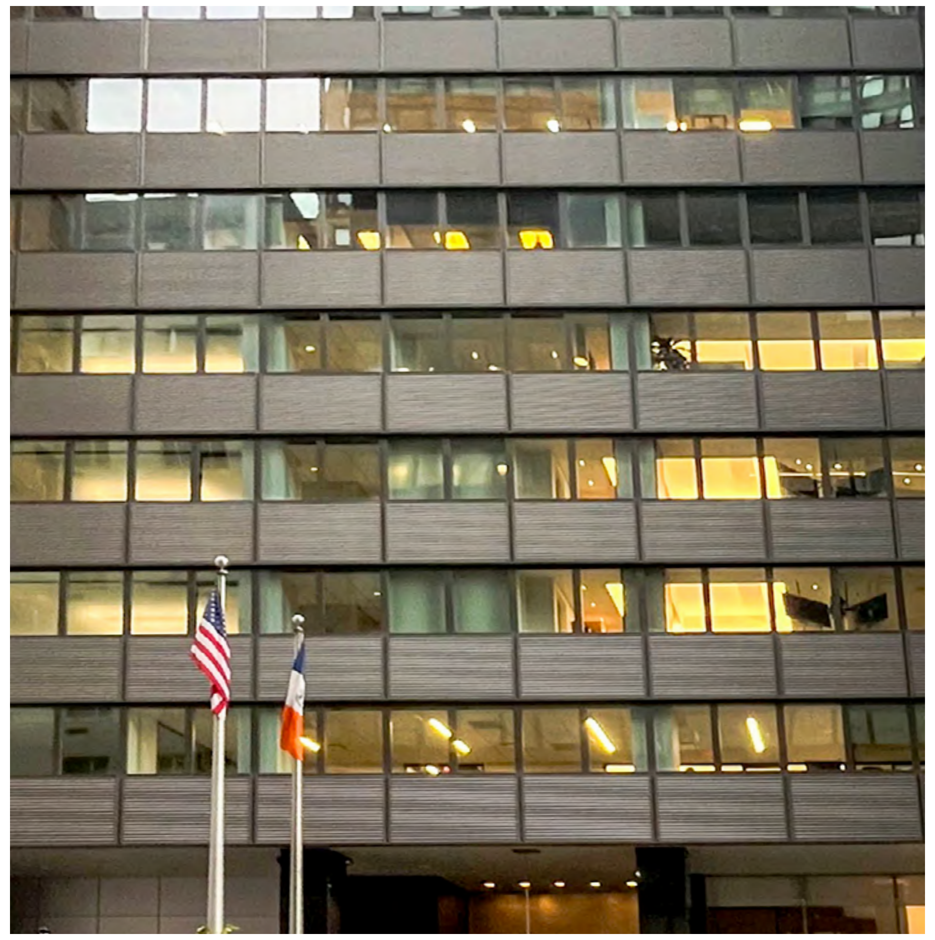
John Mandyck

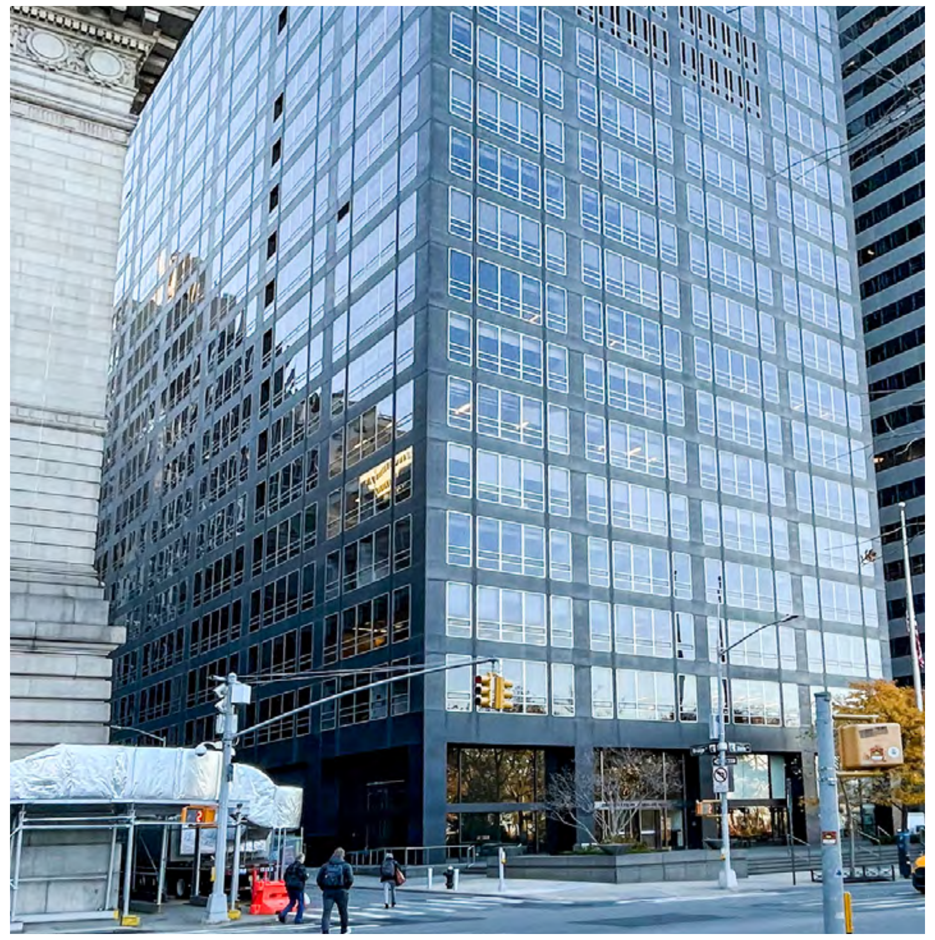
CEO | Urban Green Council

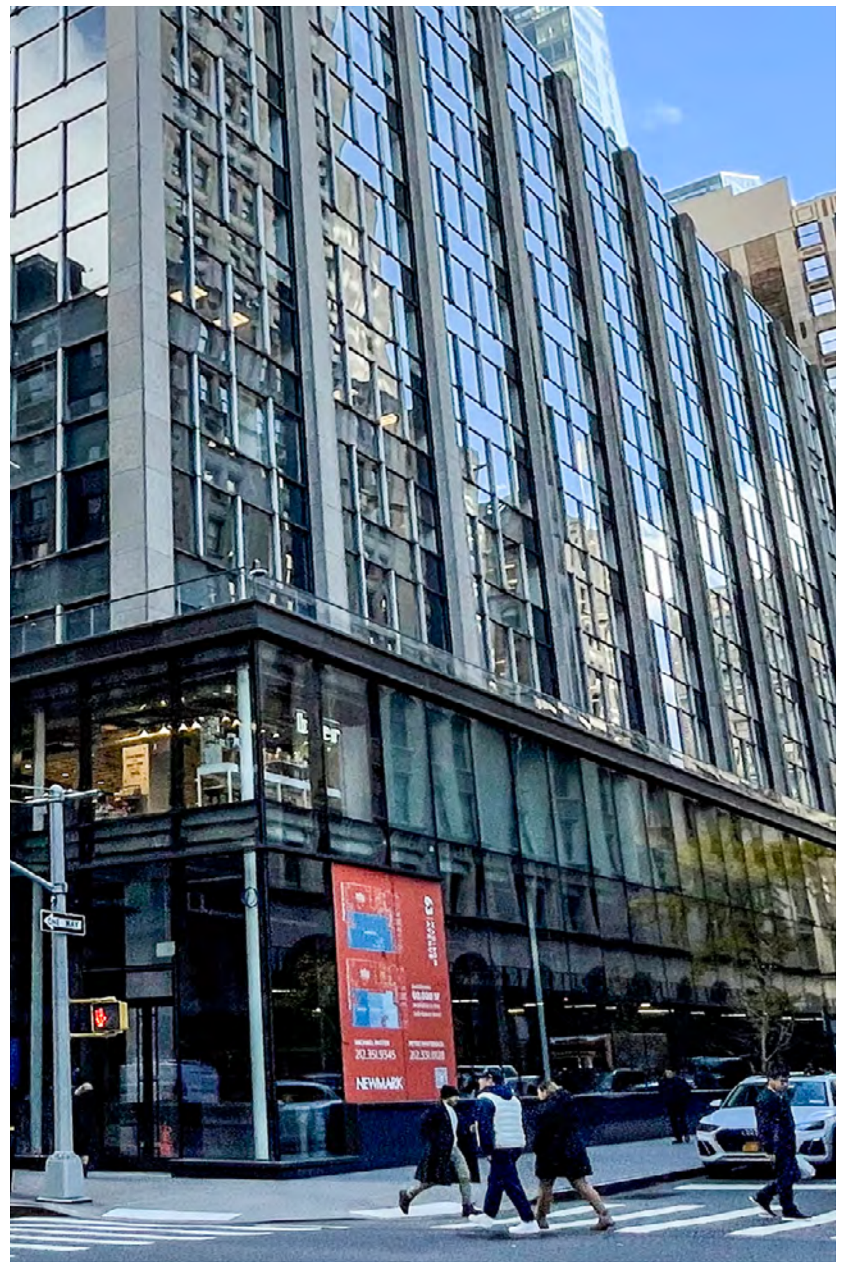
Study Findings

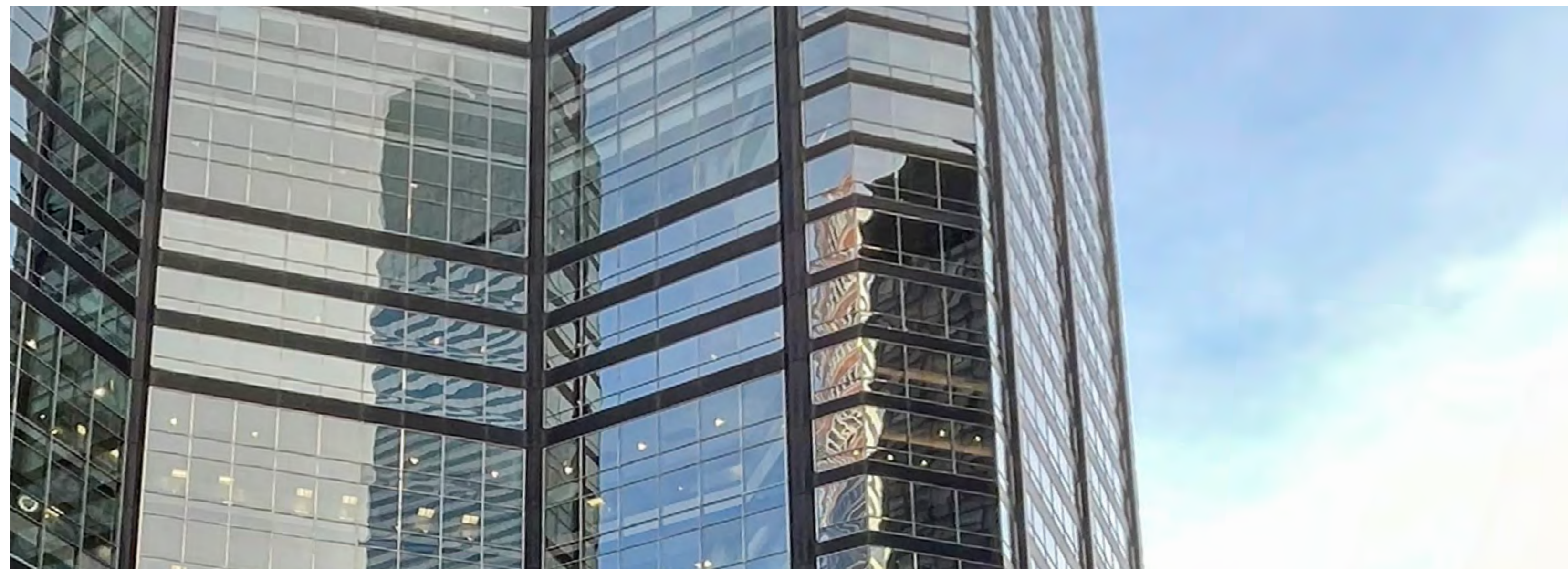
This research set out to answer a simple question: how much carbon could be saved by 2050 if New York City expanded the range of buildings eligible for office to residential conversions?

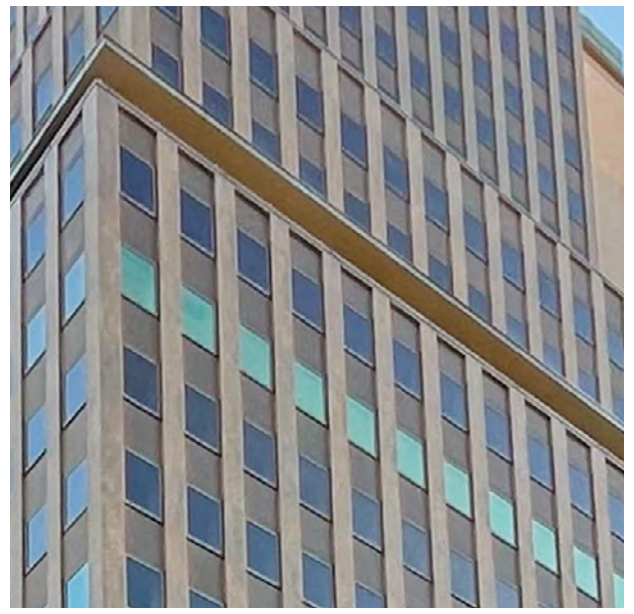
Research Aim

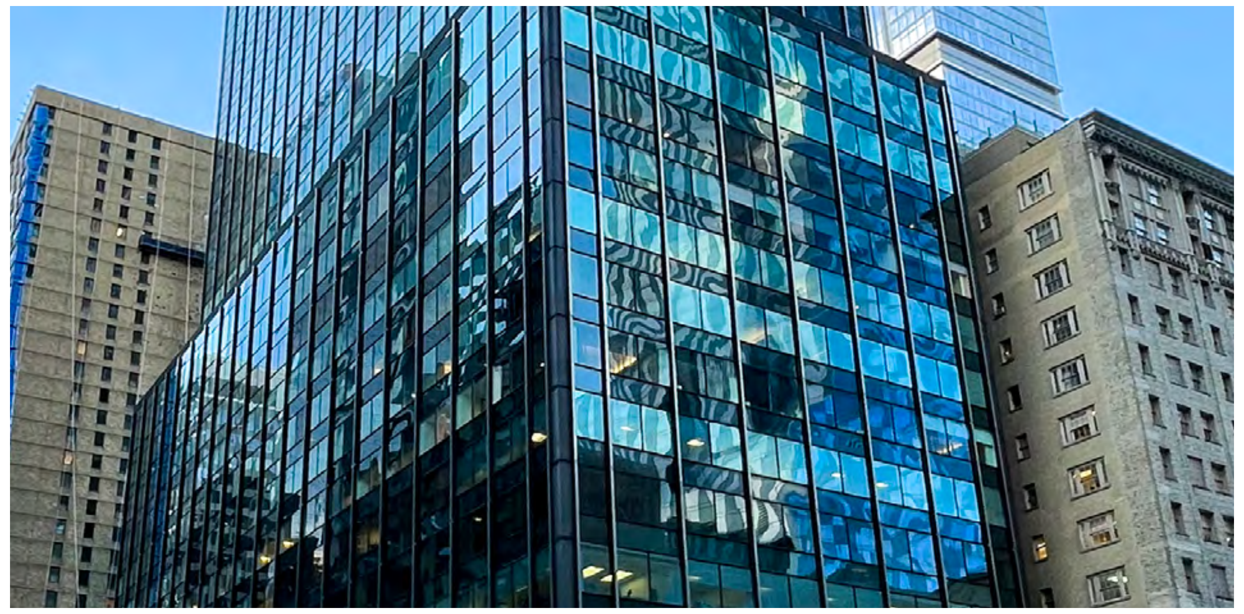












This Arup-funded study investigates the carbon implications of office to residential conversions. Expanding conversion activity is an urgent topic in New York City, given high office vacancy rates and a deep housing crisis. However, discussions on the topic in policy and real estate spheres have so far overlooked the sustainability impacts of converting and reusing these existing office buildings.

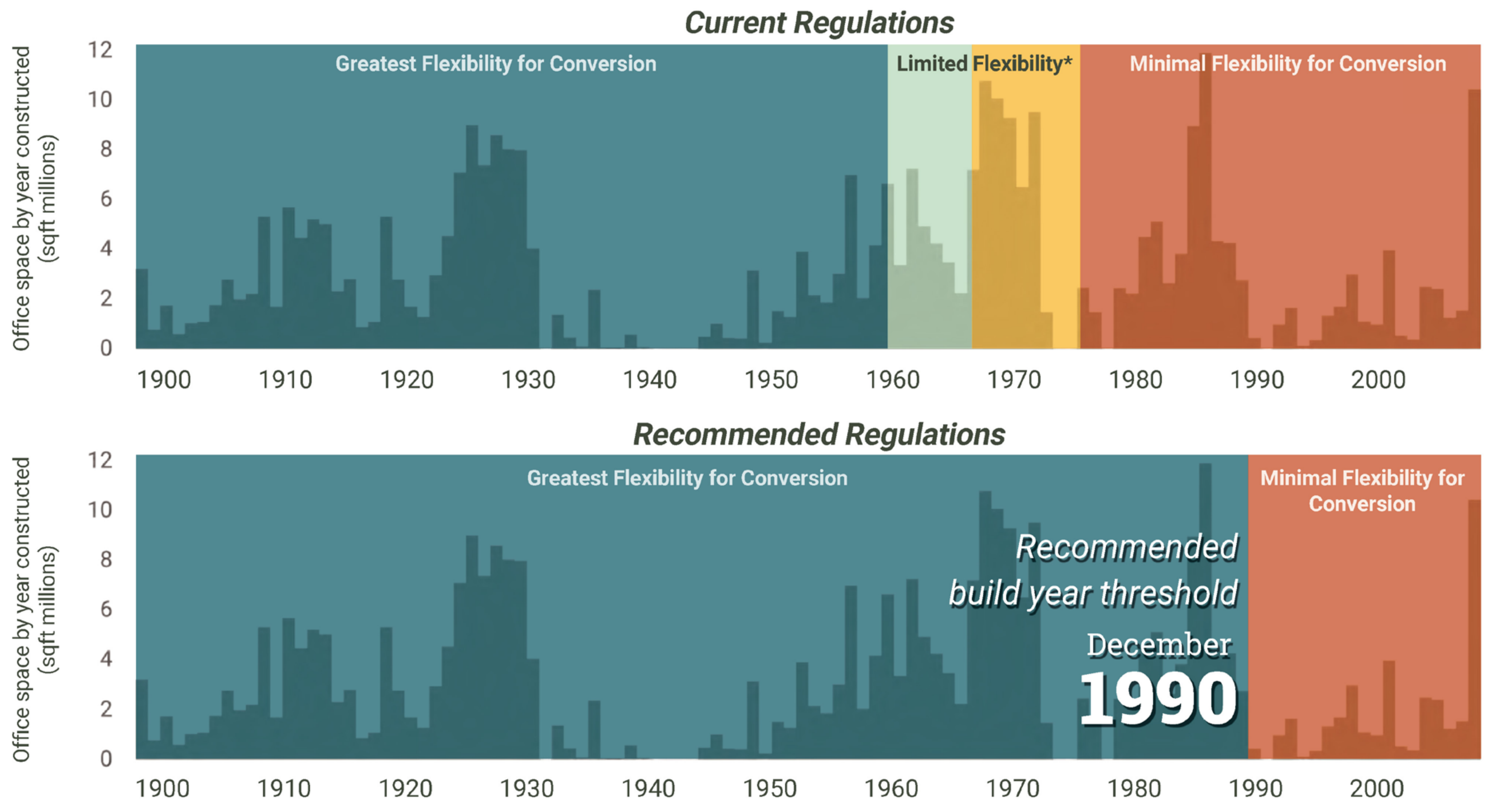
This research set out to answer a simple question: how much carbon could be saved by 2050 if New York City expanded the range of buildings eligible for office to residential conversions?

New York City Office Adaptive Reuse Study

NYC Planning's *New York City Office Adaptive Reuse Study* (January 2023) predicts that proposed zoning changes to expand office conversion eligibility could create 20,000 additional homes within the next decade. Our analysis focused on the set of buildings subject to the proposed zoning changes: Manhattan office buildings below 59th street built in the 1960s, 70s, and 80s.

The Arup team assessed the embodied and operational carbon savings that could result from the reuse and retrofit associated with converting these buildings, to understand the scale of carbon savings related to the potential change in zoning.

Figure: Comparison of Office-to-Residential Existing and Proposed Conversions Regulations by Year of Construction



** Most flexible conversion regulations are only accessible to an office building located in FiDi. Additionally office buildings permitted after 1969 can typically only transfer 12 FAR of office space to residential uses.*

Note: Chart only includes office area located in the Article 1 Chapter 5 geography in locations where residential is allowed as-of-right. Only include buildings in the following building classes: O2 thru O9 and RB/RC.

Source: New York City Department of City Planning

Source: https://econsultsolutions.com/wp-content/uploads/2023/02/ESI_NYCEDC-Adaptive-Reuse-Study_2023-01-05.pdf

Definitions: Embodied and Operational Carbon

This analysis takes a whole life carbon approach, considering both the Embodied Carbon that goes into new construction and major renovations, and the Operational Carbon from ongoing building energy use.

Embodied Carbon

Emissions associated with the materials and construction processes throughout the whole life cycle of a building, from material extraction, transportation to site, to demolition and disposal.

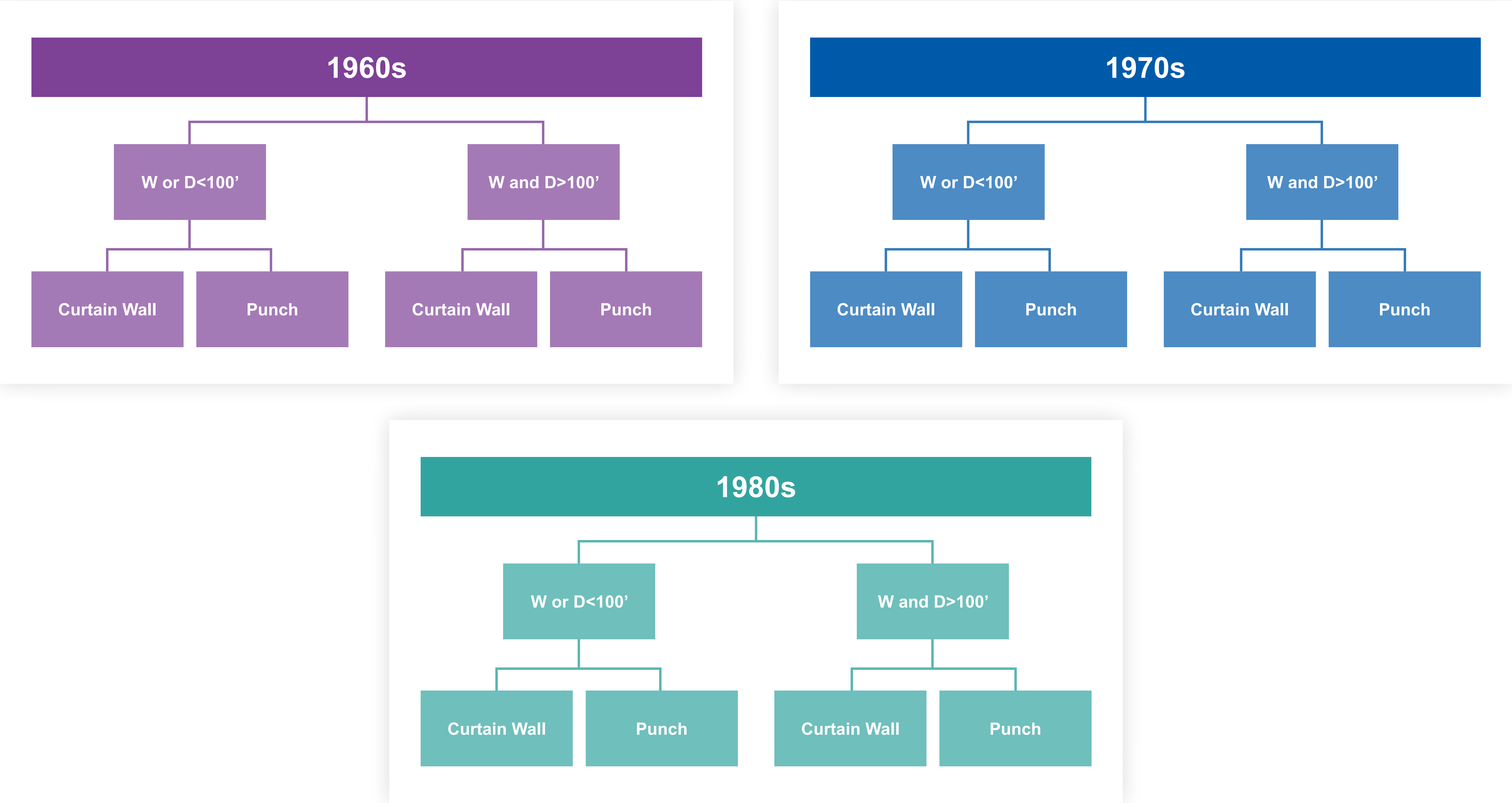
Operational Carbon

Emissions associated with the energy used to operate the building.

A typological approach

To calculate carbon savings, the team developed a typological framework for the 222 buildings in question – dividing buildings by decade, floor plate depth, and window type. These three factors impact the operational and embodied carbon savings associated with the conversion.

The team performed an in-depth carbon assessment on the resulting 12 distinct typologies, considering structural and massing changes needed to optimize deep floor plates for residential use, window or curtain wall replacement, and a range of energy and electrification improvements that would be triggered by the conversion. Results for the 12 typologies were scaled to the full dataset.



12 Typologies | 1960s

Wide Curtain Wall

Location:	63 Madison Avenue
Built:	1962
EUI:	73.5 kBtu/sq. ft.
Avg floor size:	46,853 sq. ft.
Vacancy rate:	26.6%

Wide Punch

Location:	222 Broadway
Built:	1961
EUI:	73.4 kBtu/sq. ft.
Avg floor size:	24,392 sq. ft.
Vacancy rate:	63.1%

Narrow Curtain Wall

Location:	111 East 58th Street
Built:	1969
EUI:	78.4 kBtu/sq. ft.
Avg floor size:	16,576 sq. ft.
Vacancy rate:	N/A

Narrow Punch

Location:	1180 Avenue of the Americas
Built:	1963
EUI:	60.5 kBtu/sq. ft.
Avg floor size:	14,898 sq. ft.
Vacancy rate:	64.7%

12 Typologies | 1970s

Wide Curtain Wall

Location:	888 7th Avenue
Built:	1970
EUI:	87.7 kBtu/sq. ft.
Avg floor size:	19,252 sq. ft.
Vacancy rate:	8.2%

Wide Punch

Location:	24 State Street
Built:	1971
EUI:	86.7 kBtu/sq. ft.
Avg floor size:	25,627 sq. ft.
Vacancy rate:	N/A

Narrow Curtain Wall

Location:	800 3rd Avenue
Built:	1970
EUI:	108.2 kBtu/sq. ft.
Avg floor size:	12,832 sq. ft.
Vacancy rate:	19.9%

Narrow Punch

Location:	88 Pine Street
Built:	1973
EUI:	87.2 kBtu/sq. ft.
Avg floor size:	20,781 sq. ft.
Vacancy rate:	27.3%

12 Typologies | 1980s

Wide Curtain Wall

Location:	875 3rd Avenue
Built:	1982
EUI:	58.5 kBtu/sq. ft.
Avg floor size:	21,868 sq. ft.
Vacancy rate:	6.0%

Wide Punch

Location:	512 Madison Ave
Built:	1982
EUI:	77.4 kBtu/sq. ft.
Avg floor size:	23,611 sq. ft.
Vacancy rate:	N/A

Narrow Curtain Wall

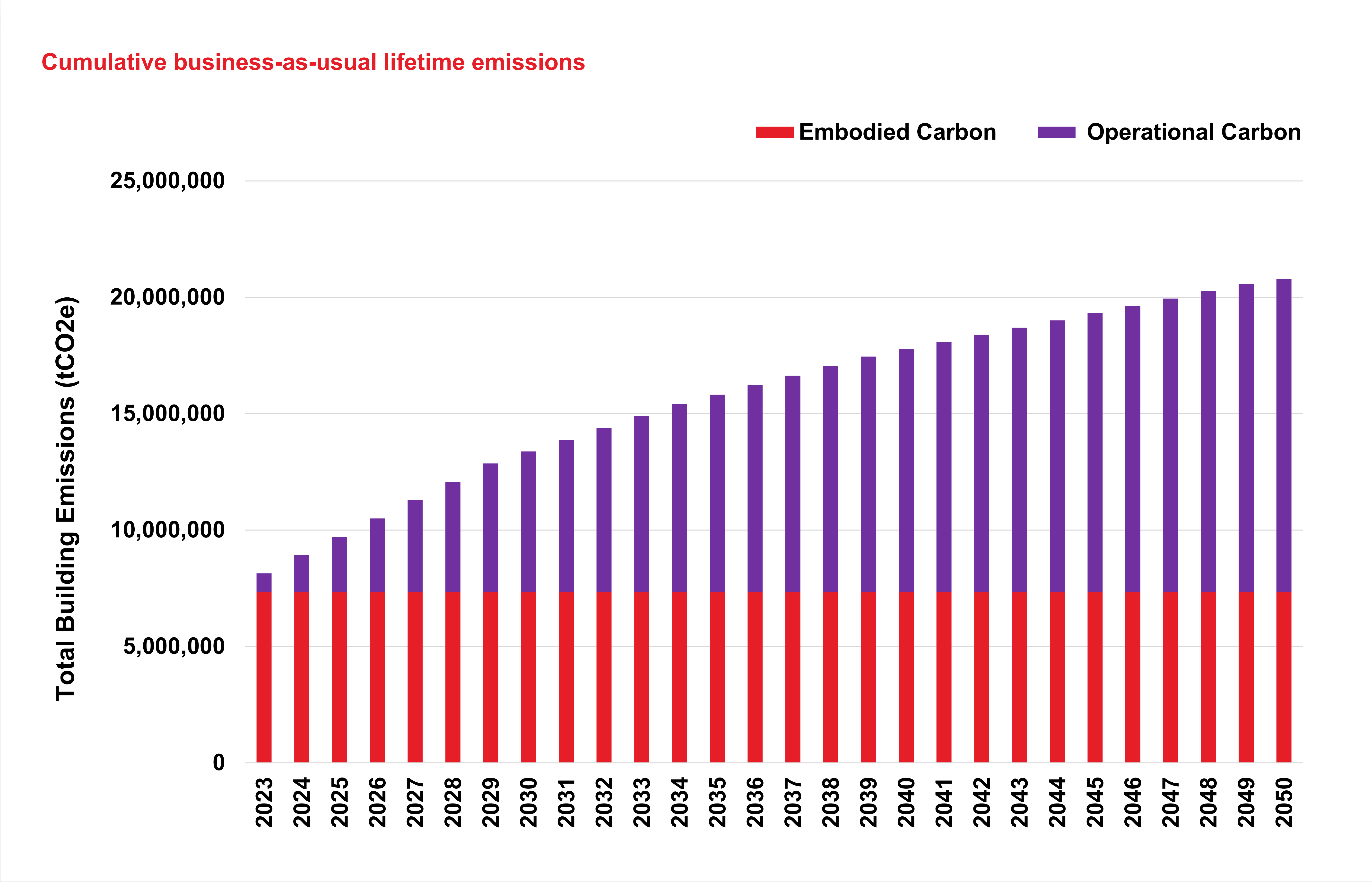
Location:	135 East 57th Street
Built:	1987
EUI:	63.4 kBtu/sq. ft.
Avg floor size:	12,417 sq. ft.
Vacancy rate:	63.2%

Narrow Punch

Location:	45 Broadway
Built:	1983
EUI:	55.7 kBtu/sq. ft.
Avg floor size:	11,881 sq. ft.
Vacancy rate:	19.1%

Results Summary | Baseline

We compared the results to a business-as-usual baseline case in which the footprint of the additional homes are created from ground up new construction, and the existing office buildings are left to operate as they do today.

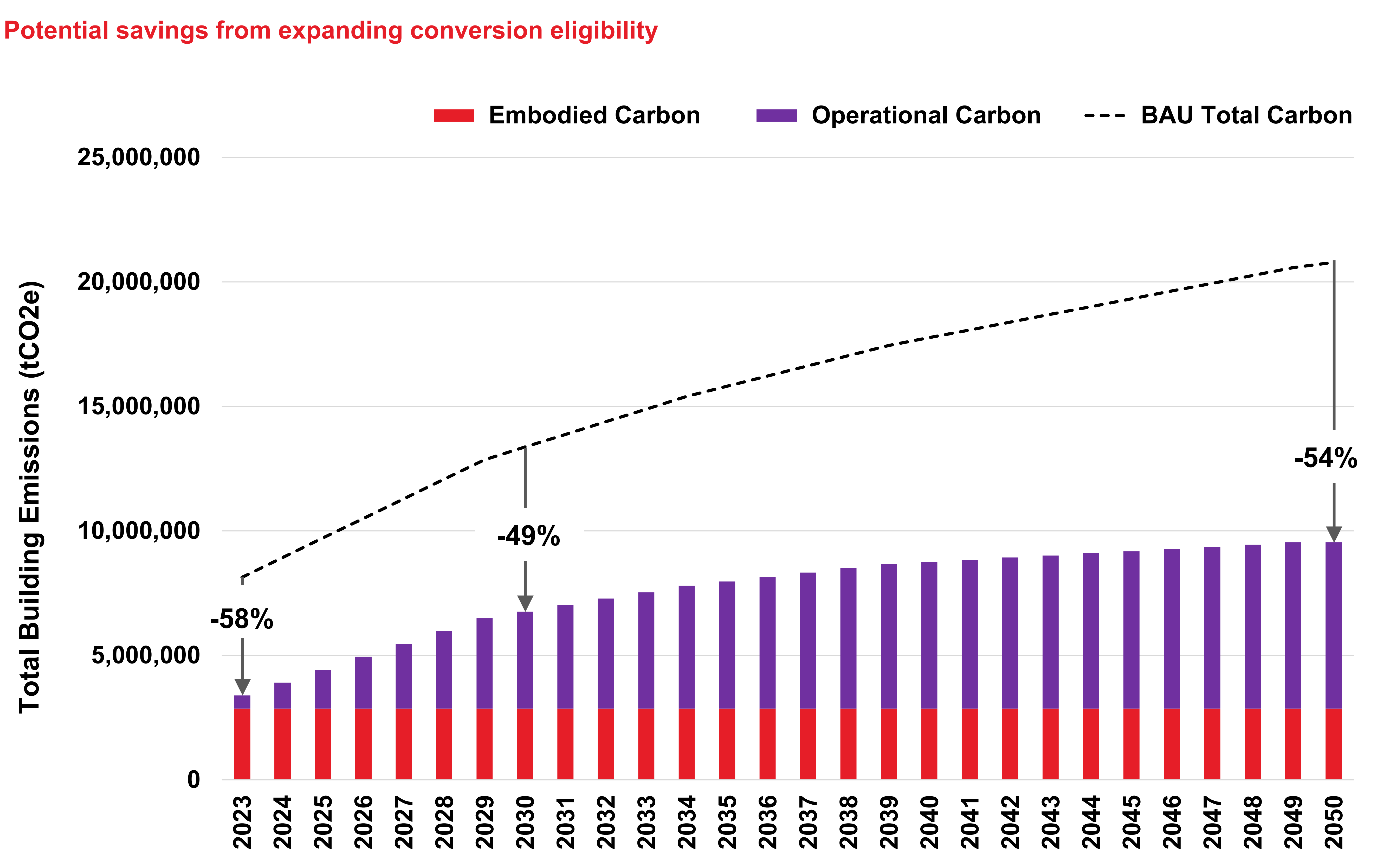


Embodied carbon:	149,015,772 sq. ft. of residential new construction
Operational carbon:	Progression of current operational emissions for the 222 commercial buildings, with grid decarbonization

Results Summary | Savings

The carbon savings that could result from the conversions are the difference between this business-as-usual case, and the case where the 222 buildings are reused and retrofit for residential use – accounting for the embodied carbon of needed structural changes, window and curtain wall replacements, and energy efficiency upgrades performed in the process.

Expanding conversion eligibility could result in a 54% reduction in whole life carbon emissions by 2050 below the business-as-usual condition. The cumulative impact of the potential savings is significant – by 2050, total carbon savings could amount to the annual emissions from 2.3 million passenger vehicles.



Embodied carbon:	149,015,772 sq. ft. of residential housing created from office to residential conversions instead of ground up new construction
Operational carbon:	222 existing office buildings are retrofit/electrified through conversion

Results Corollary 1: Local Law 97 Implications

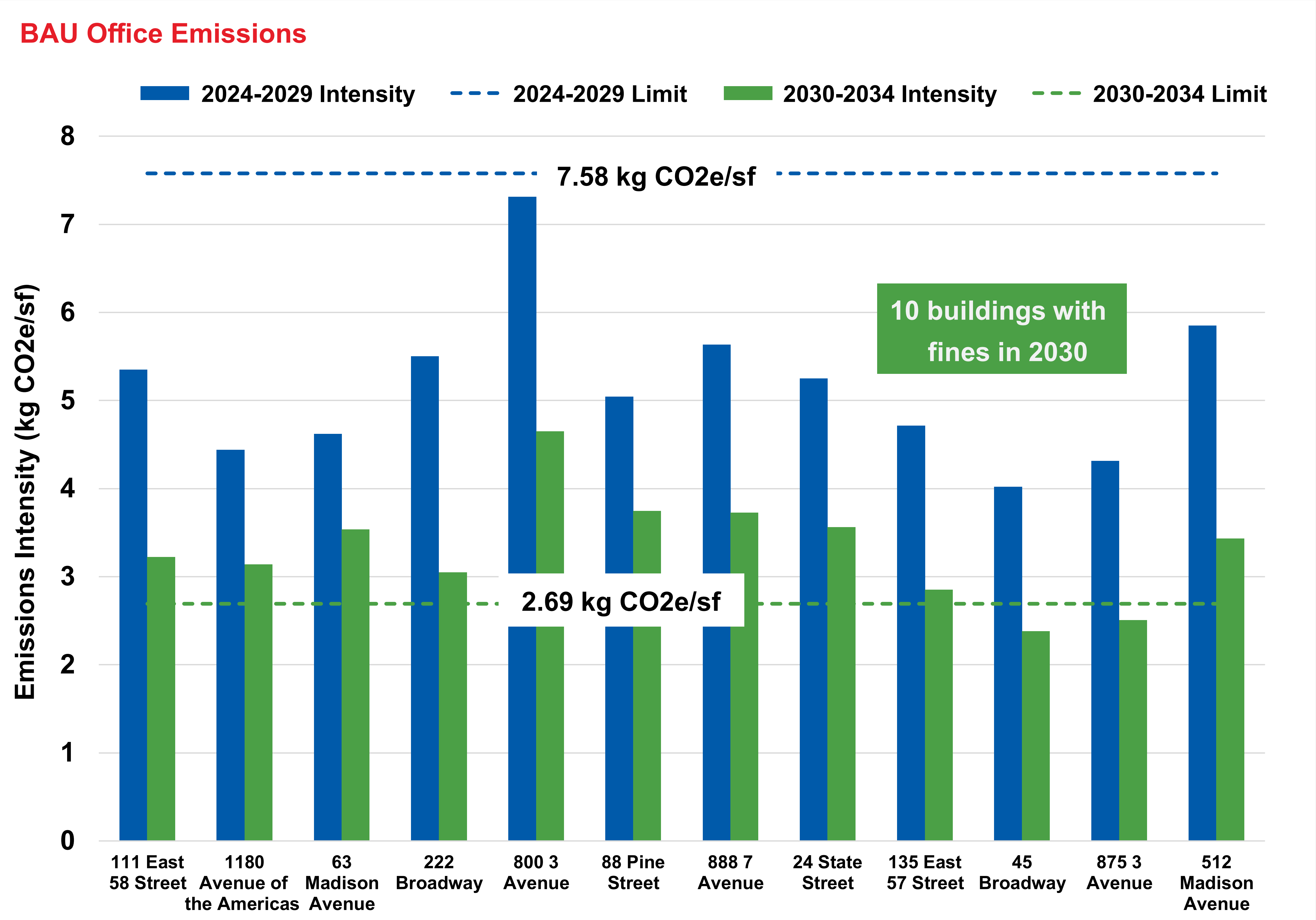
The impact of conversions on Local Law 97 (LL97) compliance is a notable corollary that can be drawn from these research results. In the business-as-usual case, 10 out of the 12 typologies see emissions intensities beyond the 2030 LL97 limits for office buildings. The existing office buildings in question are some of the worst performing buildings in the city, and many of the full set of 222 are likely to experience fines due to excessive carbon emissions in 2030.

In the case where the 12 typological office buildings are converted to residential, all buildings comply with the 2030 LL97 residential emissions intensity limits. The emissions improvements result from the electrification and building retrofits that are assumed to occur during conversion.

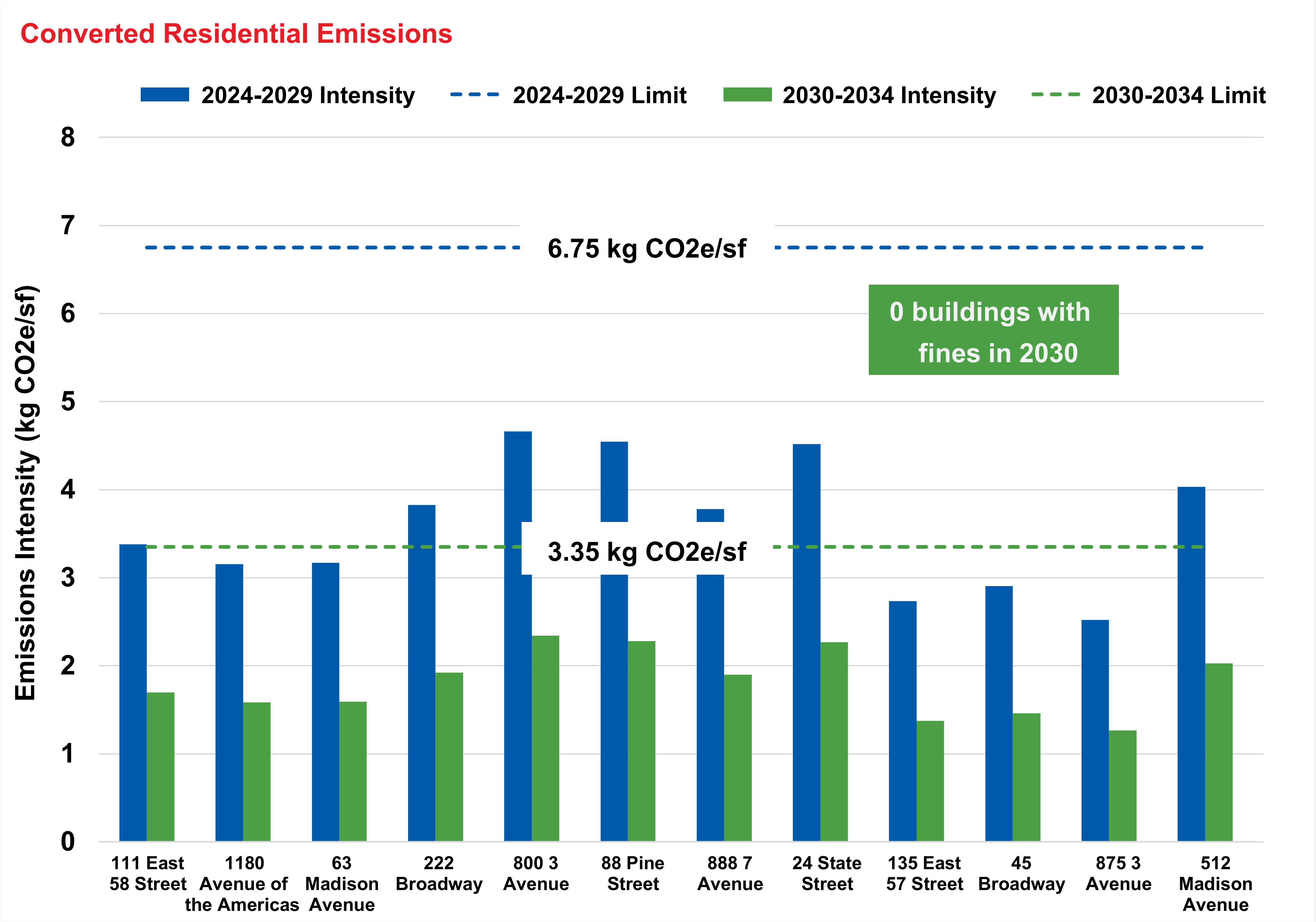
Expanding flexibility for office to residential conversions could provide developers and property owners with additional incentive to undertake the retrofits required to comply with Local Law 97, making such actions a win-win for the city in terms of housing creation and decarbonization goals.

Results Corollary 1: Local Law 97 Implications

Expanding conversion eligibility will help the city and building owners make progress towards LL97 goals.



Existing office building performance for 12 selected typologies relative to LL97 office emissions limits.



Same 12 buildings after residential conversion, relative to LL97 multifamily housing emissions limits.

Results Corollary 2: Carbon Payback of Façade Replacement

Case Study: 800 3rd Avenue (Narrow, Curtain Wall, 1970)

This study held the conservative assumption that a full façade replacement would be undertaken for curtain wall buildings during conversion, due to the requirement for operable windows in residential use, and the assumed poor condition of existing curtain walls built 30-60 years ago.

The façade replacement has a significant associated embodied carbon penalty from the upfront carbon of the new envelope. This carbon cost of façade replacement has been cited as a criticism of Local Law 97, which incentivizes façade replacement for operational efficiency without considering the upfront emissions such actions would generate. The results of this study allowed us to assess the carbon payback from a new curtain wall façade using one of our typologies.

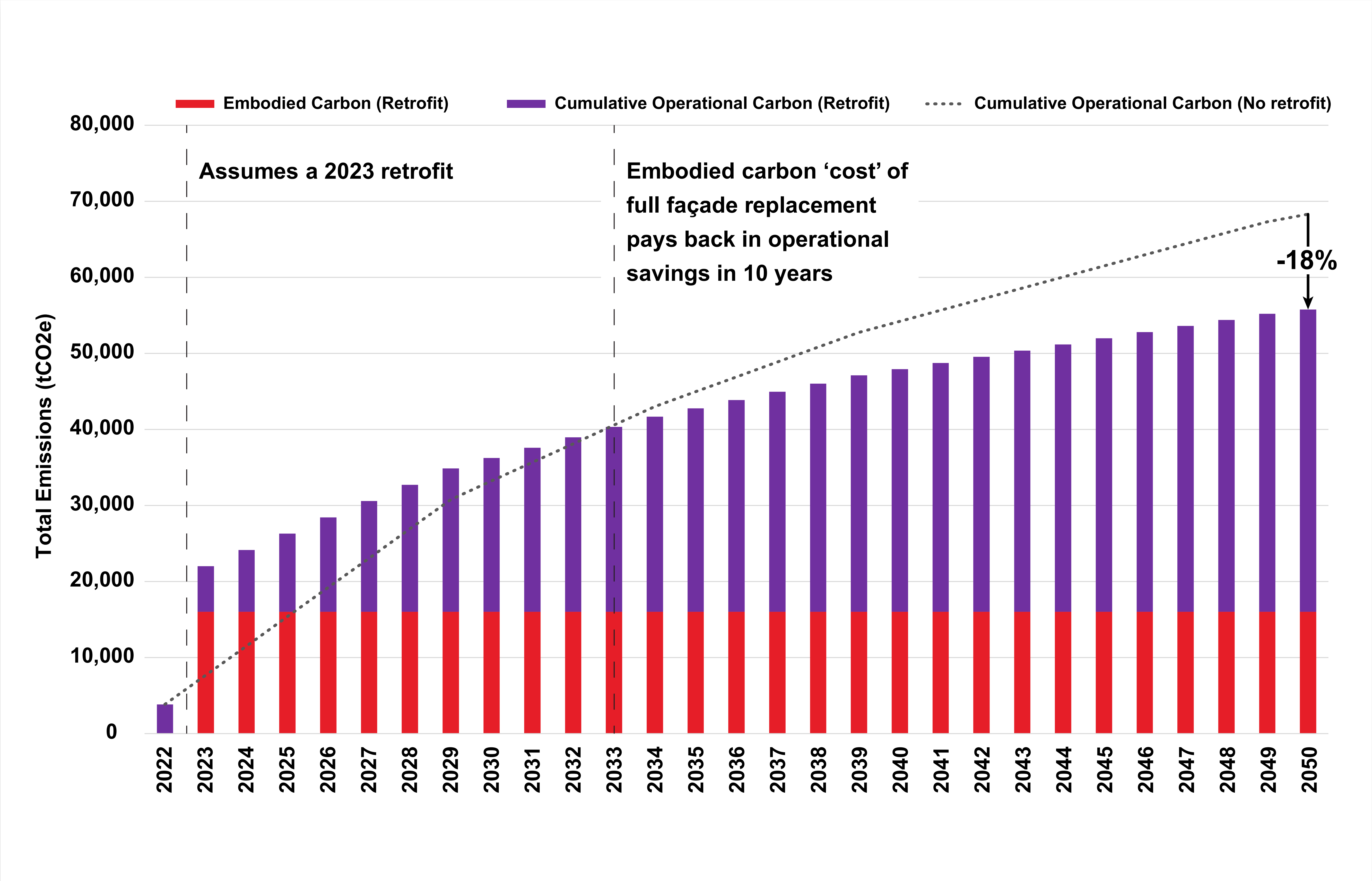
We discovered that the upfront embodied carbon 'spend' from a curtain wall replacement could payback in operational efficiency in 10 years, and could result in 18% savings in whole life carbon by 2050.

As these conversions are further evaluated, it will be important to consider whether full facade replacement is truly required. Retrofitting the existing façade in situ to meet operable window requirements and to improve façade infiltration and thermal performance could save some of the upfront embodied carbon emissions while still resulting in efficiency improvements.

Results Corollary 2: Carbon Payback of Façade Replacement

Case Study: 800 3rd Avenue (Narrow, Curtain Wall, 1970)

Operational carbon savings are achieved over the no-retrofit case through the conversion to residential use, implementation of façade ECMs, and future grid and steam emission factors.



Findings summary

The carbon story behind office to residential conversions adds further impetus, from a sustainability perspective, for both expanding conversion eligibility and providing incentives to encourage conversion. This study provides an additional carbon lens through which policy makers and property owners can view the benefits of converting existing office buildings into residential use.

The zoning resolution currently under consideration could reduce carbon emissions from the set of office buildings in question by up to 49% by 2030 and 54% by 2050. Carbon savings come from both embodied carbon savings from building reuse (-61% by 2050), and operational carbon savings from retrofit and electrification (-50% by 2050). In addition to creating homes for New Yorkers, the proposed reforms could save over 6.5 million tons of CO_2e by 2030, and over 11 million tons by 2050, the equivalent of annual emissions from 2.3 million passenger vehicles.

+149M sq. ft.
of housing for New Yorkers

-6.5Mt
of CO_2e by 2030

-11Mt
of CO_2e by 2050

Methodology

Typology Selection

Embodied Carbon

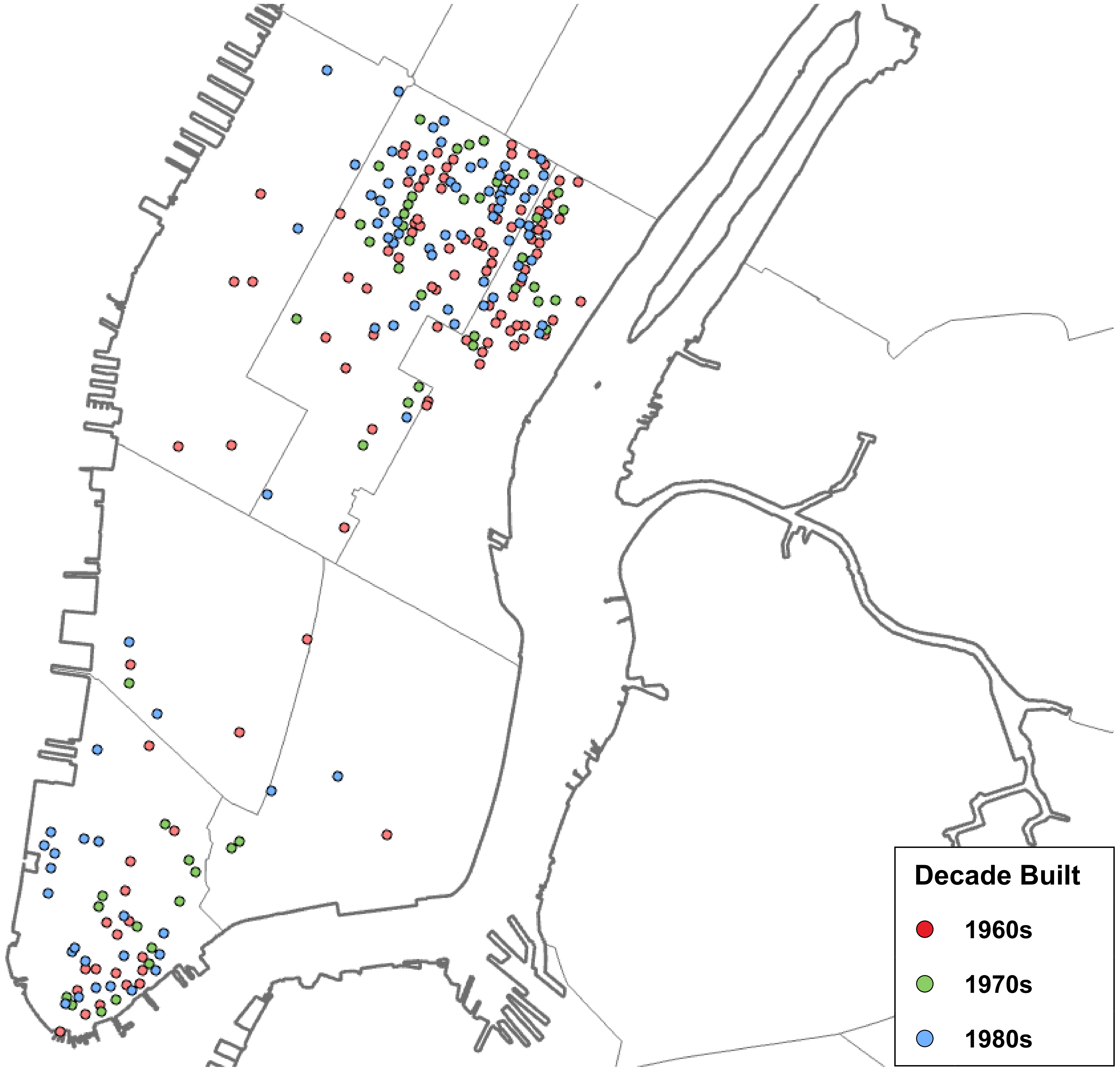
Operational Carbon

Methodology Overview | Typology selection

Identifying a building dataset

The scope of this study focused on the subset of buildings that are being considered for zoning changes by the city's planning department to enable additional office to residential conversions.

The focus per NYC Planning's *New York City Office Adaptive Reuse Study* (January 2023) is buildings built between 1960 and December 31 1990, located in Manhattan Districts 1,2,3,4,5,6, and in building classes O2-O9 (office buildings), RB (office space condominiums) and RC (mixture of commercial types). This study also filtered for buildings over 10,000 square feet. This results in 222 buildings in the dataset, indicated on the map at right by decade and location.



Methodology Overview | Typology selection

Typology grouping

The team narrowed down the 222 office buildings in our dataset into 12 distinct typologies. These office buildings were organized by decade built (1960s, 1970s, 1980s), floor plate depth, and window type.

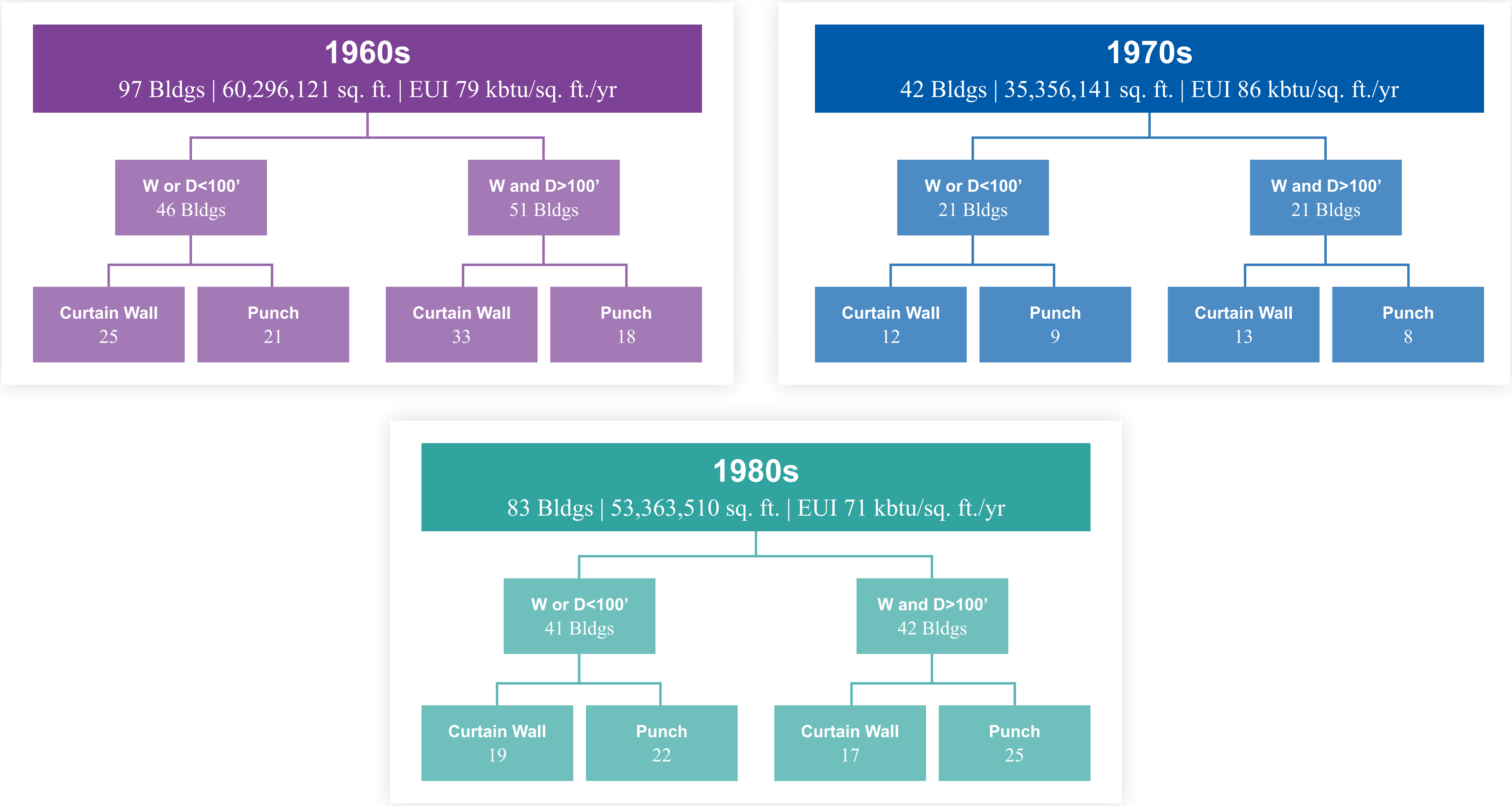
Filtering by floor plate (typical) depth allowed us to determine which buildings would likely require structural modifications for conversion. We assumed that buildings with a lot width and depth greater than 100 feet would require carving into the façade, or another significant structural and massing change, to provide enough light and air into deep floor plates (typical) to allow for efficient distribution of residential units. From the wide lot group, we filtered out tower buildings sitting on podiums, and lots with building footprints that only occupy a small portion of the lot.

This study makes the conservative assumption that windows in all buildings will need to be replaced to provide operable windows, as required for residential units, and to improve an assumed poor façade condition. To understand the embodied and operational carbon implications of window replacement, we further divide buildings into “curtain wall” and “punch” window buildings.

“Punch” windows have openings that are separated by opaque wall construction. “Curtain wall” buildings have independent enclosure systems covering the entire exterior of the building. This distinction was made from visual inspection of building images only. Curtain wall buildings are assumed to be entirely reclad, while punch windows will have only the fenestration replaced.

Methodology Overview | Typology selection

Typology grouping continued



Methodology Overview | Typology selection

Typology selection

Among the entire group of 222 buildings, we selected one example building from each of the twelve identified typologies. A standard score was developed for both site EUI and building area to understand deviation of each building from the mean of each typology group. By finding the absolute sum of the two standardized values, we then identified the building with the most "average" performance for site EUI and building floor area of all buildings in that typology. The most "average" buildings are selected as the 12 representative typologies and indicated in the chart at right.

Building address	Year built	Floor plate	Façade type	Site EUI (kBtu/ft²/yr)	Building area (ft²)
111 EAST 58 STREET	1969	Narrow	Curtain	78.4	596,734
1180 AVENUE OF THE AMERICAS	1963	Narrow	Punch	60.5	327,766
63 MADISON AVENUE	1962	Wide	Curtain	73.5	702,793
222 BROADWAY	1961	Wide	Punch	73.4	756,138
800 3 AVENUE	1970	Narrow	Curtain	108.2	526,124
88 PINE STREET	1973	Narrow	Punch	87.2	664,990
888 7 AVENUE	1970	Wide	Curtain	87.7	866,359
24 STATE STREET	1971	Wide	Punch	86.7	896,956
135 EAST 57 STREET	1987	Narrow	Curtain	63.4	397,354
45 BROADWAY	1983	Narrow	Punch	55.7	368,315
875 3 AVENUE	1982	Wide	Curtain	58.5	634,175
512 MADISON AVENUE	1982	Wide	Punch	77.4	1,015,287

Methodology Overview | Embodied Carbon

Calculation Approach

The methodology for estimating the embodied carbon associated with the conversions varies depending on typology. For wide typologies requiring structural intervention, analysis included estimating the embodied carbon associated with the demolition and disposal of the structure from the carving required (1). It also considered the upfront embodied carbon from the production and construction of the structure of assumed additional FAR that would be added to the building to balance any area lost by the carving (2).

Analysis of both the 'punch' and 'curtain wall' building typologies considered the embodied carbon associated with the demolition and disposal of existing windows, and the production and construction of new windows and curtain walls (3/4).

Example: 24 State Street – 1970s, 'Wide', with 'Punch' windows

Methodology Overview | Embodied Carbon

Data and Benchmarks

This analysis considered embodied carbon associated with the production and construction (A stage) of the retrofitted components, as well as the end-of-life stage (C stage) of demolition of existing building components. In this study, only embodied carbon of the enclosure and structural systems were included. Embodied carbon was not considered for MEP systems and interior components due to limited sources of robust embodied carbon data. The baseline used for comparison was the embodied carbon associated with the production and construction phase only (A stage) of a ground-up construction of a new residential apartment building with a concrete-steel hybrid structure and either punch or curtain wall enclosure.

Arup referenced EHDD Architecture's EPIC tool to provide a benchmark for A-phase embodied carbon values for hybrid concrete-steel structural systems.

A benchmark value of 350 kg CO_2e/m^2 was used for upfront emissions from new structural systems.

Arup also referenced Payette's Kaleidoscope embodied carbon design tool for the façade elements. A benchmark value of 125 kg CO_2e/m^2 was used for a curtain wall with aluminum spandrel and 103 kg CO_2e/m^2 was used for a concrete precast wall. An additional 10% of the A phase embodied carbon was assumed to account for end-of-life C phase embodied carbon for both structures and enclosure.

Methodology Overview | Embodied Carbon

Midtown Green Case Study

Our analysis of the structural implications of converting an existing office building with a wide floor plate into a residential building was developed from Arup's 2023 Metals in Construction competition submission, titled 'Midtown Green.' This conversion included floor plate modification and selective demolition that would allow for new apartment layouts with appropriate amounts of light and air. The area "cut-out" of the existing office building was then added on top of the building to maintain the same FAR.

Using this study as reference, the additional structure needed and the resulting change in surface area was factored into the embodied carbon analysis for the 'wide' building typologies. The 'narrow' building typologies did not require structural modifications and therefore no embodied carbon was associated with structural systems for narrow building retrofits.

Midtown Green, Metals in Construction 2023, Arup and SCHORN

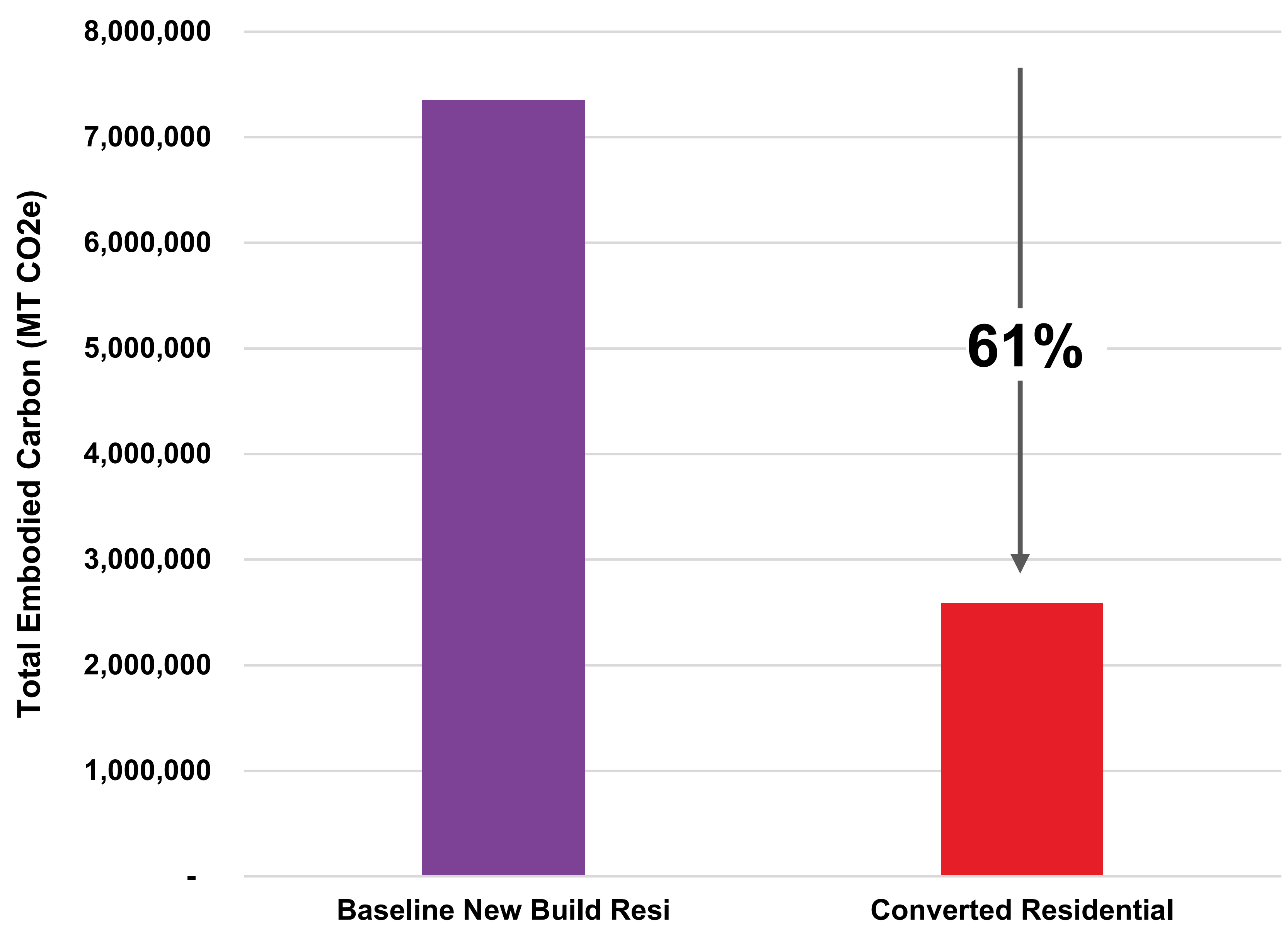
Methodology Overview | Embodied Carbon

Applying Embodied Carbon Calculations Across the Dataset

Embodied carbon associated with the demolition and replacement of enclosure and structure was scaled across the data-set using the rules established for each typology. We used building area, length, depth, and number of floors to calculate surface area, assuming a 12’ floor-to-floor height. For the wide typologies requiring structural intervention, the ratio of existing to additional square footage based on the ‘Midtown Green’ project was used to calculate the embodied carbon associated with the new structure. The ratio of the change in surface area from this example project was also used to calculate embodied carbon associated with new façade elements.

The result is that the total embodied carbon associated with office to residential conversions in this dataset reflects a 61% decrease from the embodied carbon associated with new construction of an equivalent area.

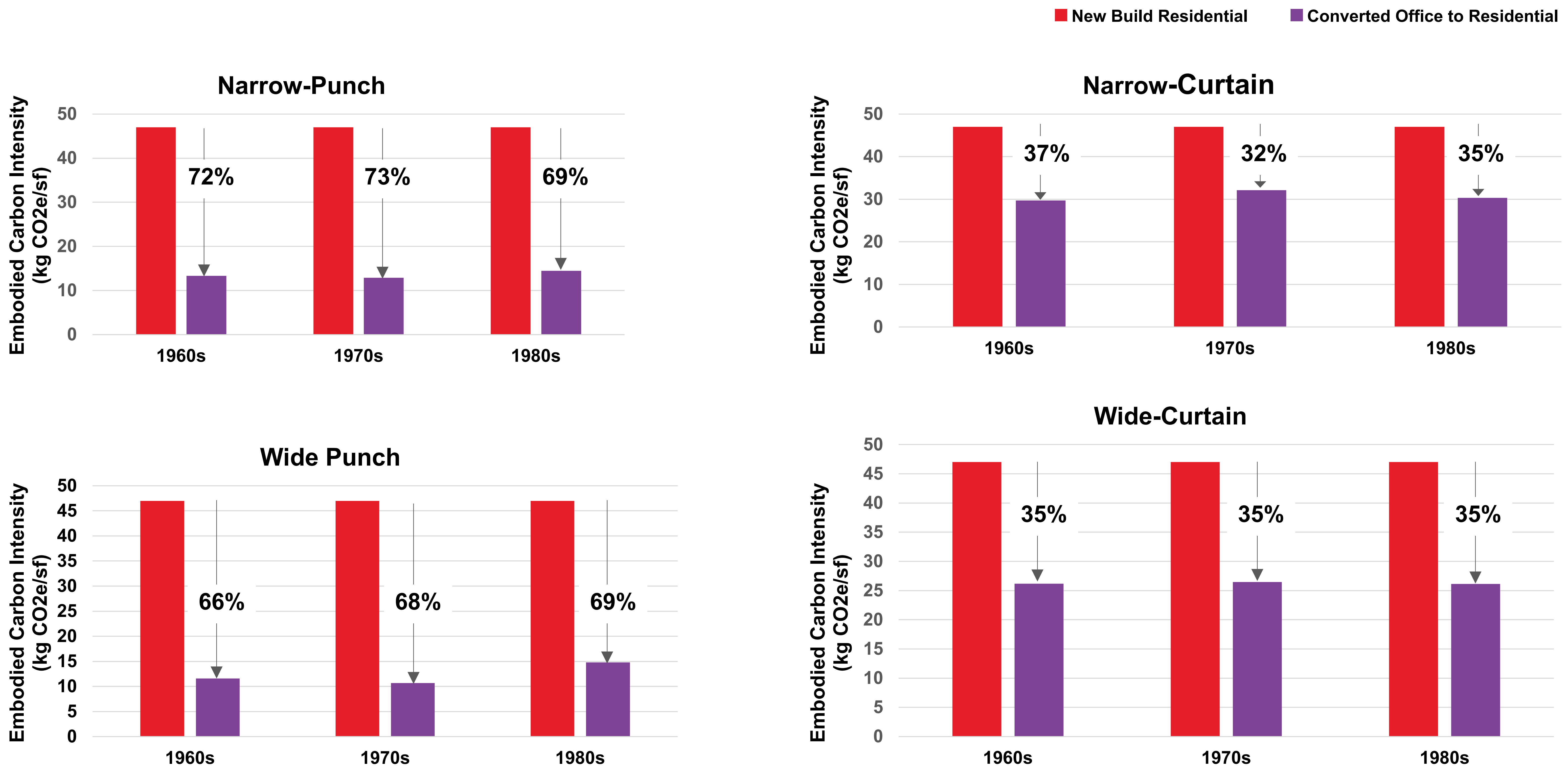
Total Embodied Carbon of Dataset



Methodology Overview | Embodied Carbon

Embodied Carbon Reduction per Typology

Embodied carbon savings below the baseline of new residential construction vary depending on building typology. Punch window typologies show a greater reduction in embodied carbon than curtain wall buildings, because only windows are demolished and replaced as opposed to a full facade. Additionally, narrow typologies require less carbon to convert than wide buildings because no structural changes are required.



Methodology Overview | Operational Carbon

EUI Conversion from Office to Residential Use

The energy use intensities (EUI) of all office buildings in the New York City dataset were converted to their residential equivalents to account for the changes in building use. Since the baseline site EUI of a multi-family residential building in NYC is 55 kBtu/sq. ft. according to the Architecture 2030 Zero tool, the decade out of the 1960s, 1970s, and 1980s with the greatest number of office buildings was made to be the one with an average converted site EUI of 55. Because the 1960s had the greatest number of buildings of the three decades (97 buildings total) and the median EUI of the set, the average EUI of this time period for residential buildings was made to be 55. The average site EUI of the 1970s and 19780s were scaled using the original ratios between the average office site EUI of the 1960s, 1970s, and 1980s.

By maintaining the original proportions of differences in EUI between the decades, inherent efficiencies and inefficiencies between buildings were accounted for when converting the use of the buildings. This resulted in a decade-average site EUI of 55 kBtu/sq. ft. for 1960s converted buildings, 60 for the 1970s, and 50 for the 1980s. The EUI of each individual office building in the dataset was then scaled by applying the percentage EUI reduction observed from the average existing office building and converted residential per decade. This equated to about a 30% reduction from the existing office EUI to converted residential building EUI, for each building in the dataset.

Average Office Site EUIs

1960-1969: 79 kbtu/sq. ft./yr
1970-1979: 86 kbtu/sq. ft./yr
1980-1990: 71 kbtu/sq. ft./yr

↓

Converted Residential Site EUIs:

1960-1969: 55 kbtu/sq. ft./yr
1970-1979: 60 kbtu/sq. ft./yr
1980-1990: 50 kbtu/sq. ft./yr

Methodology Overview | Operational Carbon

Applicable Energy Conservation Measures per Typology

Once the residential baseline EUI per building was established in the dataset, the impacts of implementing lighting, HVAC, and façade energy conservation measures (ECM) were calculated. The results of energy modelling studies for 1965-1990 existing multifamily residential buildings from Arup's Carbon-Free Boston study were used to estimate projected ECM savings. The reductions in site EUI estimated for lighting reduction, window replacement, increased wall insulation, reduced air infiltration, and heating, ventilation, and air conditioning (HVAC) and domestic hot water (DHW) electrification were applied based on the existing building's façade typology.

For buildings with punch windows, the converted building EUI was estimated based on projected EUI savings from implementing lighting reduction, HVAC and DHW electrification, and window replacement. Projected EUI savings from lighting reduction, HVAC and DHW electrification, and full façade replacement were applied to buildings with curtain wall facades. The full façade replacement is characterized by a window replacement consistent with the punch window scenario, as well as increased wall insulation and reduced air infiltration ECMs. We assume that residential conversions will necessitate full-building electrification as per Local Law 154, which prohibits on-site fossil fuel combustion for major renovations beginning in 2027.

Punch

-1.3%
Lighting reduction

-7.4%
HVAC and DHW electrification

-3.8%
Window replacement

Curtain Wall

-1.3%
Lighting reduction

-7.4%
HVAC and DHW electrification

-3.8%
Window replacement

-5.0%
Increase wall insulation

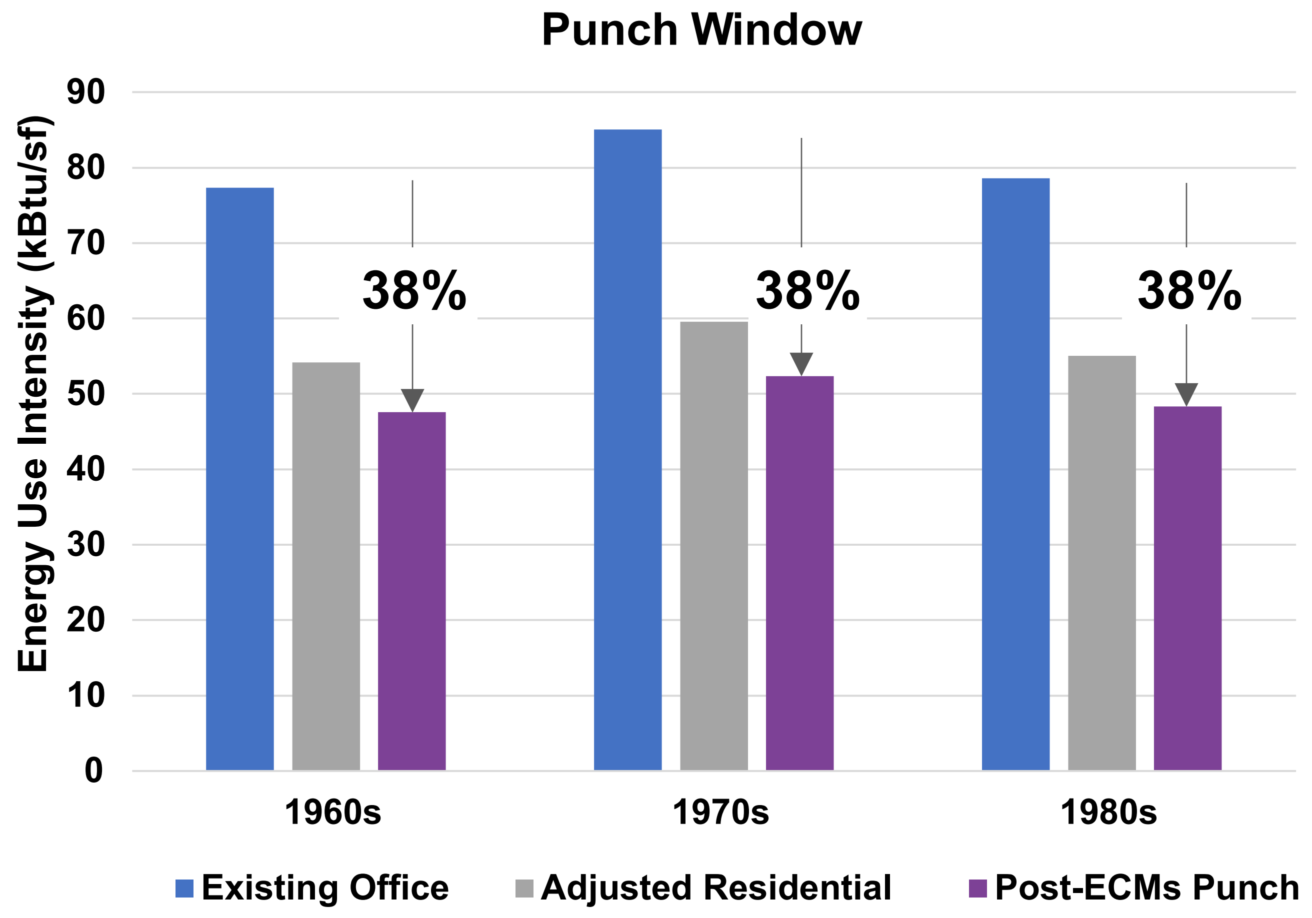
-12.9%
Reduce air infiltration

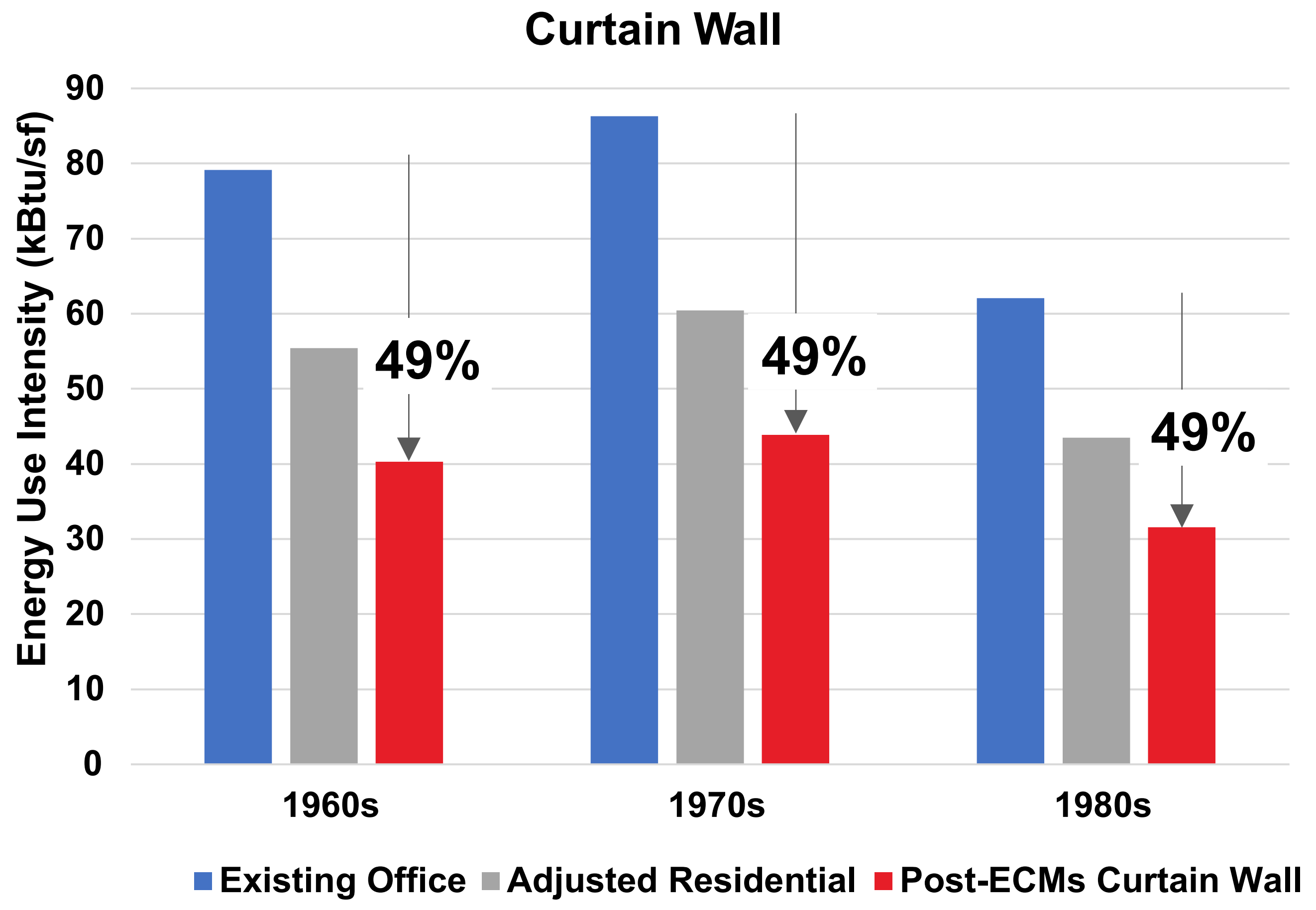
Triggered by Local Law 154

Methodology Overview | Operational Carbon

EUI Post-Residential Scaling and ECM Applications per Typology

Operational carbon savings below current performance are more significant for curtain wall buildings because of the additional energy efficiency improvements accounted for from full façade replacement.





Methodology Overview | Operational Carbon

Grid Emissions Intensity Factors

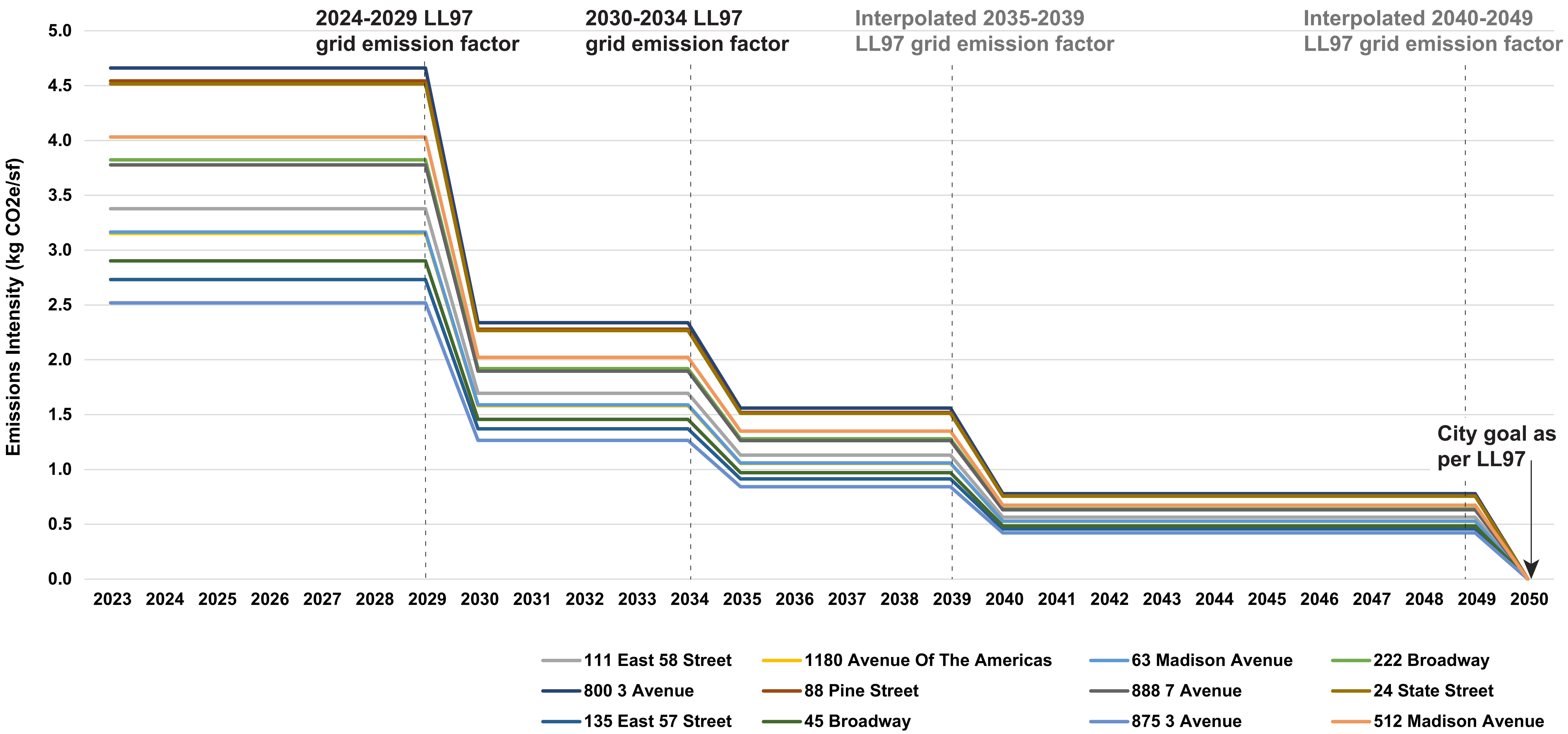
After applying the respective office-to-residential EUI conversion factors and the appropriate EUI percent reductions from ECMs by building typology, the resulting EUI and building areas were multiplied by the appropriate grid emission factors to calculate the expected CO_2e emissions out to 2050. The grid, natural gas, and district steam emission factors for Local Law 97 compliance periods 2024-2029 and 2030-2034 were sourced from the most recently adopted LL97 rules as of January 2023. For future compliance periods (2035-2039 and 2040-2049) with unpublished grid and steam emission factors from LL97, the electric emission factor was interpolated between the last known factor for 2030-2034 and the goal of 0 by 2050.

The steam emission factor was decreased at the linear ~4% decrease rate observed from the 2024-2029 and 2030-2034 factors to project forward the potential 2035-2039 and 2040-2049 emission factors. This conservative approach was adopted because Con Edison does not yet have tangible decarbonization plans in place for their steam production. The baseline emissions of the existing office buildings were calculated by applying the current electricity, natural gas, and/or steam emission factors as per Local Law 97 by the associated usage of each, per building. Projected CO_2e emissions of the all-electric converted residential buildings were calculated through 2050 using the published and interpolated Local Law 97 grid emissions factors per compliance period, as shown on the following page.

Methodology Overview | Operational Carbon

Yearly Emissions Intensity of Typology Buildings Post-Conversions to 2050

Per published local law 97 factors as of august 2023



Data sources

Building-Level Characteristics and Energy Data

1. Basic building information
   PLUTO and MapPLUTO (nyc.gov)
2. Energy Usage/EUI
   Energy and Water Data Disclosure for Local Law 84 2022 (Data for Calendar Year 2021) | NYC Open Data (cityofnewyork.us)
3. Energy benchmarking
   Benchmarking and Energy Efficiency Rating - Buildings (nyc.gov)

Whole-Life Carbon Calculations

Embodied Carbon

1. Office to Residential 'Wide' typology structural changes reference
   Arup's Metals In Construction competition submission 2023- "Midtown Green"
2. Structural Embodied Carbon reference
   EHDD's EPIC Tool
3. Enclosure Embodied Carbon reference
   Payette's Kaleidoscope Tool

Operational Carbon

1. Multifamily residential EUI reference
   Architecture 2030 Zero tool
2. ECM impact estimations
   Carbon-Free Boston Buildings Technical Report 2019
   – Supplemented by Arup modeling data and results
3. Local Law 97 emission factors and limits by typology
   DOB Local Law 97 Adopted Rules, Effective January 19, 2023

Contact

Report Authors

Tess McNamara
e: Tess.McNamara@arup.com

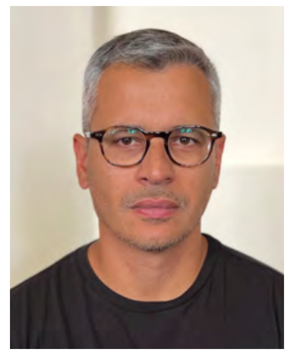
Monami Waki
e: monami.waki@arup.com

Katherine Schwartz
e: katherine.schwartz@arup.com

Wei Xiao

Contributors

David Farnsworth
e: David.Farnsworth@arup.com



Raju Mann

Lauren Wingo

Pallavi Mantha

Amy Liu Pathak

William Kovacs