# Analyzing Embodied Carbon for Retrofit and New Construction

## Case Study: The Beacon

**NYSERDA Buildings of Excellence Early Design Support Report**

PAUL A. CASTRUCCI, ARCHITECTS
PASSIVE HOUSE DESIGN FIRM

NEW YORK STATE OF OPPORTUNITY. | NYSERDA

# Overview

**In the push for carbon neutrality in the built environment, embodied carbon is an increasingly important factor for policy makers, designers, builders, and developers. To avoid the most catastrophic global warming scenarios, we know that we have to reduce our carbon footprint quickly. Carbon emitted in the next decade is critically important to staying below the carbon tipping point. However, the building industry is still early on in adopting embodied carbon as a metric for decision making across phases of the construction process.**

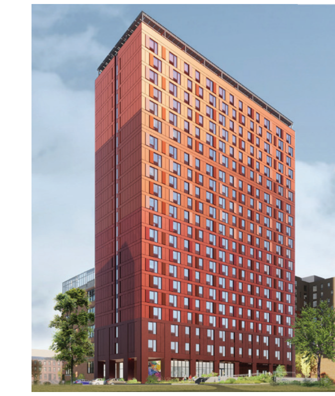
**How much emphasis should we place on embodied carbon in relation to operational carbon? When does it make sense to build new versus re-use an existing structure? When we are specifying assemblies, which materials are most important to consider in driving down embodied carbon? This report addresses these important questions surrounding embodied carbon in the built environment of New York City.**

**Using the Beacon project in East Harlem as a case study, we compare and contrast two very different building types that are part of the same project. The site contains a new construction, affordable housing building and an adaptive re-use school building, transforming into a Multi-Service Community Facility building with a rooftop addition. We examine overall embodied carbon, how material and construction choices affect total carbon footprint and operational carbon, and how new construction compares to adaptive re-use for embodied and operational carbon. These contrasting building types offer a unique opportunity to inform our understanding of embodied carbon in our work, and we hope that this report will be used by the building industry in our shared pursuit of a carbon neutral future.**

# Case Study + Process

## CASE STUDY: THE BEACON

The Beacon is an exciting project that combines much needed affordable housing with the adaptive re-use conversion of an existing school building into a local community center. The Beacon is located at 413 East 120th Street in East Harlem, a culturally rich and historic neighborhood in Upper Manhattan. This predominantly residential neighborhood is nestled between both private and public multi-family housing: NYCHA's Senator Robert F. Wagner ("Triborough Houses") is located to the east and Acacia Gardens to the west.



RESIDENTIAL
NEW CONSTRUCTION
200,032 SF

The project has two major buildings:

1. **New Construction Residential Tower:** 21 story building with 266 affordable housing units. This building is designed to be a poured concrete structure with prefabricated metal panel façade. This building is on the North portion of the site. The new construction building is 200,032 SF.
2. **Adaptive Re-Use Multi-Service Center (MSC) Building:** Existing 5 story school building slated for adaptive re-use, along with a one story greenhouse addition. The existing building has a concrete structure with historic masonry envelope. Retrofit strategies will be focused on the interior of the existing building to preserve the existing, contextual façade. The adaptive re-use building is 66,391 SF.

MULTI-SERVICE CENTER
ADAPTIVE RE-USE
66,391 SF

## PROCESS

At the end of Schematic Design for both the adaptive re-use and new construction projects, the design teams produced drawings and narratives that outlined the scope of work, including proposed structural, thermal envelope, fenestration and MEP systems. Using these specifications, our consultant, ZeroEnergy Design, used BEAM software to assess the embodied carbon of both the new building and the adaptive re-use. [1] Our team used this data to further delineate the embodied carbon by phase of construction using established databases, including The Structural Carbon Tool Version 2 from The Institute of Structural Engineers and The Inventory of Carbon and Energy Version 2.0 from Building Services Research and Information Association (BSRIA). [2]

In order to compare embodied carbon to operational carbon, the team created energy models for two scope packages for each building:

1. **Baseline Scope:** This scope package meets, but does not exceed, 2022 NYC Energy Code requirements.
2. **Passive House Scope:** This scope package meets Passive House certification requirements.

Using these models, we established the annual energy use of both buildings, and converted to annual carbon emissions using BE-EX's online carbon footprint calculator. [3] We also analyzed how different material and system choices in key categories - structure,insulation, and windows - would affect the overall embodied carbon. The team analyzed net changes in embodied carbon when each of these alternatives were used independently.

# Results

- The new construction building has 13x as much embodied carbon as the adaptive re-use.
- The new construction building has 3x as much embodied carbon per SF as the adaptive re-use building.
- Concrete (structrual, foundation and slabs) accounts for 3/4ths of the embodied carbon in the new construction building.
- The windows account for 2/3rds of the embodied carbon in the adaptive re-use building.

The key driver of increased embodied carbon in new construction is the need to build a new structural system. Concrete from foundations and structure is the leading contributor to total embodied carbon.

For the adaptive re-use building, we are able to retain the existing concrete foundation and structure, so that 'smaller' design decisions such as window frame type have a larger impact on relative embodied carbon performance.

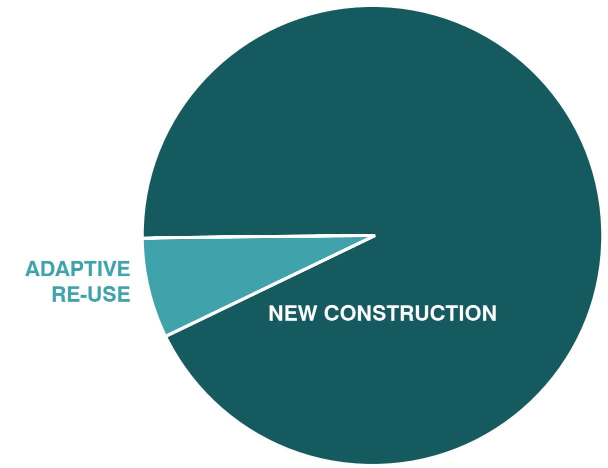



**FIG. 1** TOTAL EMBODIED CARBON ACROSS SITE


**FIG. 2** ADAPTIVE RE-USE CARBON INTENSITY


**FIG. 3** NEW CONSTRUCTION CARBON INTENSITY

ADAPTIVE RE-USE

EMBODIED CARBON

Total
**419 tCO2e**

Carbon Intensity
**0.0063 tCO2e/SF**

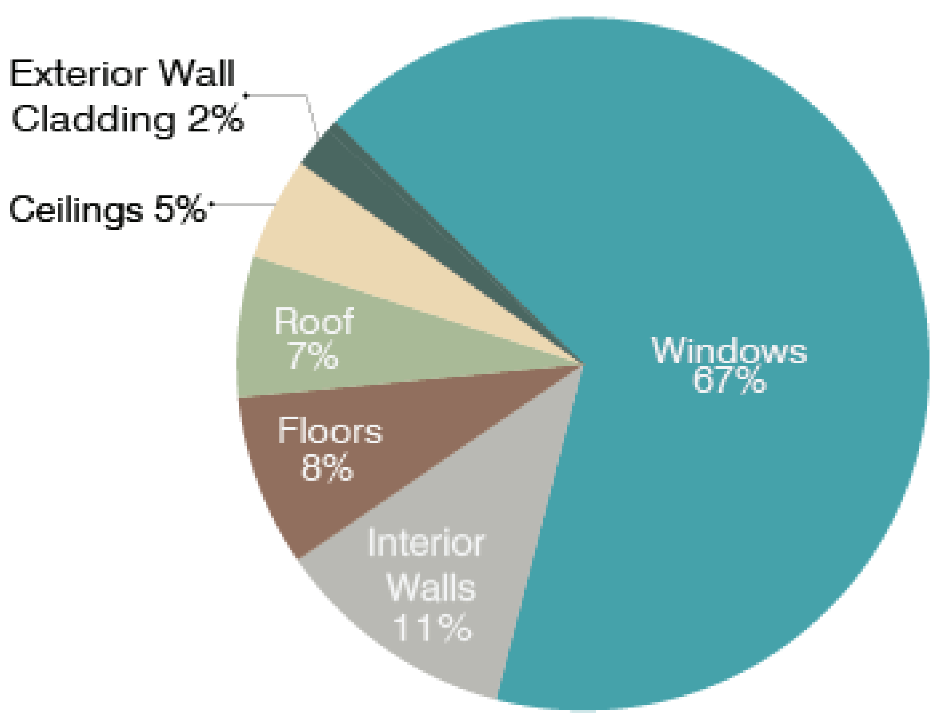



**FIG. 4** ADAPTIVE RE-USE EMBODIED CARBON EMISSIONS BY ASSEMBLY

NEW CONSTRUCTION

EMBODIED CARBON

Total
**5,586 tCO2e**

Carbon Intensity
**0.0215 tCO2e/SF**

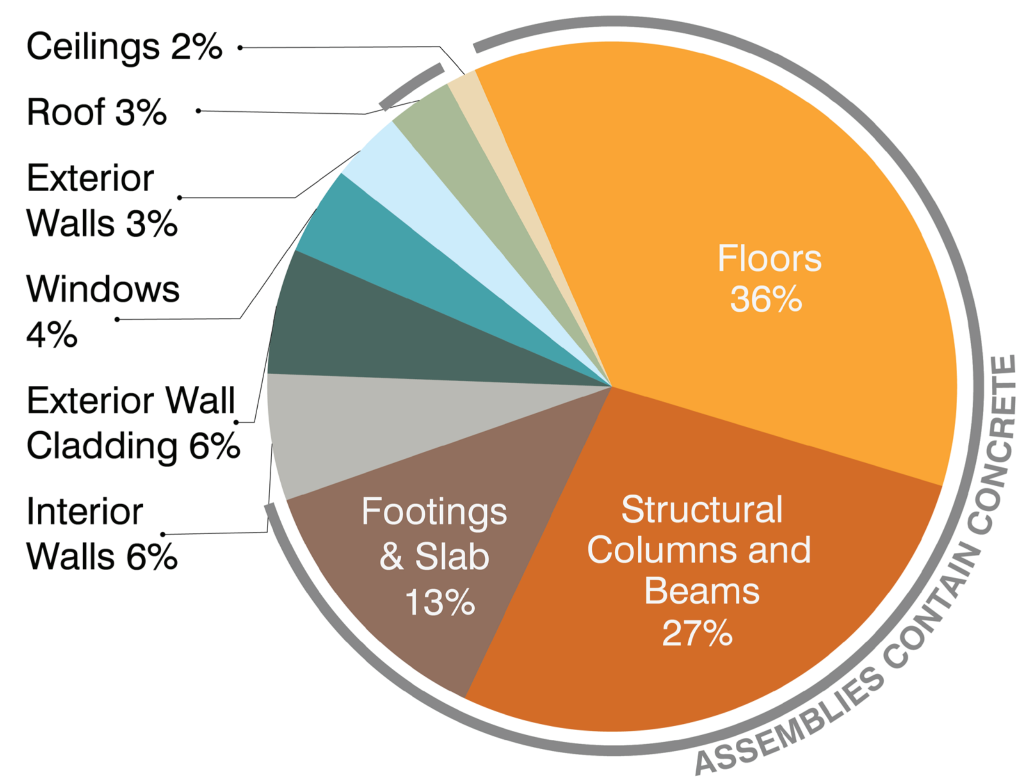



**FIG. 5** NEW CONSTRUCTION EMBODIED CARBON EMISSIONS BY ASSEMBLY

# Embodied Carbon vs Operational Carbon

The Passive House scopes for both the new construction and adaptive re-use yield significant operational carbon savings compared to their respective 2020 NYECC code-compliant scopes. The Passive House new construction emits 30% less carbon, and the adaptive re-use emits 40% less carbon.

The new construction Passive House scope emits roughly the same operational carbon per SF as the adaptive re-use. This facilitates the comparison of embodied carbon in the life cycle carbon footprint of a building.

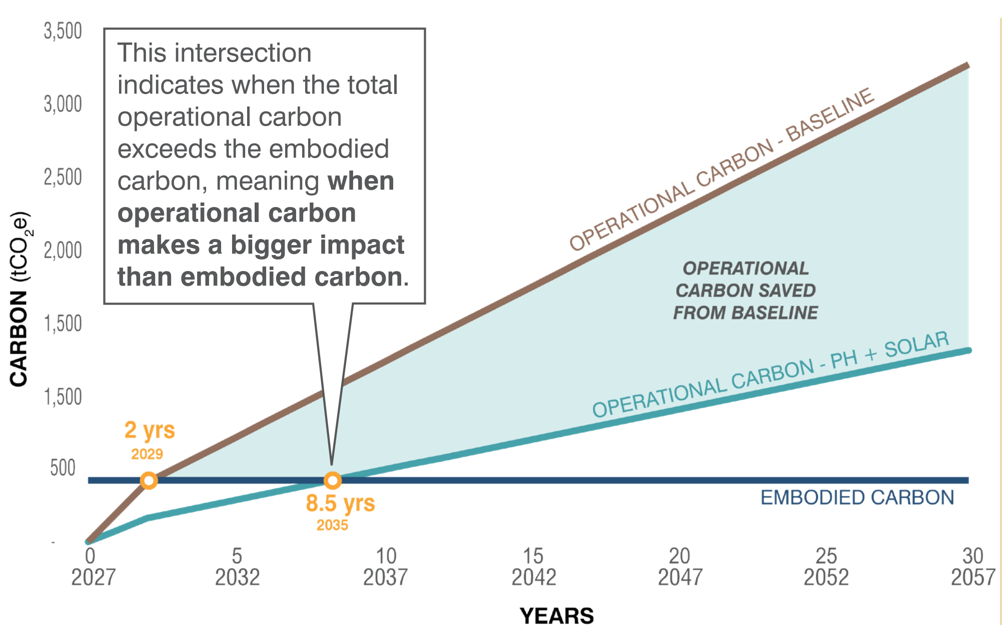
On a total carbon intensity basis, considering both embodied and operational carbon, the adaptive re-use building outperforms the new construction building past the critical 2050 threshold. **Even though the adaptive re-use has an operational carbon intensity roughly equal to the new construction building, the initial embodied carbon generated by the new building significantly increases the total carbon footprint of the building in the critical timeframe between now and 2050. As buildings become more efficient, the effect of embodied carbon grows proportionally larger.**

For the new construction building, the operational carbon generated by the Baseline scope is equal to the total embodied carbon in about 16 years. The timeline is lengthened by almost 2x for the Passive House scope, where the operational carbon generated equals total embodied carbon after about 29 years. This tells us two things: 1) The Passive House scope is significantly reducing the total carbon footprint of the building, and 2) after addressing operational carbon through Passive House, careful design to minimize embodied carbon is essential for creating truly low carbon buildings.

For the adaptive re-use building, both the embodied carbon and operational carbon is significantly lowered, but the pattern remains. The operational carbon generated by the Baseline scope is equal to the total embodied carbon in just over 2 years. Using the Passive House scope, the timeline is nearly doubled, where the total operational carbon generated is equal to the embodied carbon after just after 8 years.

## ADAPTIVE RE-USE

| OPERATIONAL CARBON | BASE CASE | PASSIVE HOUSE + SOLAR |
|---|---|---|
| | Total | Total |
| 2024-29 | **203 tCO2e/yr** | **81 tCO2e/yr** |
| 2030+ | 102 tCO2e/yr | 41 tCO2e/yr |
| | Carbon Intensity | Carbon Intensity |
| 2024-29 | **0.0031 tCO2e/SF/yr** | **0.0012 tCO2e/SF/yr** |
| 2030+ | 0.0015 tCO2e/SF/yr | 0.0006 tCO2e/SF/yr |




**MATERIAL SCOPE**

**Structural:** Existing

**Windows:** Aluminum

**Insulation:** EPS

**Exterior Facade:** Existing

**Interior Walls:** Wood Stud at exterior wall and steel studs for partitions

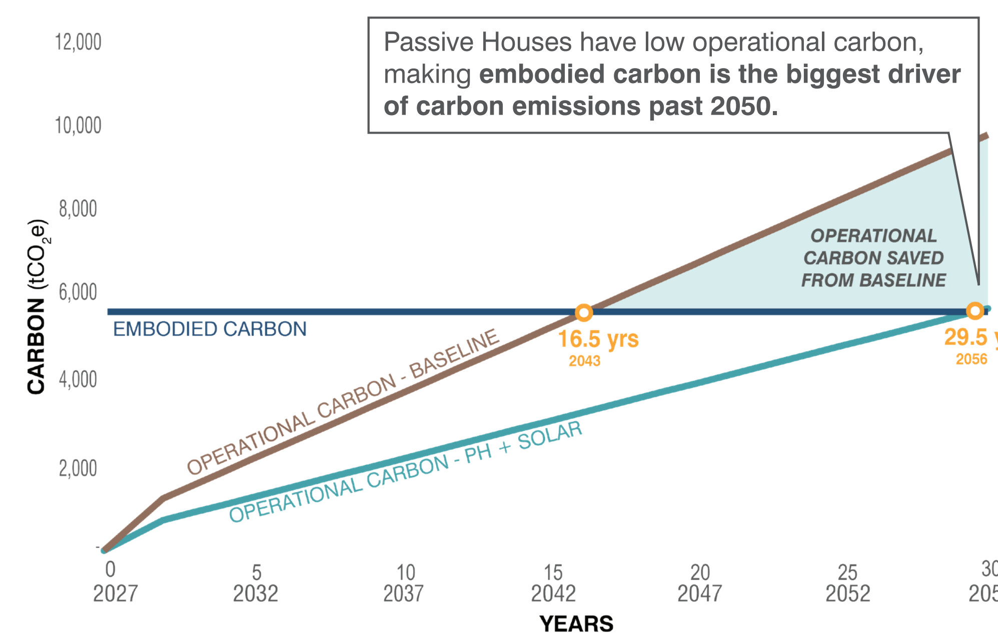
**Foundation and Footing:** Existing

**Roof:** 6" polyiso with EPDM membrane

**FIG. 6 ADAPTIVE RE-USE**
**OPERATION CARBON VS. EMBODIED CARBON**

## NEW CONSTRUCTION

| OPERATIONAL CARBON | BASE CASE | PASSIVE HOUSE + SOLAR |
|---|---|---|
| | Total | Total |
| 2024-29 | **606 tCO2e/yr** | **353 tCO2e/yr** |
| 2030+ | 304 tCO2e/yr | 177 tCO2e/yr |
| | Carbon Intensity | Carbon Intensity |
| 2024-29 | **0.0023 tCO2e/SF/yr** | **0.0014 tCO2e/SF/yr** |
| 2030+ | 0.0012 tCO2e/SF/yr | 0.0007 tCO2e/SF/yr |




**MATERIAL SCOPE**

**Structural:** Concrete columns

**Windows:** uPVC triple glazed

**Insulation:** EPS

**Exterior Facade:** Steel infill with EIFS

**Interior Walls:** Steel Stud

**Foundation and Footing:** Insulated concrete slab and uninsulated footing

**Roof:** 6" polyiso with EPDM membrane

**FIG. 7 NEW CONSTRUCTION**
**OPERATION CARBON VS. EMBODIED CARBON**

# Material Drivers

### ADAPTIVE RE-USE

- **The most impactful assemblies are windows and insulation.**
- **Windows account for 67% of the building's embodied carbon in the adaptive re-use building.**
- Changing the interior furred walls from steel to wood decreases the buildings embodied carbon by 3%.
- Changing the interior insulation from fiberglass to spray foam increases the embodied carbon by 15%, while operational performance may only slightly increase.

### NEW CONSTRUCTION

- **The most impactful assembly is structure, where we should focus on limiting concrete.**
- **Structural concrete dominates the total embodied carbon, where concrete contributes 85% to the total carbon emissions.**
- EIFS and uPVC windows are the highest contributors after concrete, totaling 5% and 4% respectively.

We reviewed material alternatives for structural systems, insulation, and window types that could still reach Passive House performance, a helpful method for making better material choices.

- The most impactful low carbon solution varies between new construction and adaptive re-use. For all projects, evaluating alternatives for windows like uPVC can lower embodied and operational carbon, though the relative impact of this decision is much greater in adaptive re-use. Aluminum windows are consistently a large contributor in new construction and adaptive re-use.
- The material alternatives for the residential building show that structure can have the biggest impact on total embodied carbon, ranging from an added 9% (CMU Block Walls) to a reduction of 52% (mass timber). Aluminum windows have an oversized impact for their mass in the building compared to structure, whereas insulation is negligible.
- The need for new, carbon intensive, structural systems is eliminated for the adaptive re-use. This elevates the importance of other components, like window frame, stud framing, and insulation material. Aluminum windows contribute 67% of the total carbon, and changes to stud and insulation material contribute a range of 3-15%.

ADAPTIVE RE-USE

| CATEGORY | ALTERNATIVES | EMBODIED CARBON (kg CO2e) | EMBODIED CARBON INTENSITY (kg CO2e/SF) | PERCENTAGE CHANGE |
|---|---|---|---|---|
| BASE SCOPE | - | 379,792 | 7.5 | - |
| STRUCTURE | STEEL STUDS | 389,843 | 7.7 | 3% |
| INSULATION | MINERAL WOOL | 413,762 | 8.1 | 9% |
| | CLOSED-CELL SPRAY FOAM | 435,693 | 8.6 | 15% |

NEW CONSTRUCTION

| CATEGORY | ALTERNATIVES | EMBODIED CARBON (kg CO2e) | EMBODIED CARBON INTENSITY (kg CO2e/SF) | PERCENTAGE CHANGE |
|---|---|---|---|---|
| BASE SCOPE | - | 5,067,257 | 20.0 | - |
| STRUCTURE | BLOCK WALLS | 5,542,718 | 21.9 | 9% |
| | CLT | 2,413,698 | 9.5 | -52% |
| WINDOWS | ALUMINUM WINDOWS | 5,464,423 | 21.6 | 8% |
| INSULATION | RIGID MINERAL WOOL | 5,073,395 | 20.0 | 0.1% |

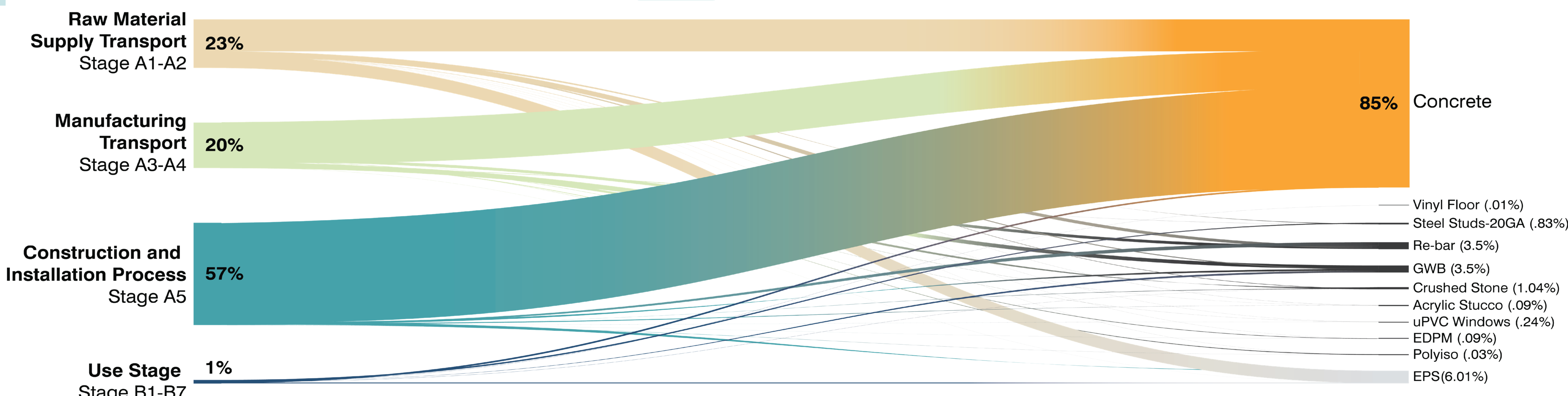



FIG. 8 NEW CONSTRUCTION EMBODIED CARBON BY STAGE AND MATERIAL

# Conclusion

**We are pleased to submit the results of this analysis to building owners and developers, public policy officials, builders and our fellow designers. Following our analysis, our broad stroke takeaways are as follows:**

- **From now until 2050, embodied carbon is a leading contributor of total carbon.**
- **In the pre-development process, teams should seriously consider whether the project goals can be achieved by re-using existing infrastructure.**
- **Building performance is another critical component to long term carbon emission performance. The base case energy code buildings studied emit between 2.5x to 3x the operational carbon as the Passive House buildings.**
- **If the building must be new construction, serious consideration should be given to reducing or eliminating concrete and CMU masonry in the building structure.**
- **Mass timber and wood frame are promising structural alternatives. Current building codes make implementing wood stud construction impossible in most of NYC, and mass timber and mass timber are not currently a large part of the construction market. Current building codes are weighted against wood stud construction. Mass timber and mass timber projects are limited to early adopters and run the risk of issues that arise from limited experience. Policy makers and industry leaders should coordinate to identify barriers to implementing mass timber and wood frame - including increasing the permitted height of mass timber buildings - and collaborate in addressing concerns and incentivizing alternate structural systems.**
- **For adaptive re-use, the biggest contributors to embodied carbon for the new construction are removed. This makes other categories, like windows and insulation, more impactful.**
- **Designers should strongly consider uPVC windows and low carbon intensity insulation where possible.**

ADAPTIVE RE-USE

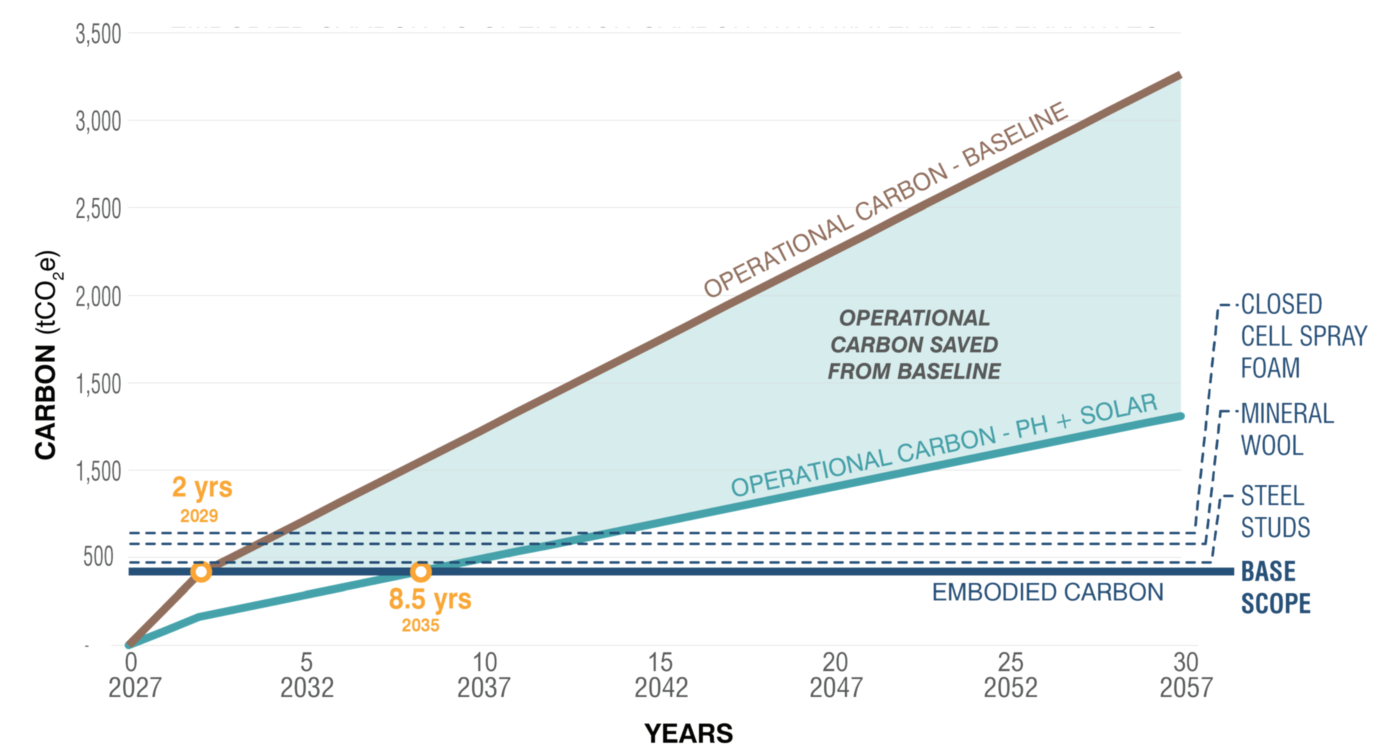



**FIG. 9** **ADAPTIVE RE-USE**
**OPERATIONAL CARBON, EMBODIED CARBON, AND MATERIAL ALTERNATIVES**

NEW CONSTRUCTION

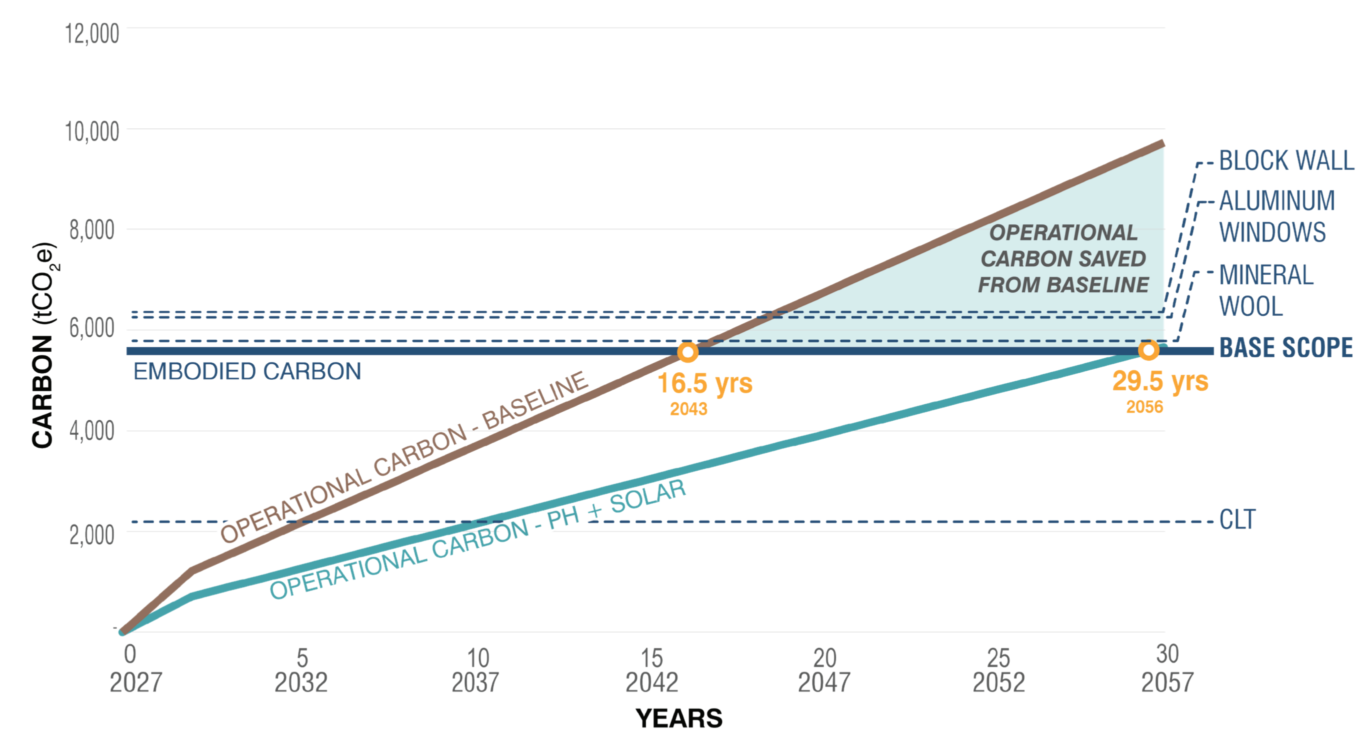



**FIG. 10** **NEW CONSTRUCTION**
**OPERATIONAL CARBON, EMBODIED CARBON, AND MATERIAL ALTERNATIVES**

# Acknowledgements and Abbreviations


## ACKNOWLEDGEMENTS

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Contributors:

- Zero Energy Design - WUFI Energy Modeling, Embodied Carbon Modeling
- The Beacon project team
- The Community Builders (TCB) - co-developer
- Ascendant Neighborhood Development (AND) - co-developer
- Body Lawson Associates, Architects and Planners- co-architect residential building
- WXY Studio - co-architect residential building
- Dagher Engineering- MEP engineer
- Robert Silman Associates - Structural engineer


## ABBREVIATIONS

**Btu** - British Thermal Unit

**DOB** - Department of Buildings of New York City
**HPD** - Housing Preservation Department of New York City
**kWh** - kilowatt hours
**kW** - kilowatt
**LL** - Local Law
**NYC** - New York City
**NYSERDA** - New York State Energy Research & Development Authority
**PCA** - Paul A. Castrucci, Architects
**PH** - Passive House
**SDA** - Solar Design Associates
**SBS** - Sentient Building Systems
**tCO2e** - Tons of Carbon Dioxide Emitted
**Therm** - 100,00 btu

## FOOTNOTES

1 BEAM
https://www.buildersforclimateaction.org/beam-estimator.html

2 The Structural Carbon Tool Version 2 from The Institute of Structural Engineers
https://www.istructe.org/resources/guidance/the-structural-carbon-tool/
The Inventory of Carbon and Energy Version 2.0 from Building Services Research and Information Association (BSRIA)
https://greenbuildingencyclopaedia.uk/wp-content/uploads/2014/07/Full-BSRIA-ICE-guide.pdf https://www.buildersforclimateaction.org/beam-estimator.html

3 Building Energy Exchange LL97 Calculator
https://be-exchange.org/ll97-calculator/


## AUTHORS

This report is written and presented by Paul A. Castrucci, Architects, PLLC, an architecture practice committed to sustainability, equity, and community. Primary authors of data analysis, narrative, data visualization, and design are Grayson Jordan and Ana Leopold. The firm was founded 30 years ago by architect and community advocate Paul A. Castrucci, R.A. to establish an architecture practice around craftsmanship, functionality, and the preservation of the environment. The firm's services are focused on new buildings that are Passive House and Net Zero certified where possible, as well as deeply sustainable rehabilitation of existing structures. We design buildings that will benefit generations to come, striving towards Net Zero buildings that are in sync with natural rhythms, solar access, shading and light, wind, and vegetative patterns. We strive to provide design solutions that integrate Passive House building techniques into the community fabric while maintaining a commitment to design excellence. Having completed NYC's first Passive House + Net Zero building (R-951 Residence), more than a dozen Passive House buildings, and a wide portfolio of projects for non-profit, and affordable housing units, we are recognized leaders in affordable, high efficiency building design. You can find us at ***www.castrucciarchitect.com.*** This report was written by Grayson Jordan and Ana Leopold at Paul A. Castrucci, Architects based on the data provided by our contributors. Additional data analysis and visualizations by Asher Charno and Aaryan Nair.