Seeing the Forest Through the Trees - A Guide to Low Carbon Wood Buildings

Energy Trust of Oregon | Net Zero Fellowship

LEVER

Team



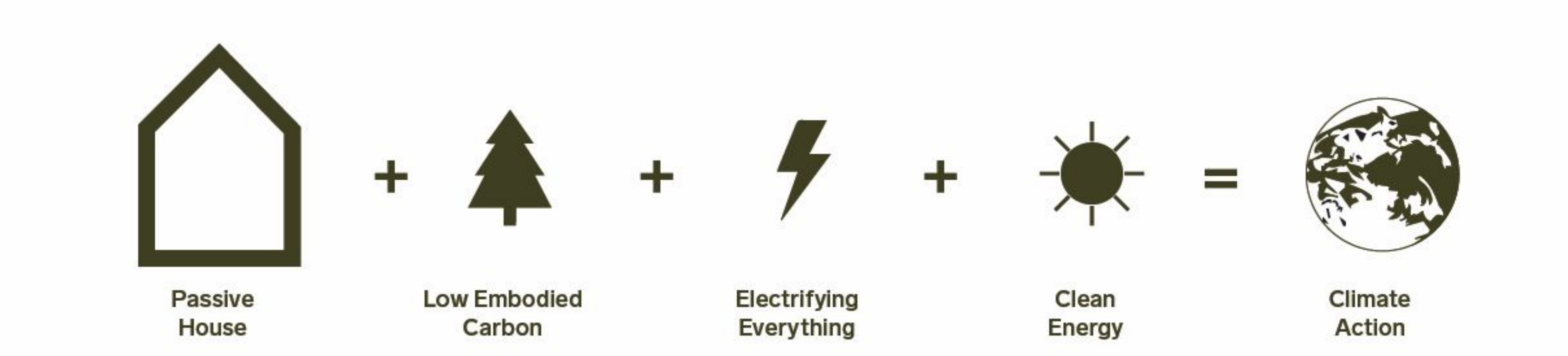
Skidmore Passivhaus

Albina Yard

LEVER Portland Mass Timber Projects

Intro + Methodology

Why this Research



- Changing climate gives urgency to rapidly decarbonize
- Relationship of energy efficiency and low embodied carbon
- Low rise wood buildings are still most prevalent construction type
- Pros and cons of Mass Timber vs Stick Frame
- Key decisions to make low carbon wood buildings
- Are Net-Zero Carbon Buildings possible?

Research Questions

- Which wood structure type has lowest embodied carbon?
- What assemblies are required to meet Passive House (PH)? (climate zone 4c)
- How do Mass Timber and Stick Framed PH assemblies compare?
- What assemblies have lowest embodied carbon?
- When is Mass Timber more appropriate than Stick Frame?
- How do we create zero-carbon or lowest carbon buildings?

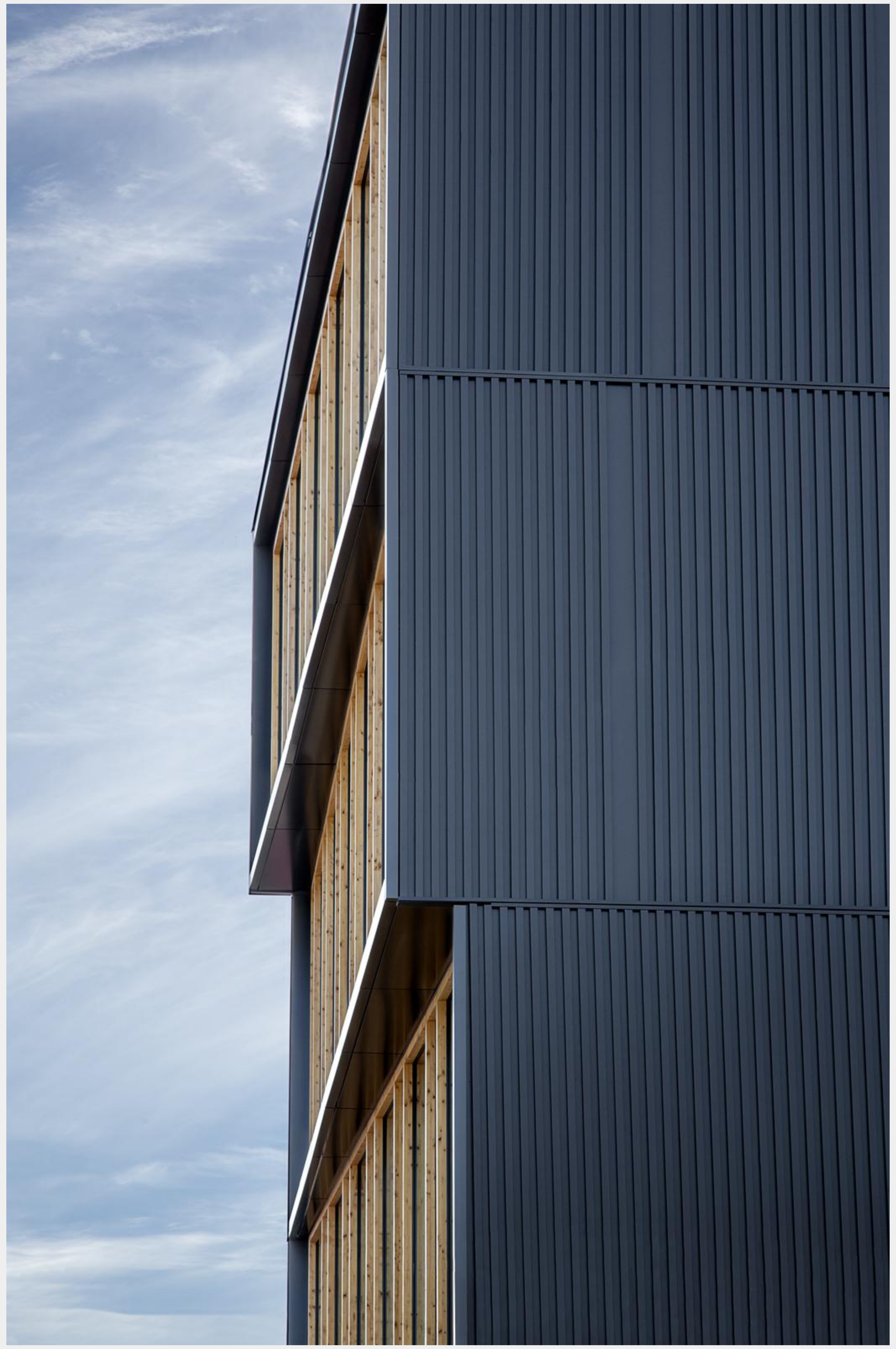
Research Goals

Three Case Study Projects:

1. Compare Exterior Building Assemblies
    - Code Minimum
    - Passive House Compliant
        - Wood Stick Framed & Mass Timber

2. Compare Embodied Carbon
    - Code Minimum
    - Passive House Compliant
        - Wood Stick Framed &Mass Timber

3. Determine Optimal Approach
    - Reduce Whole Building Carbon
    - Net Zero Carbon in 25 years if possible



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Methodology

Three Case Study Projects:

Step 1: Determine Assembly R-Values to Meet Passive House

Step 2: Estimate Embodied Carbon of Resulting Buildings

Step 3: Determine PV Array Size ideally to achieve Net Zero Carbon

Step 4: Evaluate the Embodied Carbon Calculations

Step 5: Provide Strategies and Recommendations


The Language of Carbon
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Why Carbon

Estimate full impact of emissions from construction

(impossible if measuring only energy)

Estimate emissions from buildings and also supply chains

Carbon is a universal metric

Buildings are responsible for ~39% of global carbon emissions

The Many Names of Carbon

Carbon Dioxide (C02)

Carbon Dioxide Emissions

Carbon Emissions

Carbon Dioxide Equivalent (CO2e)

Greenhouse Gas Emissions (GHG)

Global Warming Potential (GWP)

$$\underbrace{Tc}_{\text{Total Carbon}} = \underbrace{Ec}_{\text{Embodied Carbon}} + \underbrace{Oc}_{\text{Operational Carbon}}$$

Embodied Carbon

- CO_2 emissions from extraction and production of materials
- CO_2 emissions from construction
- CO_2 emissions from use of building (maintenance, replacement, repairs)
- CO_2 emissions from end-of-life (deconstruction, demolition, recycling)

Operational Carbon

- CO_2 emissions from operation of a building (heating, cooling, lighting, etc)

The Time Value of Carbon

Reducing emissions today is more valuable than reducing emissions in the future.

<u>Upfront Emissions Approach</u>

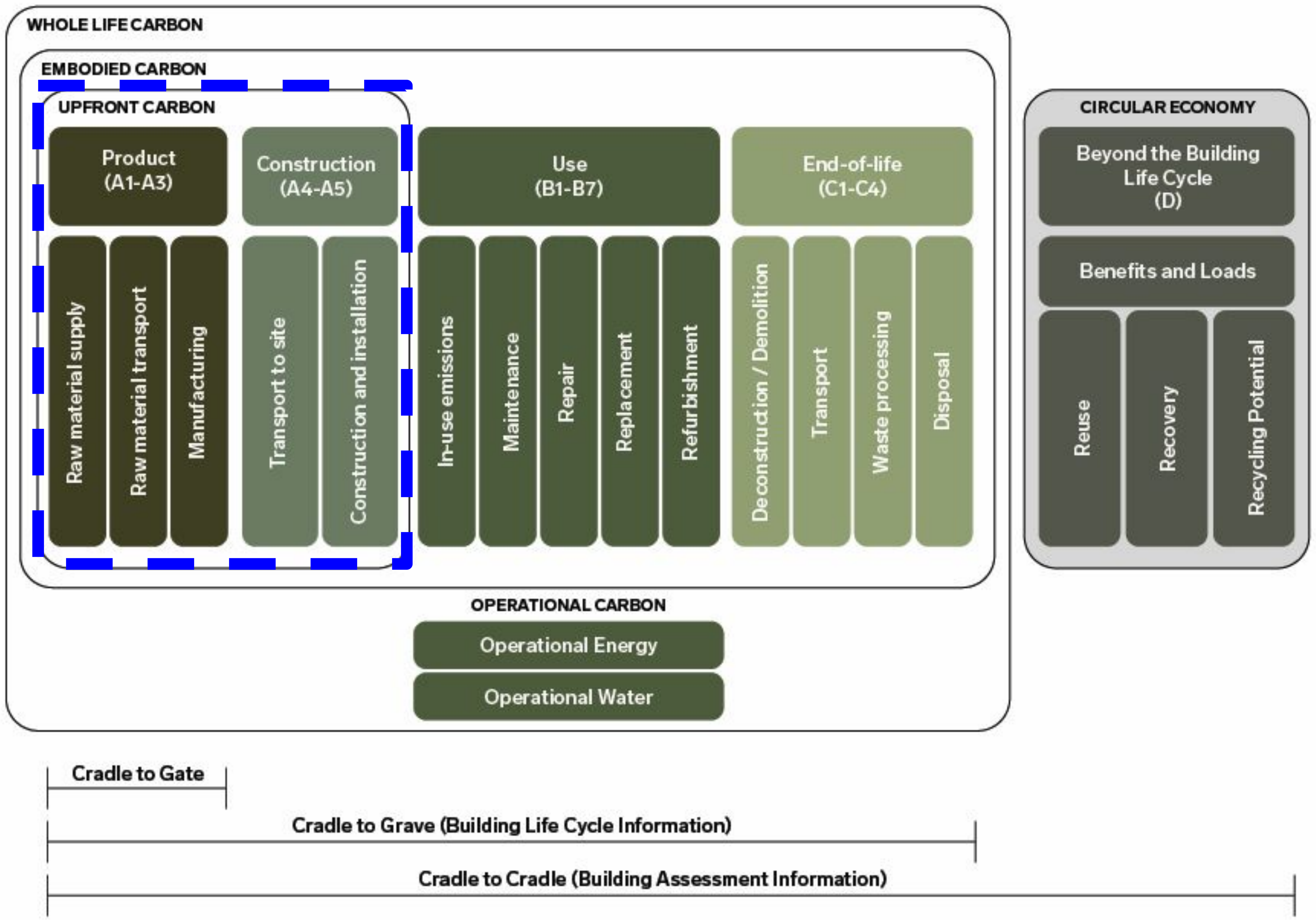
Reduce upfront emissions whenever possible, even if it means increased operational carbon emissions over the life of a building.

<u>Total Emissions Approach</u>

Select strategies that emit the least carbon over a building's lifetime, even if they result in increased upfront emissions.

Stages of Carbon

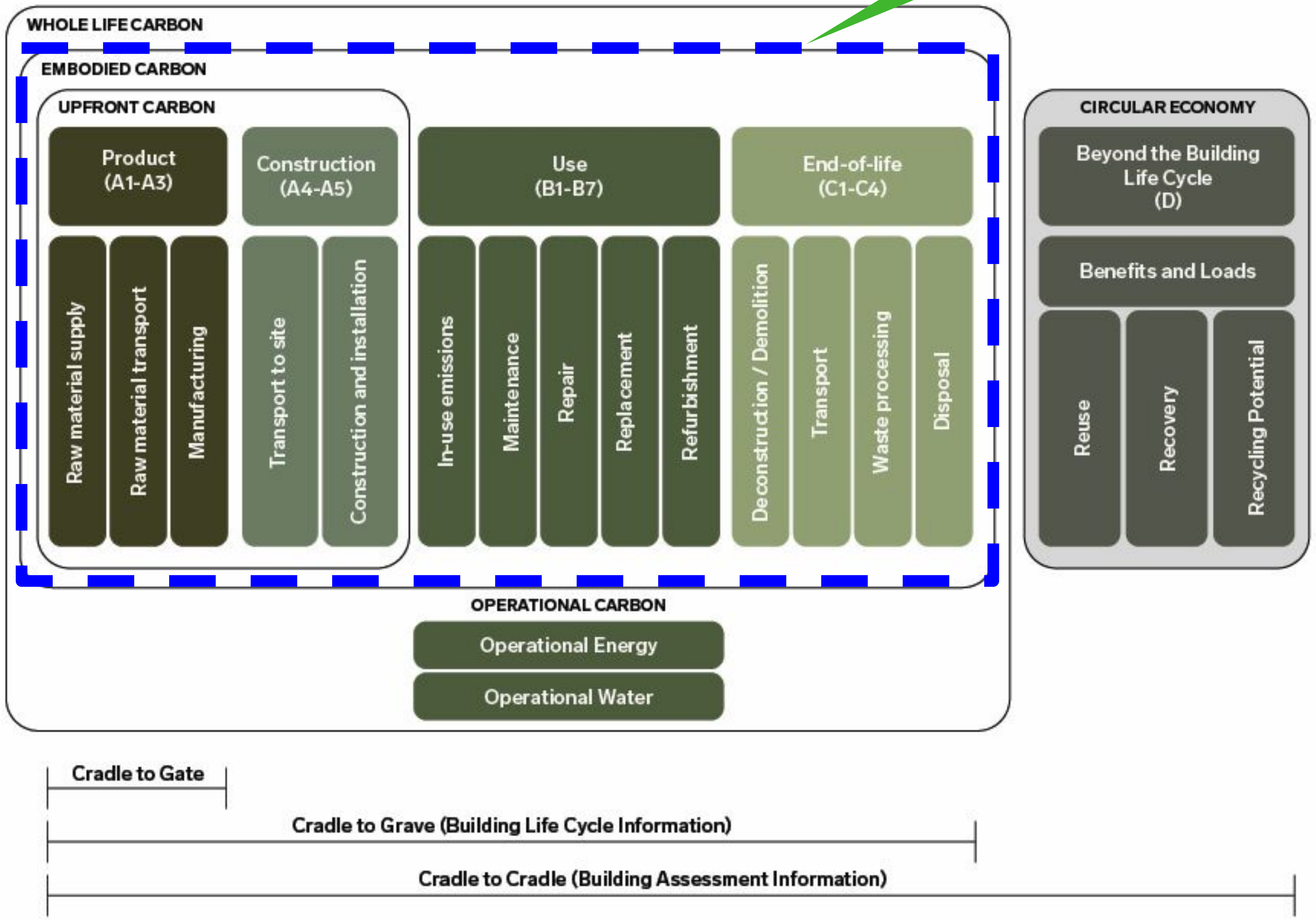
Upfront (A1-A5)



Stages of Carbon

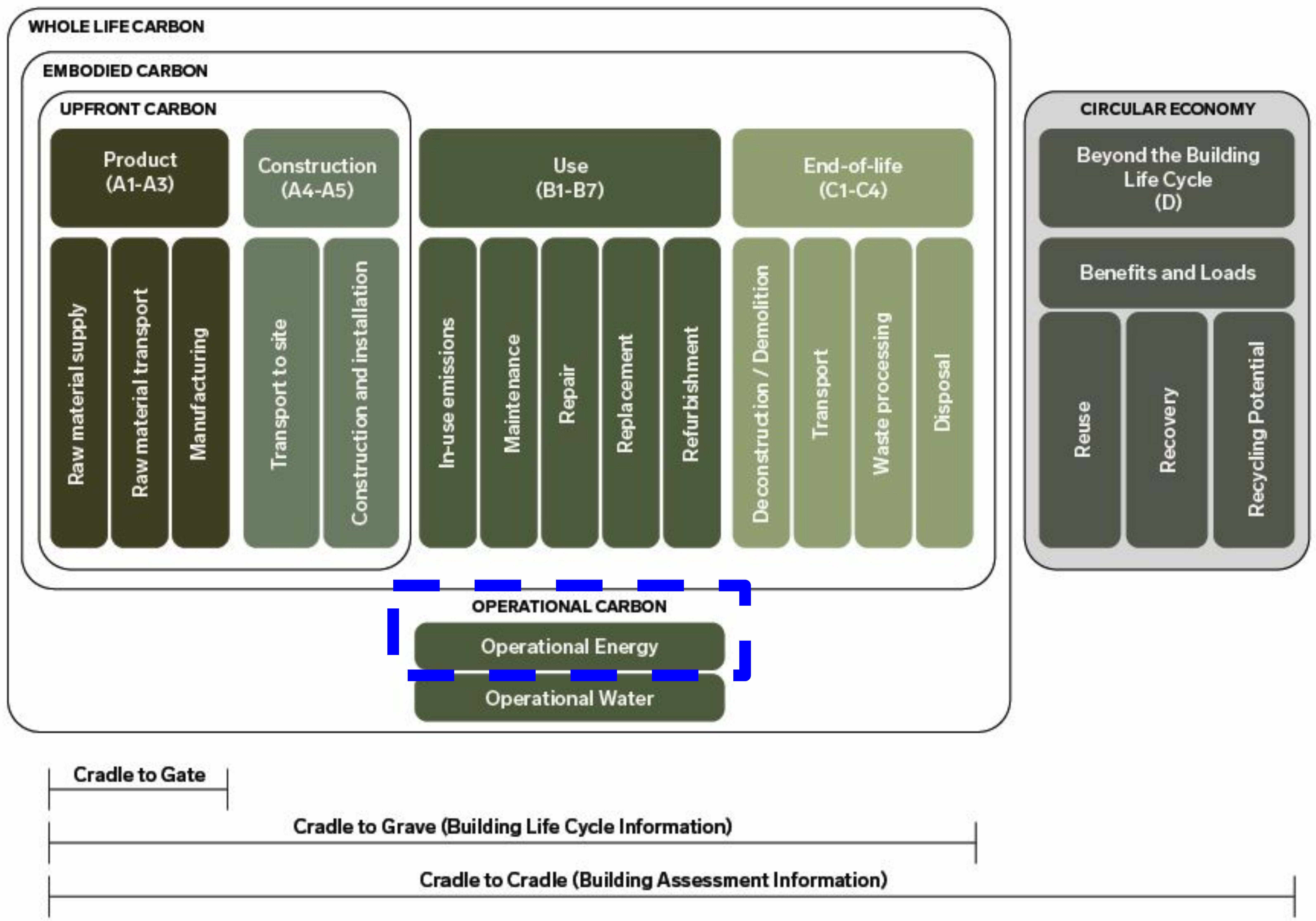
Total Embodied Carbon (A / B / C)

More comprehensive but very difficult to predict and less accurate.



Stages of Carbon

Operational Carbon




A Passive House Primer
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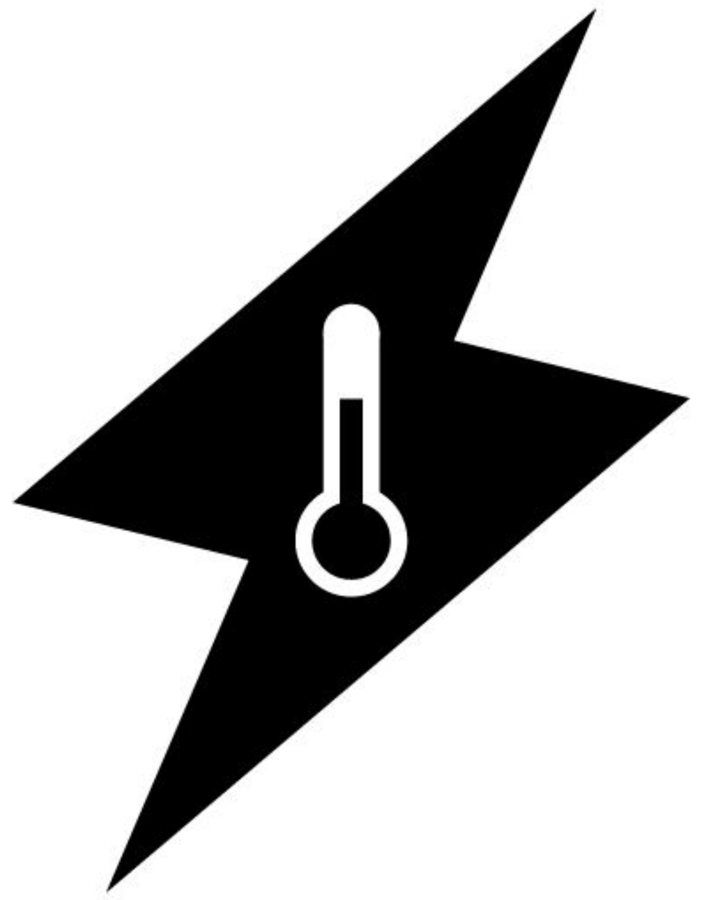
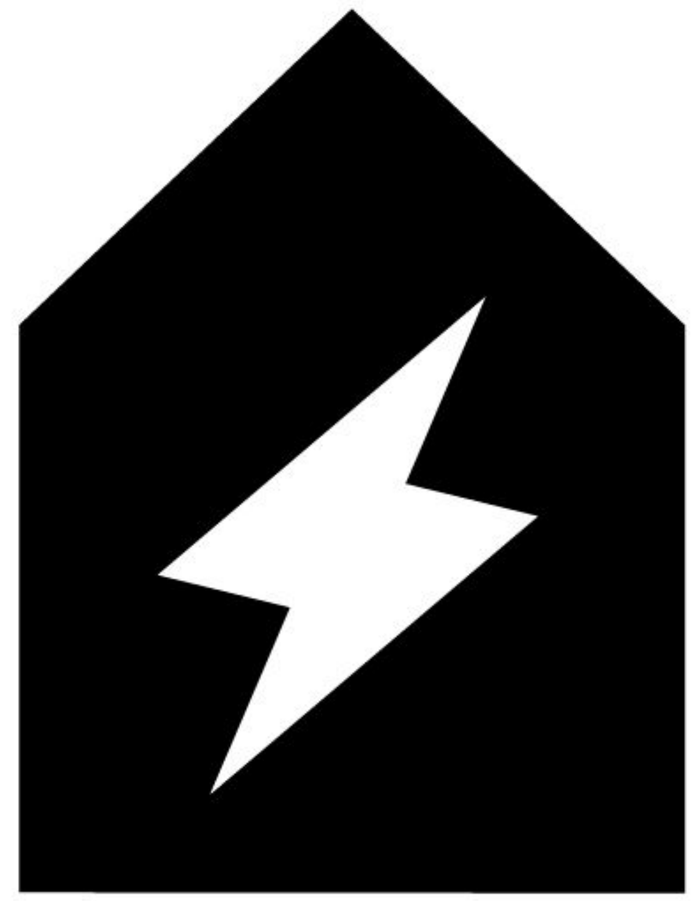
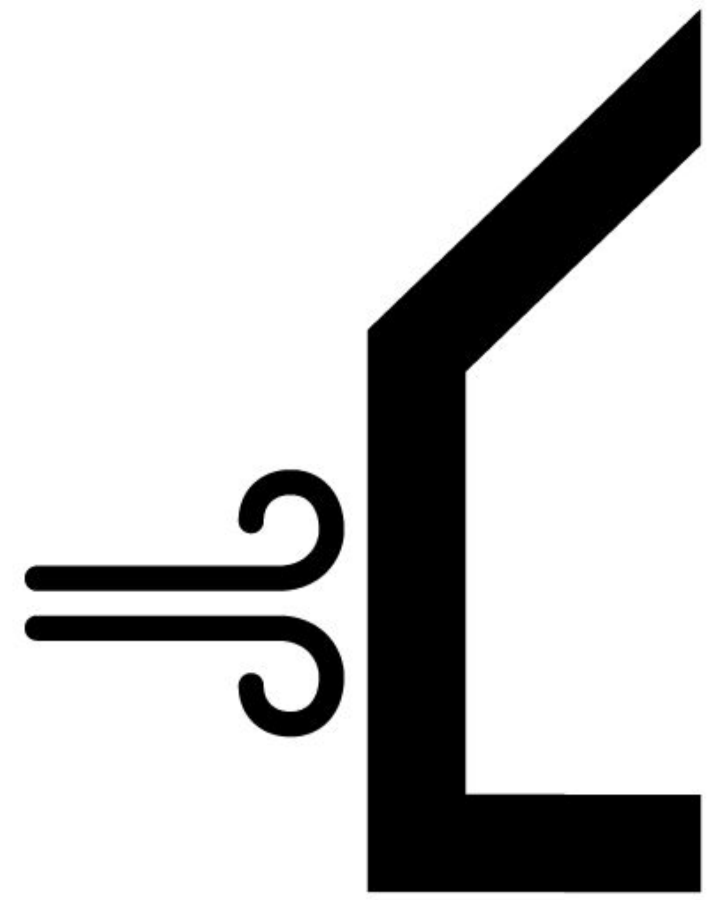
Passive House Requirements



Thermal Energy Demand



Total Energy Demand



Airtightness

- Three main performance criteria (pass / fail)
- Specialty modeling software with detailed input (Wufi Passive or PHPP)
- Third party review of modeling
- Assemblies are material agnostic (effective R-value)
- Field Verification

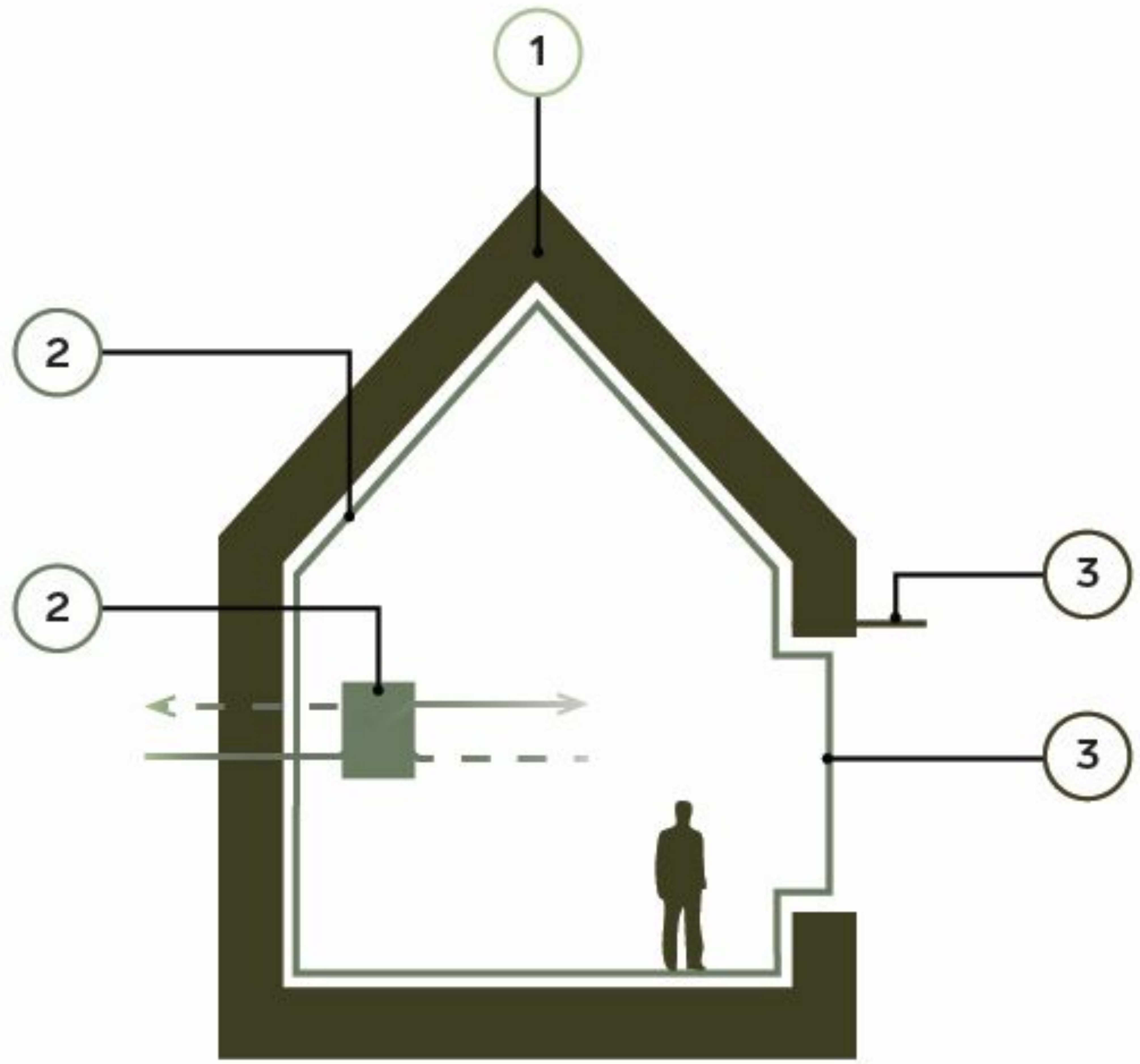
Passive House Principles

1 **Thermal Control**
Super Insulation
Thermal Bridge Free

2 **Air and Moisture Control**
Airtight Construction
Fresh Air with Heat Recovery

3 **Radiation Control**
High Performance Glazing
Shading and Daylighting

4 **Efficient Mechanical Systems**
Minimized Equipment
Efficient Distribution



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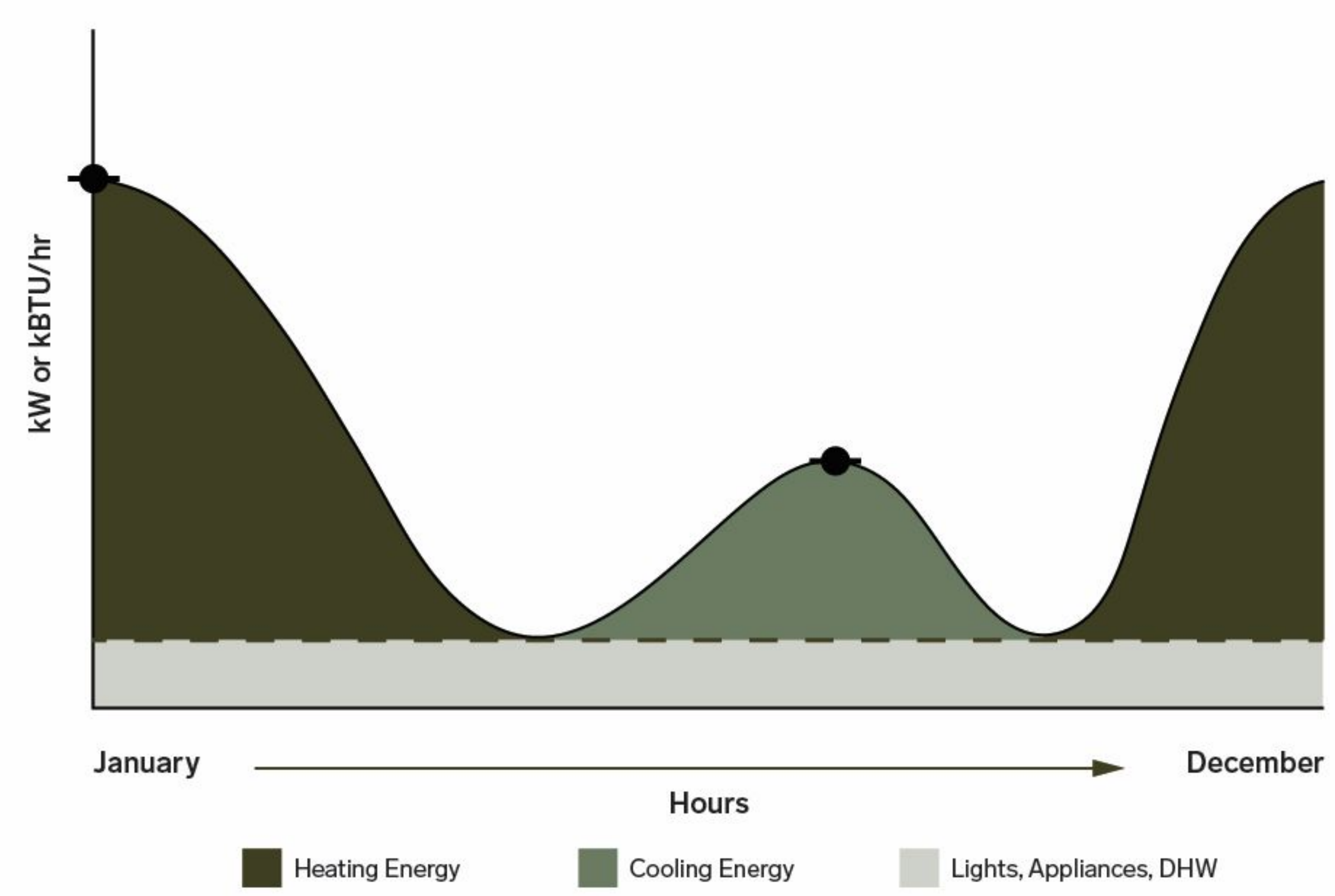
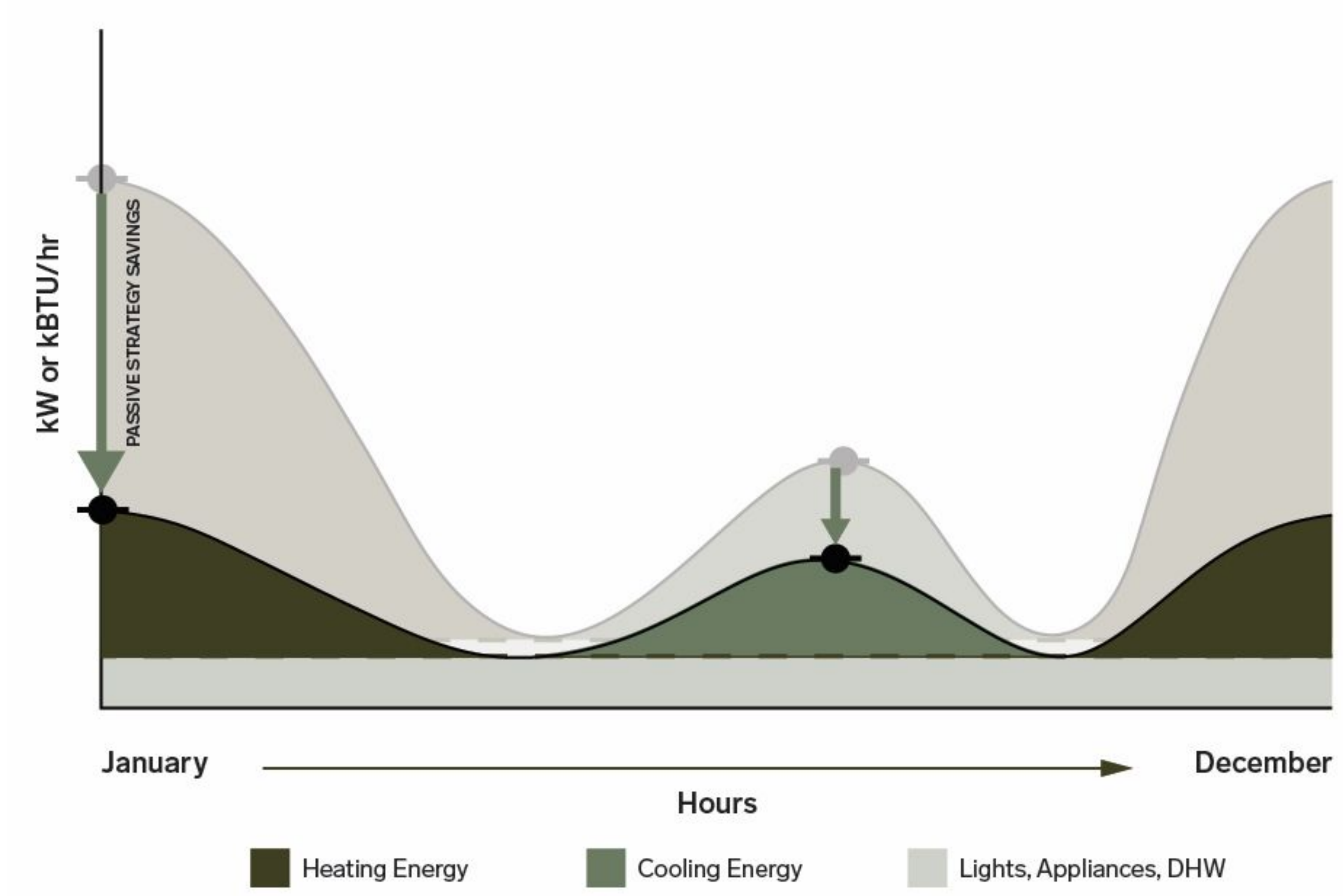
Why Passive House
(Isn't Net Zero Enough?)



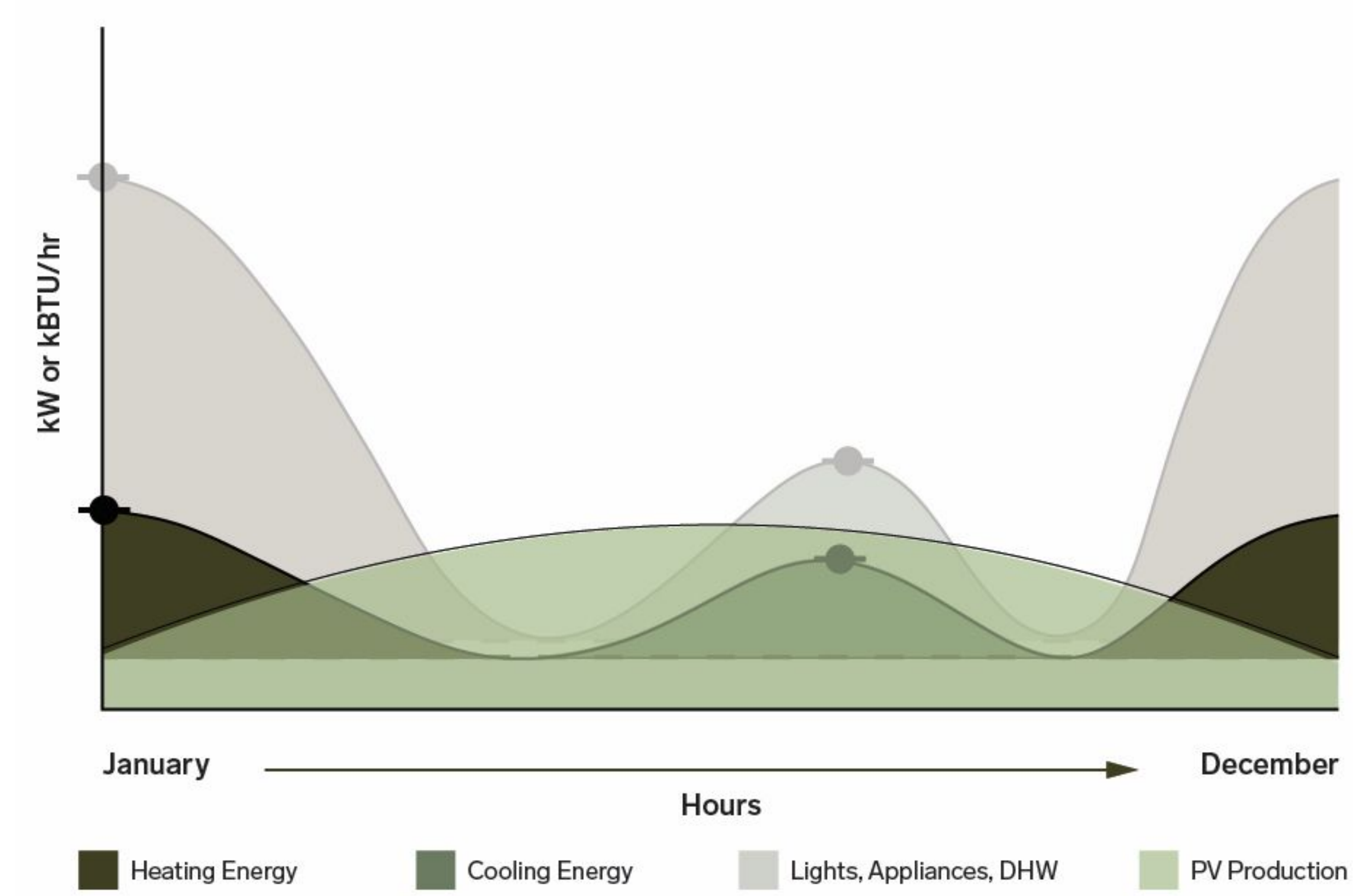
Seasonal Loads

Code Minimum



Seasonal Loads

Passive House



Seasonal Loads + Supply

Passive House + PV

All Wood Is Not Equal

Biogenic Carbon

"carbon produced in natural processes by living organisms"

Biogenic Carbon or Sequestered Carbon

- negative upfront carbon

+ emission at end of life (total embodied carbon)

Upfront Carbon only **> credit for the stored carbon (ignores future emissions)**

= incentive to use more wood?

Conservative Approach = ~~Biogenic Carbon~~

All Wood Is Not Equal

Wood EPDs used in most embodied carbon calculations represent the national average, and do not distinguish between wood sourced from specific forests or specific sites...in EPDs all wood is represented equally.

Embodied Carbon of Different Forest Management Practices and Harvest Rotations

Case Studies

Williams & Russell Development

Townhomes

Program

31,822 sf gross

24 Townhomes

2-buildings

Height

3-story

Construction

Type V-B

Black Business Hub

Program

40,000 sf gross

Below Grade Parking

Offices over Ground Floor Retail

Height

4-story

Construction

Type III-B

Affordable Apartments

Program

97,000 sf gross

85 Units of Rental Apartments

Ground Floor Amenities / Childcare

Height

6-story

Construction

Type III-A with Type I Podium (Stick Frame)

Type IV-C (Mass Timber)

Townhomes

Floor Plan

Townhomes

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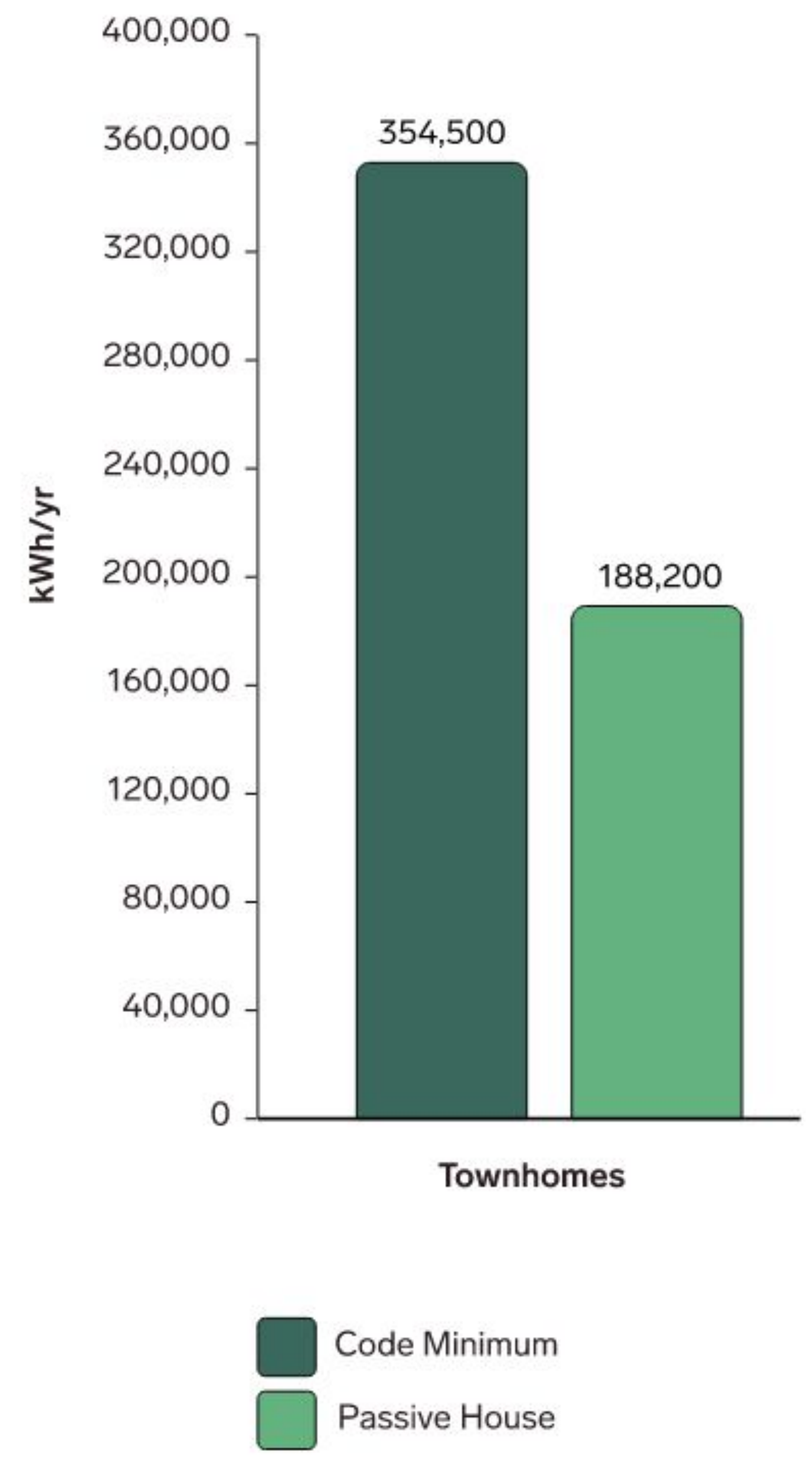
Operational Carbon Summary

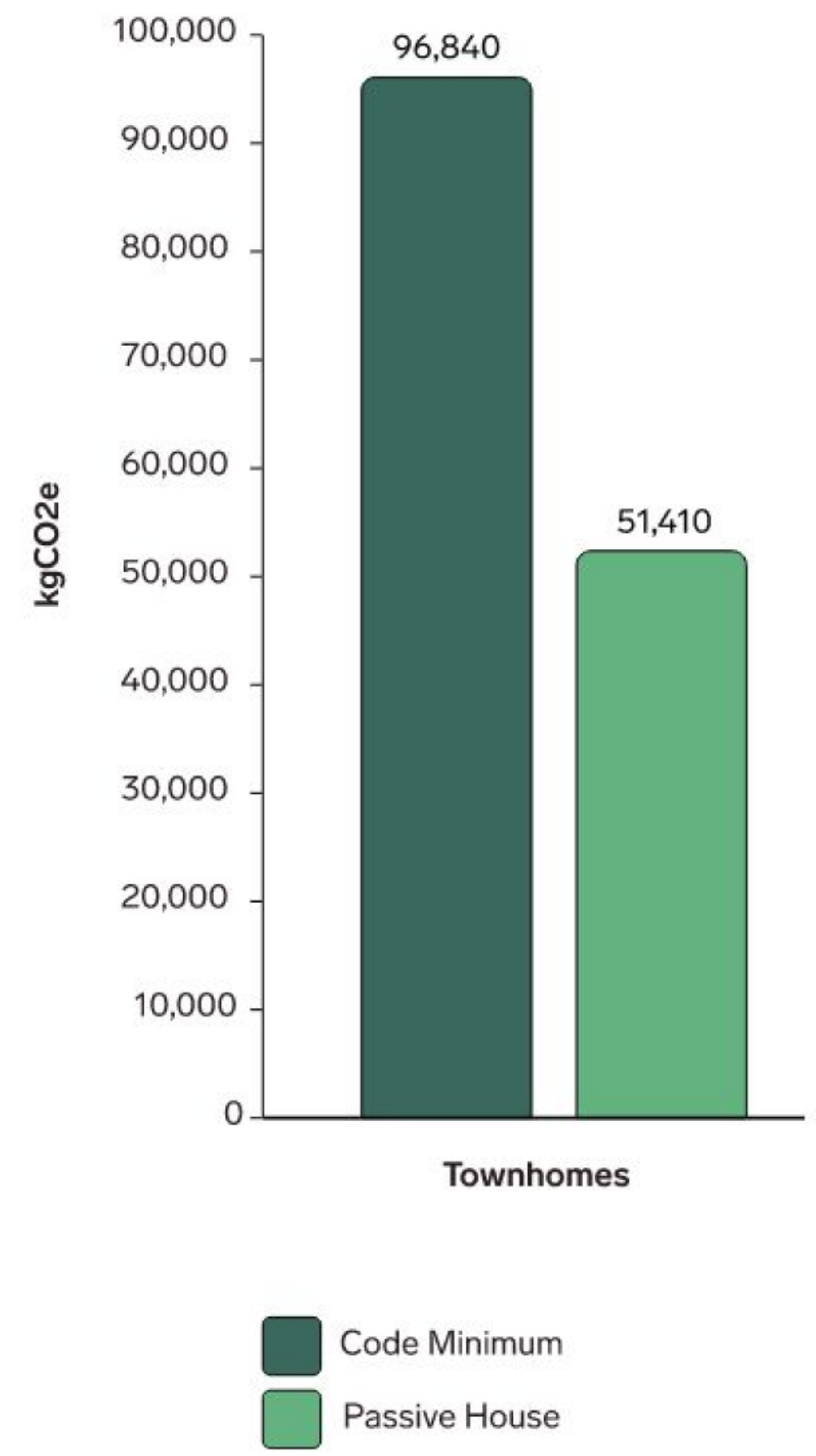
Townhomes

Energy Modeling Parameters

Component	Code Minimum	Passive House
Floor / Slab on Grade	R-0	R-15 C.I
Edge of Slab	R-15	R-15 for24"
Walls	R-21	R-26 Effective
Roof	R-49	R-59 Effective
Windows	U = .30 / SHGC = .30	U = .26 / SHGC = .18
Airtightness	.4 @ 75PA	.2 @ 75PA
Heating / Cooling	Electric Res / PTAC	Split System Heat Pump
Ventilation	Trickle Vent / Exhaust	ERV (68% Efficient)
Water Heating	Electric Resistance	Heat Pump (Hybrid)



Annual Operational Energy (kWh/yr)



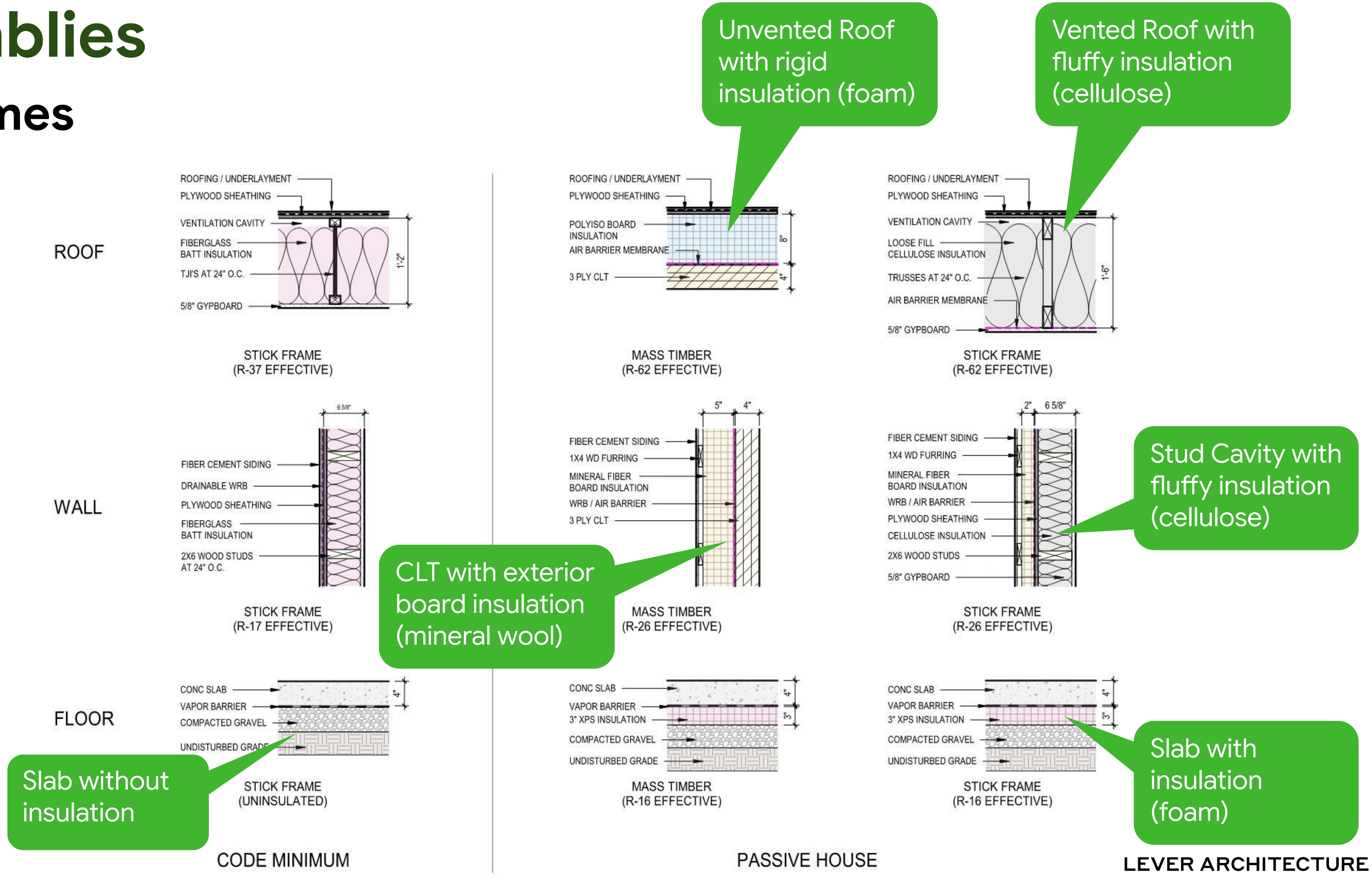
Annual Operational Carbon (kgCO2e/yr)

Improved envelope = 13% savings

Better systems = 34% savings

Assemblies

Townhomes



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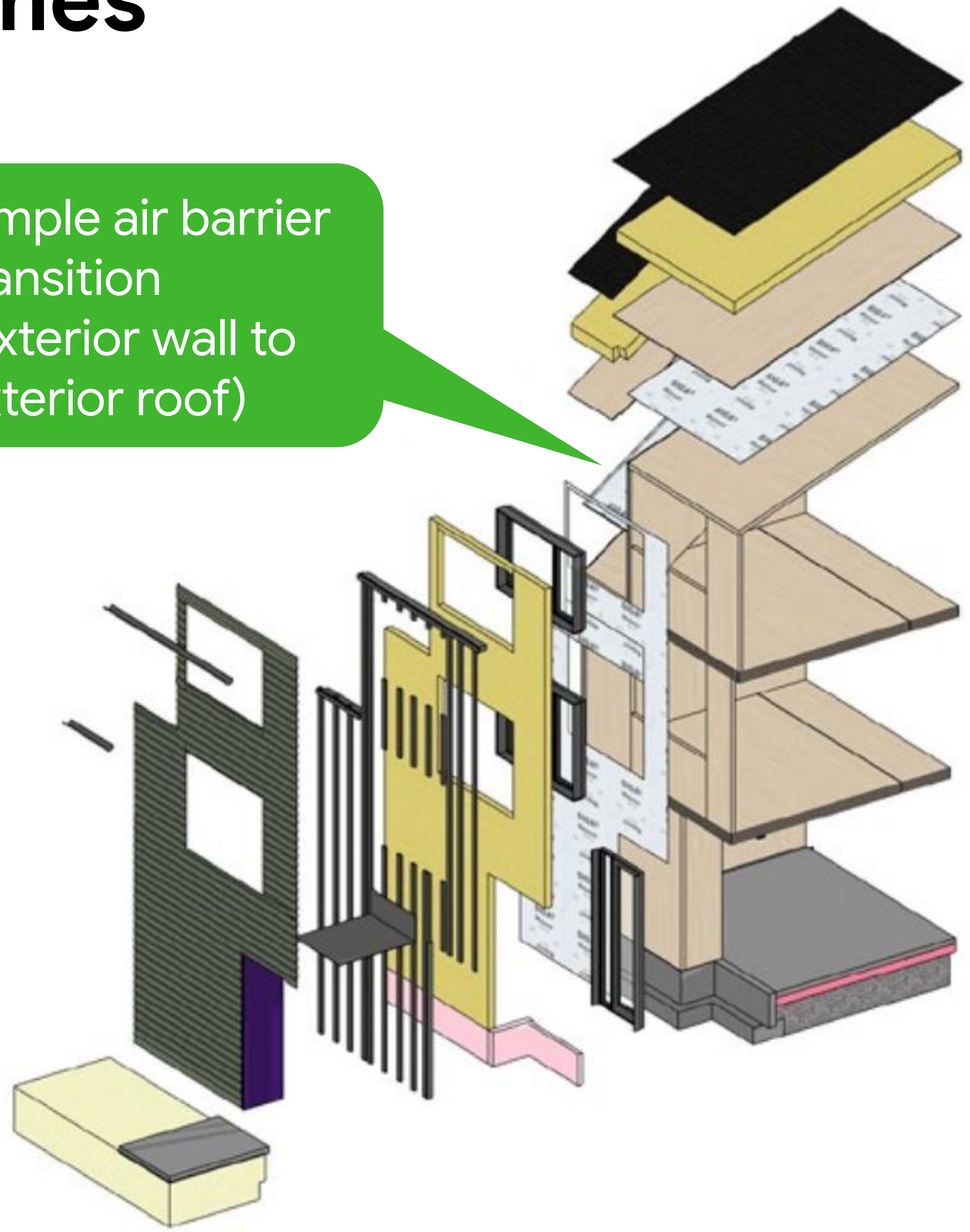
Passive House Assemblies

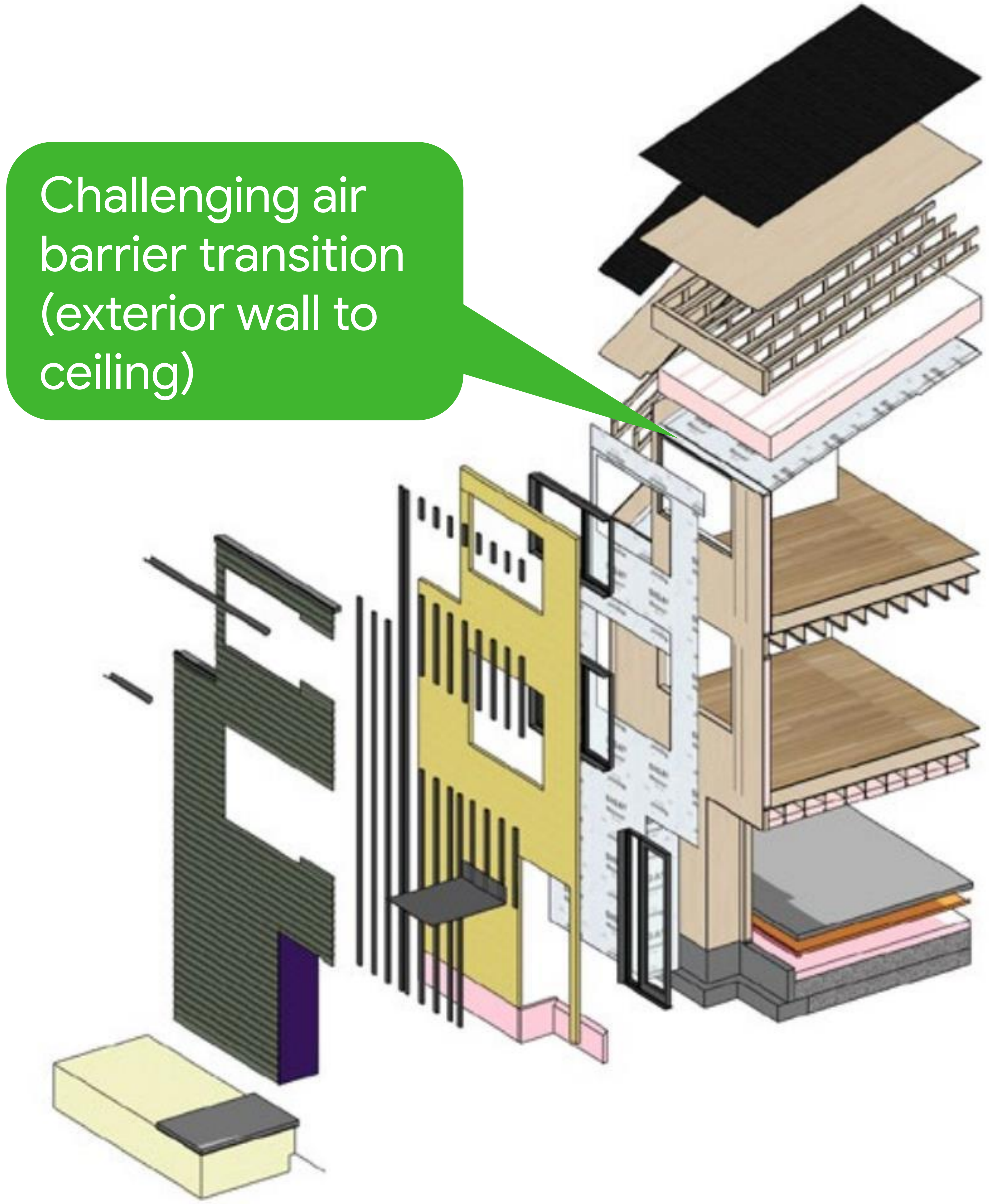
Townhomes

Simple air barrier transition (exterior wall to exterior roof)



PH Mass Timber

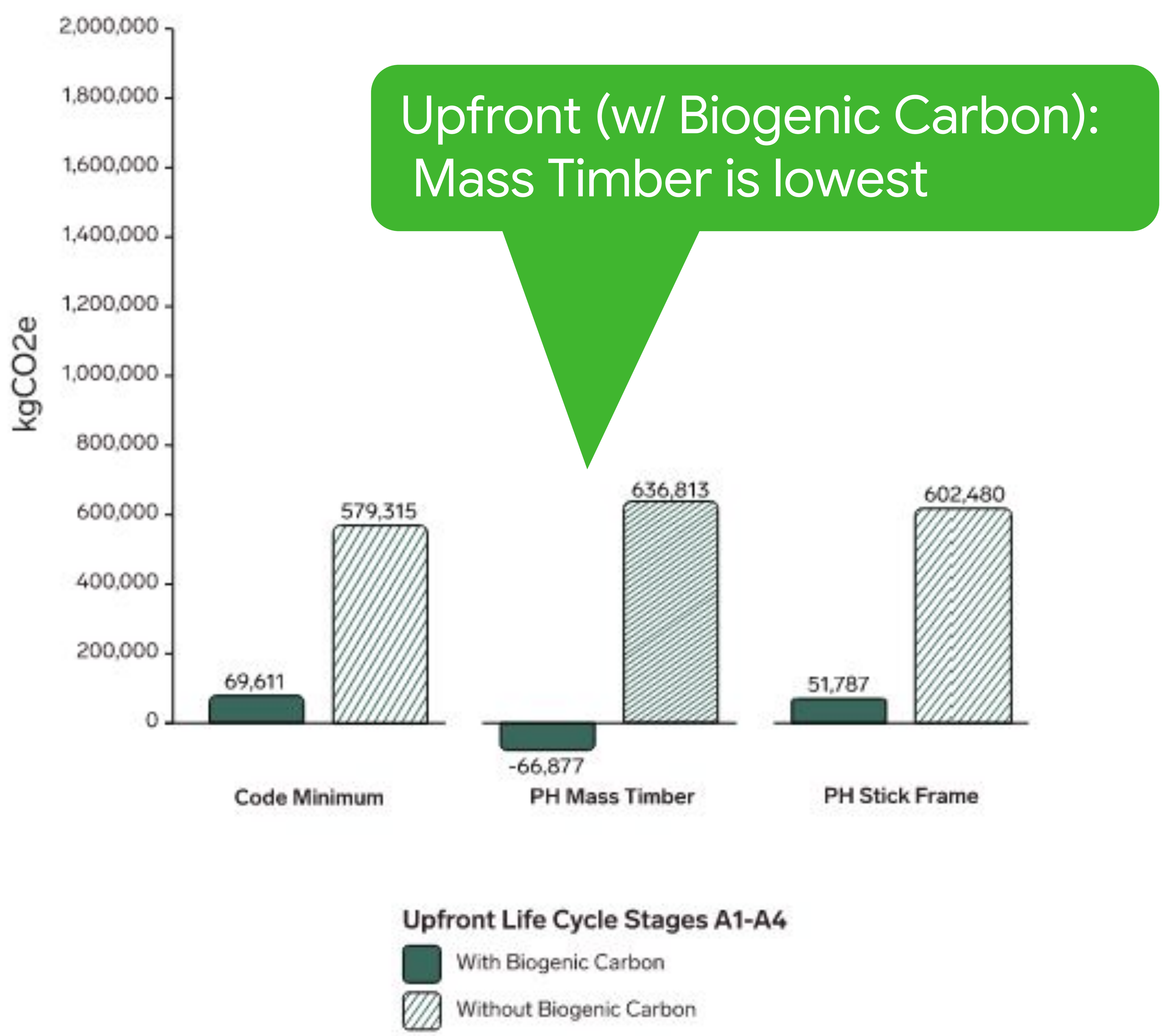
Challenging air barrier transition (exterior wall to ceiling)

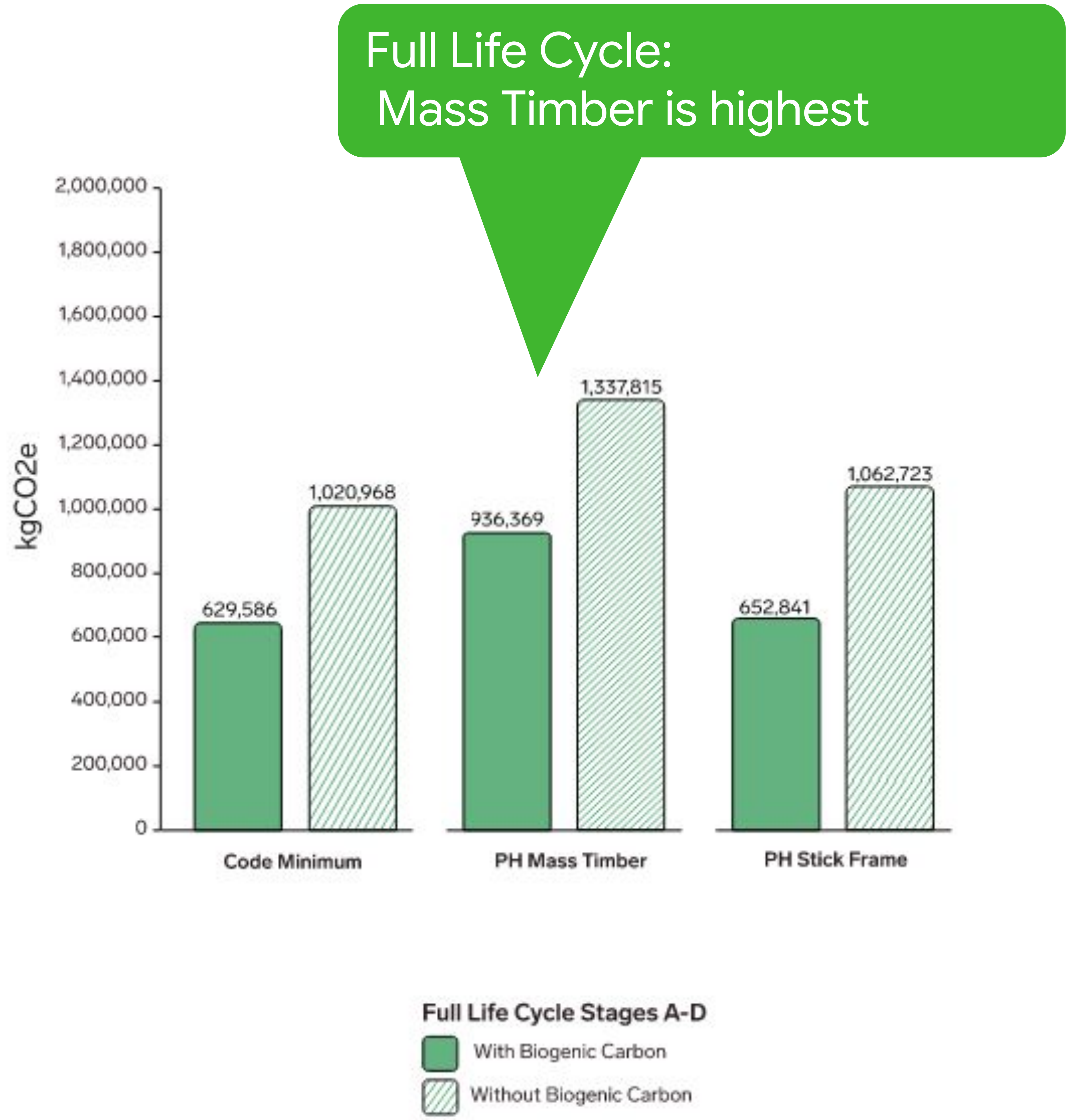


PH Stick Frame

Embodied Carbon Results

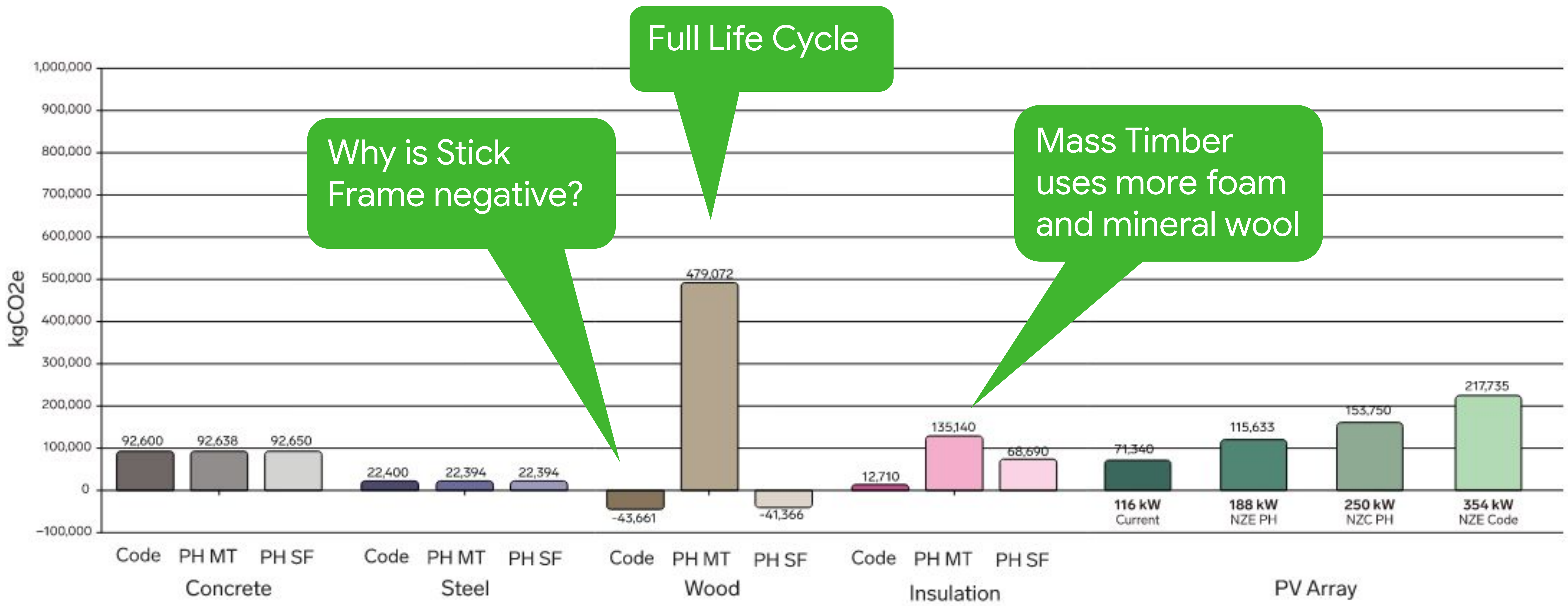
Townhomes





Embodied Carbon Results

Townhomes

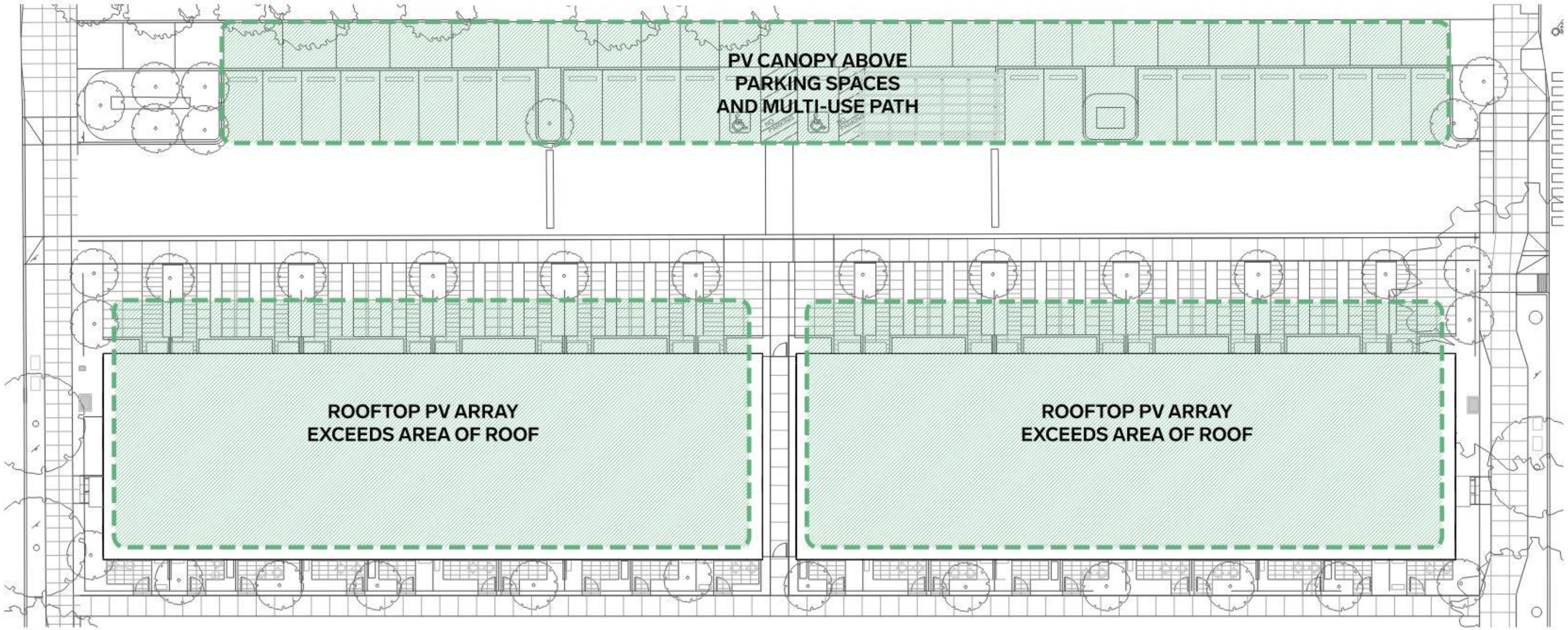


Embodied Carbon of Major Materials (Full Life Cycle with Biogenic Carbon)

On-Site Renewable Energy

Townhomes

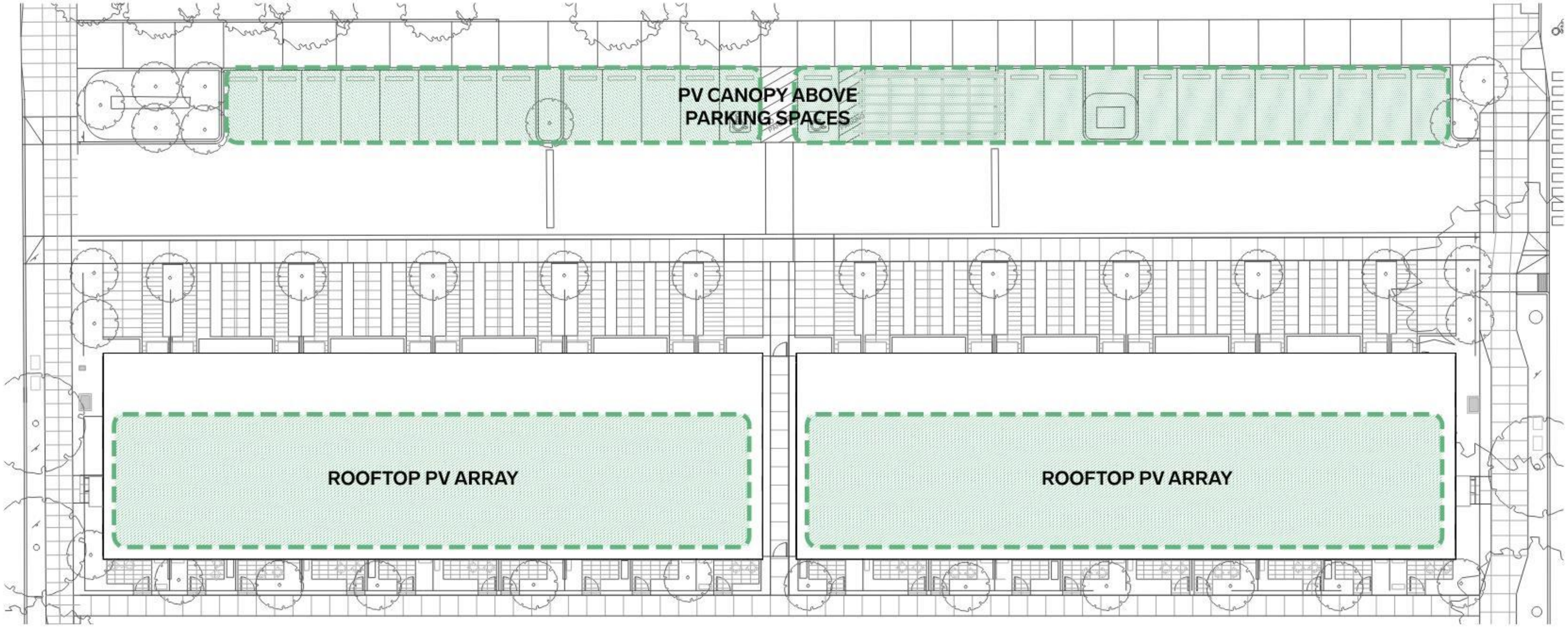
Code Minimum
354 kW PV
Net Zero Energy



On-Site Renewable Energy

Townhomes

Stick Frame Passive House
216 kW PV
Net Zero Carbon in 25 years
(Upfront w/ Biogenic Carbon)



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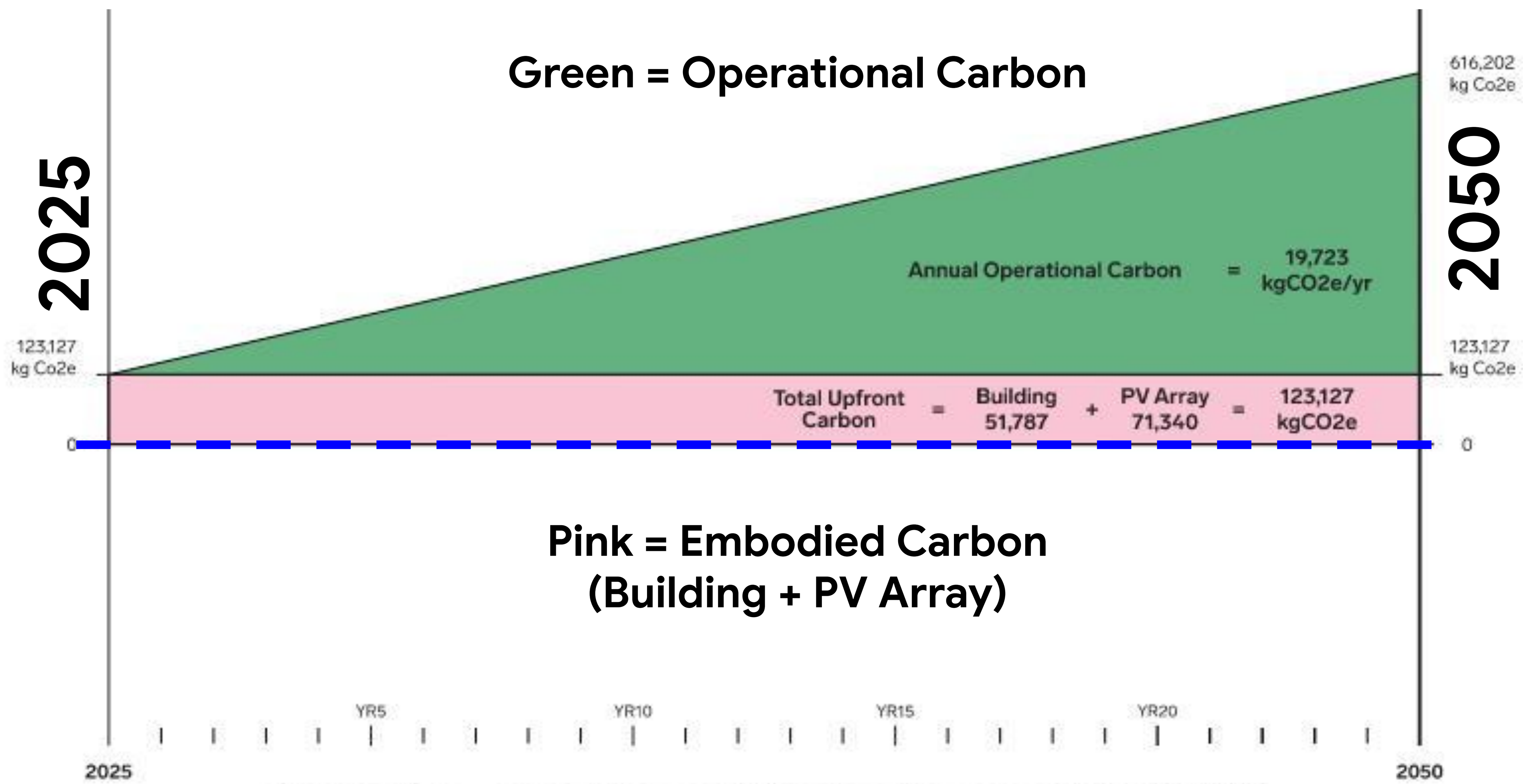
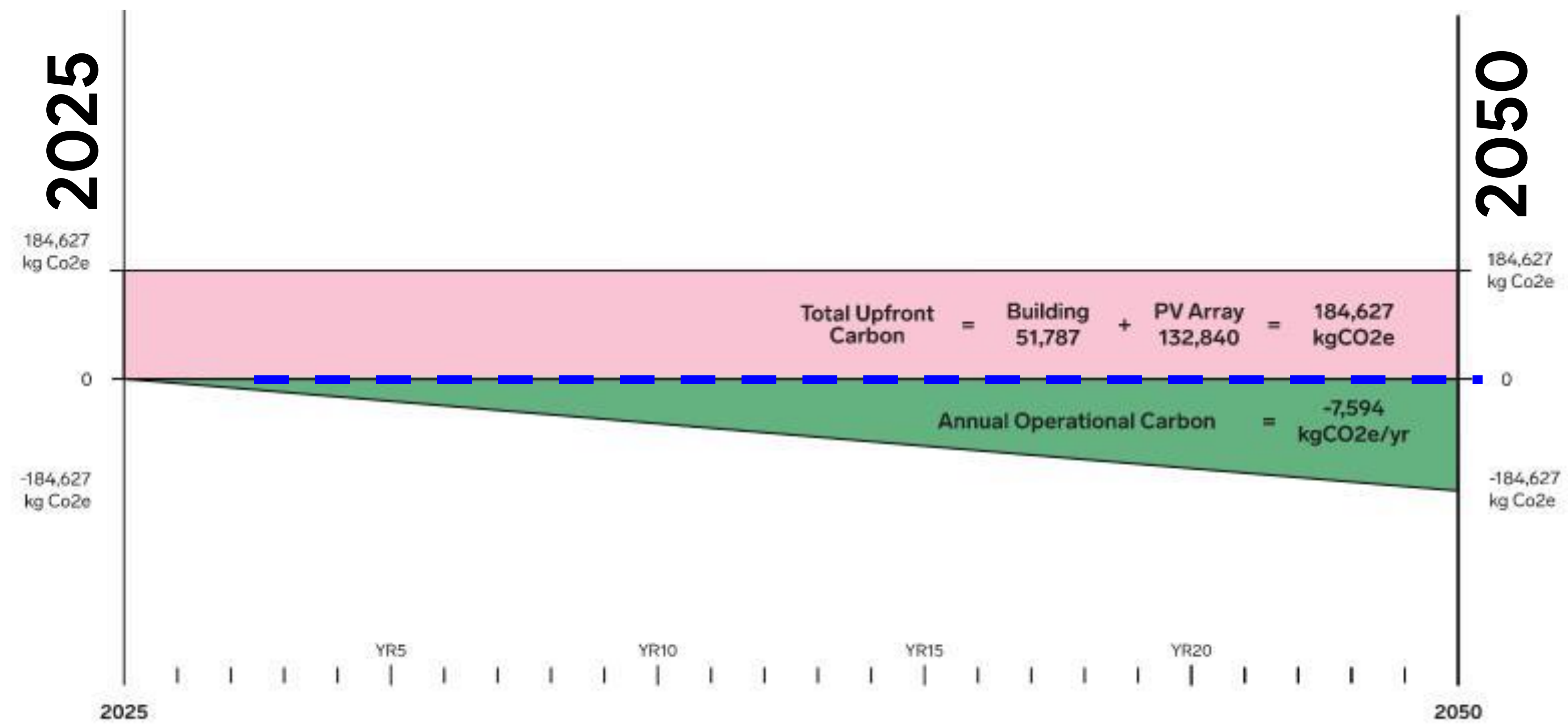
Total Carbon Scenarios - 25 years

Townhomes



Stick Frame Passive House
116 kW PV
60% Net Zero Energy Annually
(Upfront w/ Biogenic Carbon)



Stick Frame Passive House
216 kW PV
Net Zero Carbon in 25 years
(Upfront w/ Biogenic Carbon)

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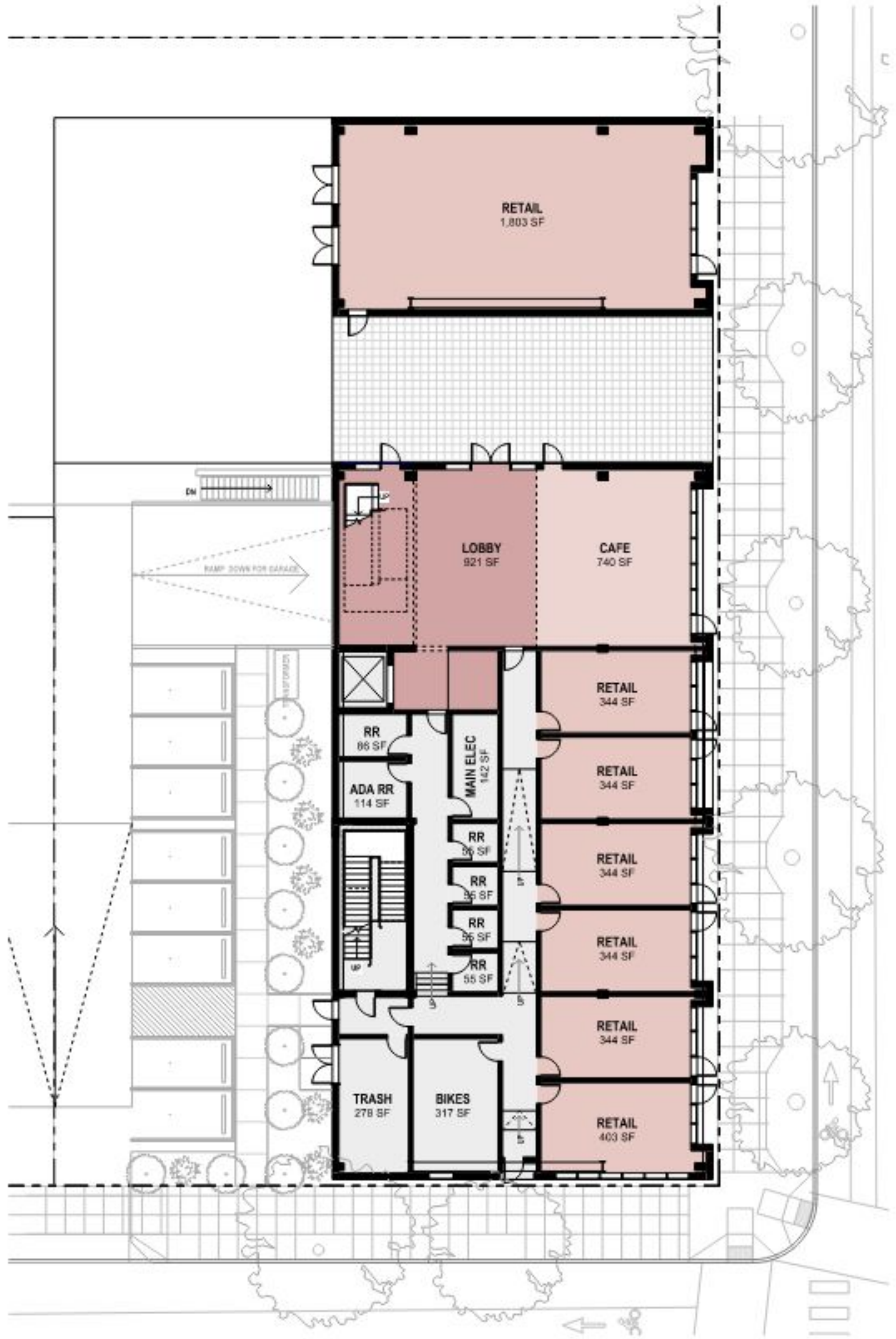
Floor Plans

Black Business Hub



LEVEL 01

LEVEL 02

LEVEL 03

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Operational Carbon Summary

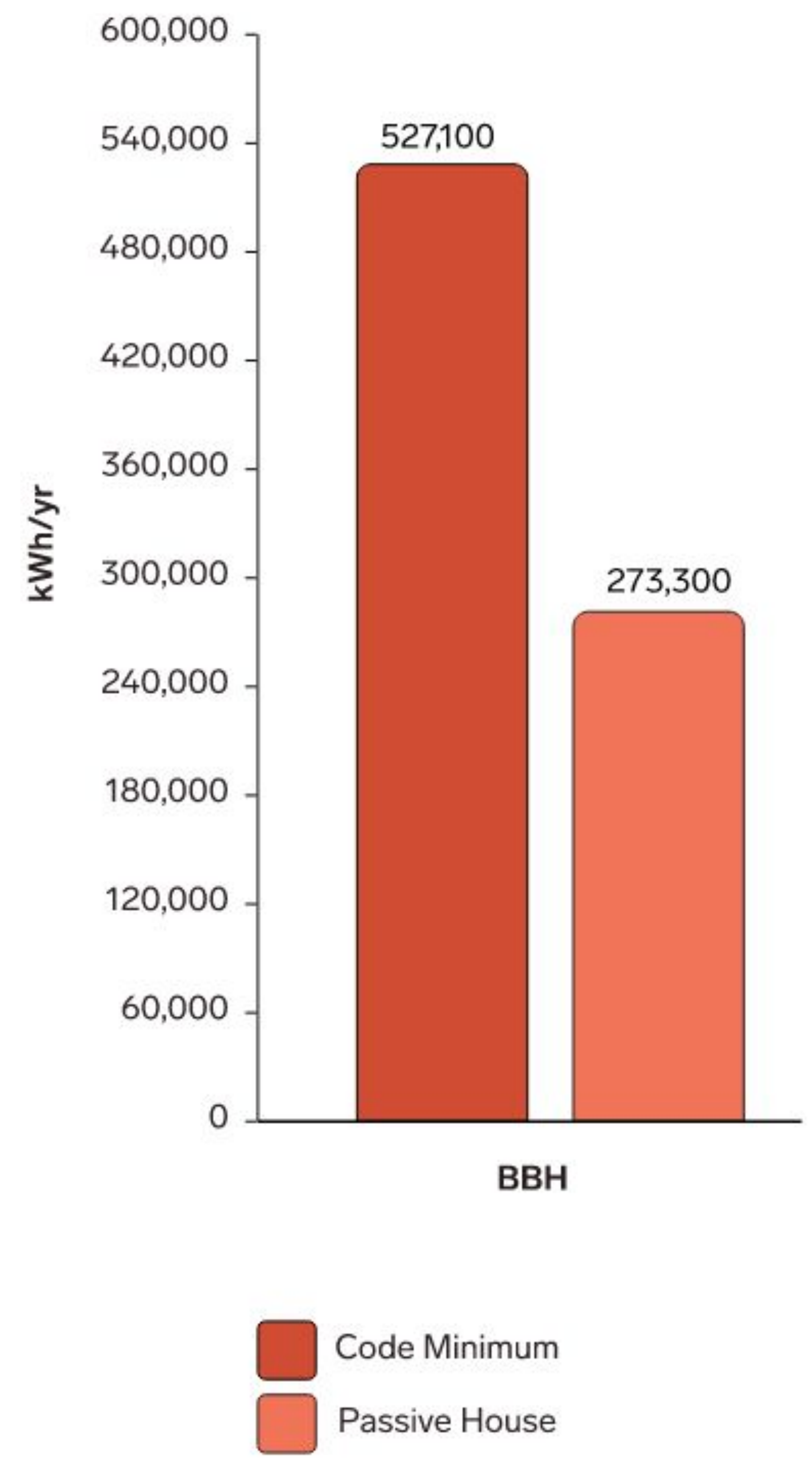
Black Business Hub

Energy Modeling Parameters

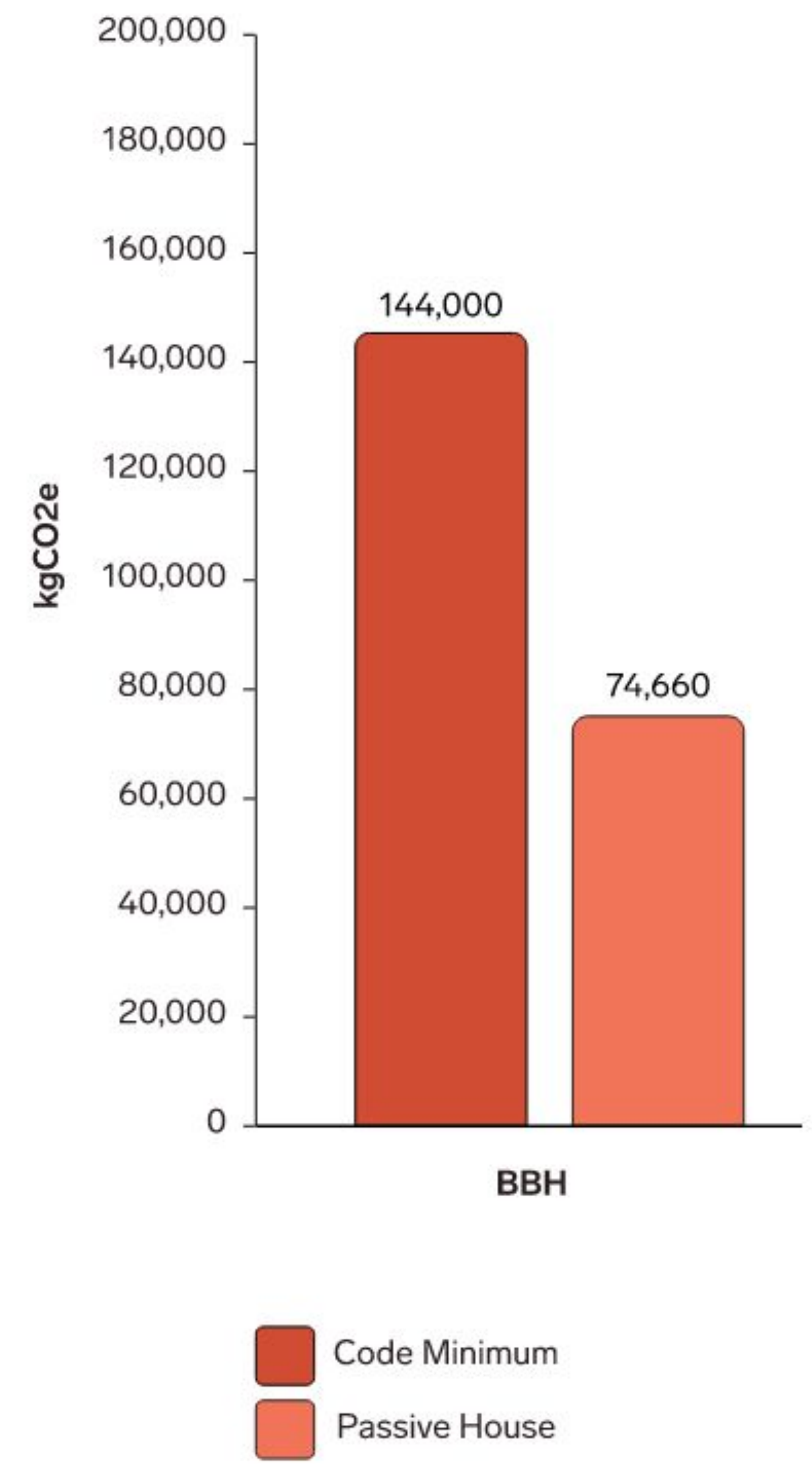
Component	Code Minimum	Passive House
Floor / Slab on Grade	R-0	R-0
Edge of Slab	R-15 for 24"	R-15 for 24"
Walls	R-19 (~R-16 Effective)	R-19 Effective
Roof	R-30 Effective	R-38 Effective
Storefront Windows	U = .36 / SHGC = .33	U = .36 / SHGC = .27
Upper Windows	U = .36 / SHGC = .33	U = .24 / SHGC = .27
Infiltration	.4 @ 75PA	.2 @ 75PA
Heating / Cooling	VAV with Elec Reheat	Split System Heat Pump
Ventilation	Code Minimum Mixed Air	ERV (68% Efficient)
Water Heating	Elec Resistance	Heat Pump

Improved envelope = 14% savings

Better systems = 34% savings



Annual Operational Energy (kWh/yr)



Annual Operational Carbon (kgCO2e/yr)

Assemblies

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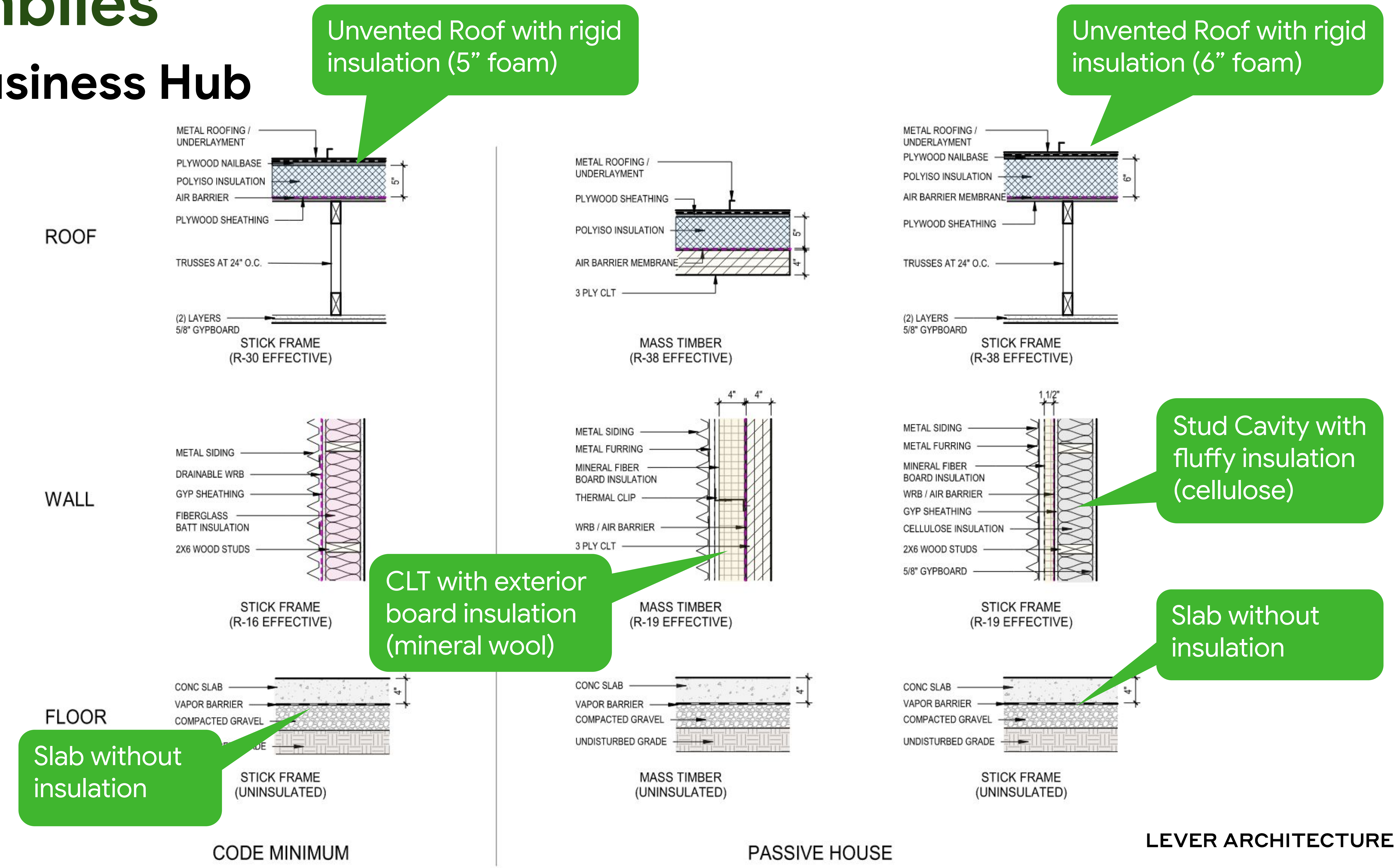

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Embodied Carbon Results (Below-Grade Parking)

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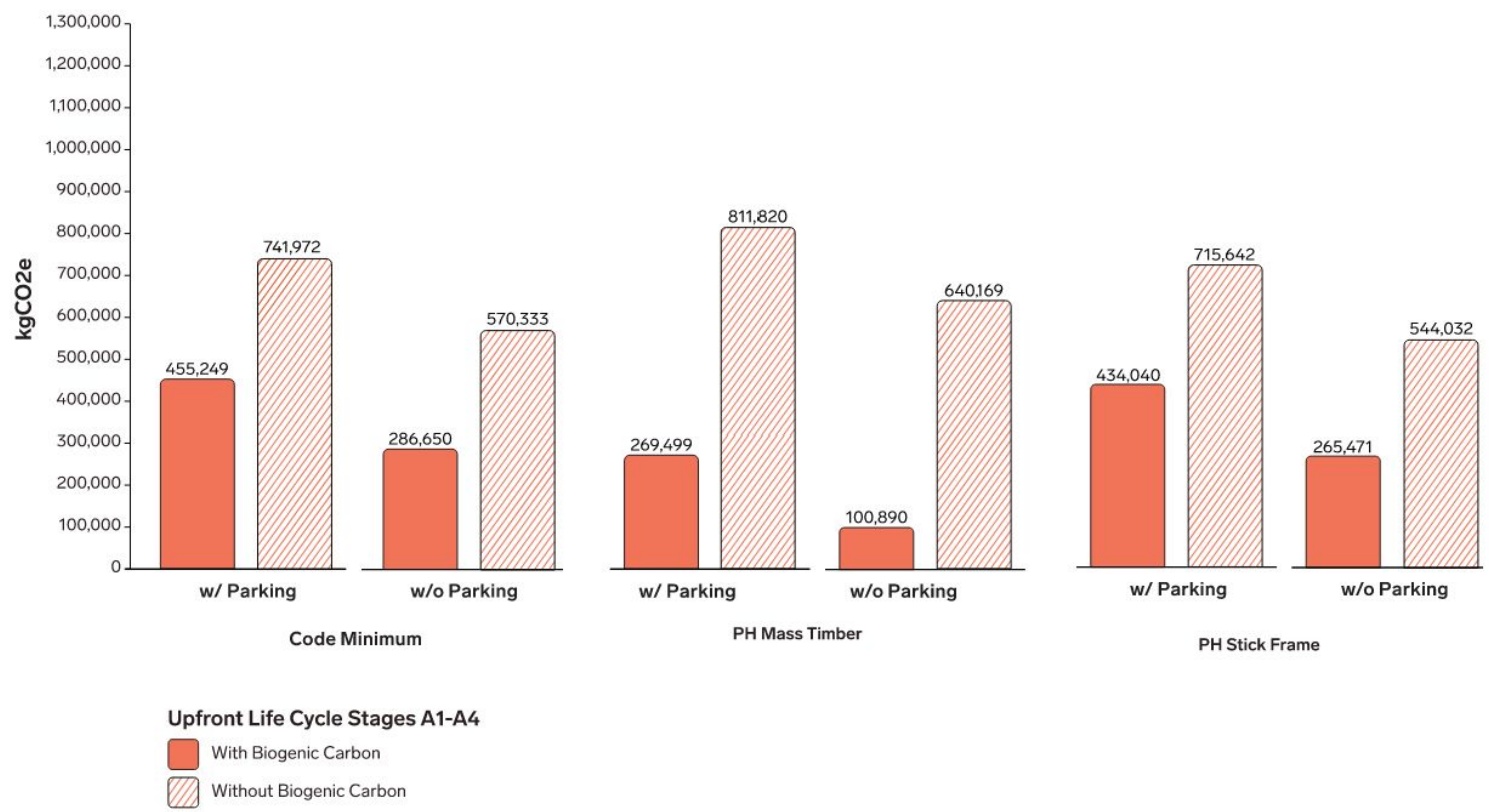
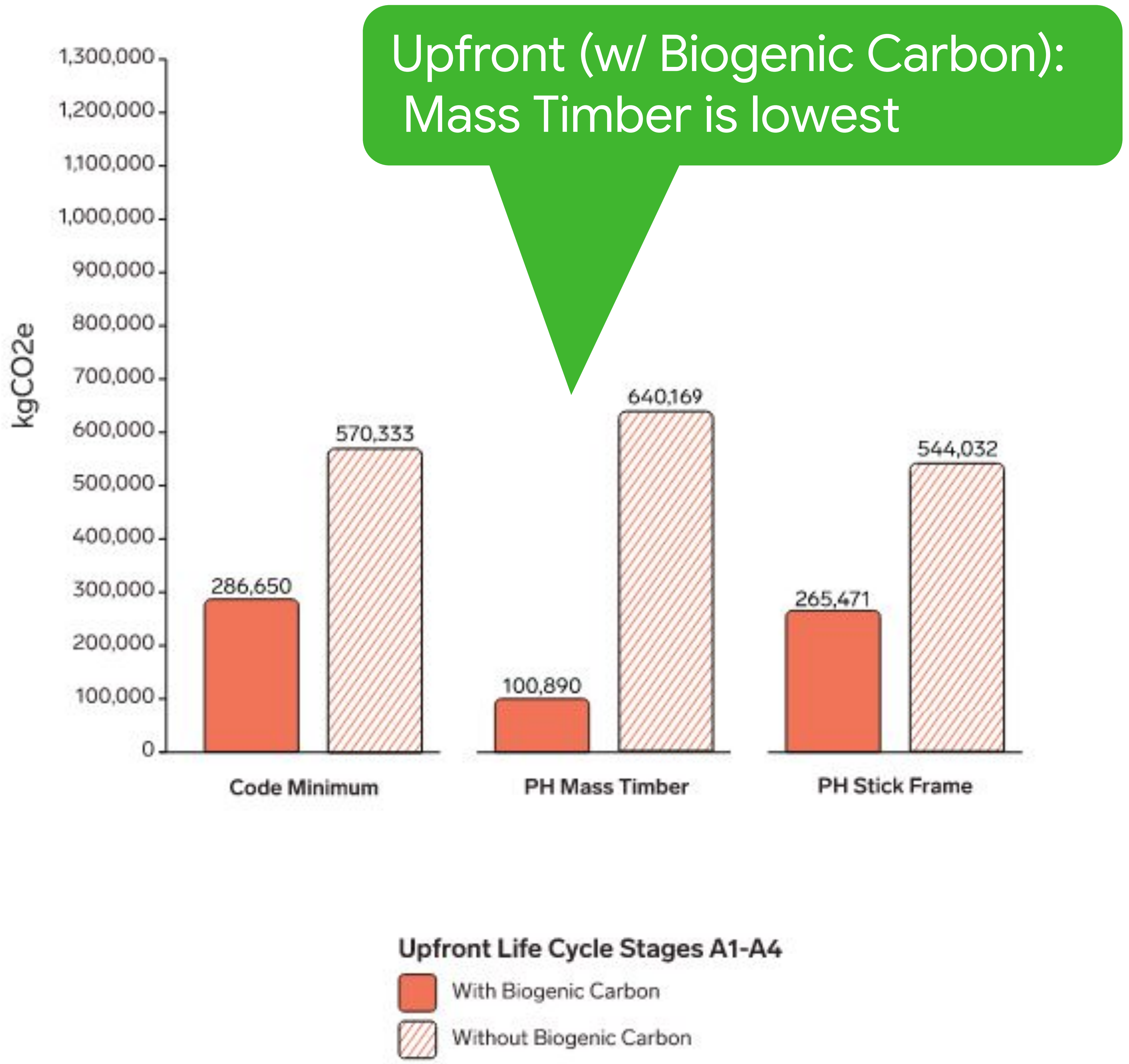
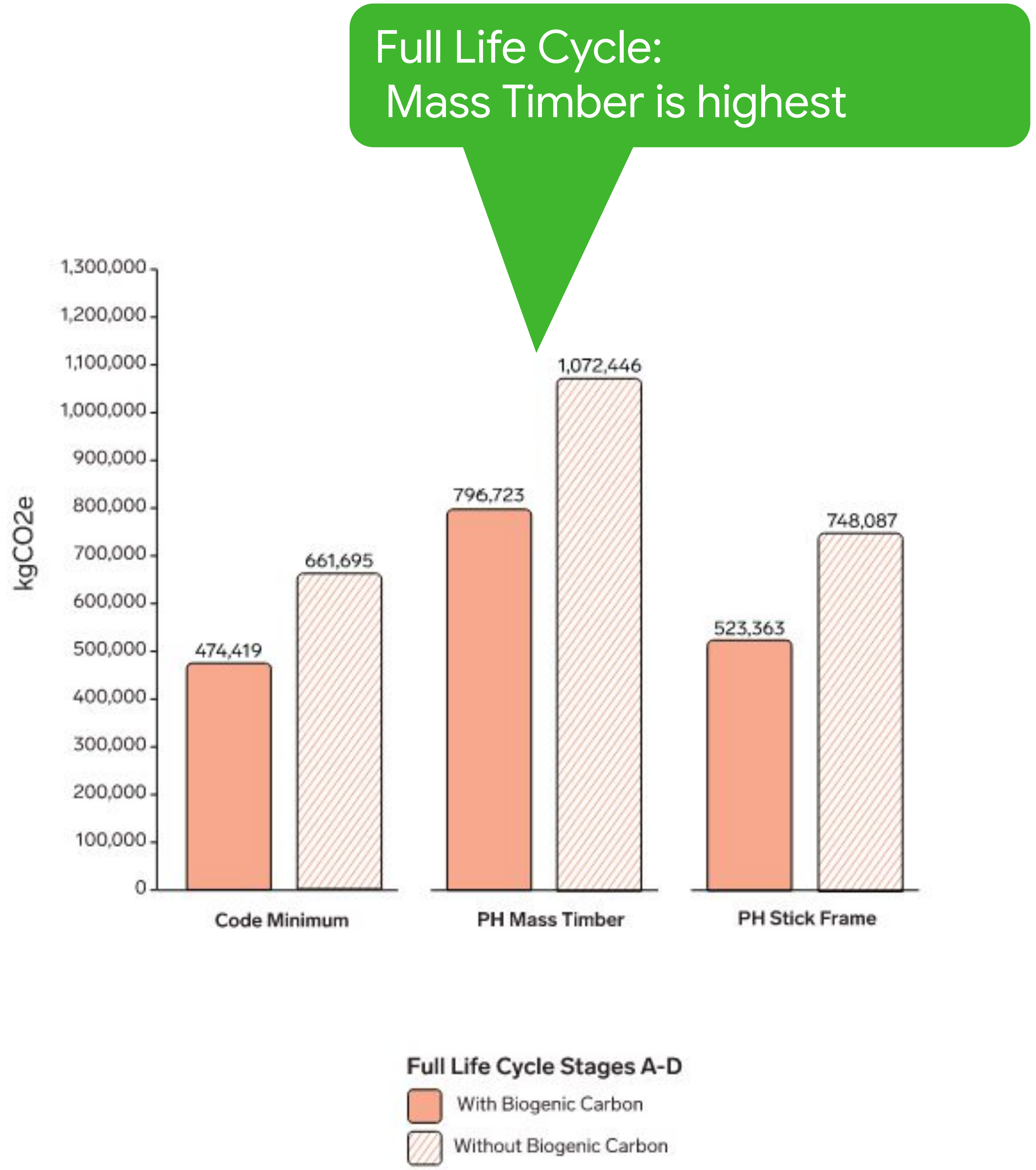
- Approximately 170,000 kgCO_2e
- More CO_2 than steel
- More CO_2 than 273 kW PV Array
- Below-grade = 4.25 kgCO_2e / sf
- Mass Timber = 3.15 kgCO_2e / sf



Embodied Carbon Results

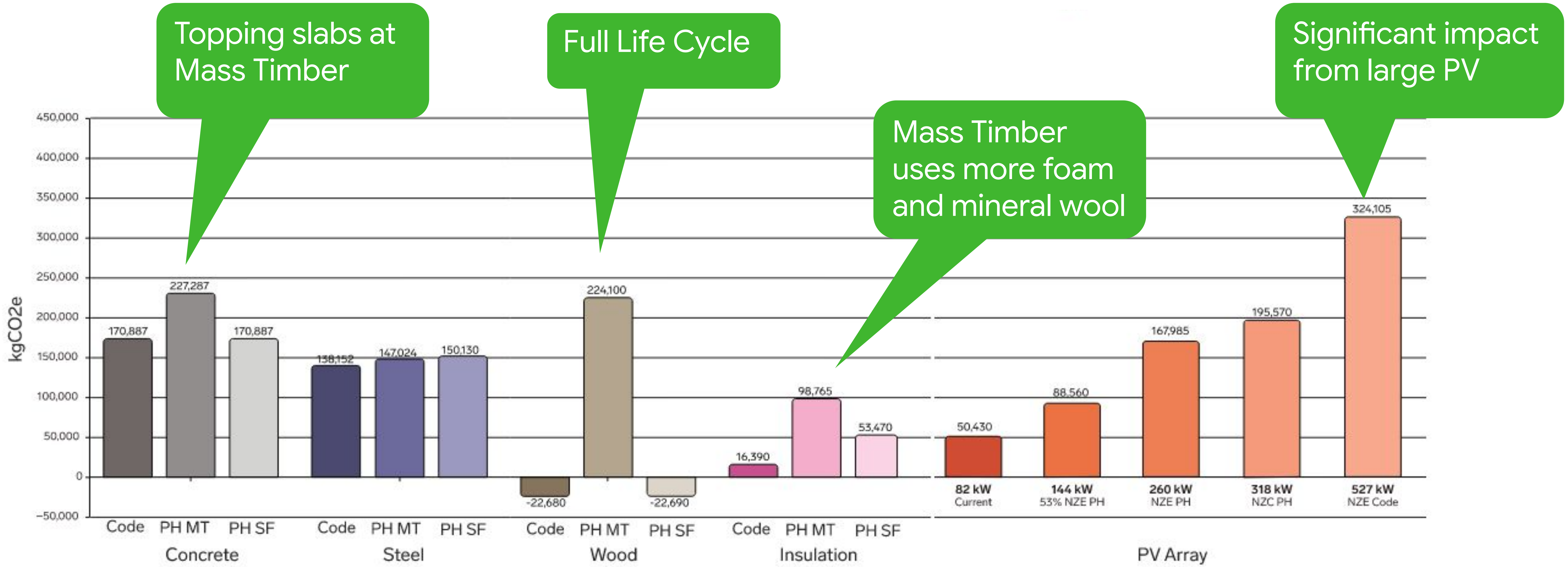
Black Business Hub





Embodied Carbon Results

Black Business Hub



Embodied Carbon of Major Materials (Full Life Cycle with Biogenic Carbon)

On-Site Renewable Energy

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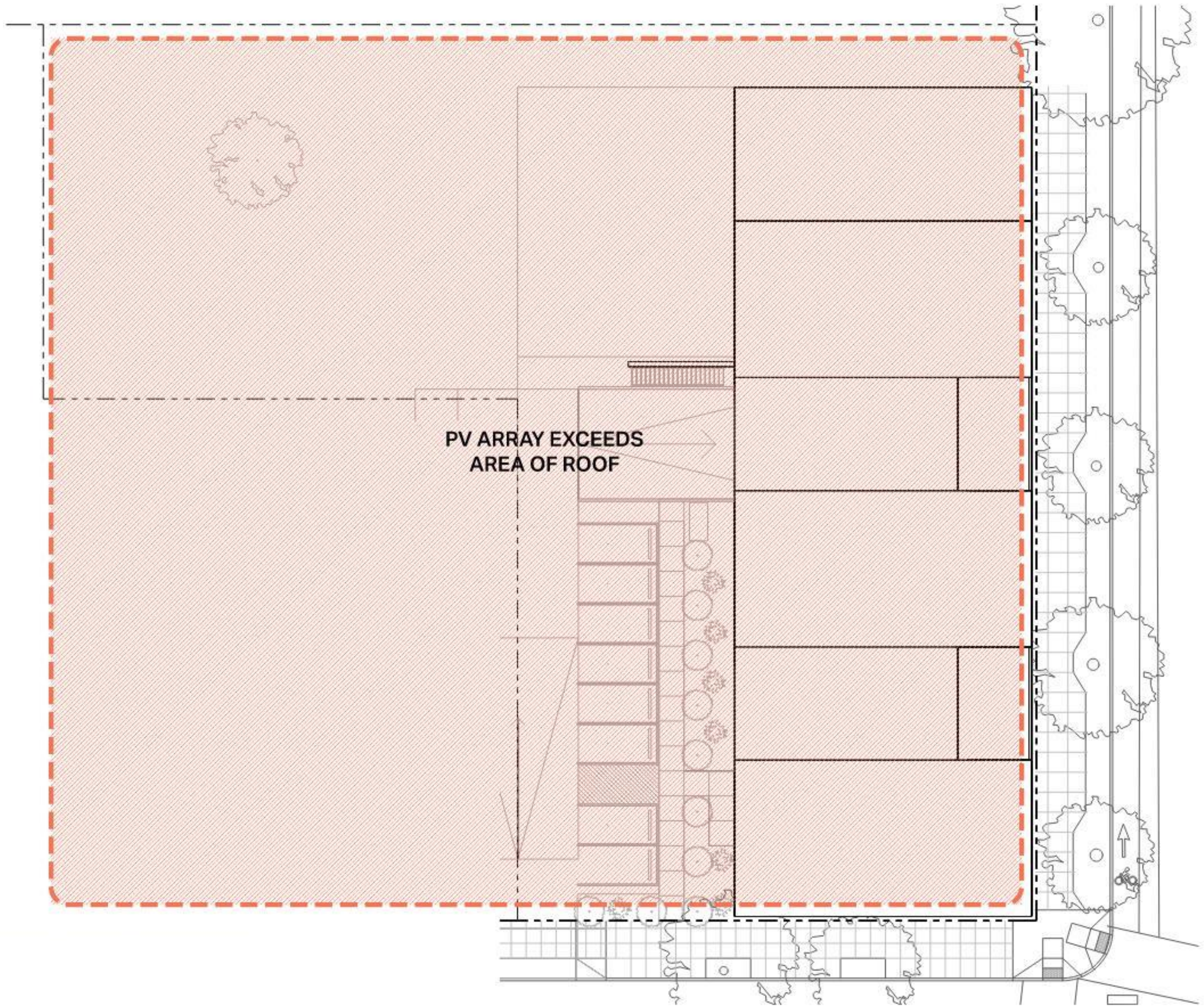


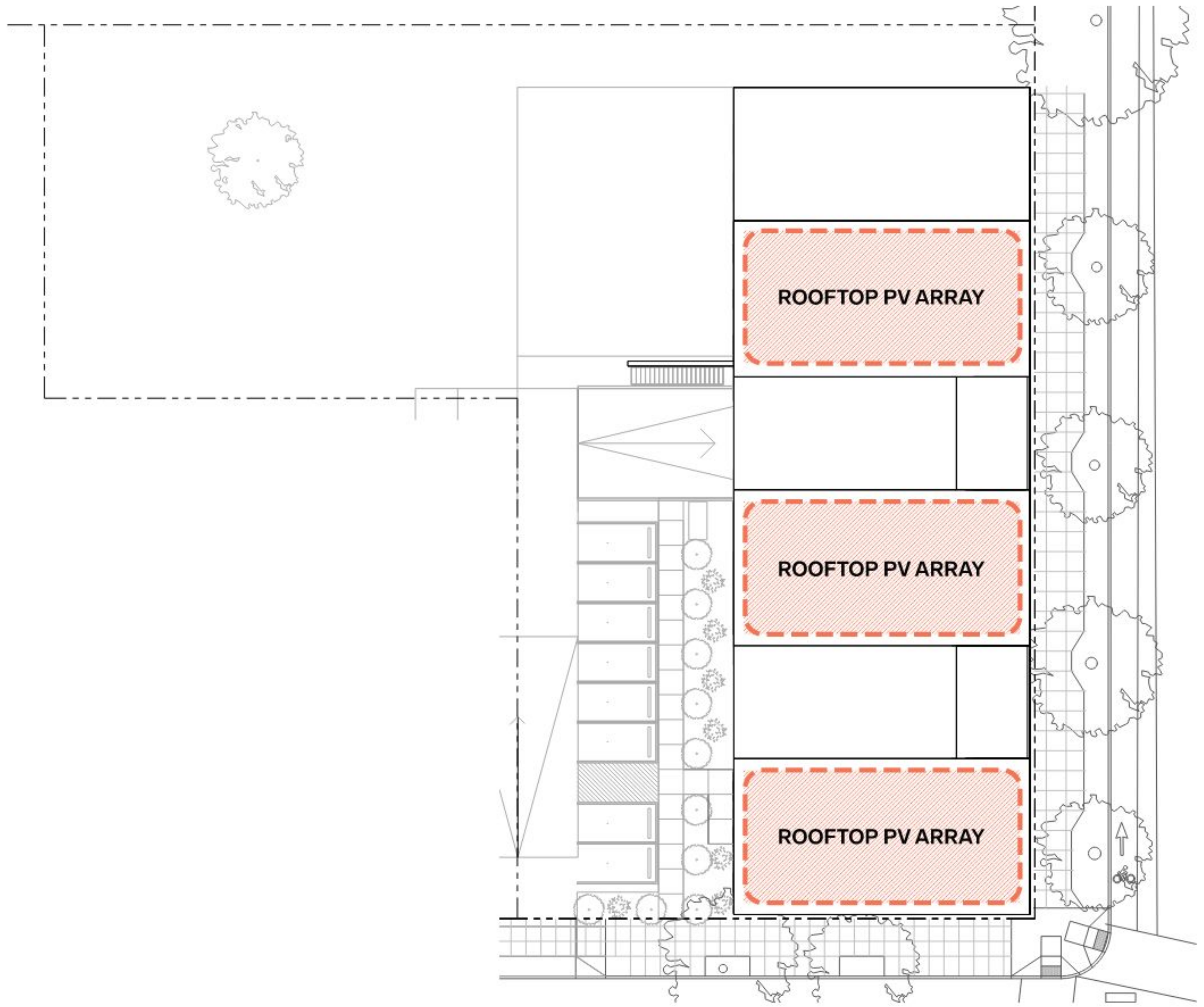
Code Minimum

527 kW PV

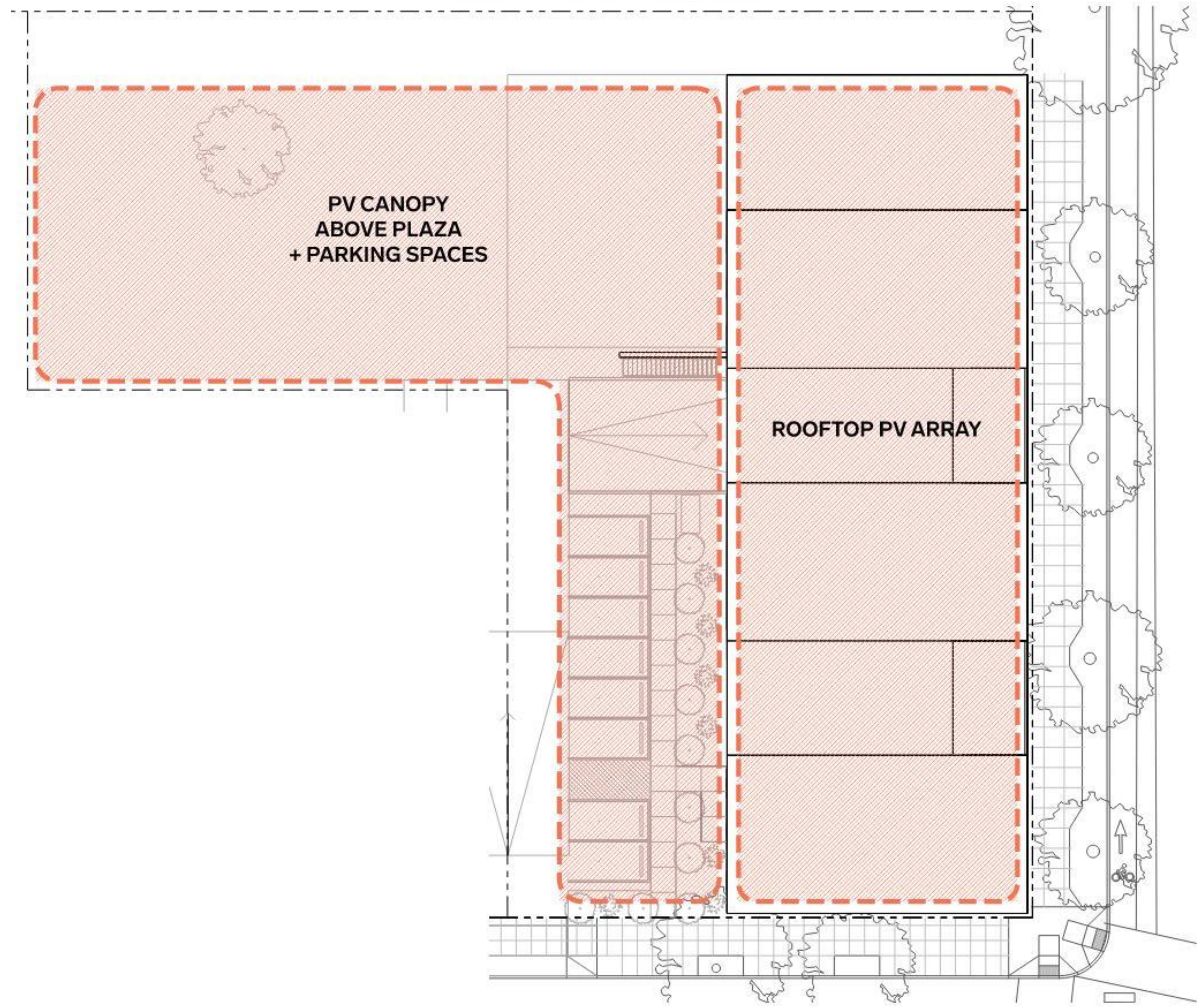
Net Zero Energy

On-Site Renewable Energy

Black Business Hub



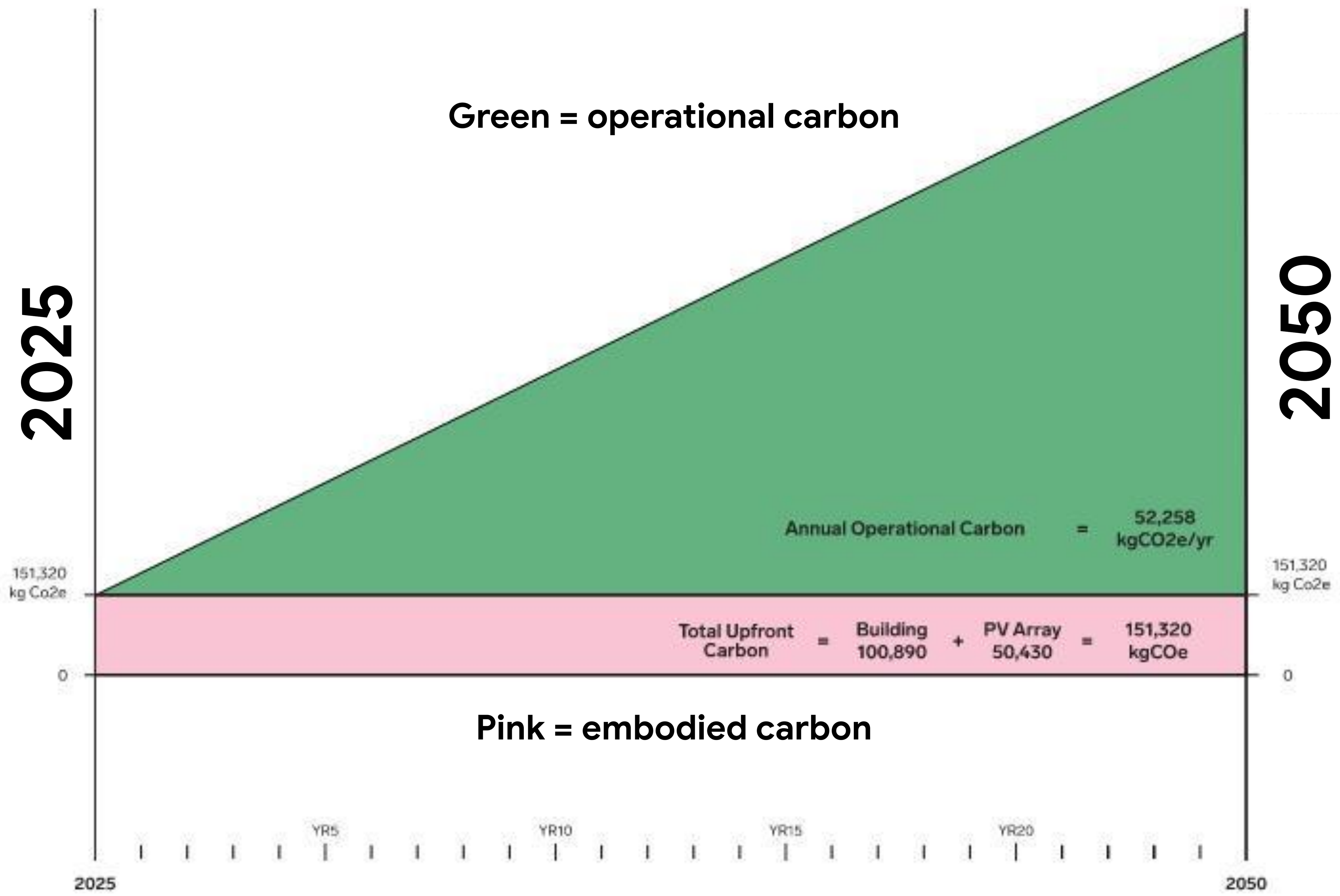
Passive House (Mass Timber)
82 kW PV
30% Net Zero Energy annually



Passive House (Mass Timber)
318 kW PV
Net Zero Carbon in 25 years
(Upfront with Biogenic Carbon)

Total Carbon Scenarios - 25 years

Black Business Hub



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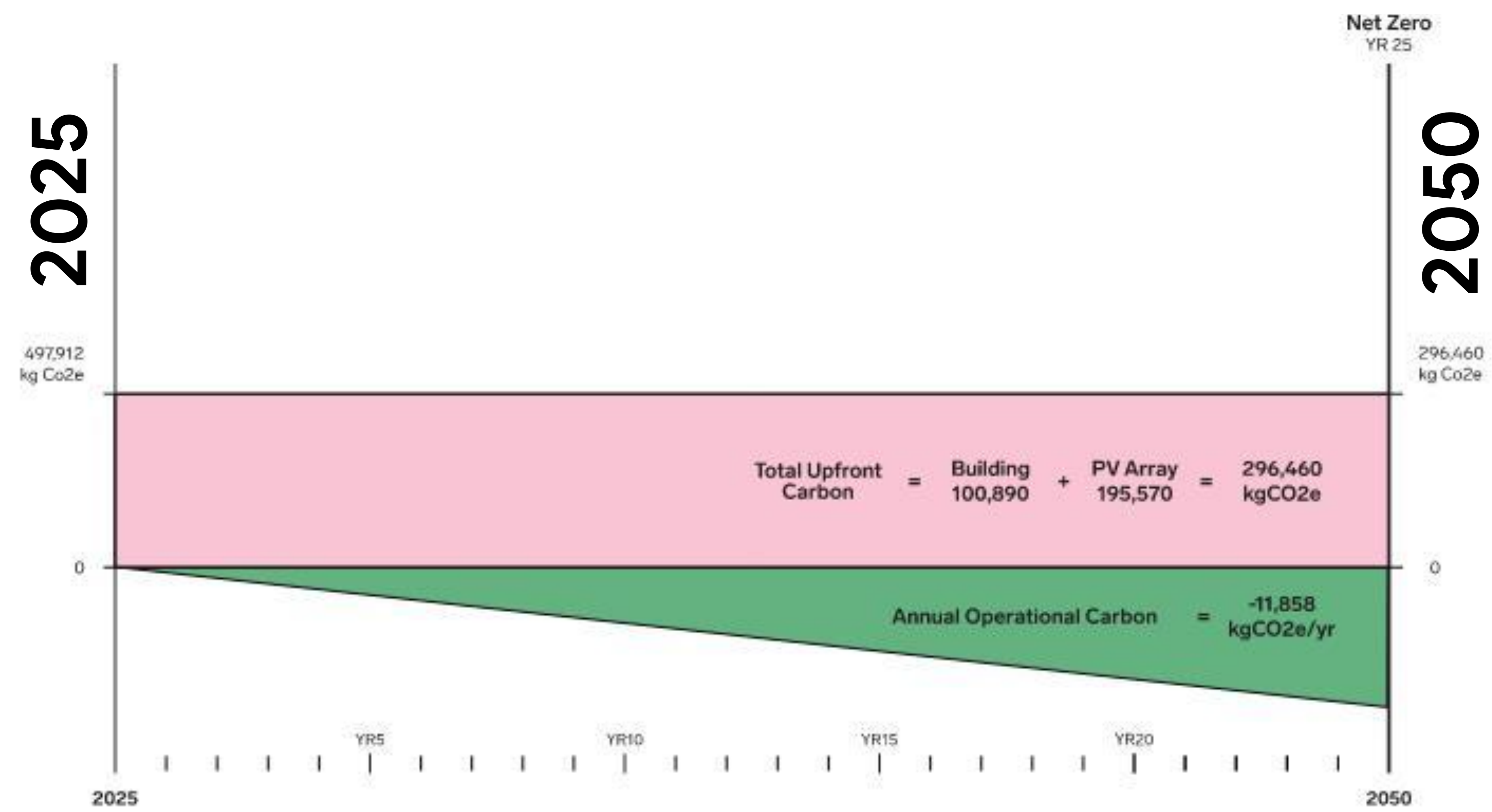

Passive House (Mass Timber)
318 kW PV
Net Zero Carbon in 25 years
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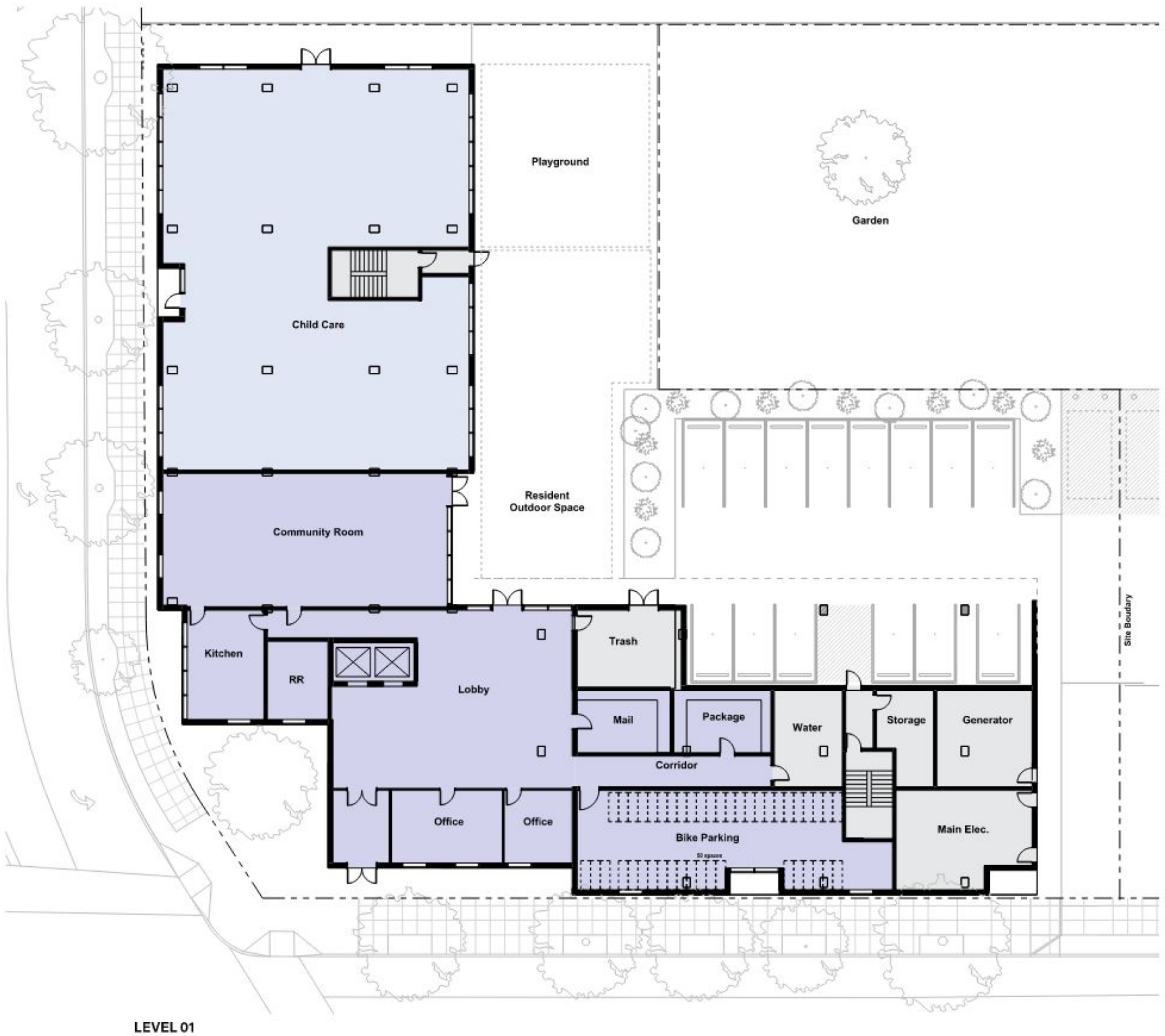
Affordable Apartments

Floor Plans

Affordable Apartments



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Operational Carbon Summary

Affordable Apartments

Energy Modeling Parameters

Component	Code Minimum	Passive House
Floor / Slab on Grade	R-0	R-0
Edge of Slab	R-15 for 24"	R-15 for 24"
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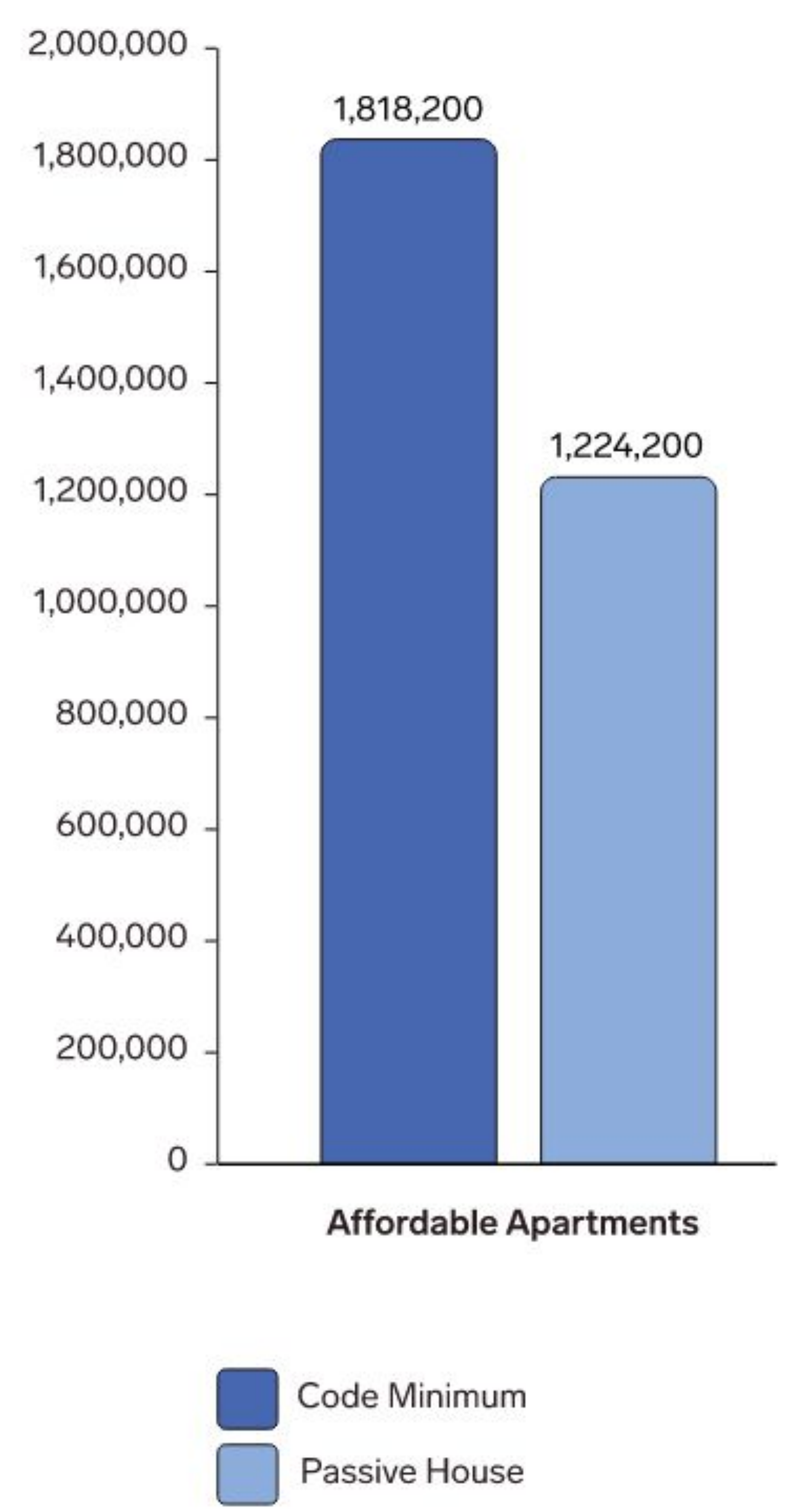
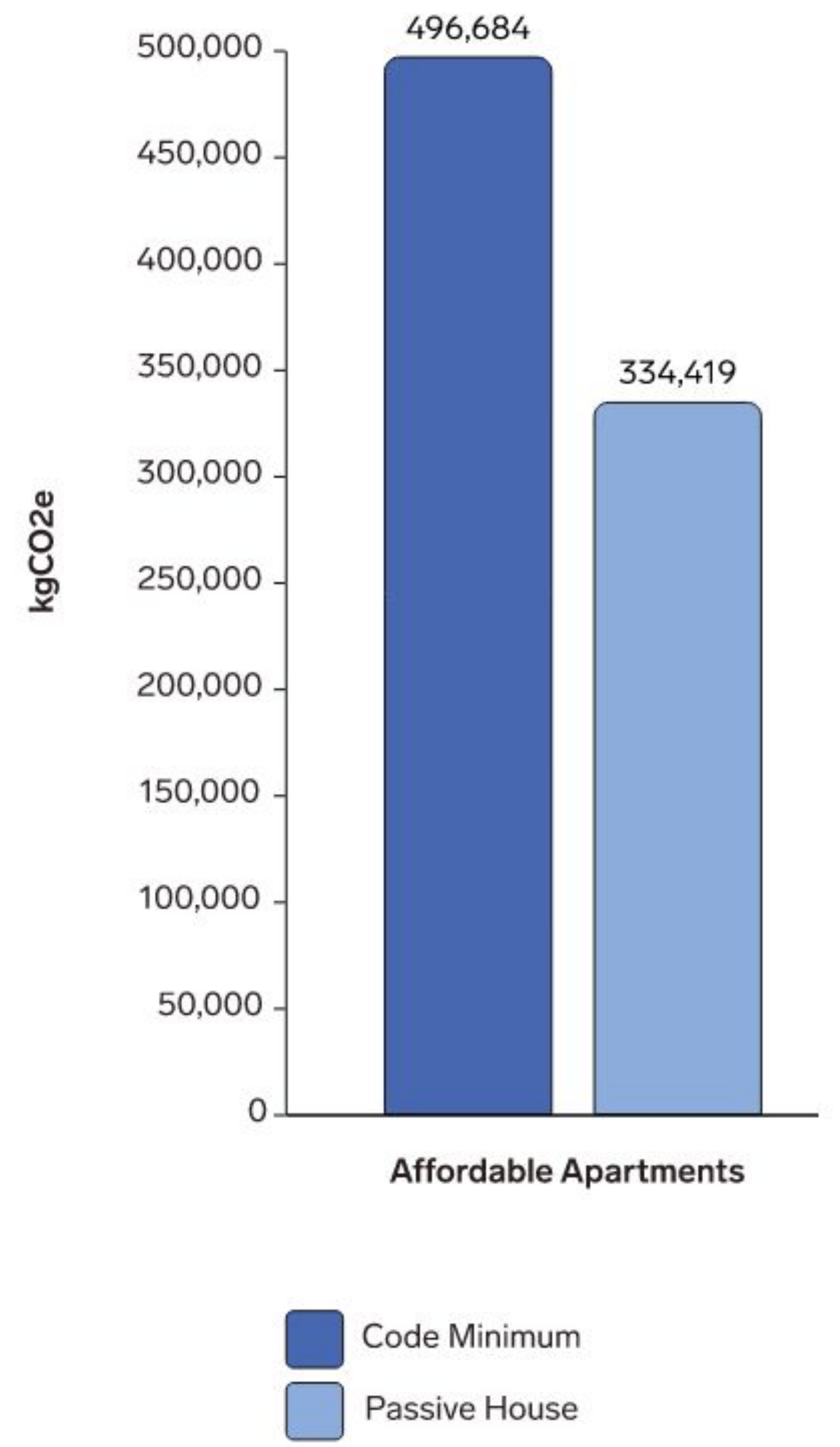
Roof	R-30 Effective	R-38 Effective
Storefront Windows	U = .36 / SHGC = .33	U = .36 / SHGC = .27
Upper Windows	U = .36 / SHGC = .33	U = .26 / SHGC = .26
Infiltration	.4 @ 75PA	.2 @ 75PA
Heating / Cooling	Electric Res / PTAC	Split System Heat Pump
Ventilation	ERV (50% Efficient)	ERV (68% Efficient)
Water Heating	Electric Resistance	Heat Pump (Central)

Improved envelope = 7% savings

Better systems = 26% savings



Annual Operational Energy (kWh/yr)



Annual Operational Carbon (kgCO2e/yr)

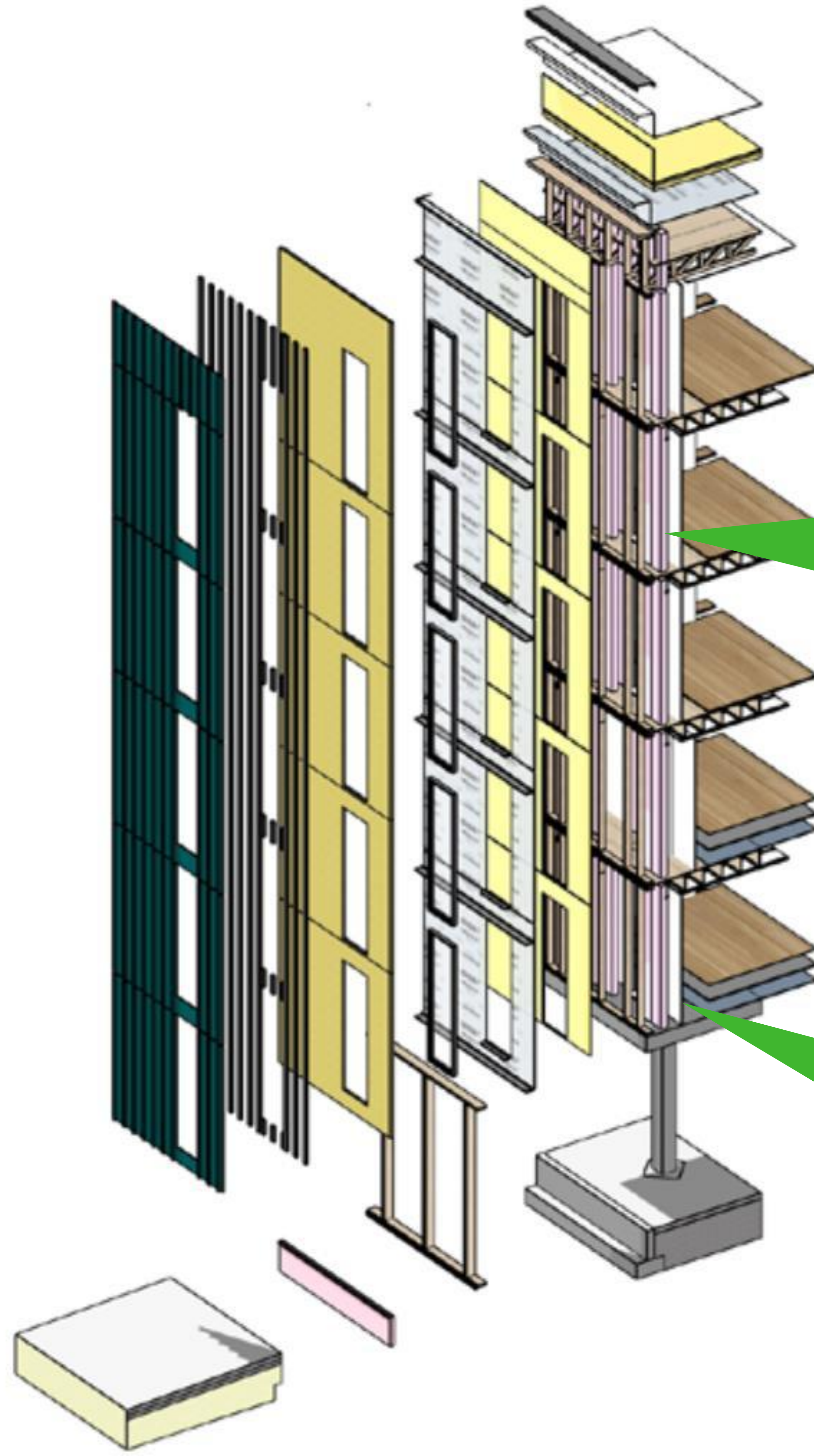
Passive House Assemblies

Affordable Apartments

Type IV-C
Interior and exterior walls are non-combustible (metal stud)

Can have exposed Mass Timber at ground floor

PH Mass Timber



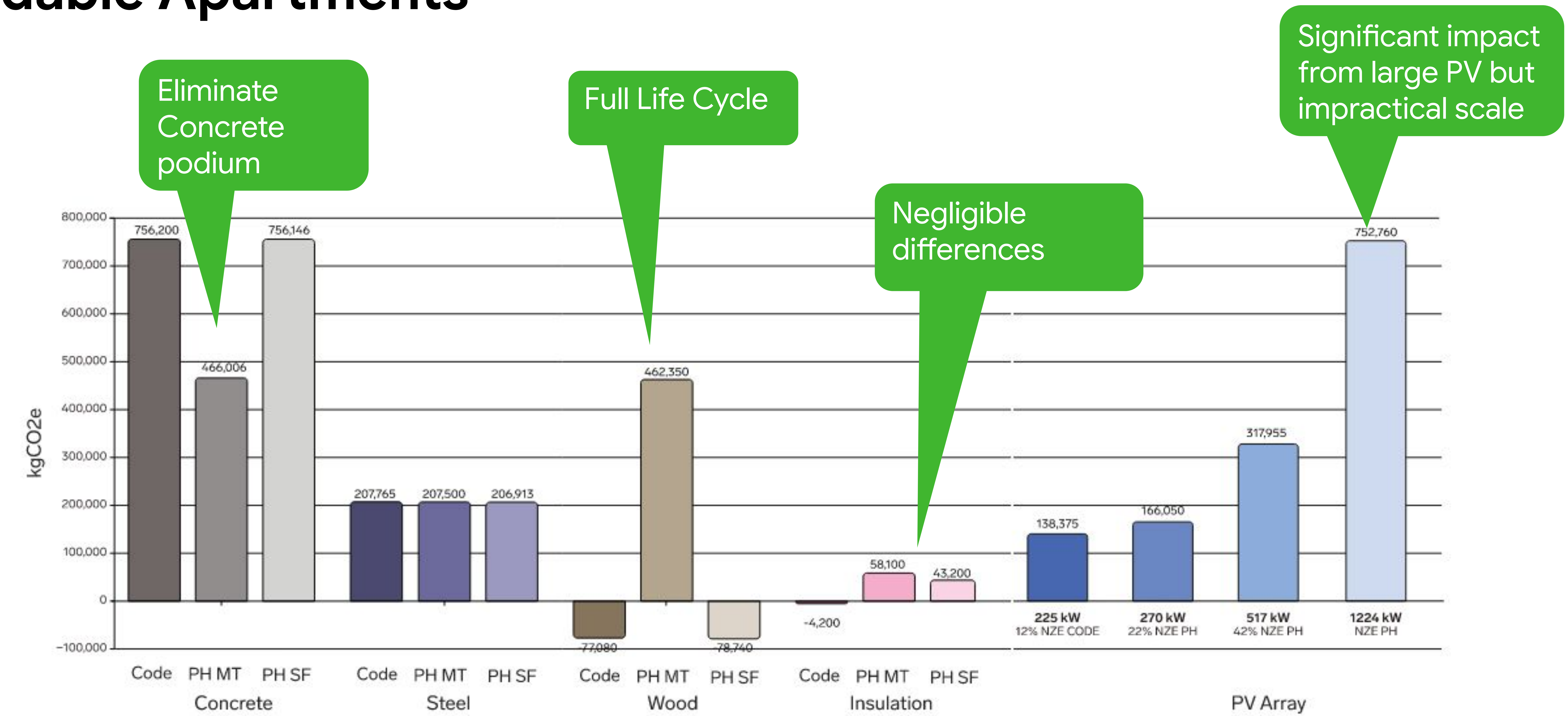
Type III-A
Exterior walls are FRT wood.
Interior walls are untreated wood.

Type I
Concrete Podium (or FP steel) at ground floor

PH Stick Frame

Embodied Carbon Results

Affordable Apartments

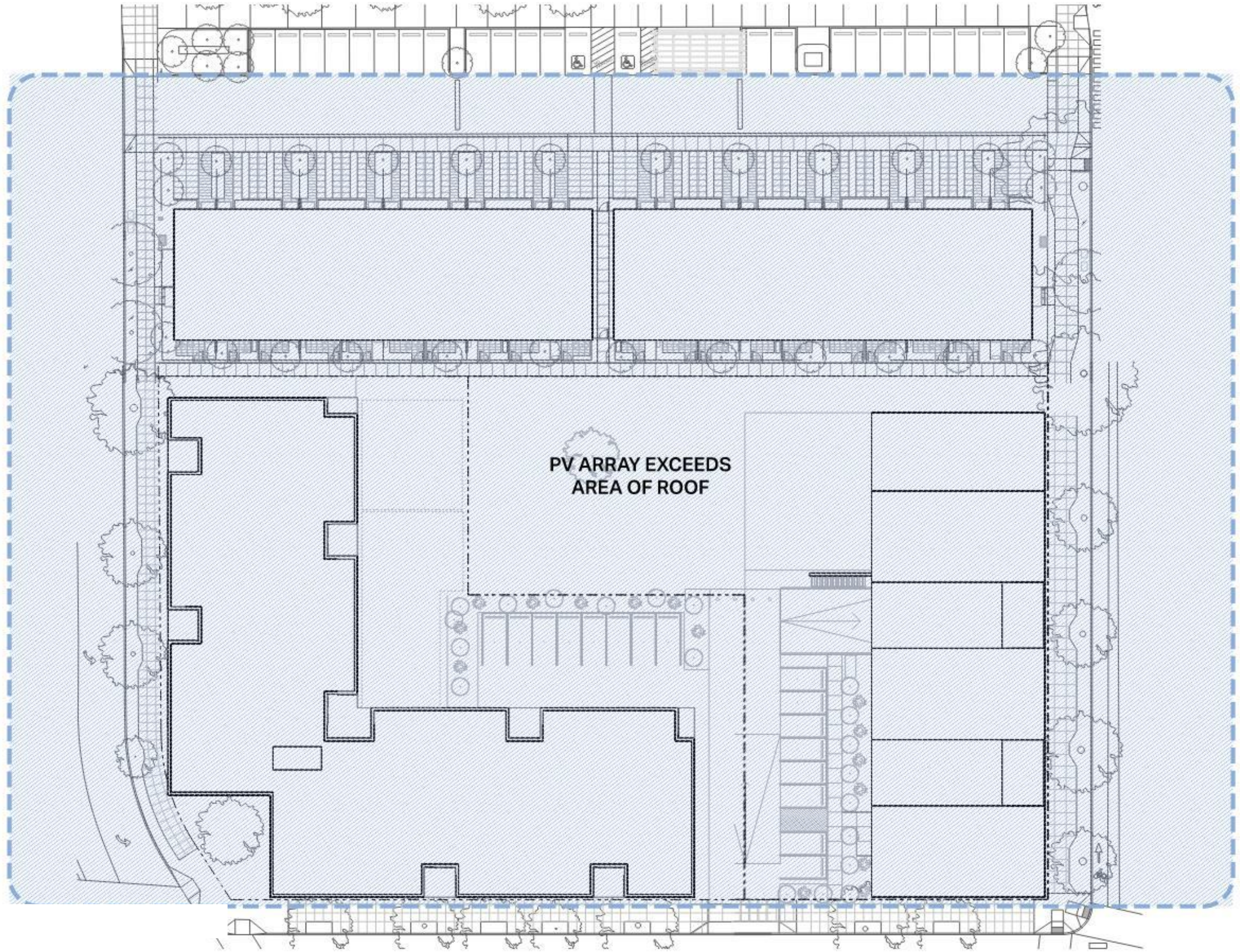


Embodied Carbon of Major Materials (Full Life Cycle with Biogenic Carbon)

On-Site Renewable Energy

Affordable Apartments

Code Minimum
1818 kW PV
Net Zero Energy



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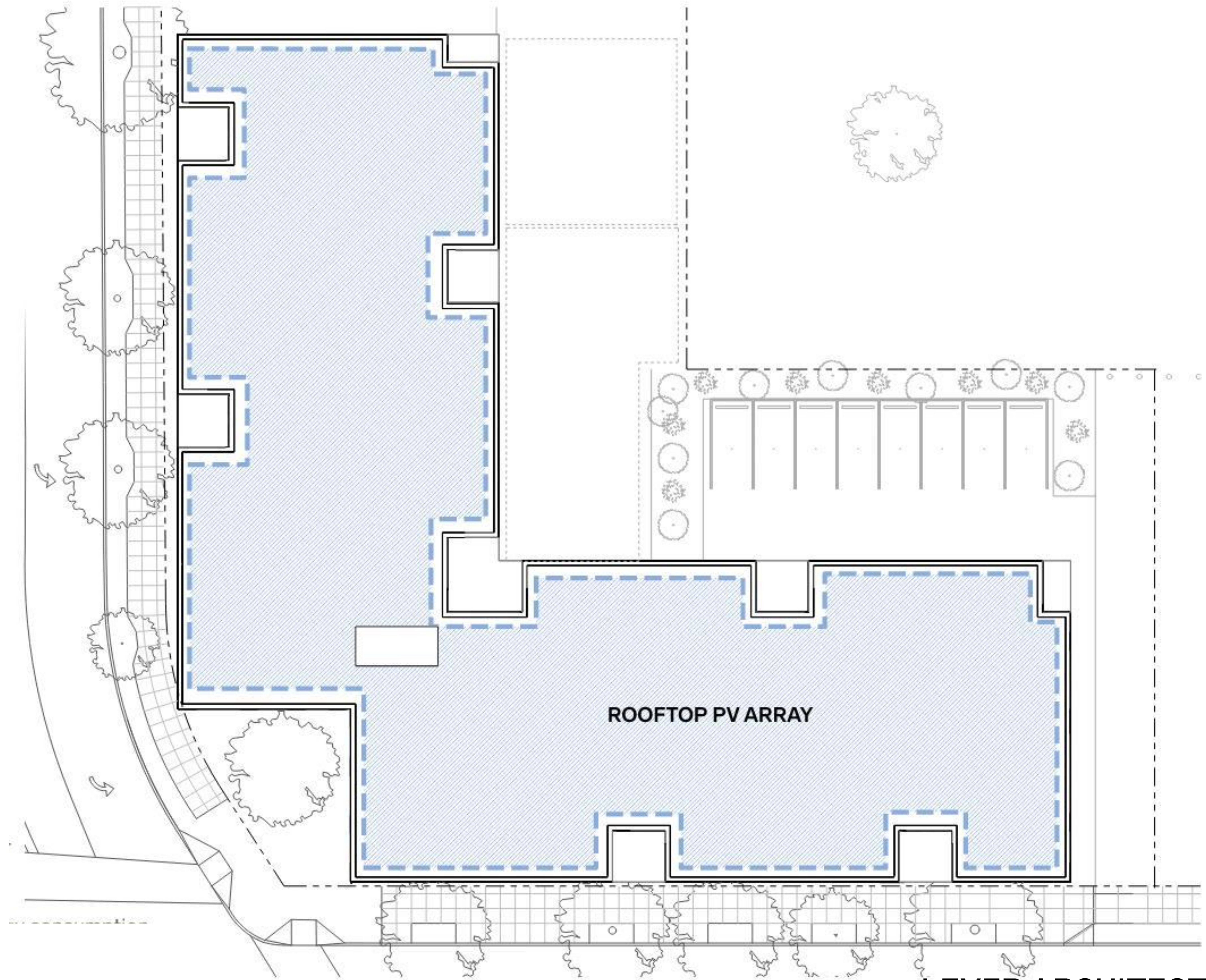
On-Site Renewable Energy

Affordable Apartments

Passive House
225 kW PV
18% Net Zero Energy



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Conclusions + Strategies

Passive House Typical Assemblies

Climate Zone 4c

- As building scale increases, differences in R-value become minimal
- Compact efficient forms result in simplified assemblies
- Deeper cavities (stick frame) are cost effective for insulation
- Continuous insulation better addresses thermal bridging
- Airtightness and thermal bridging can be biggest challenges to PH

Selecting the Structural System

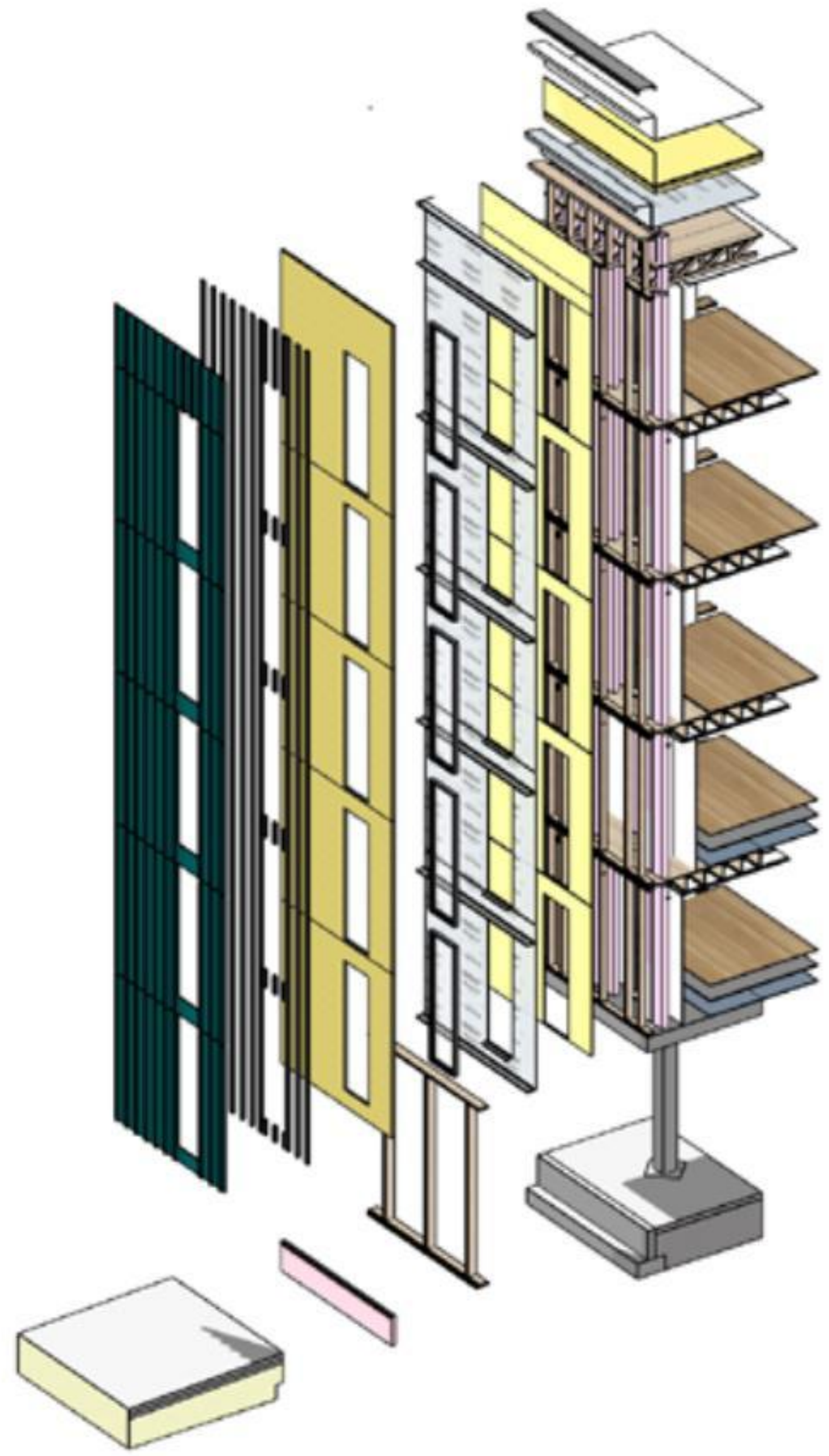
Mass Timber vs Stick Frame

Mass Timber Advantages

- Simplicity of construction
- Fewer layer of materials
- Speed of construction
- Reduced floor to floor height
- Can eliminate concrete podium
- Aesthetic qualities when exposed
- Fire resistance of structure

Mass Timber Disadvantages

- Increased quantity of wood fiber
- Exterior insulation only
- Higher embodied carbon insulation
- Challenging to conceal services
- Challenging to field modify



Stick Frame Advantages

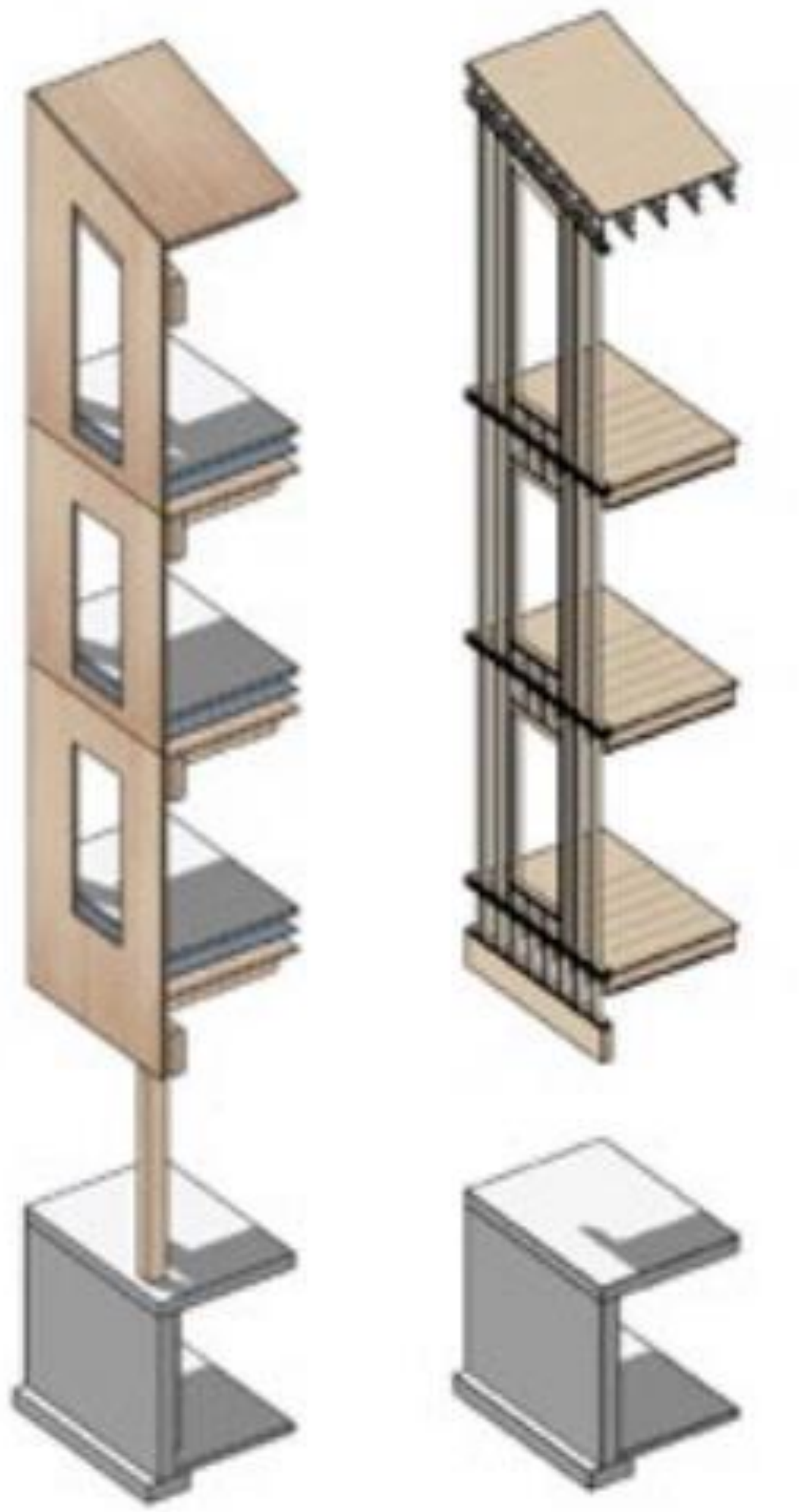
- Cavities for insulation
- Low embodied carbon cavity insulation
- Reduced quantity of wood fiber
- Cavities for distribution of services
- Easier to field modify

Stick Frame Disadvantages

- Concrete podium required (per height)
- Many layers of materials
- Longer construction schedule
- Increased floor to floor height

Selecting the Structural System

Concrete Reductions



Mass Timber

Topping slab = significant CO2e

Wet assemblies = longer schedule

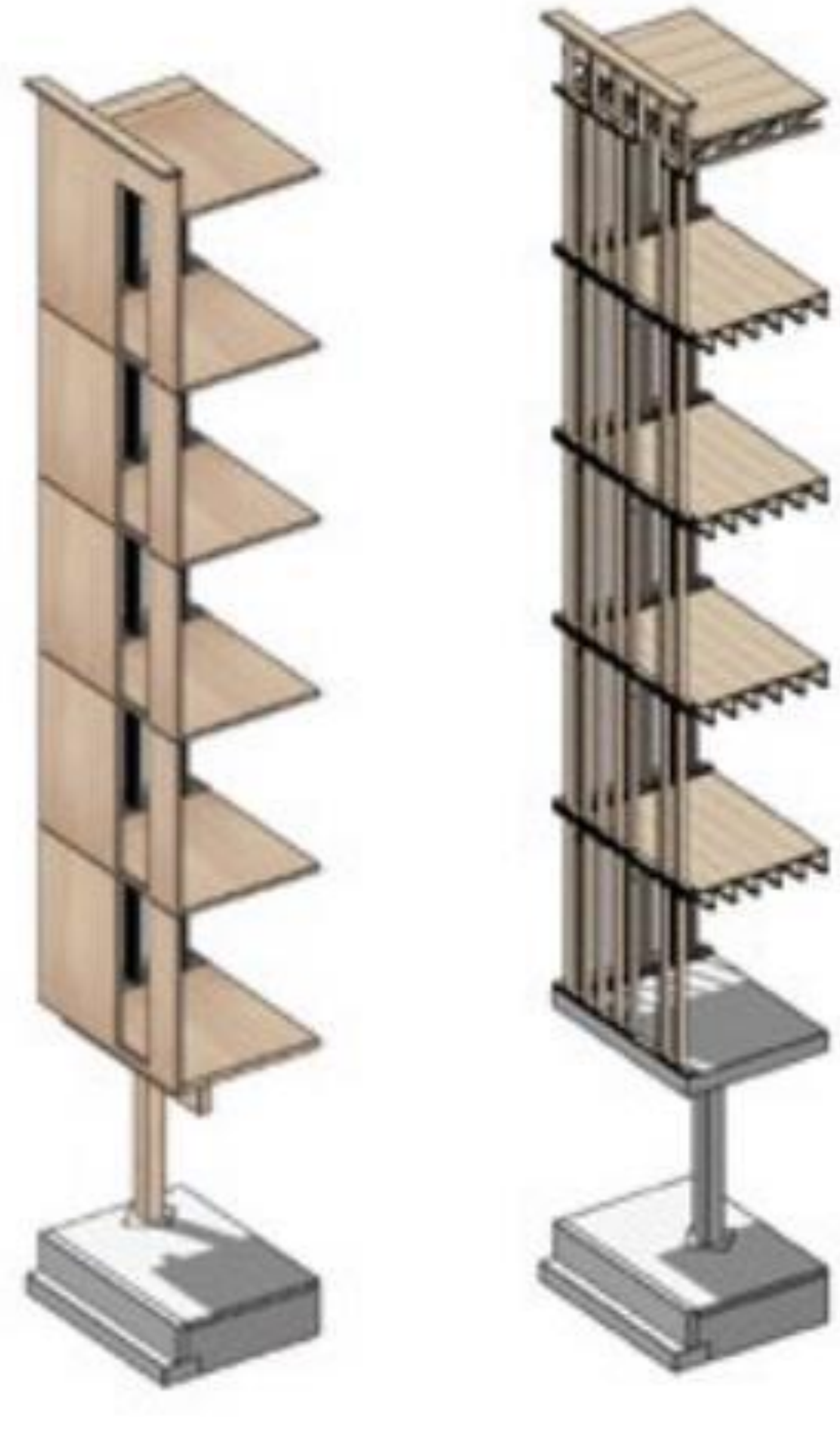
Below Grade Parking

~200% increase in upfront CO2e

Earthwork, waterproofing, core, etc

Longer schedule

Typical 4 Story Office Building



Stick Frame over Podium

Podium = significant CO2e

Podium = longer schedule

Mass Timber (Type IV-C)

No podium

Aesthetic of exposed mass timber

Non-combustible metal framing required

Typical 6 Story Apartment Building

Selecting the Structural System

Hybrid Approach

Stick frame exterior walls

- cost effective for cavity insulation
- prefabricated for speed of construction
- lowest embodied carbon insulation

Mass timber floors and roof

- for speed of construction
- aesthetic appeal (exposed)
- dry assemblies for speed
- dry assemblies for low carbon

Selecting Low Carbon Insulation

Cavity Insulation (per 100sf @ R-8)

Closed Cell Spray Polyurethane Foam (HFC Formula)

522 kg CO2e

Closed Cell Spray Polyurethane Foam (HFO Formula)

138 kg CO2e

Fiberglass Loose Fill

116 kg CO2e

Mineral Wool Batts

95 kg CO2e

Open Cell Spray Polyurethane Foam

90 kg CO2e

Fiberglass Batts

73 kg CO2e

Wool Batts

73 kg CO2e

Cellulose Loose Fill

-60 kg CO2e

Wood Fiber Batts

-74 kg CO2e

Cellulose Dense Pack

-141 kg CO2e

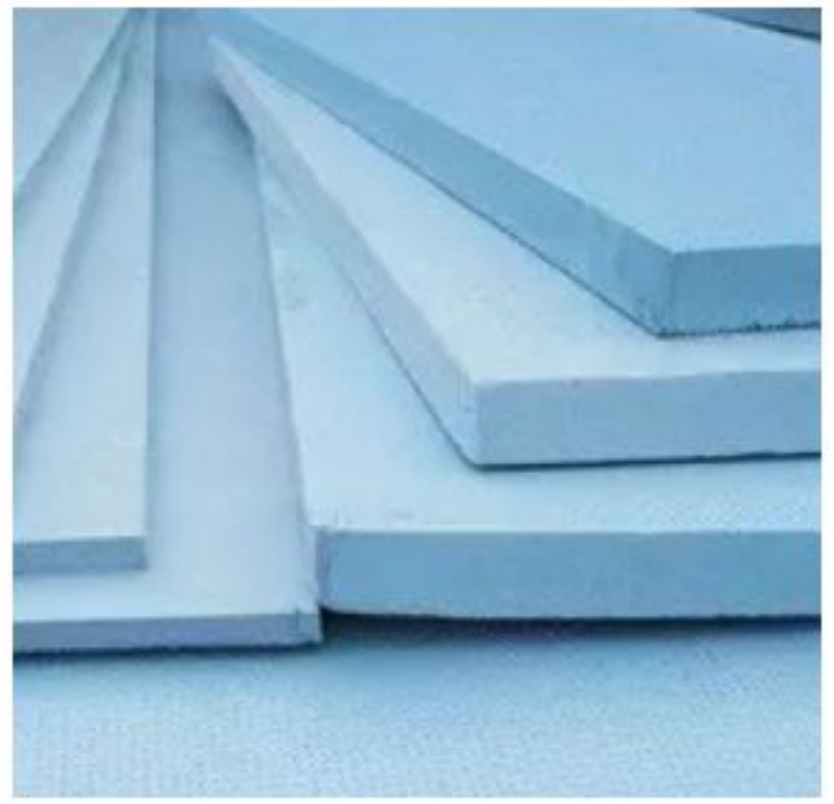
Values obtained using BEAM Estimator

LEVER ARCHITECTURE

Selecting Low Carbon Insulation

Board Insulation (per 100 sf @ R-8)

Extruded Polystyrene (XPS) (Legacy Formula)



1321 kg CO2e

Foam Glass

315 kg CO2e

Extruded Polystyrene (XPS) (Reduced GWP Formula)

221 kg CO2e

Expanded Polystyrene (EPS) (Type IX Density)

132 kg CO2e

Graphite Expanded Polystyrene (Type IX Density)

82 kg CO2e

Mineral Wool Board

63 kg CO2e

Polyisocyanurate (Polyiso)

42 kg CO2e

Cork Board

-78 kg CO2e

Wood Fiberboard

-102 kg CO2e

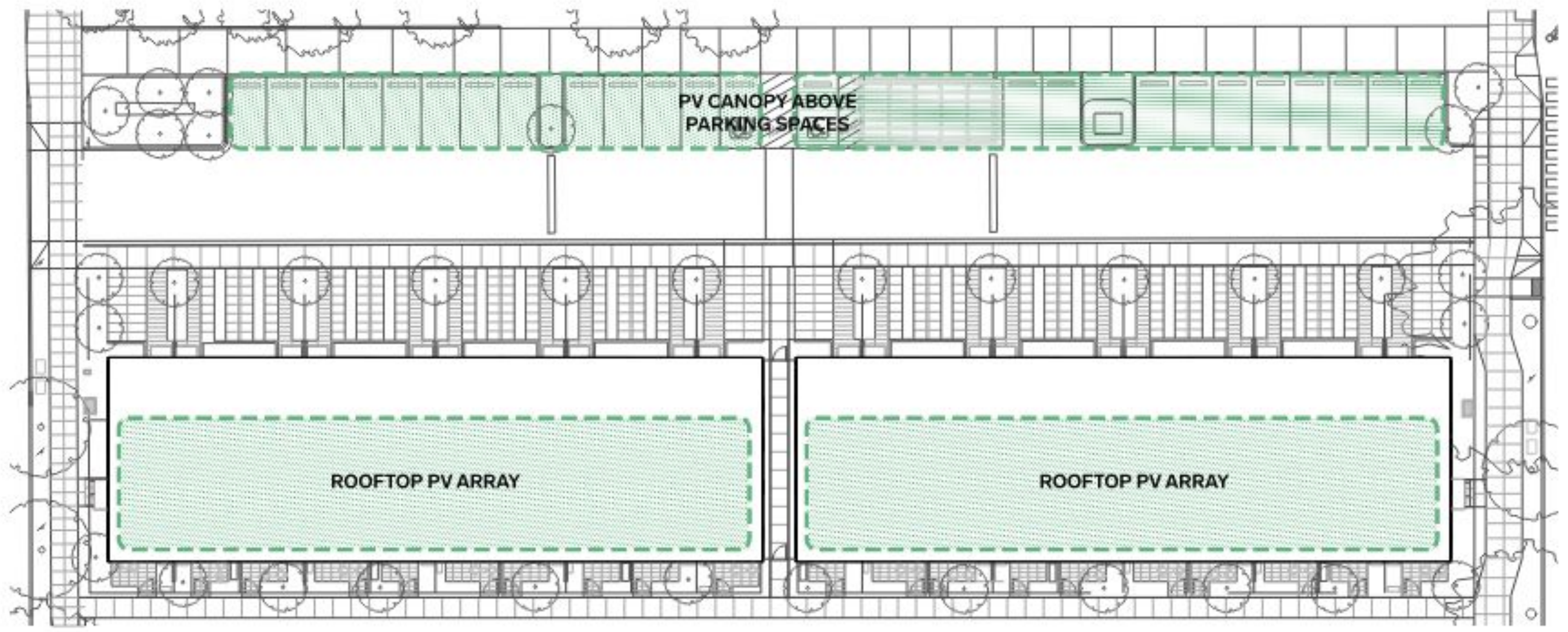
Straw Board

-1308 kg CO2e

Values obtained using BEAM Estimator

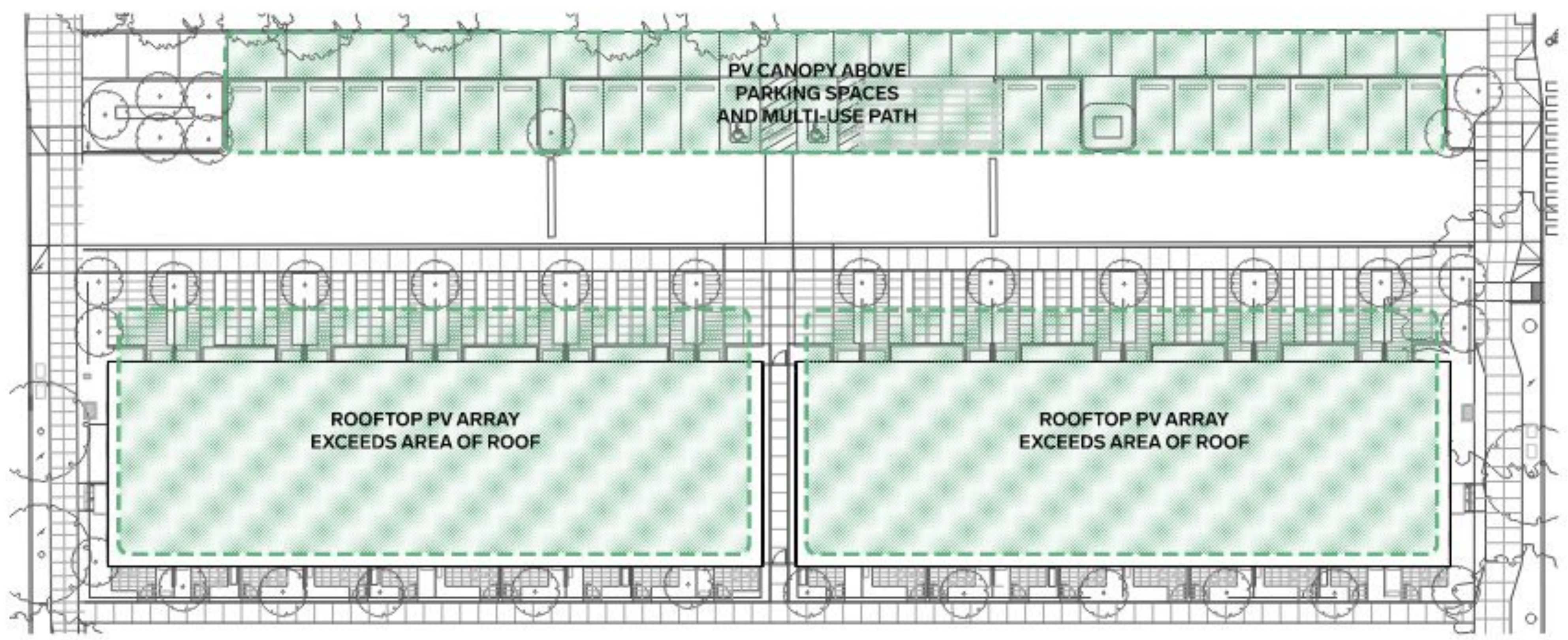
Embodied CO2 vs Operating Emissions

Code Minimum vs Passive House



216 kW Energy Positive Passive House

(Net Zero Carbon in 25 years)



354 kW Net Zero Energy Code Minimum

(exceeds available roof area)

Passive House Advantages

- Uses 52% - 67% of operational energy vs code minimum
- Significantly smaller PV array to reach NZE
- Ability to be energy positive on smaller projects
- Improved comfort (less temperature fluctuation)
- Better air quality (through airtightness and filtered ventilation)
- Increased durability (less moisture transmission / condensation)
- Reduced mechanical system sizes
- More resilient to extreme weather events

Passive House Envelope

- Reduced operational CO_2 between 7% - 14% annually
- Increased embodied CO_2e between 1% - 10%

How to Create Low Carbon Buildings

Townhomes

Strategies for 2-3 Story Townhomes

Build to Passive House

Compact forms for efficiency

Minimize concrete foundations (crawlspaces?)

Stick Frame to maximize cavity insulation

Source wood products from local and verifiable sources

Prioritize cellulose and wood fiber insulation

Minimize use of foam or other petroleum based products

Incorporate bio-based materials wherever possible

How to Create Low Carbon Buildings

Black Business Hub

Strategies for 4 Story Office

Build to Passive House

Eliminate below grade parking

Mass timber structure for speed / aesthetics / flexibility

Use dry assemblies in lieu of concrete topping slabs

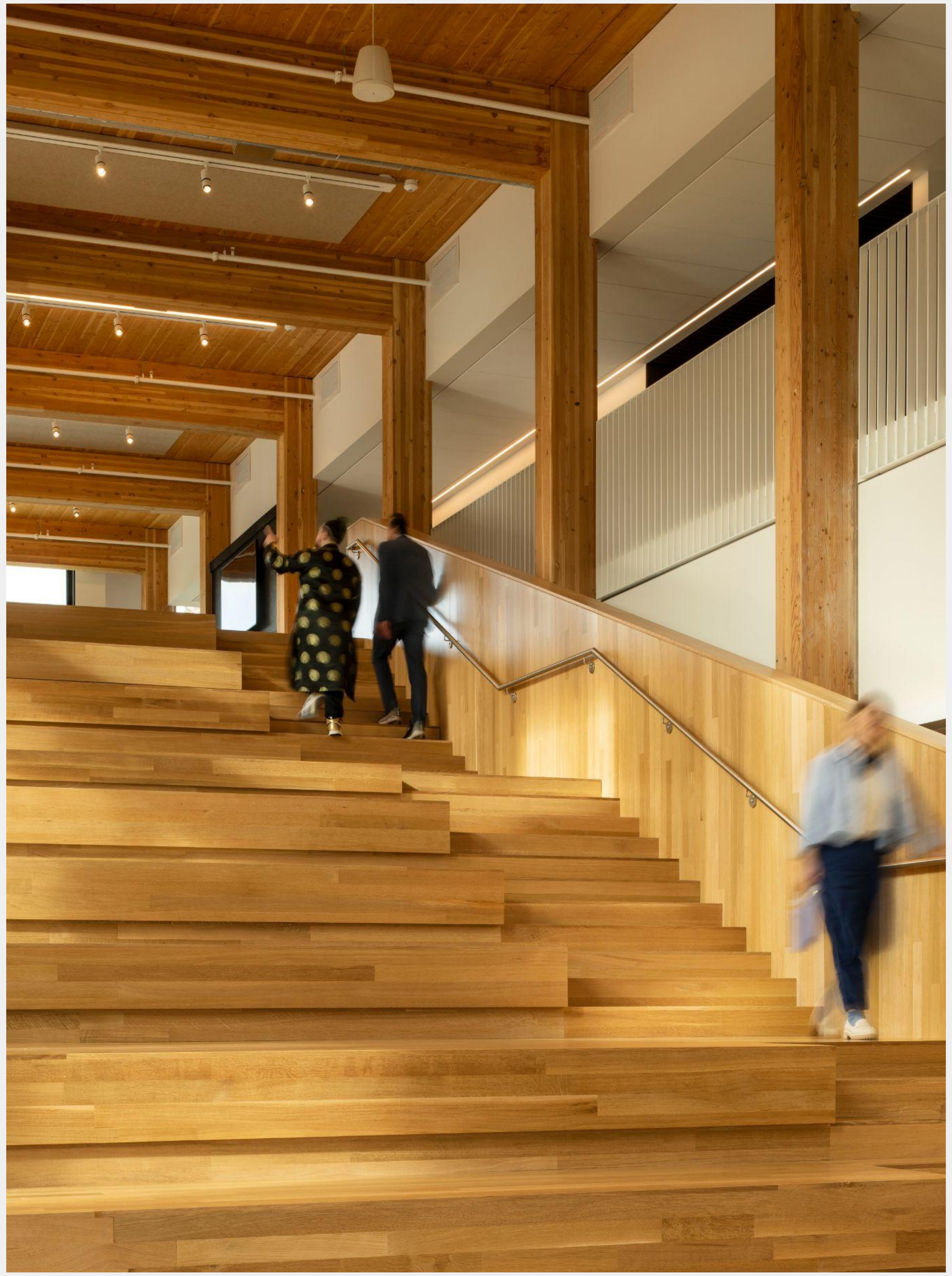
Stick frame exterior walls to maximize cavity insulation

Source wood products from local and verifiable sources

Prioritize cellulose and wood fiber insulation

Minimize use of foam or other petroleum based products

Incorporate bio-based materials wherever possible



LEVER ARCHITECTURE

How to Create Low Carbon Buildings

Affordable Apartments

Strategies for 6 Story Housing

Build to Passive House

Eliminate concrete podium if possible

Mass timber floors for speed / aesthetics / reduced height

Use dry assemblies in lieu of gypcrete topping slabs

Stick frame exterior walls to maximize cavity insulation

Source wood products from local and verifiable sources

Prioritize cellulose and wood fiber insulation

Minimize use of foam or other petroleum based products

Incorporate bio-based materials wherever possible

How to Create Low Carbon Buildings

Conclusions

Carbon modeling is in its infancy

Data accuracy is challenging with many uncertainties

Know the stages of embodied carbon

Be skeptical of zero carbon building claims

Understand that all wood is not equal

Look for verification of performance claims

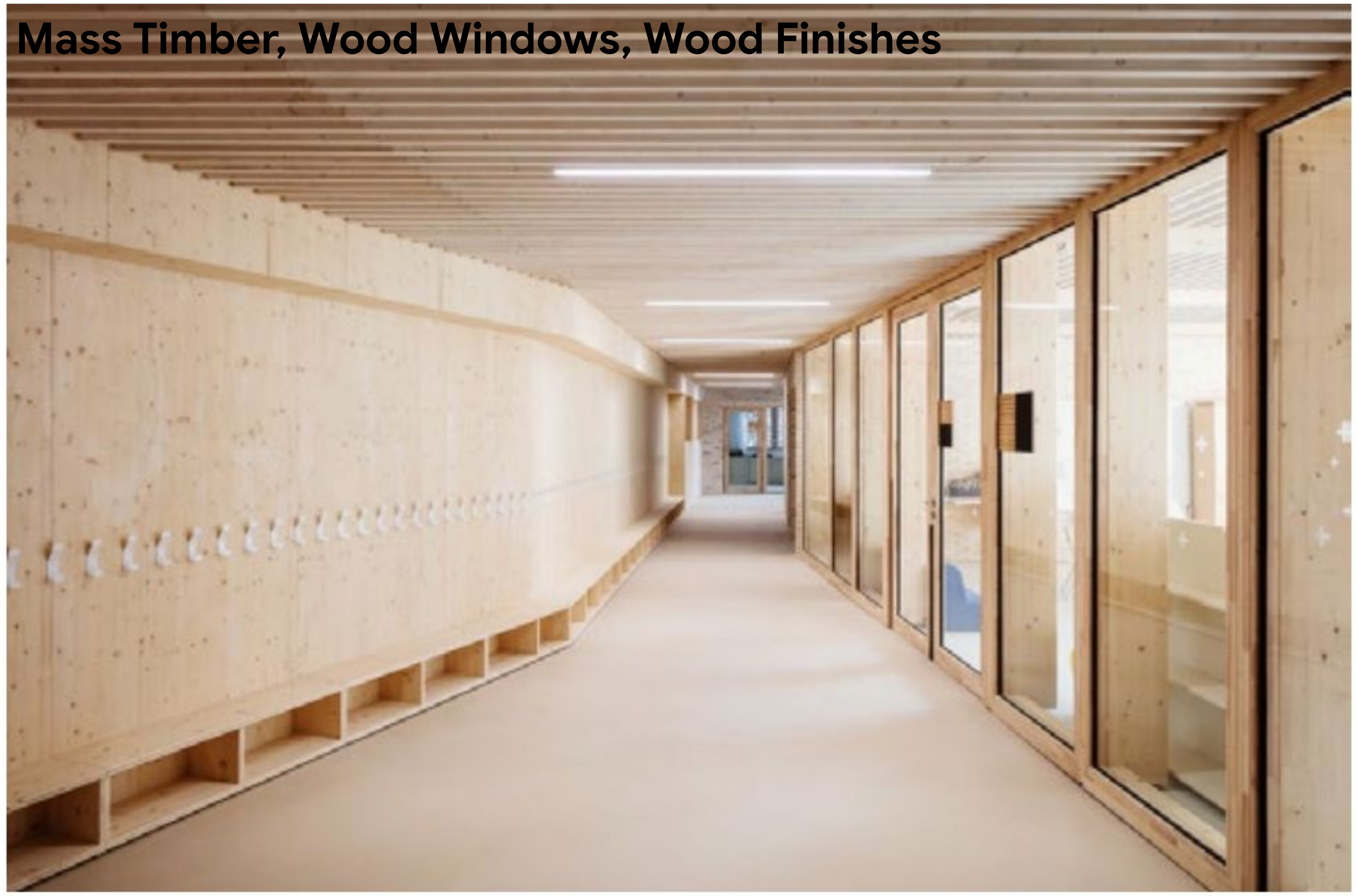
PH strategies are not the same as PH certification

The whole is usually greater than the sum of its parts

LEVER ARCHITECTURE

A Bio-based Case Study

Jeanne d’arc Nursey School in Paris France



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Thank you