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

Energy Trust of Oregon | Net Zero Fellowship

LEVER

Team

Intro + Methodology

The Language of Carbon

A Passive House Primer

All Wood Is Not Equal

Case Studies

Conclusions + Strategies

Team

LEVER ARCHITECTURE

Skidmore Passivhaus

Albina Yard

LEVER Portland Mass Timber Projects

2013 **Union Way**

2014

2015 **Framework**

2016 **Albina Yard**

2017

2018 **FLEX**

2019 **Redfox Commons**

Oregon Conservation Center

2020 **Meyer Memorial Trust Headquarters**

2021 **adidas Headquarters**

2022

2023

2024 **Thesis Headquarters**

U of O Highland Hall

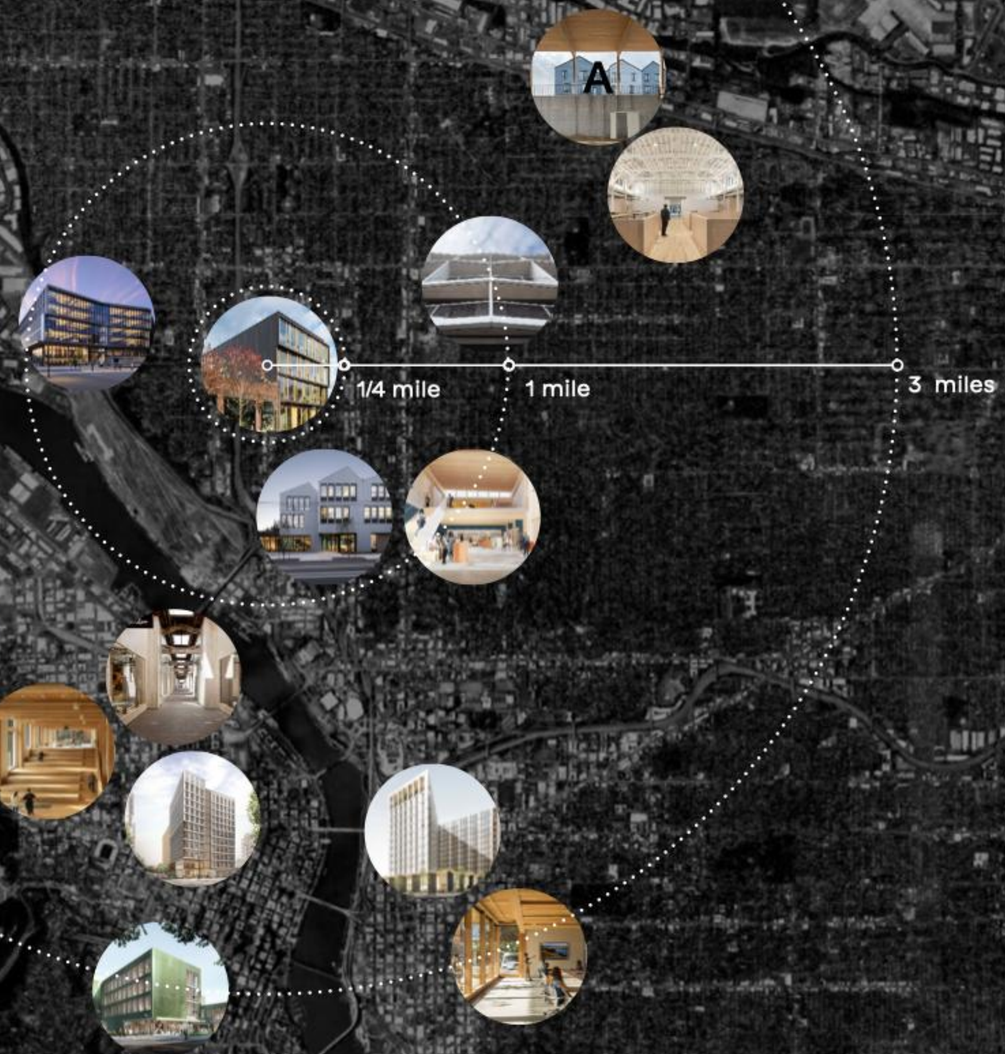
2025 **Cascada**

Dekum Court Housing

Albina Library

2026 **PSU, Schnitzer School of Art**

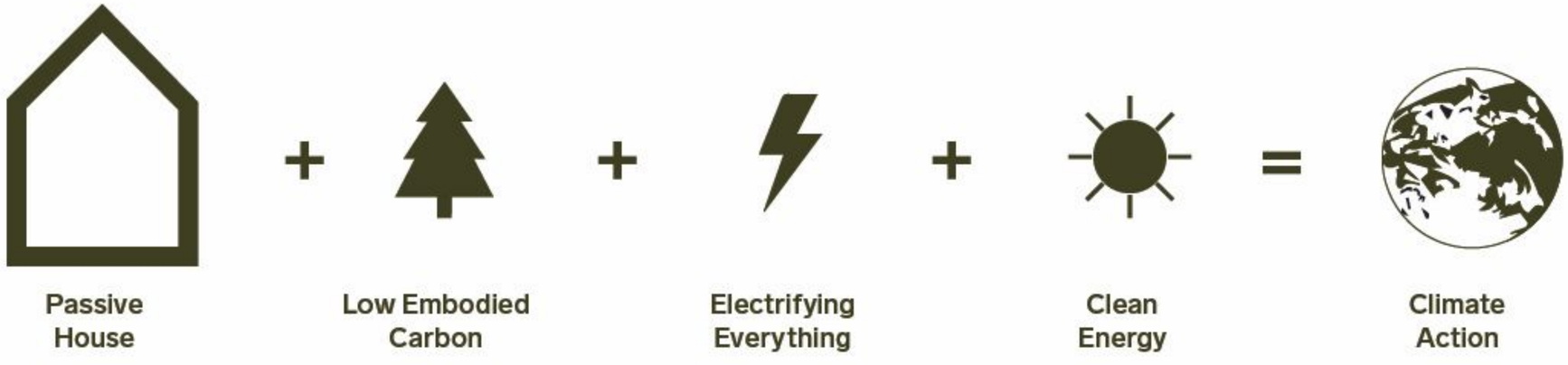
2027 **Sandy Pine**



LEVER ARCHITECTURE

Intro + Methodology

Why this Research



- Changing climate gives urgency to rapidly decarbonize
- Understand 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?

Mass Timber

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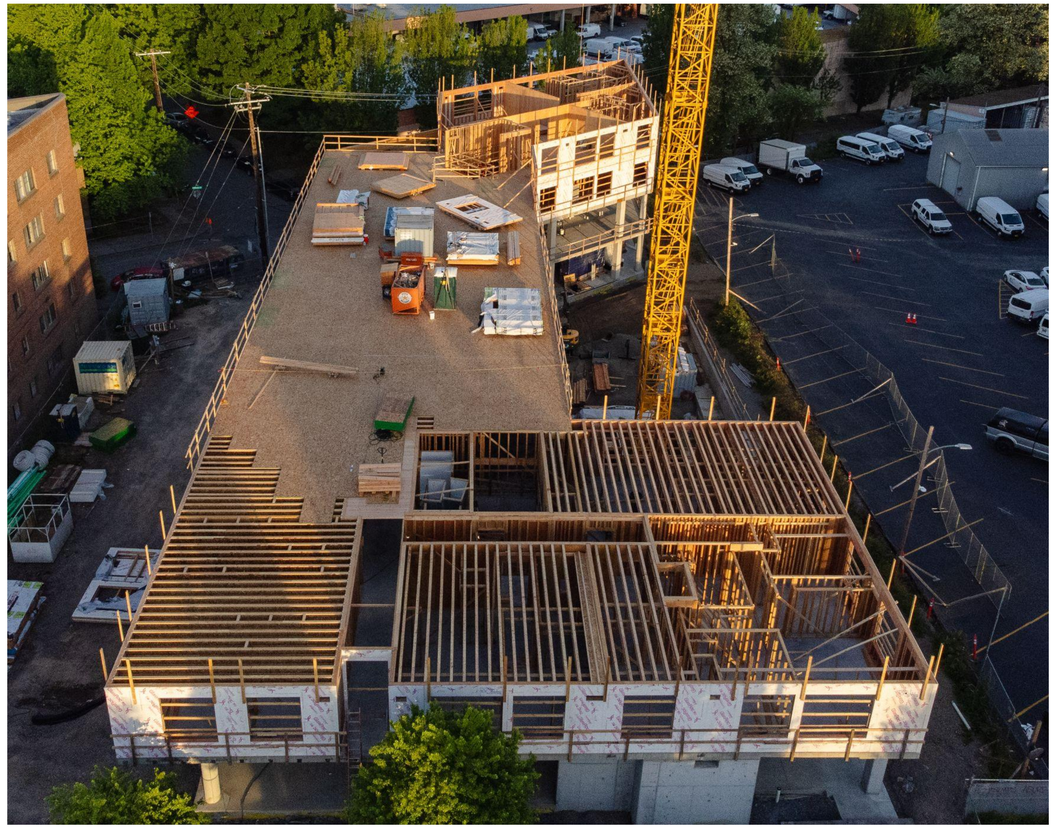
Stick Frame



Research Questions

- **Which wood structure type has lowest embodied carbon?**
- **What assemblies are required to meet Passive House?** (climate zone 4c)
- **How do Mass Timber and Stick Frame assemblies compare?**
- **What assemblies have lowest embodied carbon?**
- **When is Mass Timber more appropriate than Stick Frame?**
- **Are zero-carbon buildings feasible in today’s building climate?**

Methodology

Using 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

Williams & Russell Development

LEVER ARCHITECTURE

The Language of Carbon

LEVER ARCHITECTURE

Why Carbon

Buildings are responsible for ~39% of global carbon emissions

Carbon is a universal metric

Estimate full impact of emissions from construction

Estimate emissions from buildings and also supply chains

The Many Names of Carbon

Carbon

Carbon Dioxide (C02)

Carbon Dioxide Emissions

Carbon Emissions

Carbon Dioxide Equivalent (CO2e)

Greenhouse Gas Emissions (GHG)

Global Warming Potential (GWP)

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

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

To limit global warming to avoid irreversible climate change, reducing emissions today is more valuable than reducing emissions in the future.

Total Emissions Approach

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

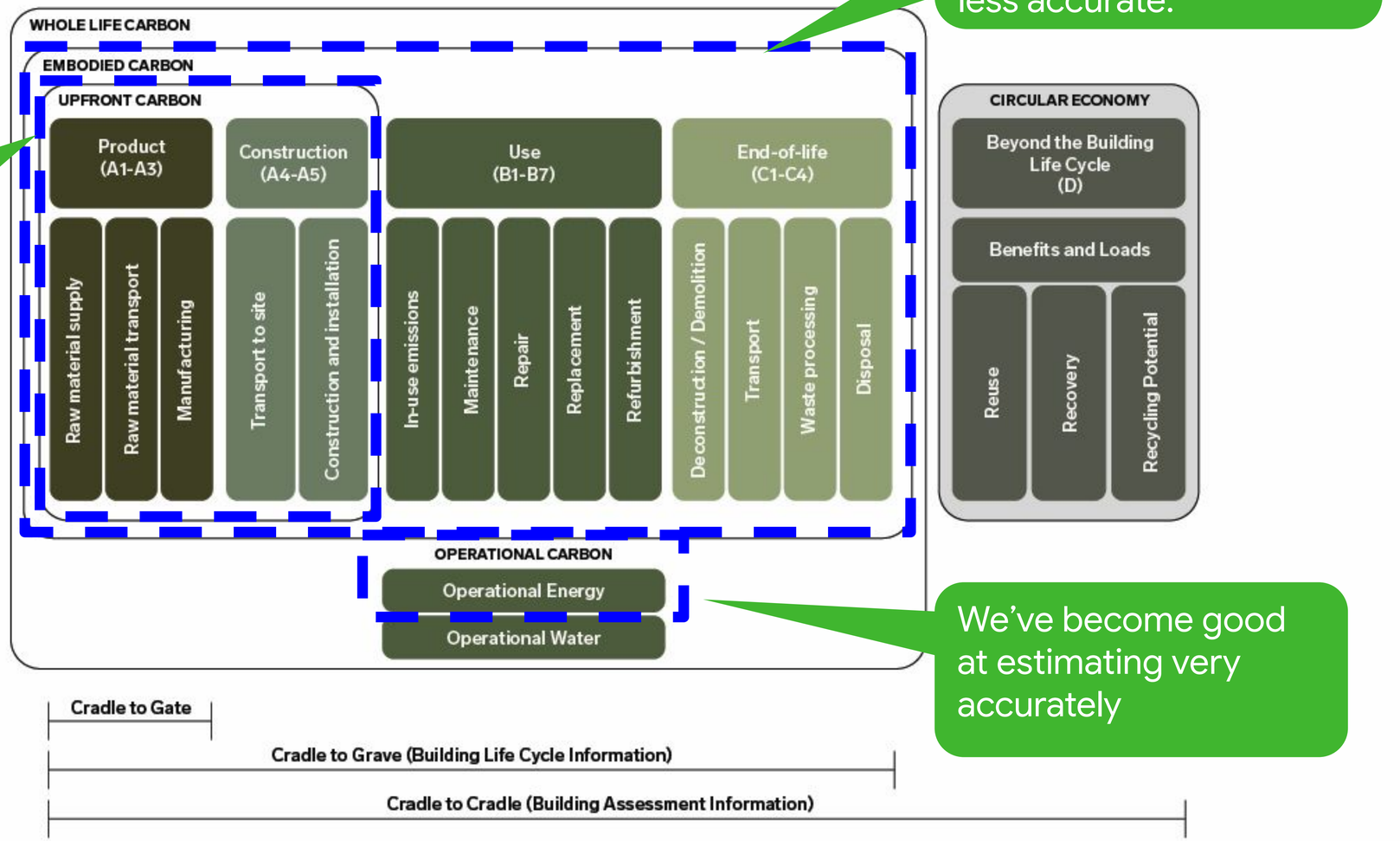
Upfront Emissions Approach

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

Stages of Carbon

Upfront is more limited but can estimate more accurately.

Full life cycle is more comprehensive but very difficult to predict and less accurate.



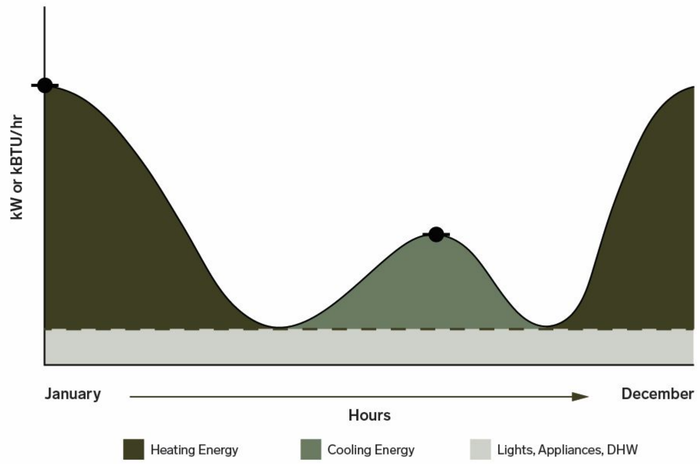
We've become good at estimating very accurately

A Passive House Primer

LEVER ARCHITECTURE

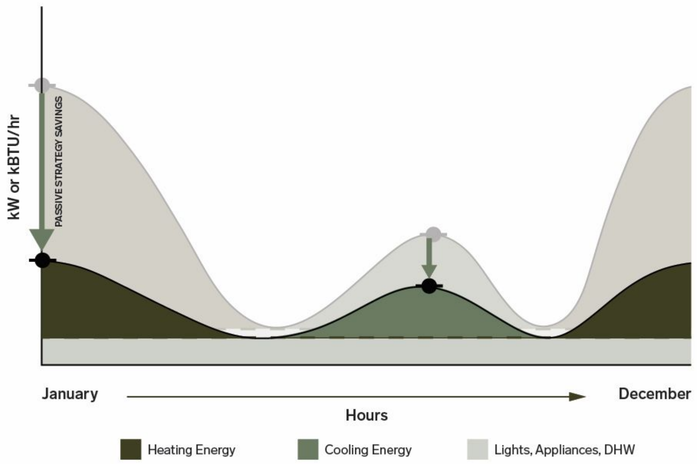
Why Passive House

(Isn’t Net Zero Enough?)



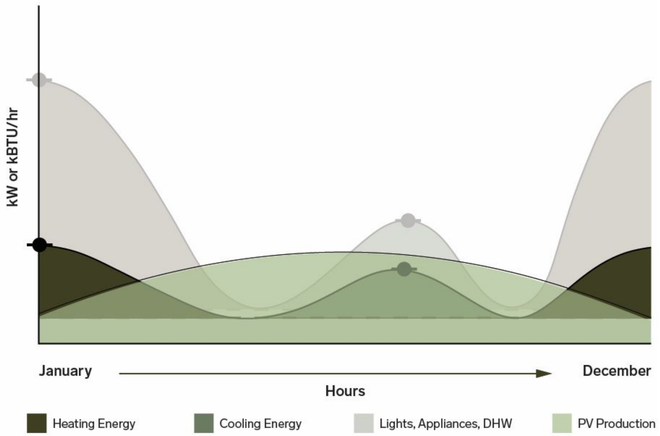
Seasonal Loads

Code Minimum



Seasonal Loads

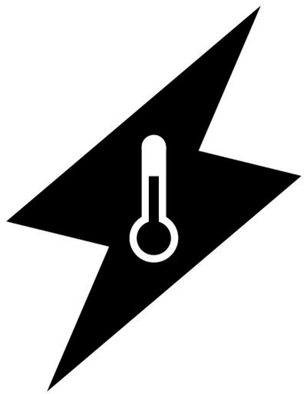
Passive House



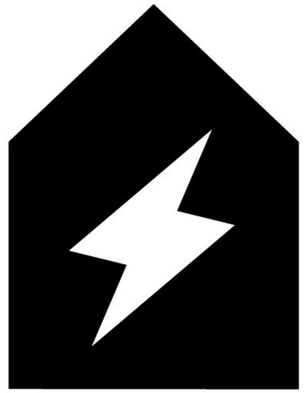
Seasonal Loads + Supply

Passive House + PV

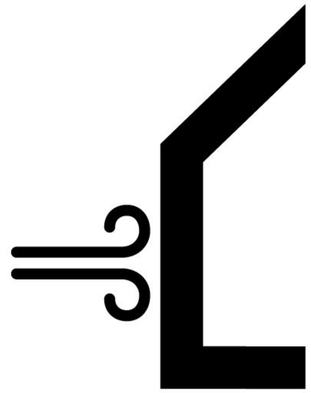
Passive House Requirements



Thermal Energy Demand



Total Energy Demand



Airtightness

- **Three main performance criteria (all pass / fail)**
- **Specialty modeling software with detailed input**
- **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**

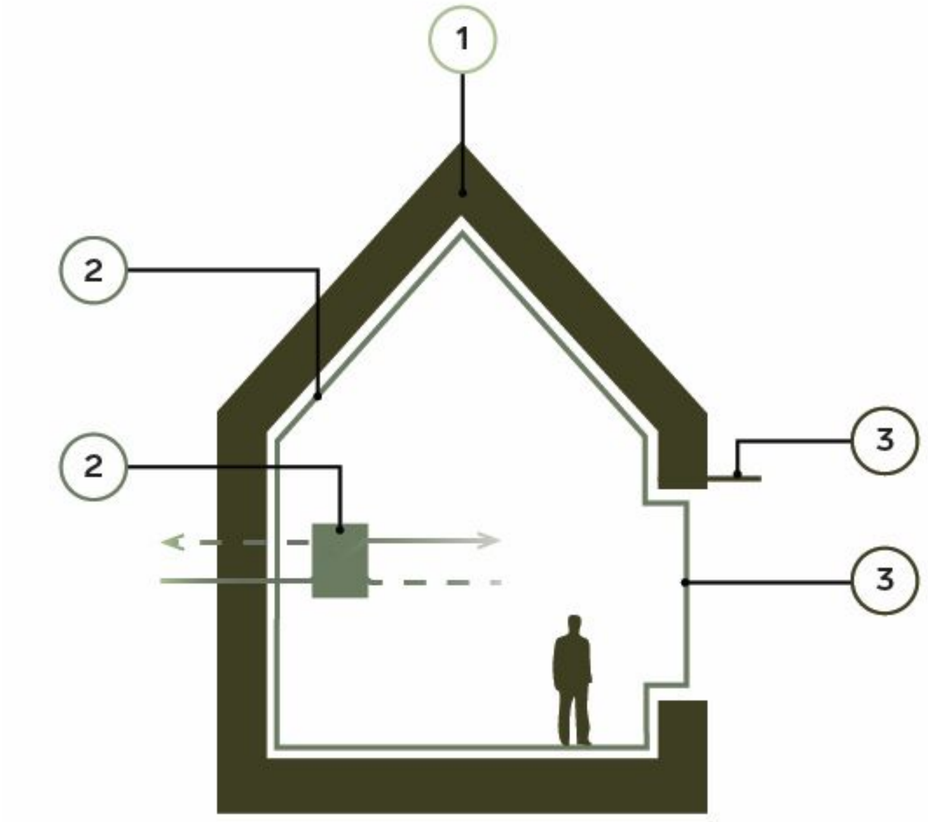
High Performance Glazing

Shading and Daylighting

4 **Efficient Mechanical Systems**

Minimized Equipment

Efficient Distribution



All Wood Is Not Equal

LEVER ARCHITECTURE

Biogenic Carbon

“carbon produced in natural processes by living organisms”

Biogenic Carbon or Sequestered Carbon

Negative upfront carbon

Emissions occur at end of life (total embodied carbon)

High degree of uncertainty in the modeling

Upfront Carbon only

Credit for the stored carbon (ignores future emissions)

Incentivize the use of more wood?

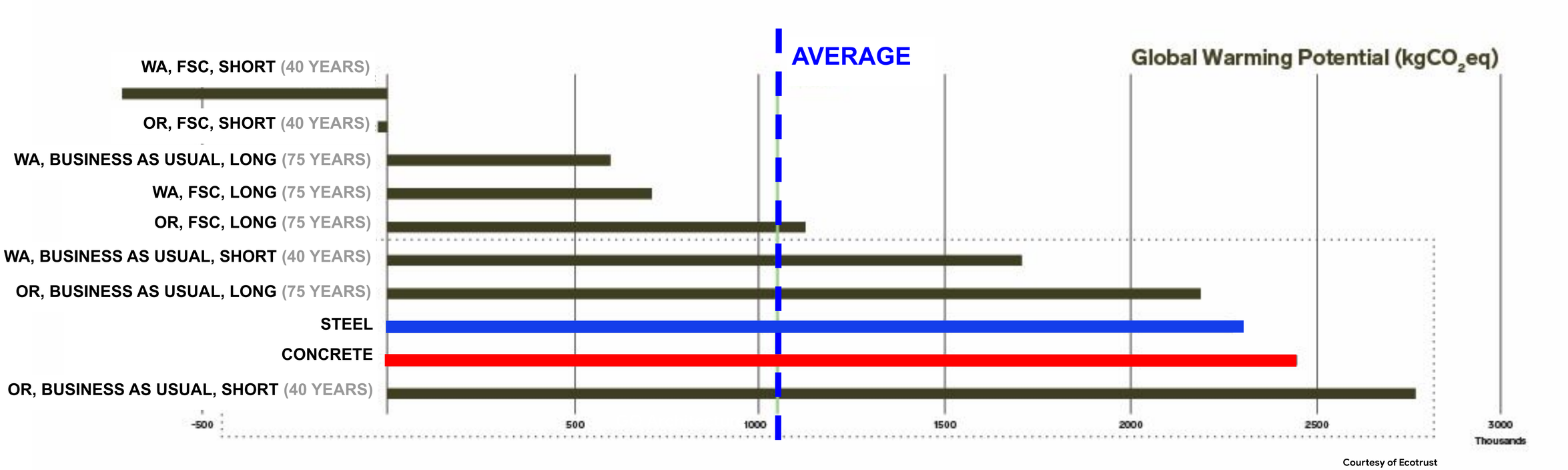
Conservative Approach

~~Biogenic Carbon~~

Always identify if it’s included

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

LEVER ARCHITECTURE

Townhomes

Program

31,822 sf gross

24 Townhomes

2-buildings

Height

2 & 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

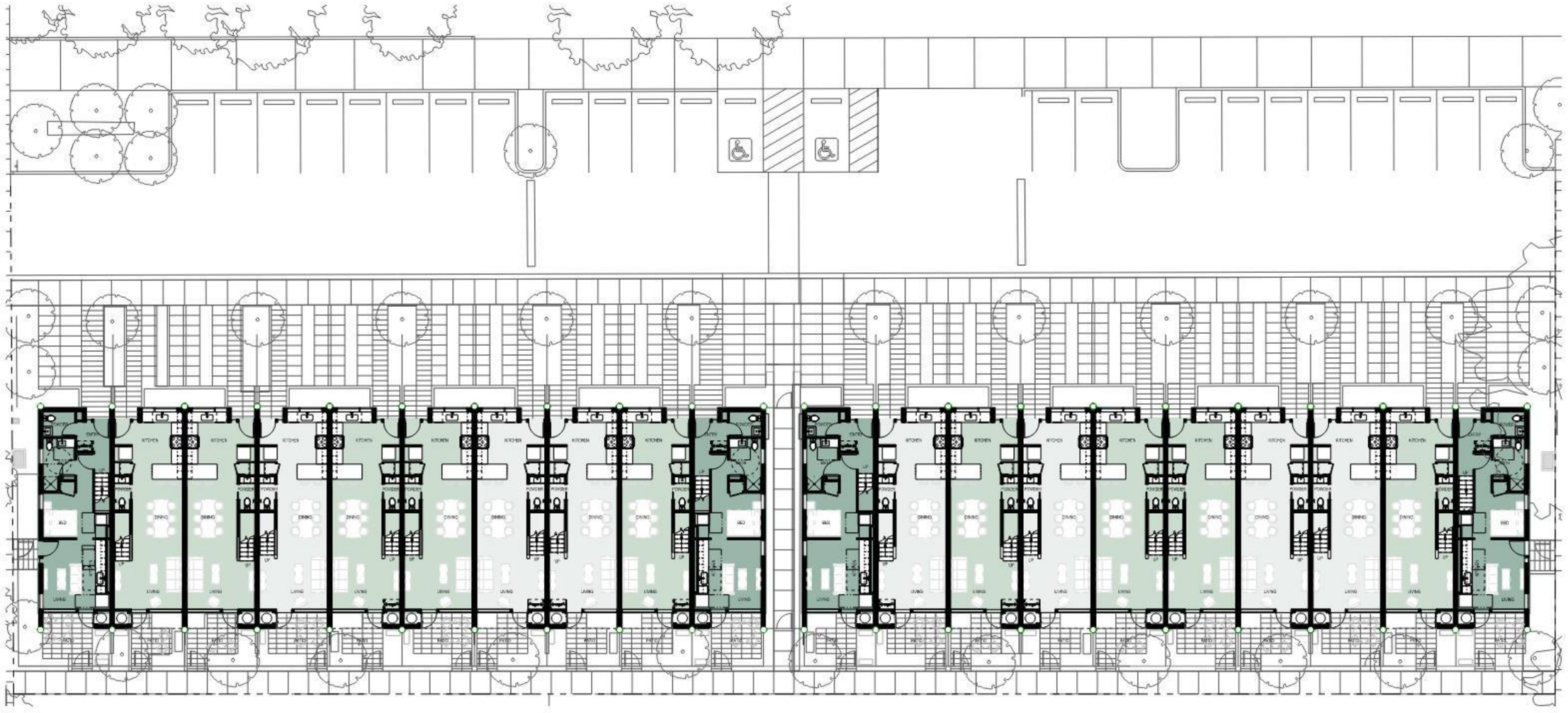
Type III-A with Type I Podium (Stick Frame)

Type IV-C (Mass Timber)

Townhomes

Floor Plan

Townhomes



LEVEL 01

Operational Carbon Summary

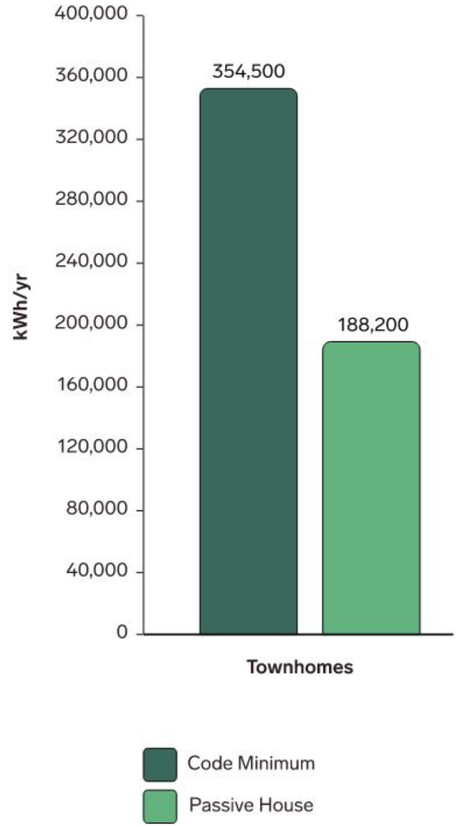
Townhomes

Energy Modeling Parameters

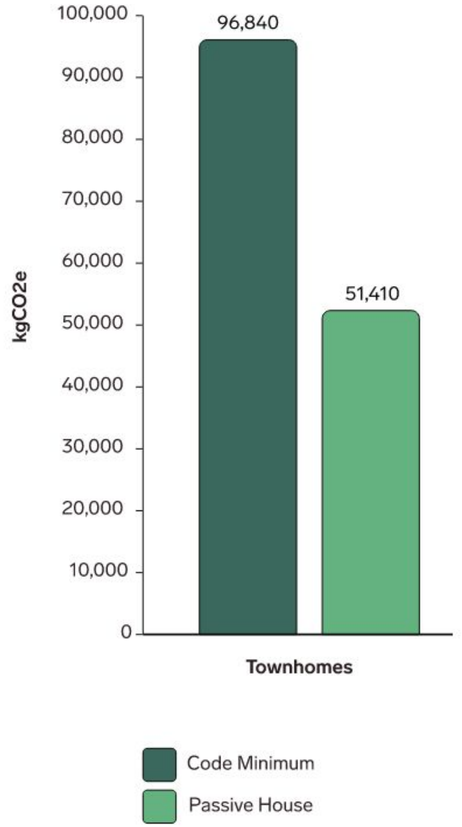
Component	Code Minimum	Passive House
Floor / Slab on Grade	R-0	R-15 C.I
Edge of Slab	R-15	R-15 for24"
Walls	R-21	R-26 Effective
Roof	R-49	R-59 Effective
Windows	U = .30 / SHGC = .30	U = .26 / SHGC = .18
Airtightness	.4 @ 75PA	.2 @ 75PA
Heating / Cooling	Electric Res / PTAC	Split System Heat Pump
Ventilation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

Improved envelope = 13% savings

Better systems = 34% savings



Annual Operational Energy (kWh/yr)



Annual Operational Carbon (kgCO2e/yr)

Assemblies

Townhomes

Unvented Roof with rigid insulation (foam)

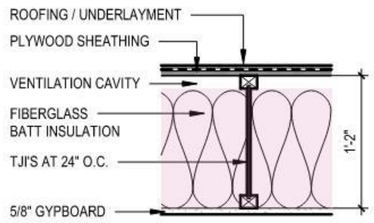
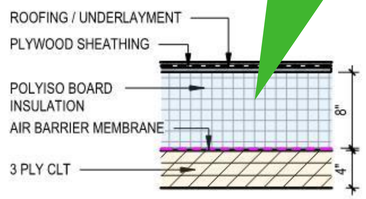
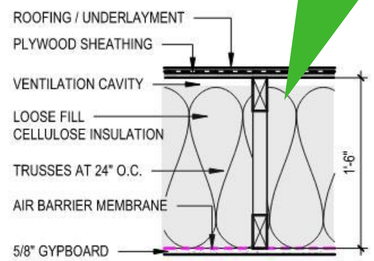
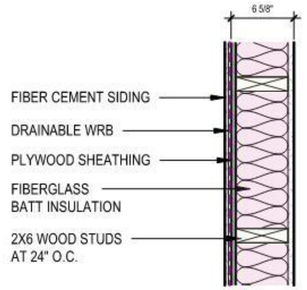
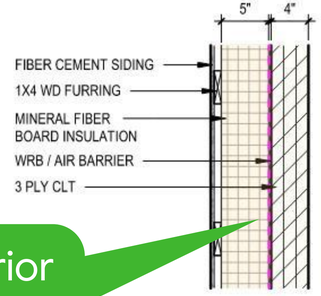
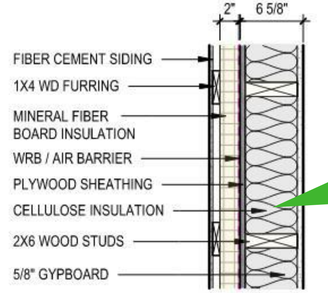
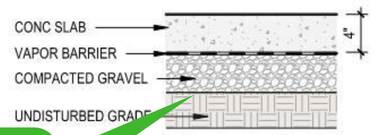
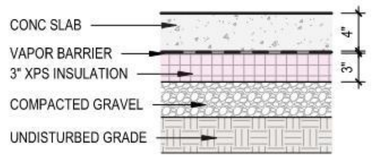
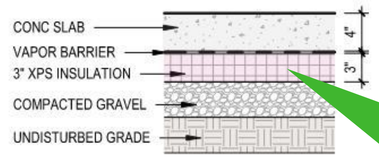
Vented Roof with fluffy insulation (cellulose)

Stud Cavity with fluffy insulation (cellulose)

CLT with exterior board insulation (mineral wool)

Slab without insulation

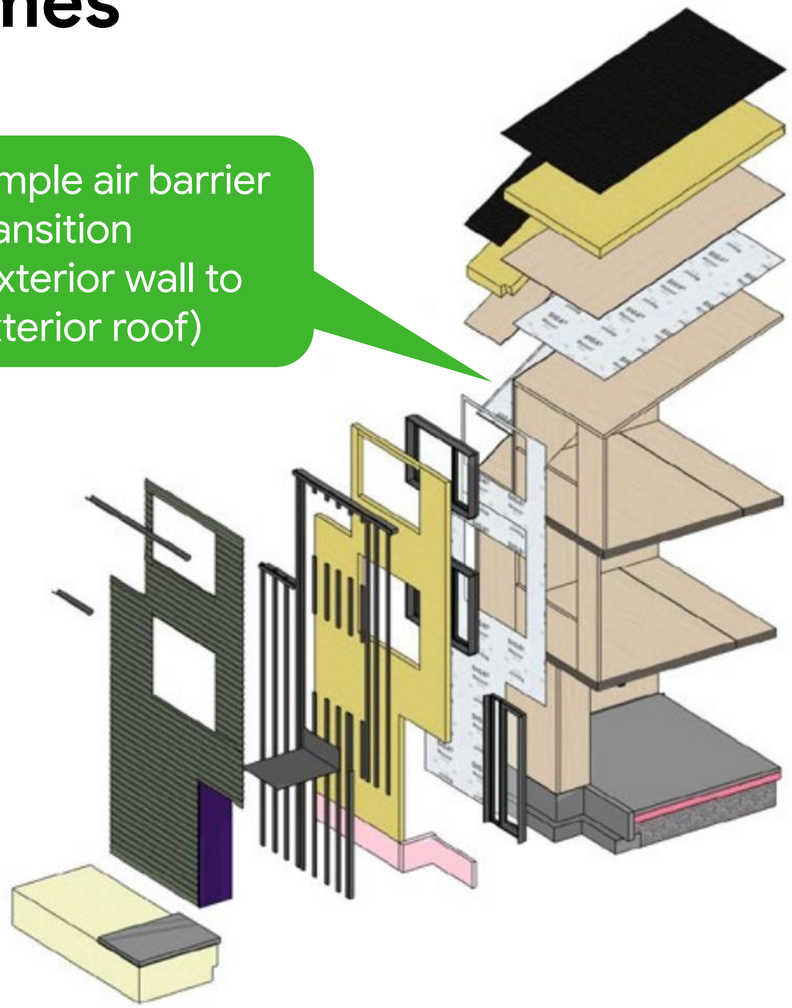
Slab with insulation (foam)

	CODE MINIMUM	PASSIVE HOUSE	
ROOF	 STICK FRAME (R-37 EFFECTIVE)	 MASS TIMBER (R-62 EFFECTIVE)	 STICK FRAME (R-62 EFFECTIVE)
WALL	 STICK FRAME (R-17 EFFECTIVE)	 MASS TIMBER (R-26 EFFECTIVE)	 STICK FRAME (R-26 EFFECTIVE)
FLOOR	 STICK FRAME (UNINSULATED)	 MASS TIMBER (R-16 EFFECTIVE)	 STICK FRAME (R-16 EFFECTIVE)

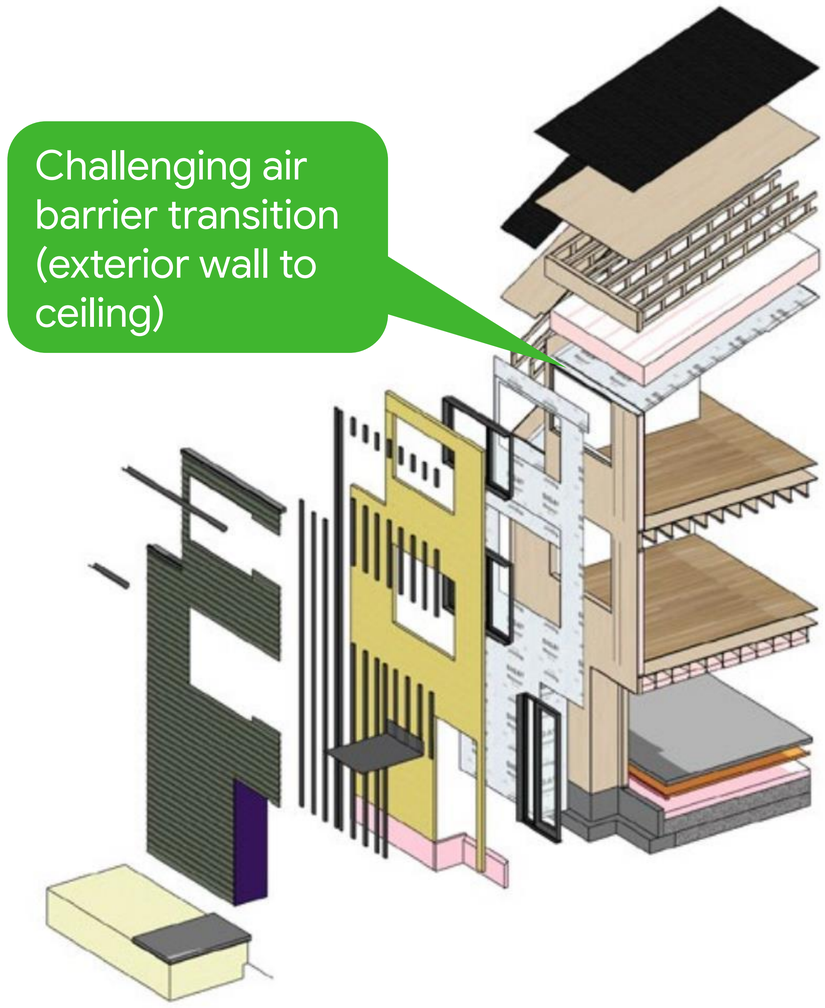
LEVER ARCHITECTURE

Passive House Assemblies

Townhomes



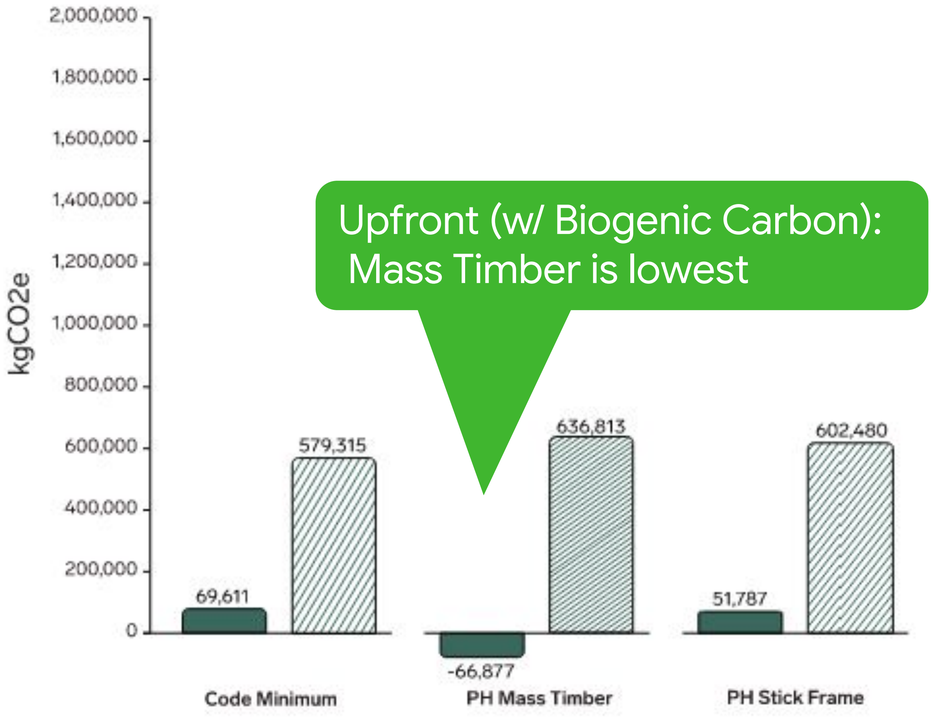
PH Mass Timber

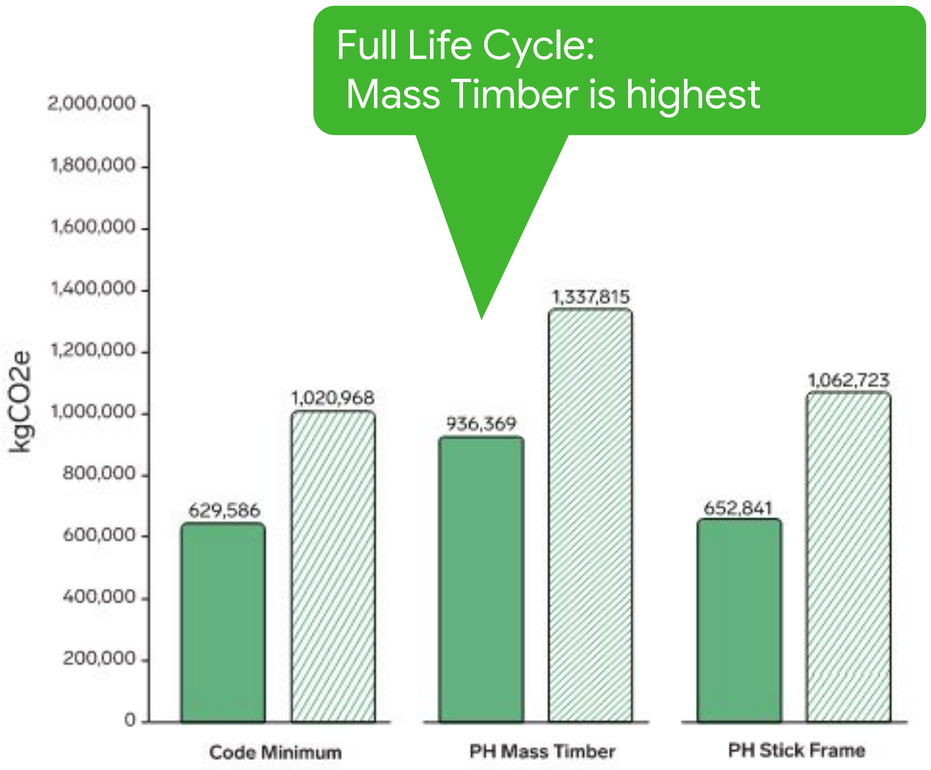


PH Stick Frame

Embodied Carbon Results

Townhomes





Upfront Life Cycle Stages A1-A4

With Biogenic Carbon

Without Biogenic Carbon

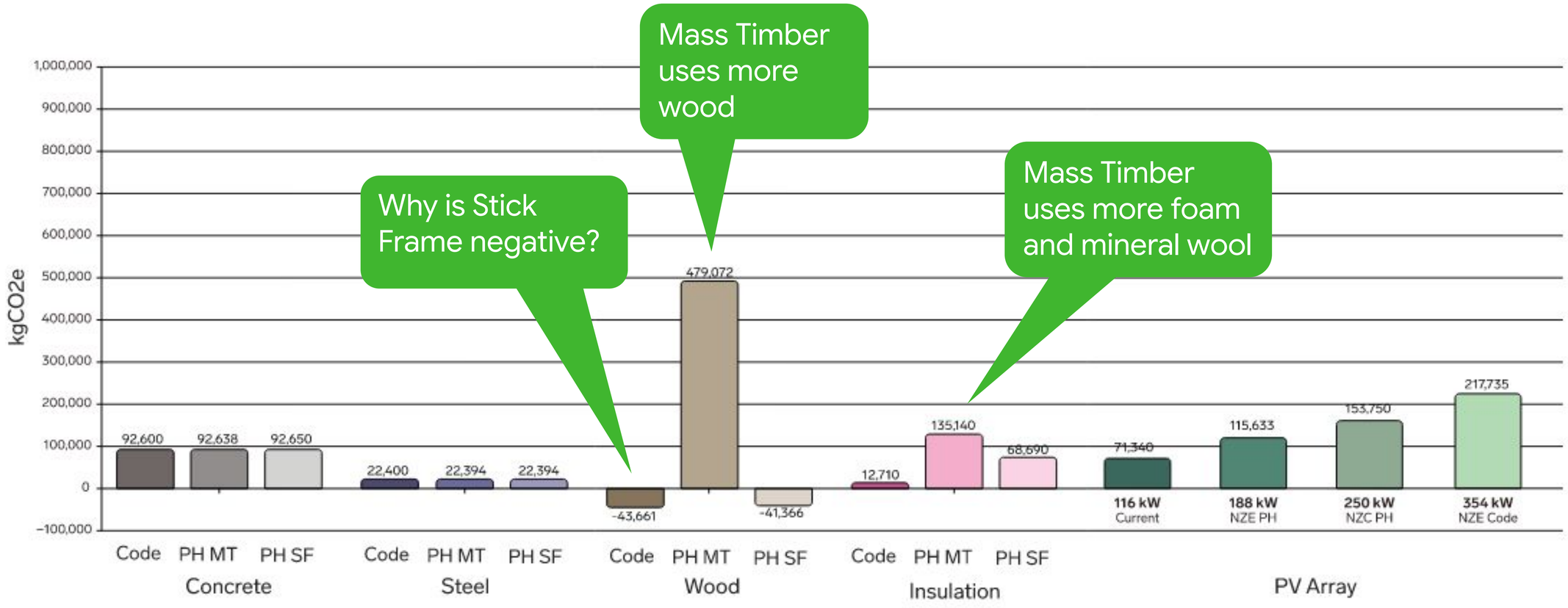
Full Life Cycle Stages A-D

With Biogenic Carbon

Without Biogenic Carbon

Embodied Carbon Results

Townhomes

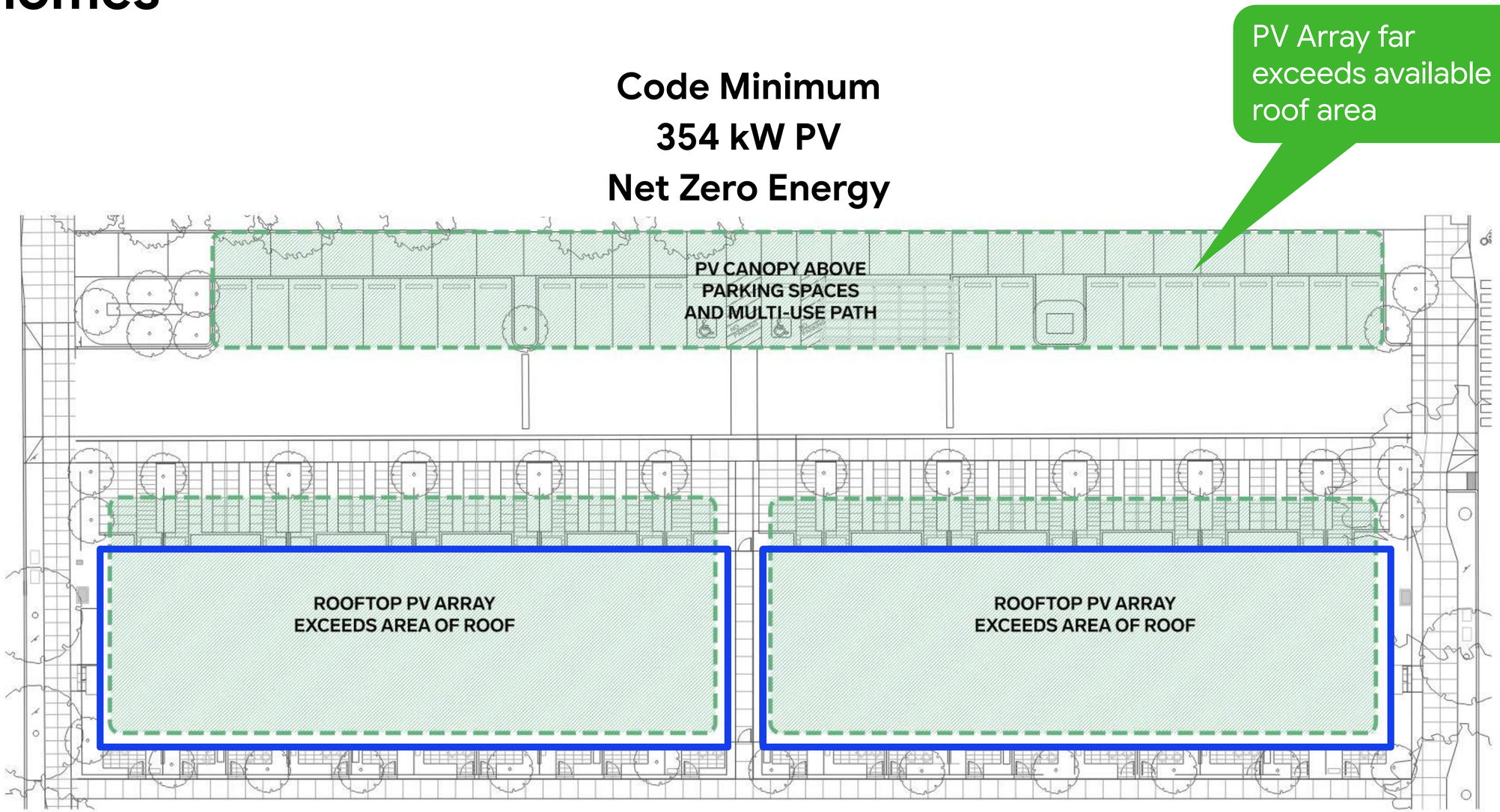


Embodied Carbon of Major Materials (Full Life Cycle with Biogenic Carbon)

On-Site Renewable Energy

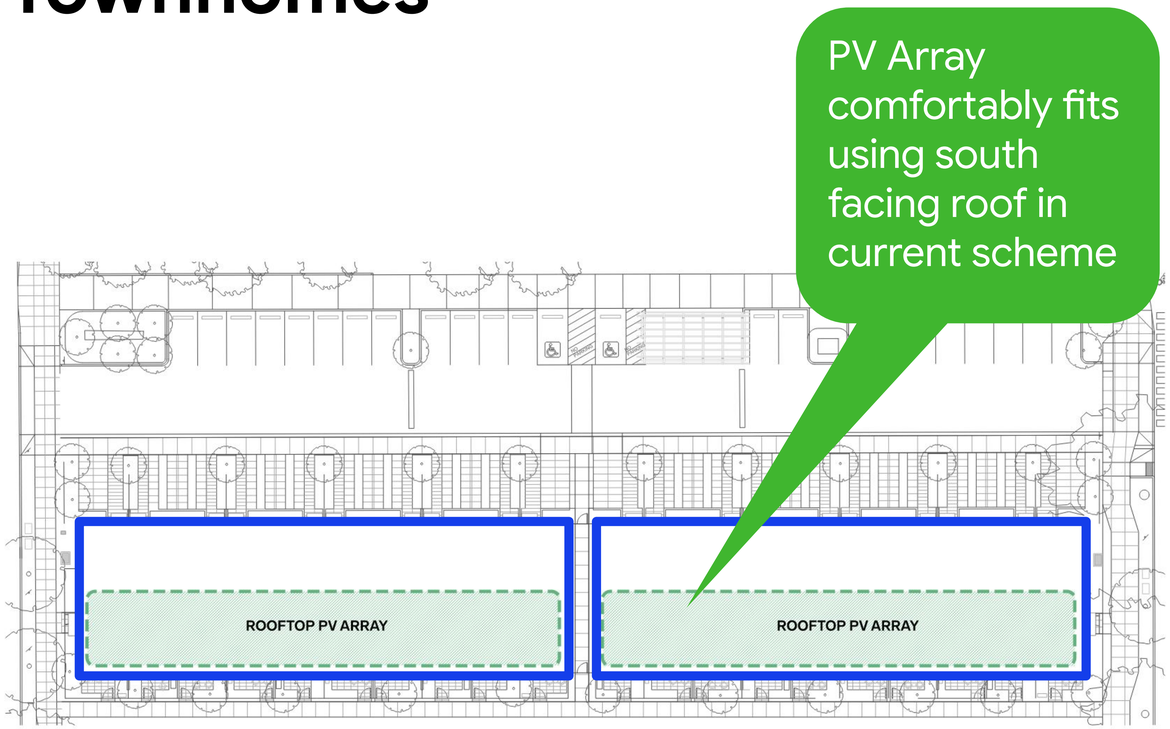
Townhomes

Code Minimum
354 kW PV
Net Zero Energy

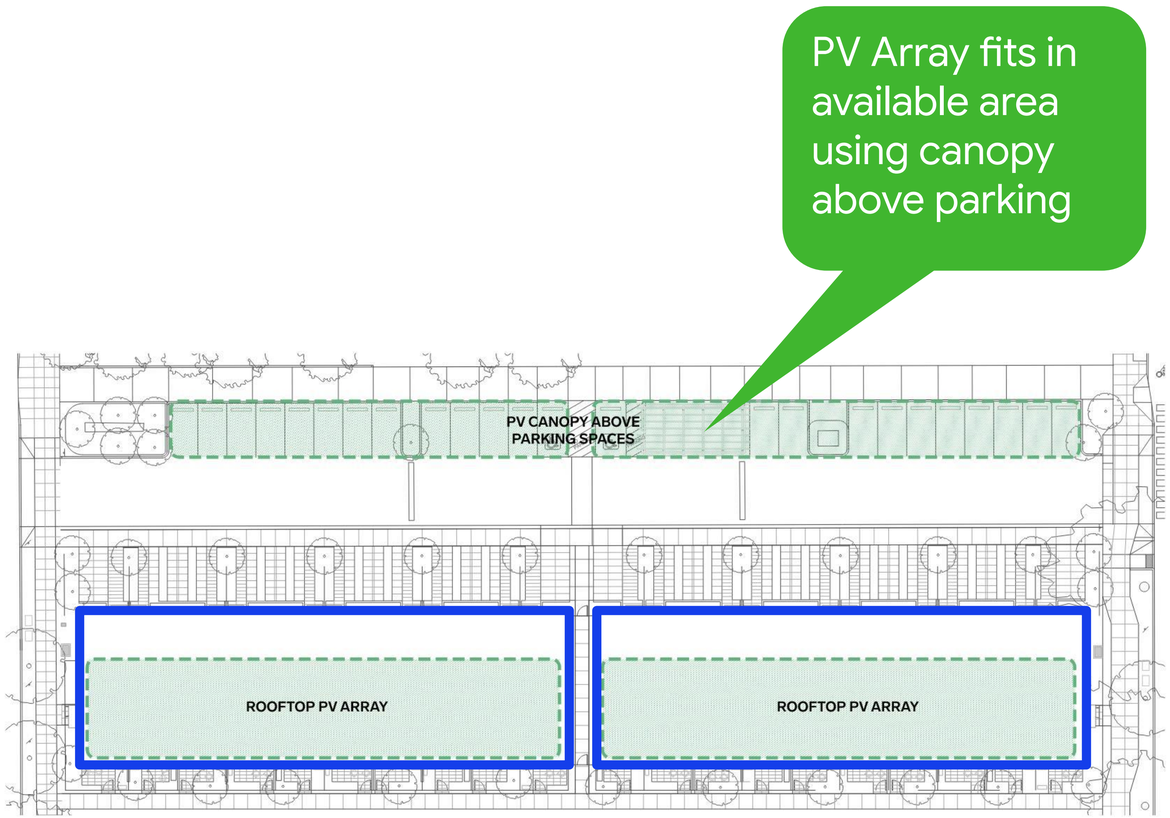


On-Site Renewable Energy

Townhomes



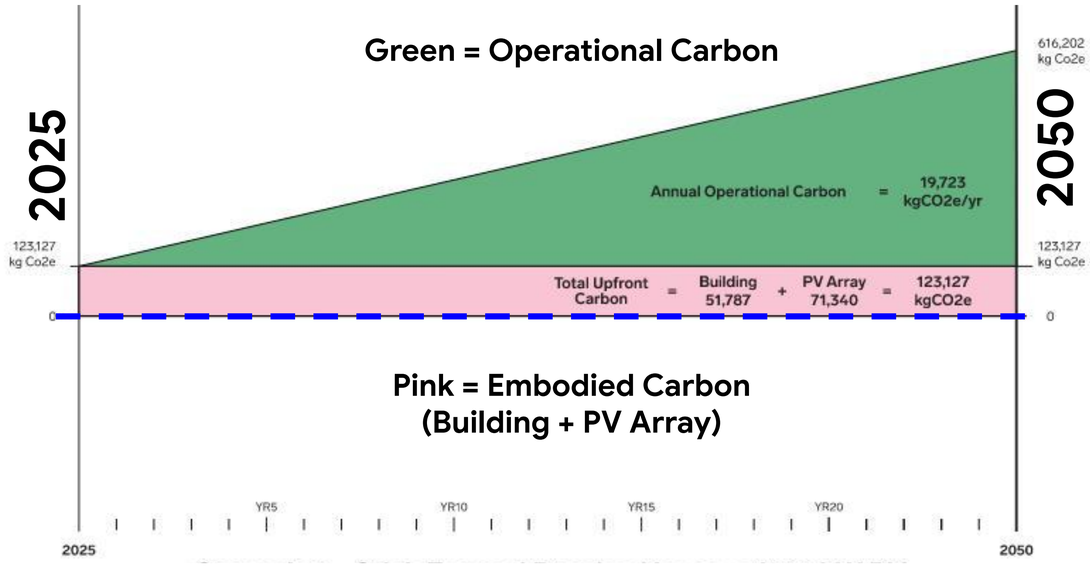
Stick Frame Passive House
116 kW PV
60% Net Zero Energy



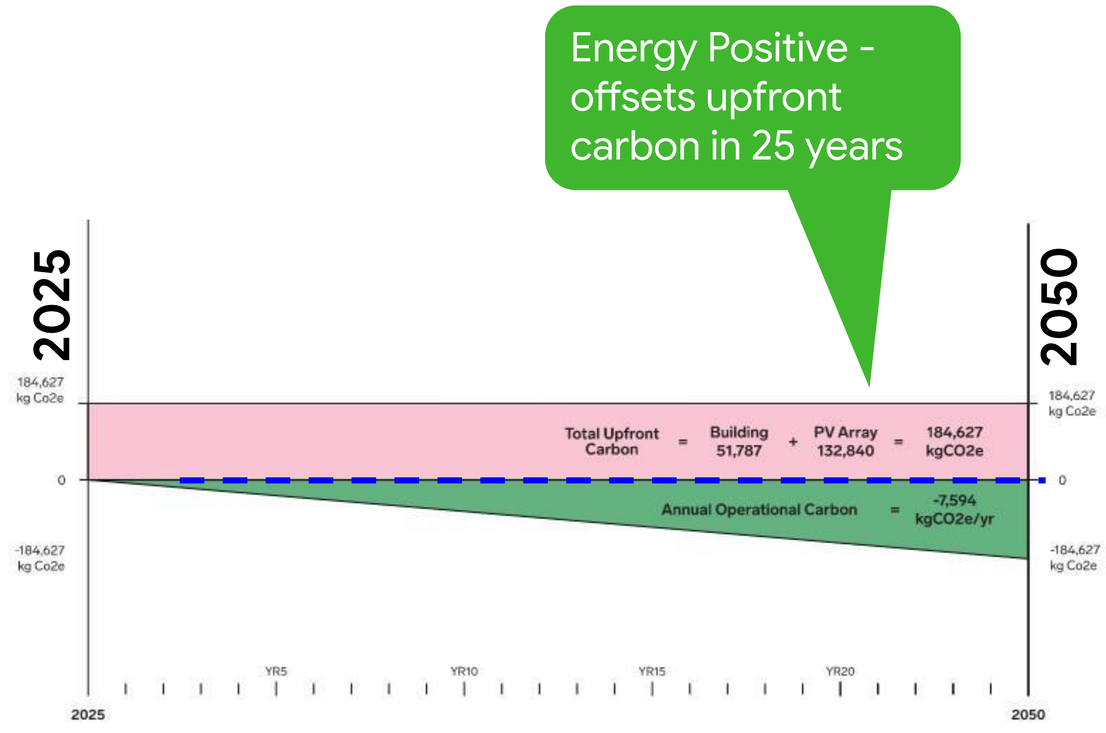
Stick Frame Passive House
216 kW PV
Net Zero Carbon in 25 years
(Upfront w/ Biogenic Carbon)

Total Carbon Scenarios - 25 years

Townhomes



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

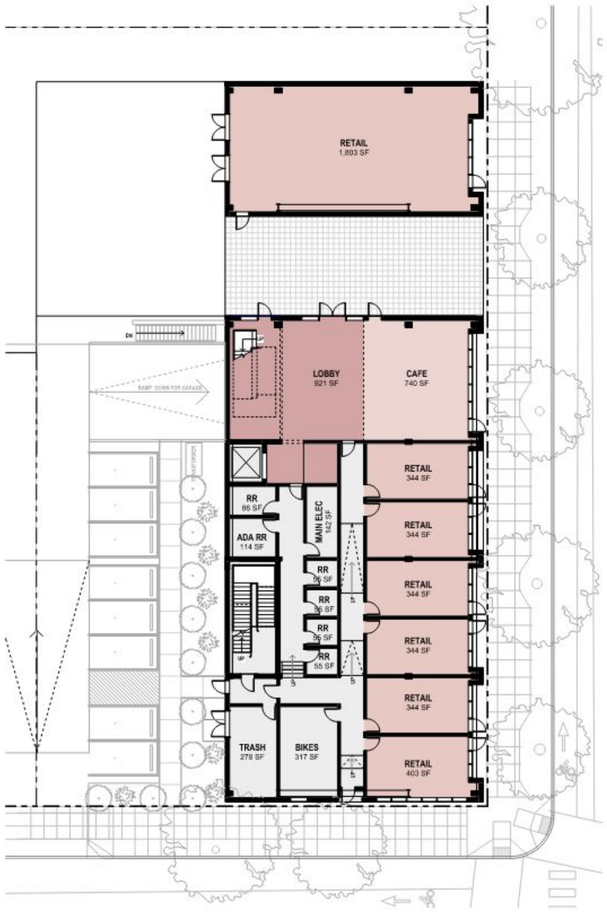


Stick Frame Passive House
216 kW PV
Net Zero Carbon in 25 years
(Upfront w/ Biogenic Carbon)

Black Business Hub

Floor Plans

Black Business Hub



LEVEL 01

LEVEL 02

LEVEL 03

Operational Carbon Summary

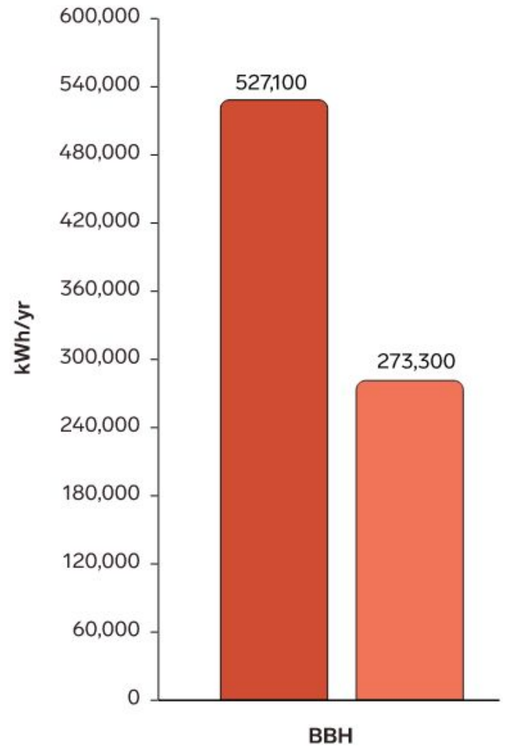
Black Business Hub

Energy Modeling Parameters

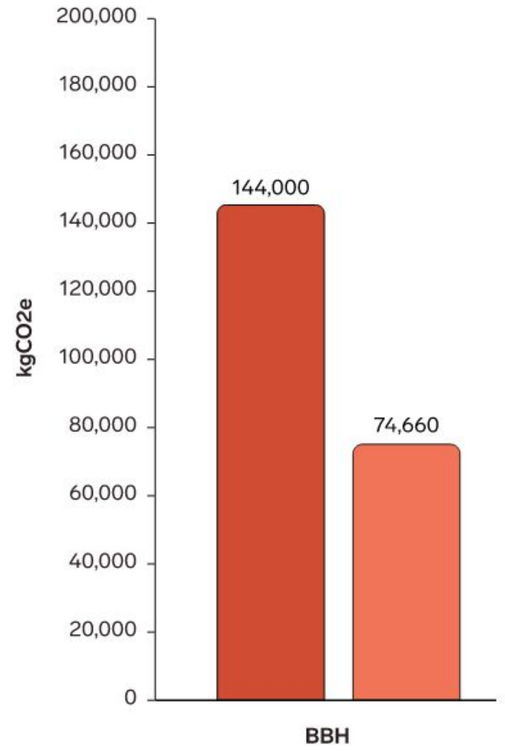
Component	Code Minimum	Passive House
Floor / Slab on Grade	R-0	R-0
Edge of Slab	R-15 for 24"	R-15 for 24"
Walls	R-19 (~R-16 Effective)	R-19 Effective
Roof	R-30 Effective	R-38 Effective
Storefront Windows	U = .36 / SHGC = .33	U = .36 / SHGC = .27
Upper Windows	U = .36 / SHGC = .33	U = .24 / SHGC = .27
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

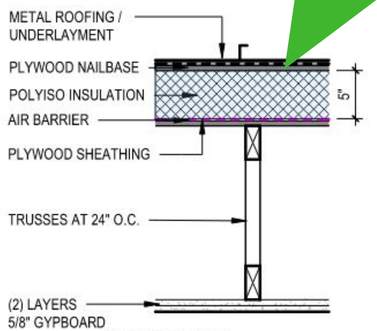
Black Business Hub

ROOF

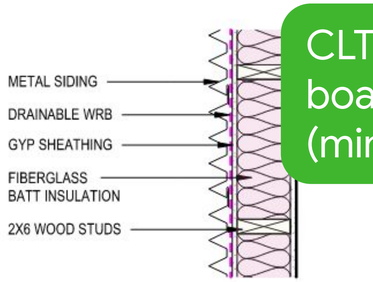
WALL

FLOOR

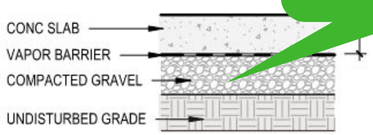
CODE MINIMUM



STICK FRAME
(R-30 EFFECTIVE)



STICK FRAME
(R-16 EFFECTIVE)

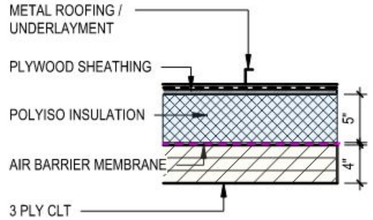


STICK FRAME
(UNINSULATED)

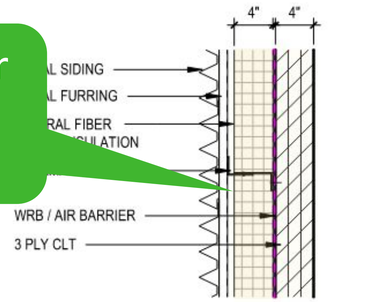
Unvented Roof with rigid insulation (5” foam)

CLT with exterior board insulation (mineral wool)

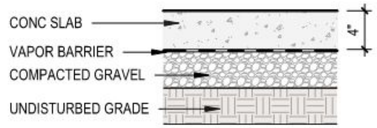
Slab without insulation



MASS TIMBER
(R-38 EFFECTIVE)



MASS TIMBER
(R-19 EFFECTIVE)



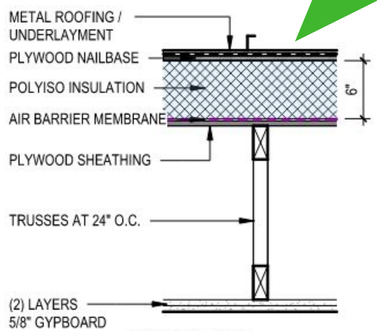
MASS TIMBER
(UNINSULATED)

PASSIVE HOUSE

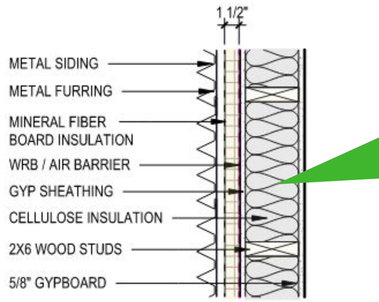
Unvented Roof with rigid insulation (6” foam)

Stud Cavity with fluffy insulation (cellulose)

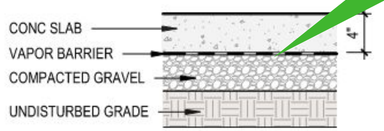
Slab without insulation



STICK FRAME
(R-38 EFFECTIVE)



STICK FRAME
(R-19 EFFECTIVE)



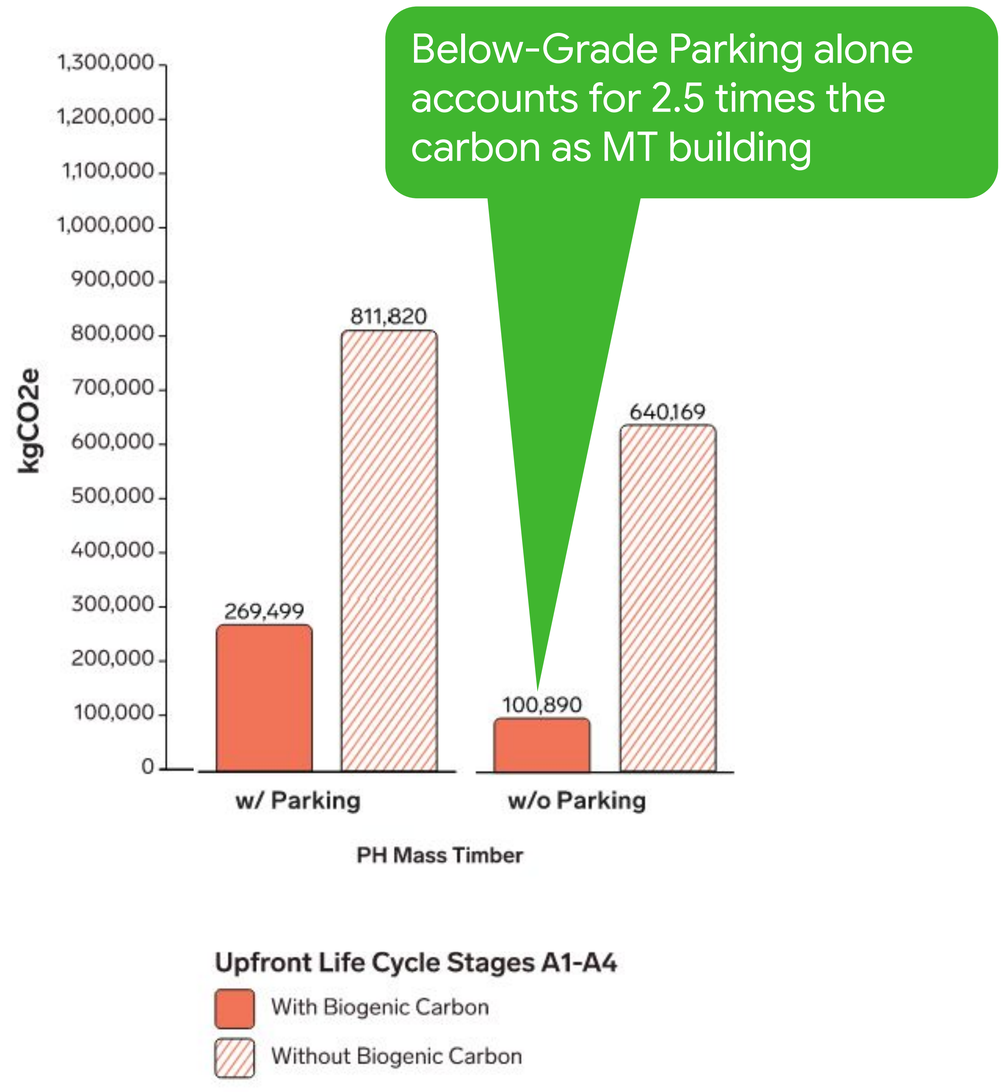
STICK FRAME
(UNINSULATED)

LEVER ARCHITECTURE

Embodied Carbon Results (Below-Grade Parking)

Black Business Hub

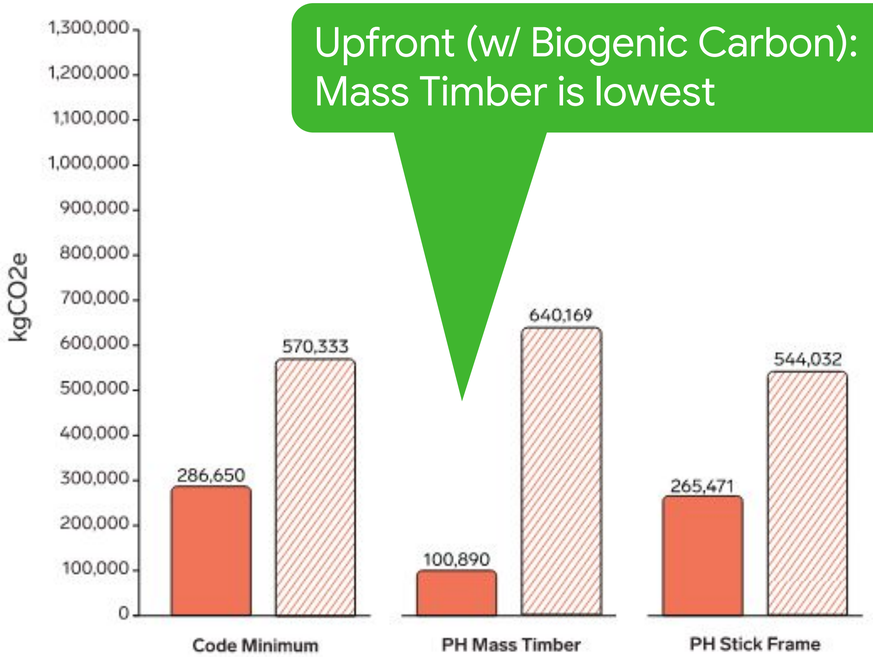
- **Upfront Carbon = ~ 170,000 kgCO2e**
- **More Upfront CO2 than entire Mass Timber Building**
- **More Upfront CO2 than 273 kW PV Array**



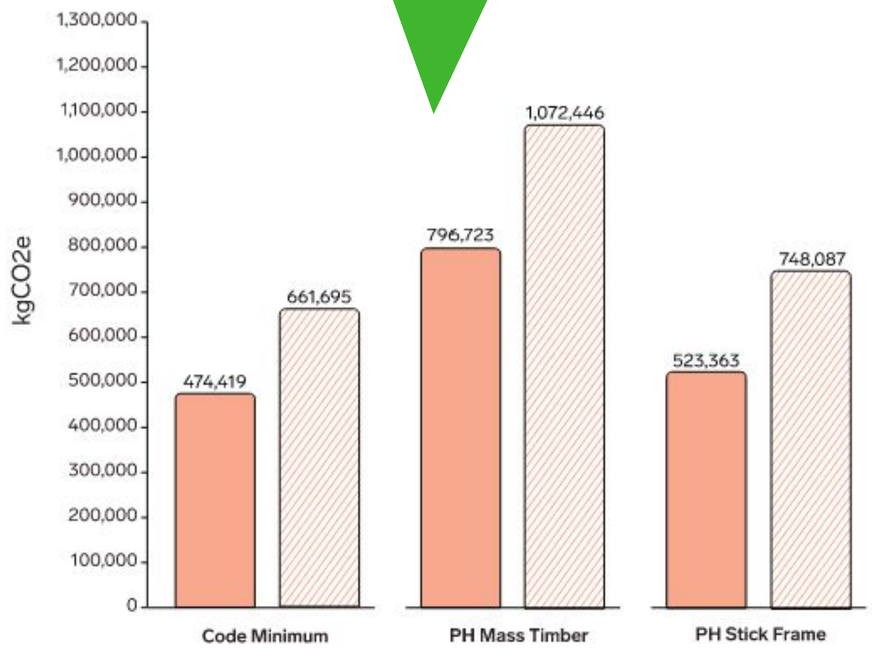
Embodied Carbon Results

Black Business Hub

Upfront (w/ Biogenic Carbon):
Mass Timber is lowest



Full Life Cycle:
Mass Timber is highest



Upfront Life Cycle Stages A1-A4

With Biogenic Carbon

Without Biogenic Carbon

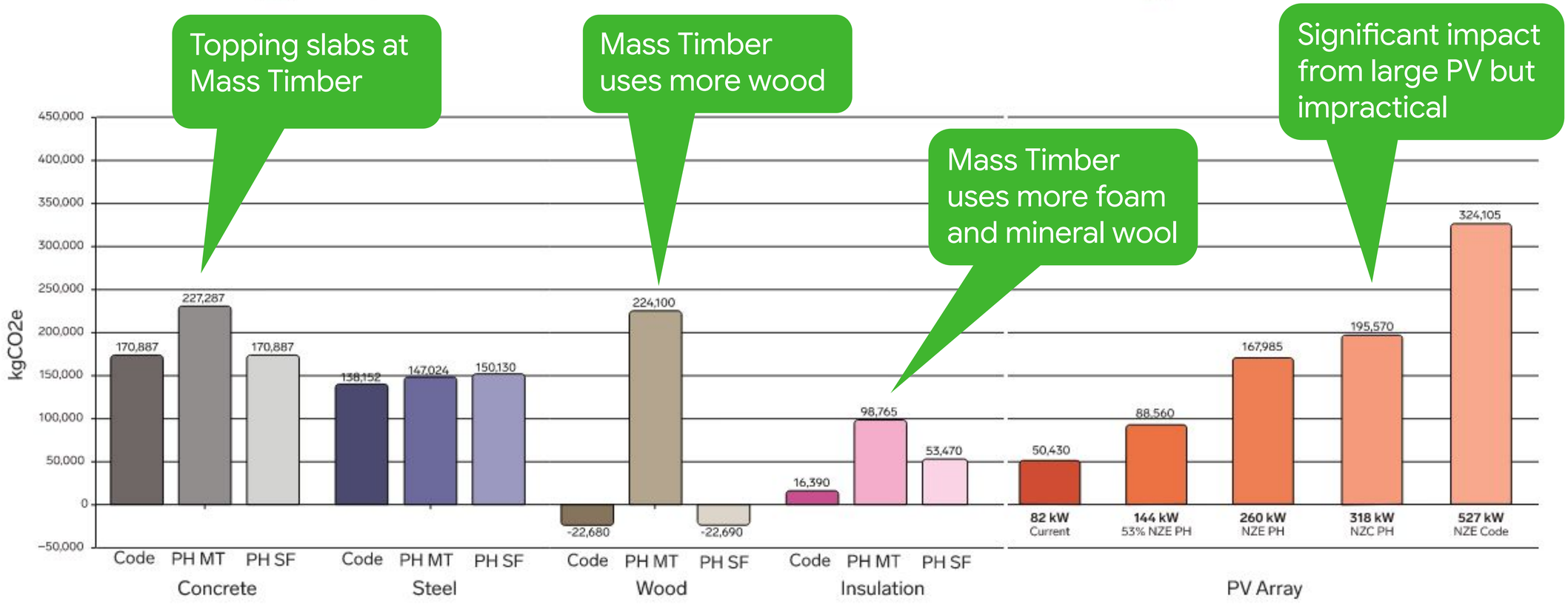
Full Life Cycle Stages A-D

With Biogenic Carbon

Without Biogenic Carbon

Embodied Carbon Results

Black Business Hub

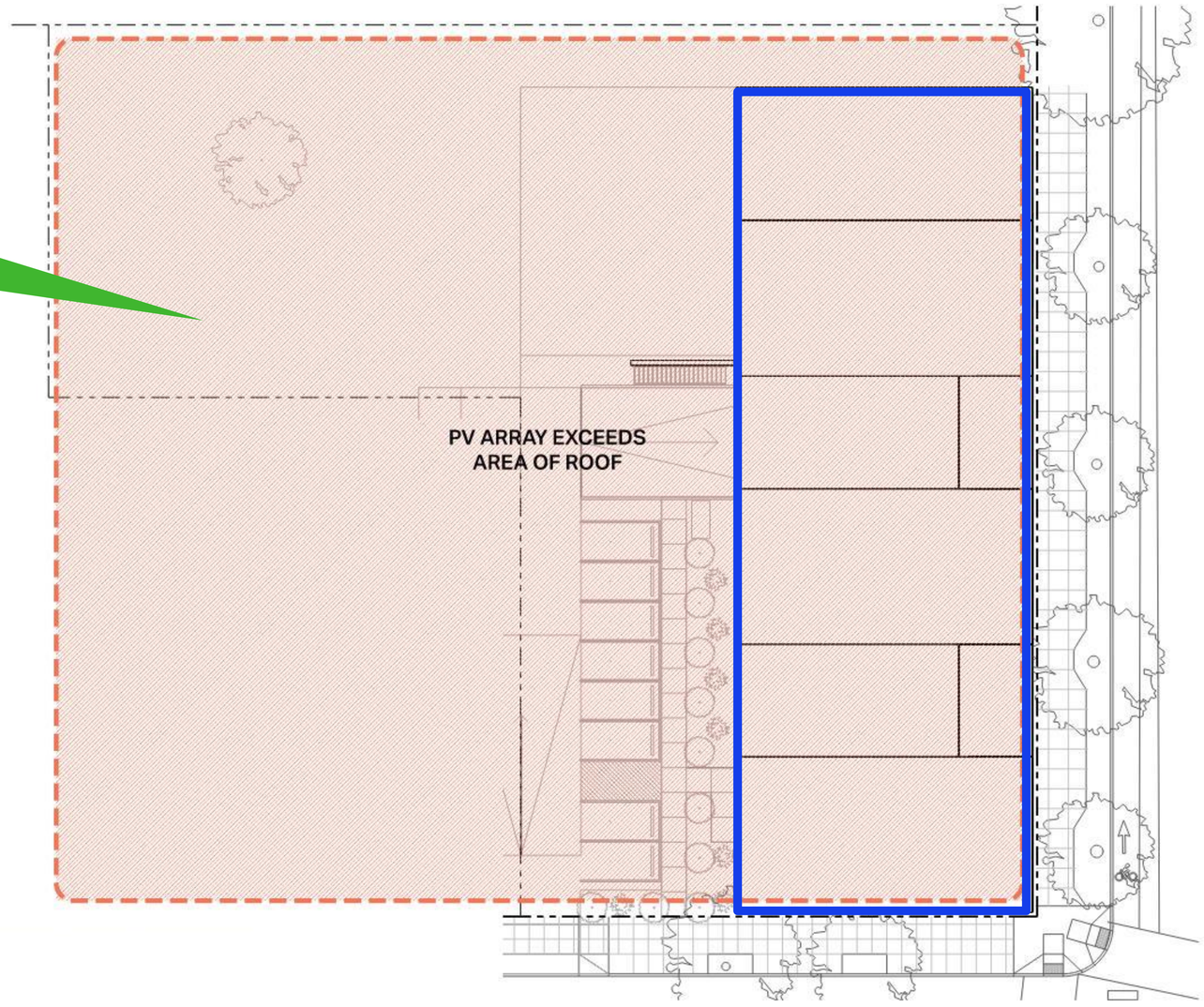


Embodied Carbon of Major Materials (Full Life Cycle with Biogenic Carbon)

On-Site Renewable Energy

Black Business Hub

PV Array far exceeds available roof area



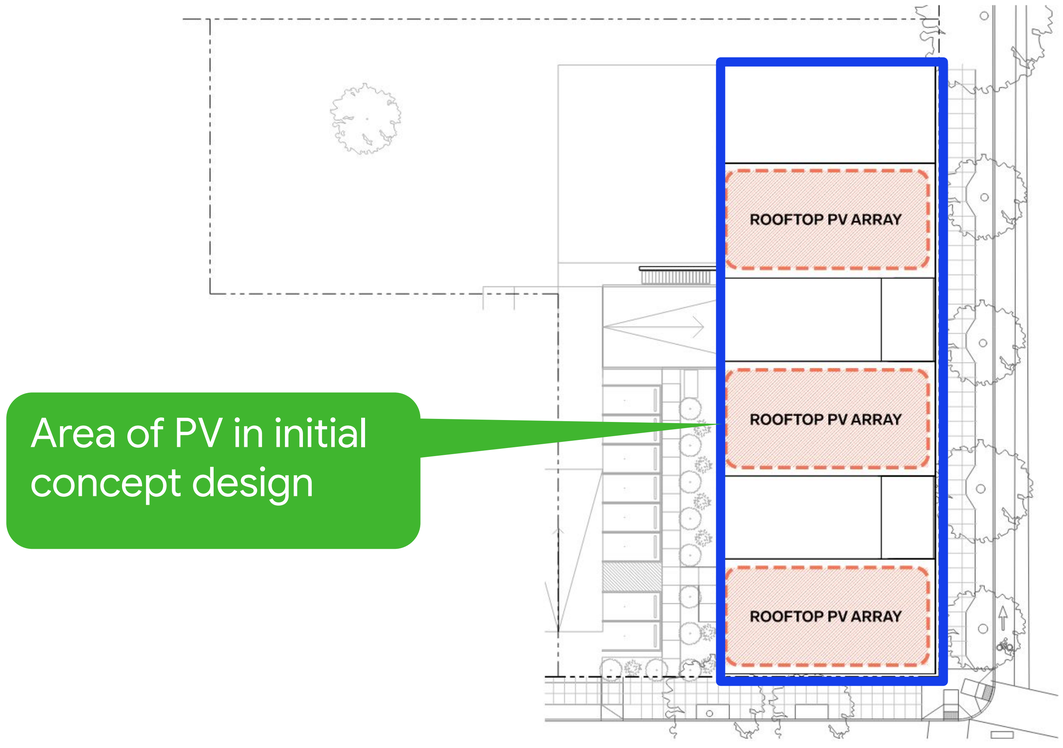
Code Minimum

527 kW PV

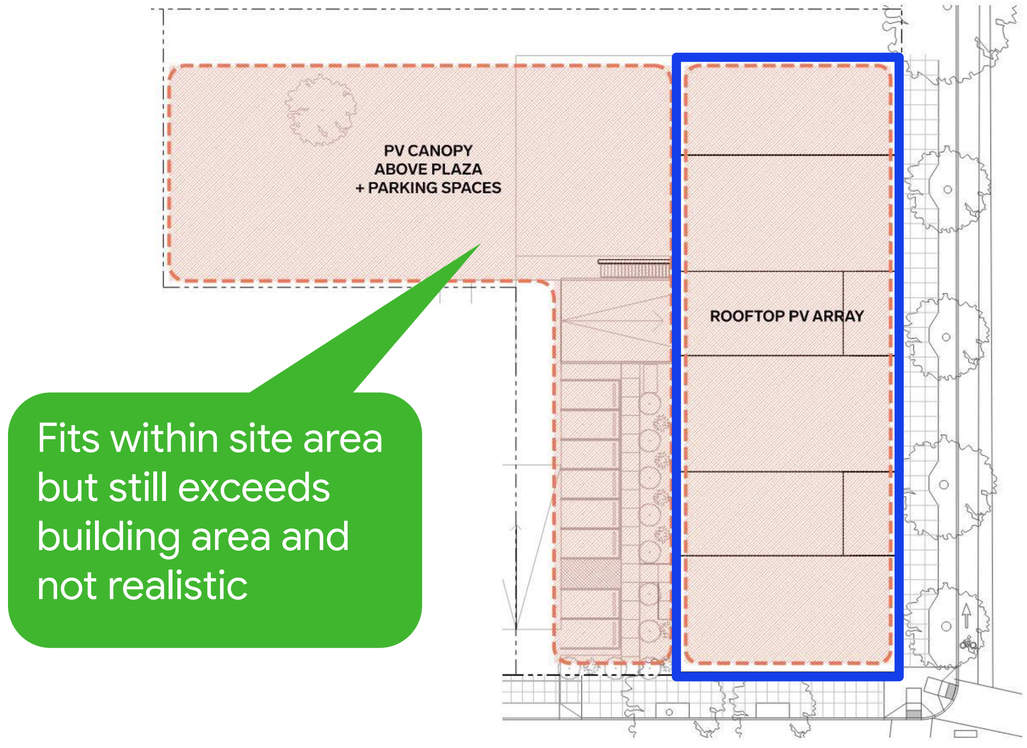
Net Zero Energy

On-Site Renewable Energy

Black Business Hub



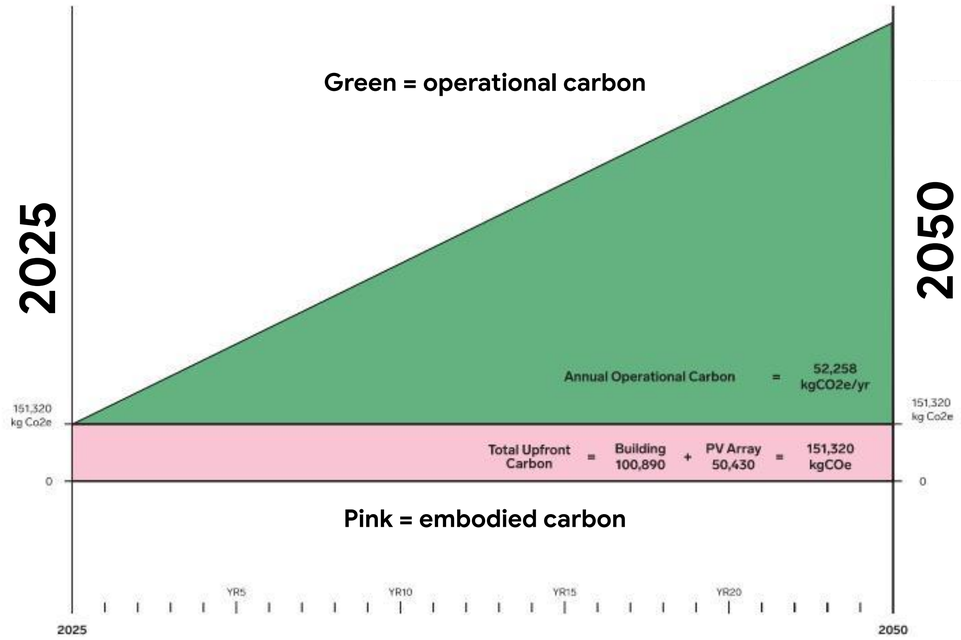
Passive House (Mass Timber)
82 kW PV
30% Net Zero Energy annually



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



Passive House (Mass Timber)
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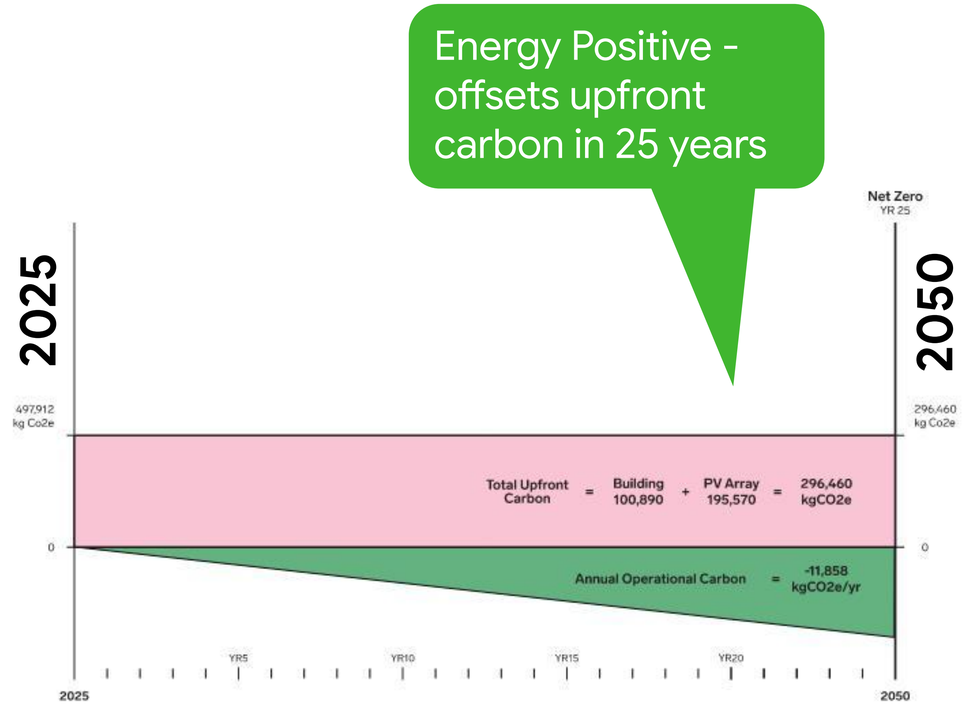
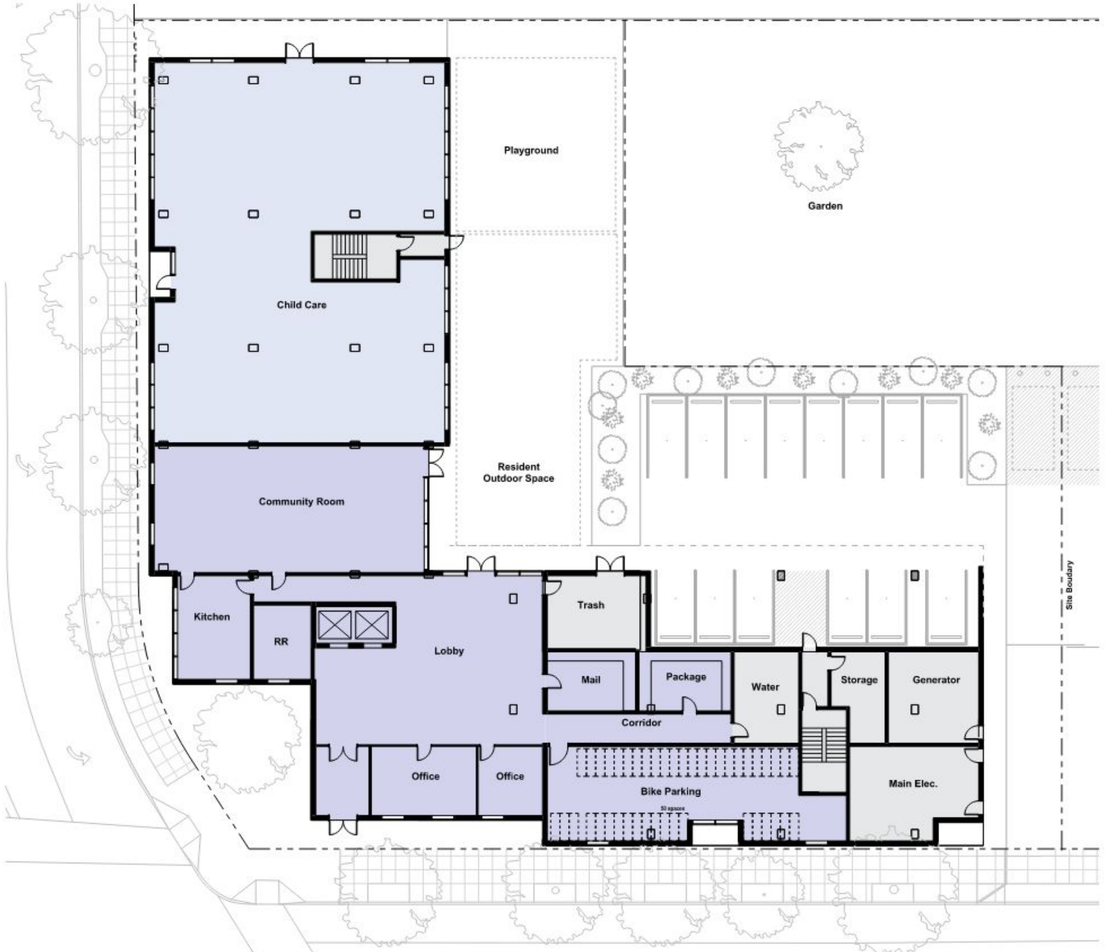


Passive House (Mass Timber)
318 kW PV
Net Zero Carbon in 25 years
(Upfront with Biogenic Carbon)

Affordable Apartments

Floor Plans

Affordable Apartments



LEVEL 01

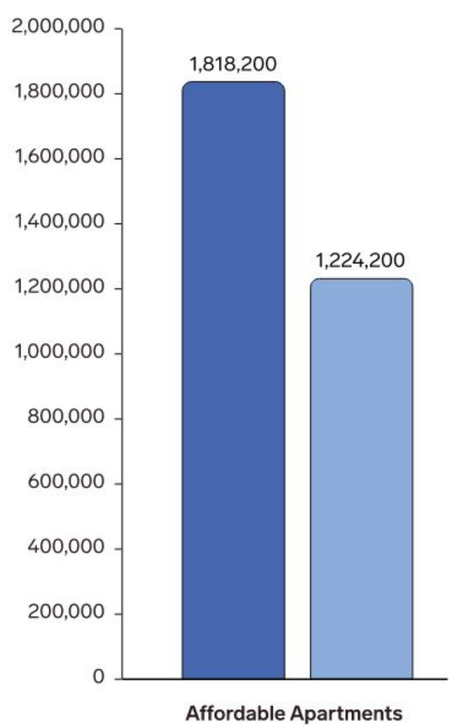
LEVEL 02

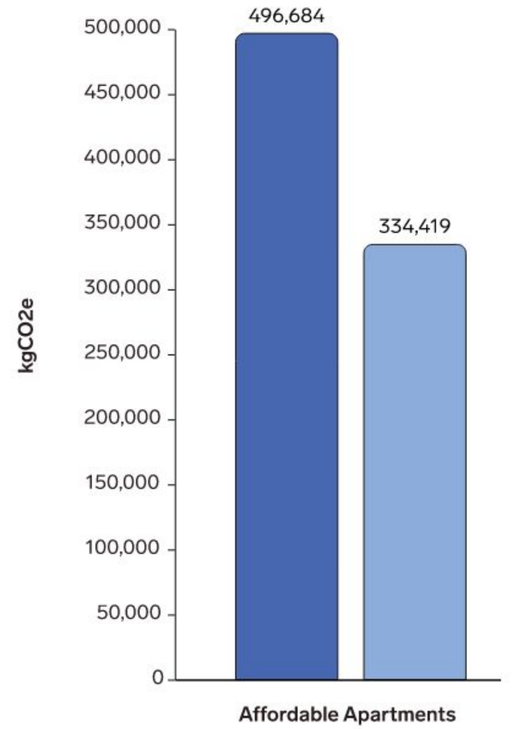
Operational Carbon Summary

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"
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 = .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

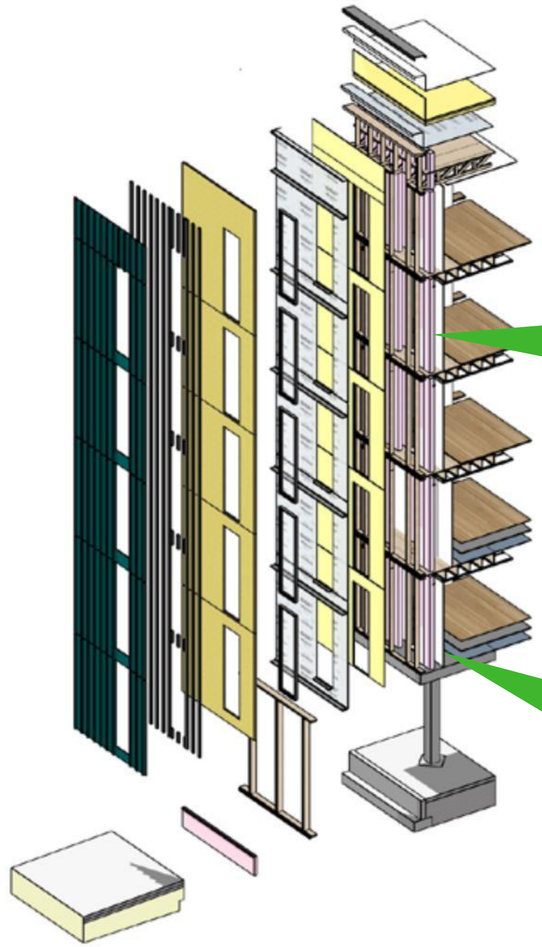
Passive House Assemblies

Affordable Apartments

Type IV-C
All framed walls are metal stud

Can have exposed Mass Timber at ground floor

PH Mass Timber



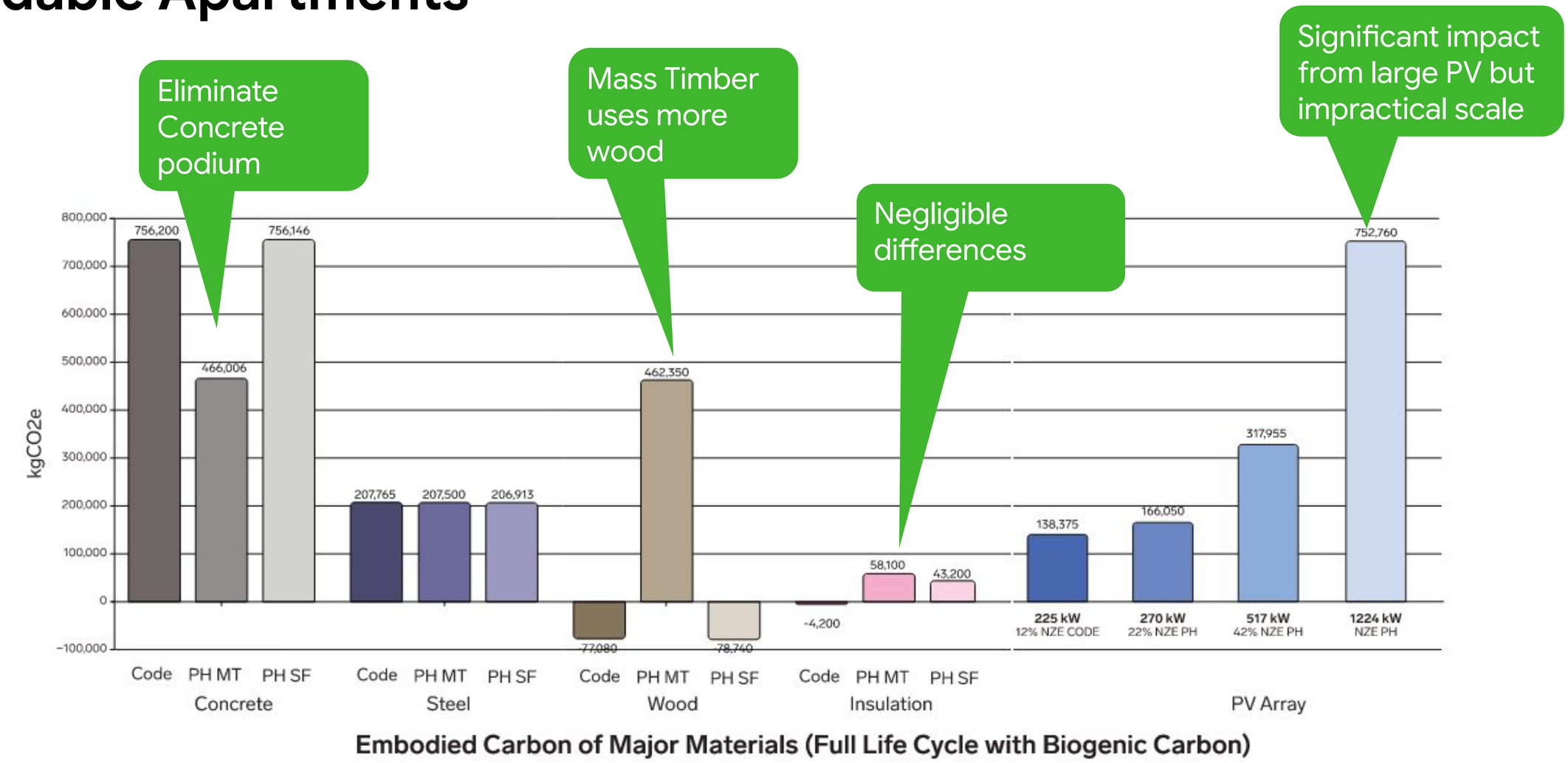
Type III-A
All framed walls are wood

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

PH Stick Frame

Embodied Carbon Results

Affordable Apartments



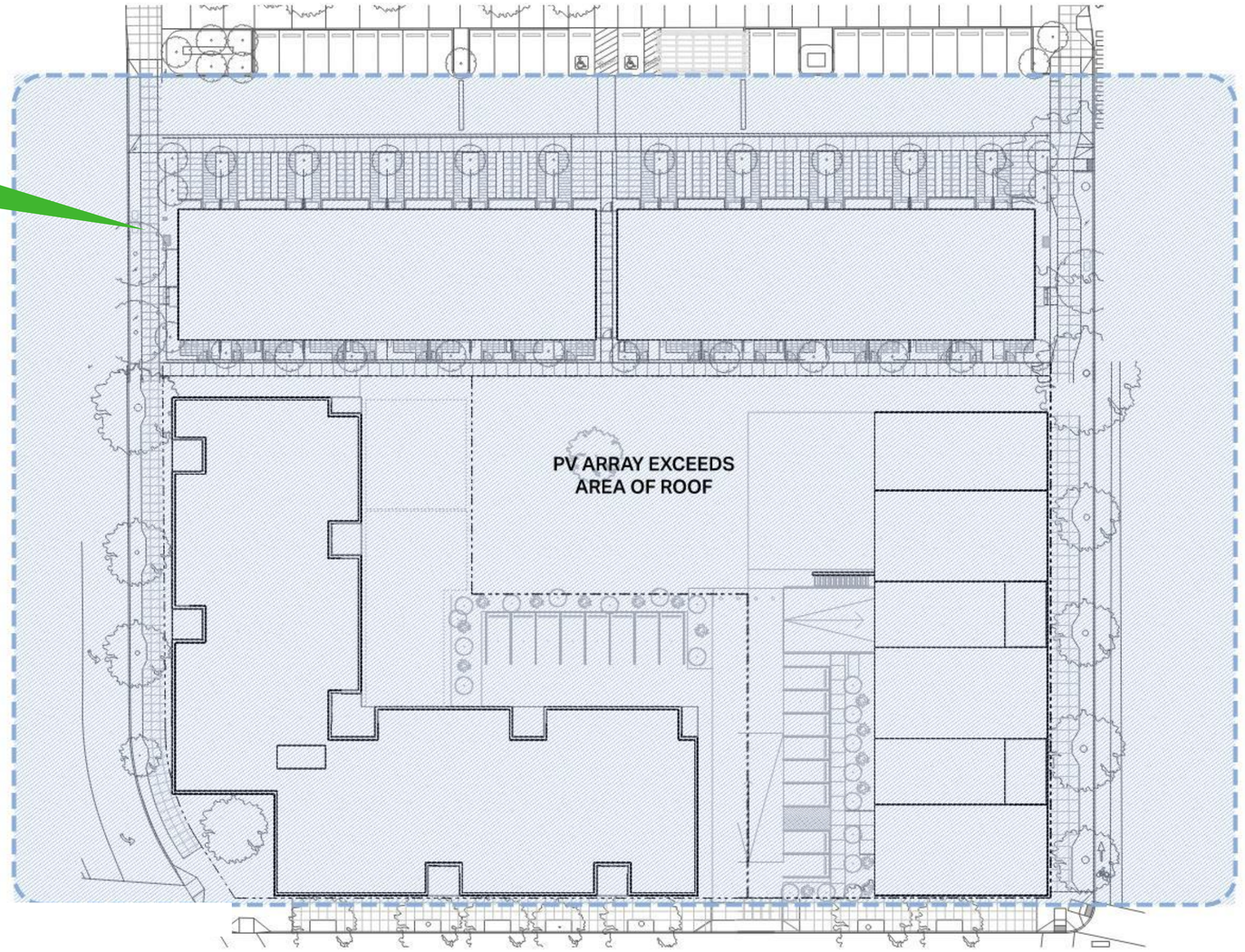
Embodied Carbon of Major Materials (Full Life Cycle with Biogenic Carbon)

On-Site Renewable Energy

Affordable Apartments

PV Array required far exceeds available site area!

Code Minimum
1818 kW PV
Net Zero Energy



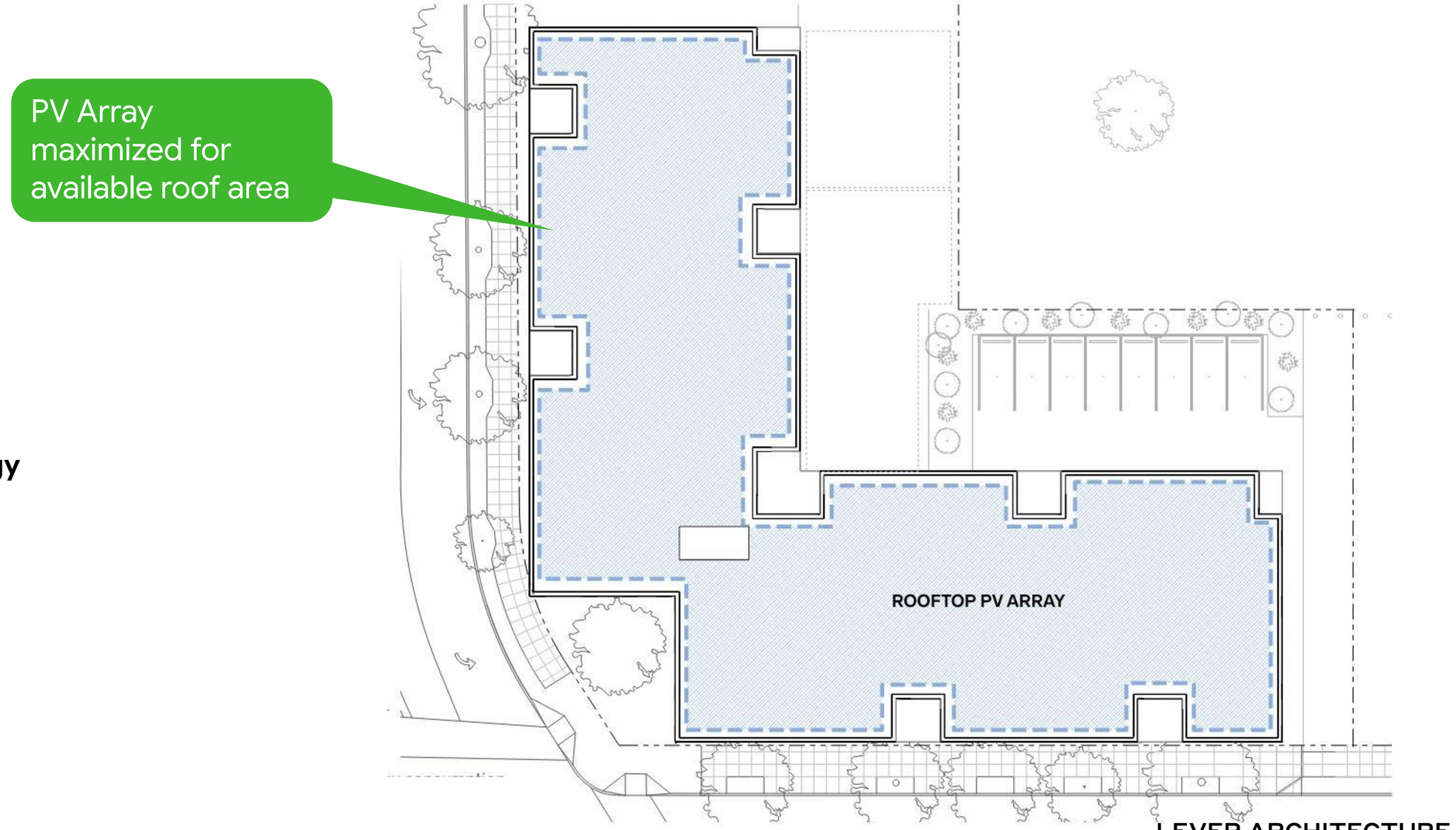
LEVER ARCHITECTURE

On-Site Renewable Energy

Affordable Apartments

Passive House
225 kW PV

18% Net Zero Energy



LEVER ARCHITECTURE

Conclusions + Strategies

LEVER ARCHITECTURE

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 Low Carbon Insulation

Cavity Insulation (per 100sf @ R-8)

Highest

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

Negative

Cellulose Loose Fill

-60 kg CO2e

Wood Fiber Batts

-74 kg CO2e

Cellulose Dense Pack

-141 kg CO2e

Lowest

Values obtained using BEAM Estimator

LEVER ARCHITECTURE

Selecting Low Carbon Insulation

Board Insulation (per 100 sf @ R-8)

Highest

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

Lowest

Negative

Values obtained using BEAM Estimator

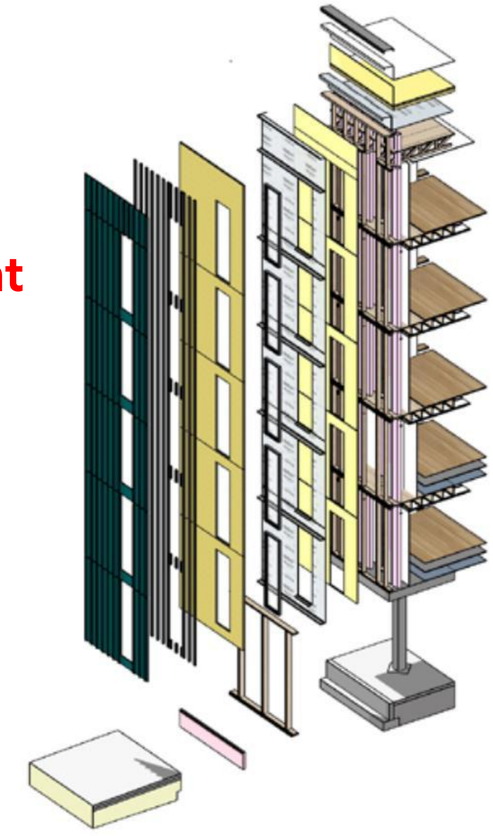
LEVER ARCHITECTURE

Selecting the Structural System

Mass Timber vs Stick Frame

Mass Timber Advantages

- Speed of construction
- Reduced floor to floor height
- No concrete podium req'd
- Aesthetic qualities
- Fire resistance of structure
- Simplicity of construction
- Fewer layers

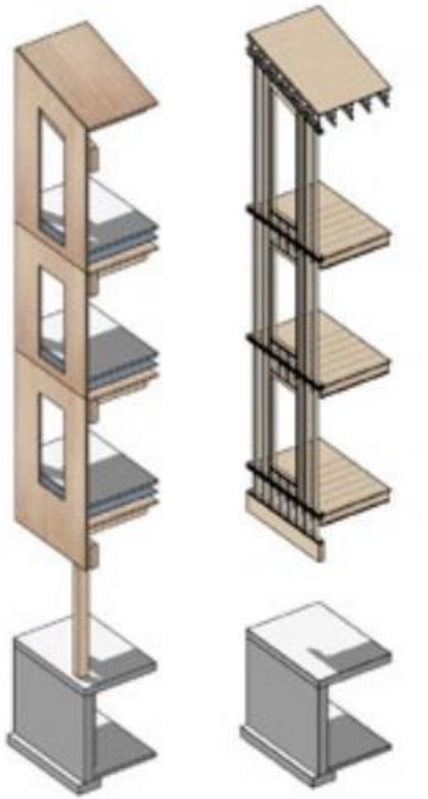


Stick Frame Advantages

- Cavities for insulation
- Low carbon cavity insulation
- Less wood fiber
- Cavities for services
- Easier to field modify
- No specialized labor

Selecting the Structural System

Concrete Reductions



Mass Timber

Topping slab = significant CO2e

Wet assemblies = longer schedule

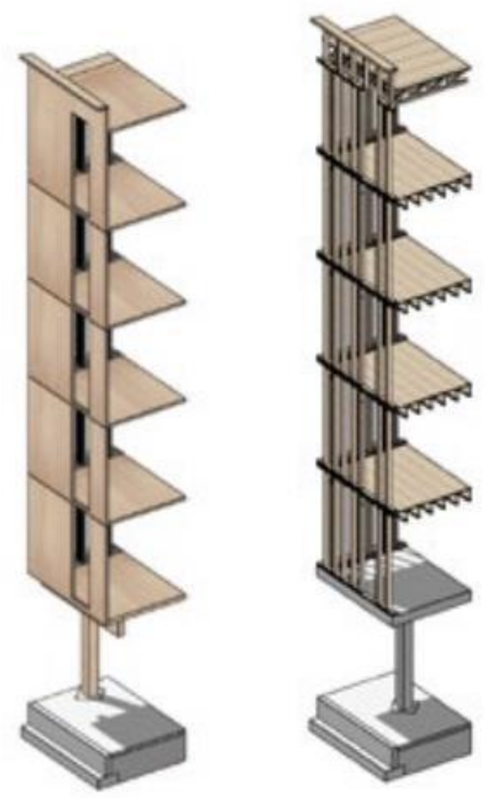
Below Grade Parking

~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 = CO2e reduction

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

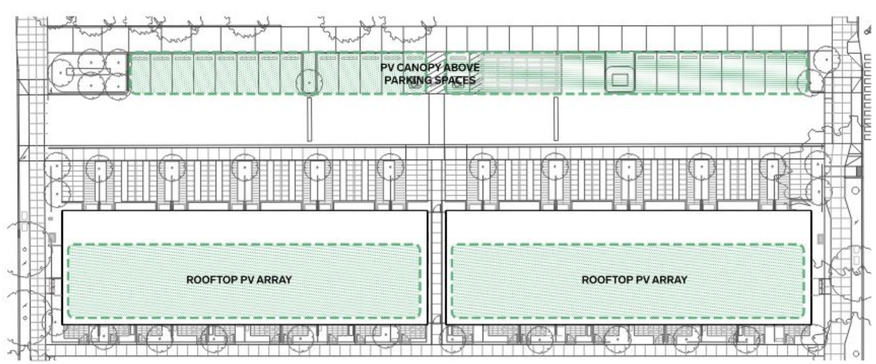
Mass timber floors and roof

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

Public Architecture

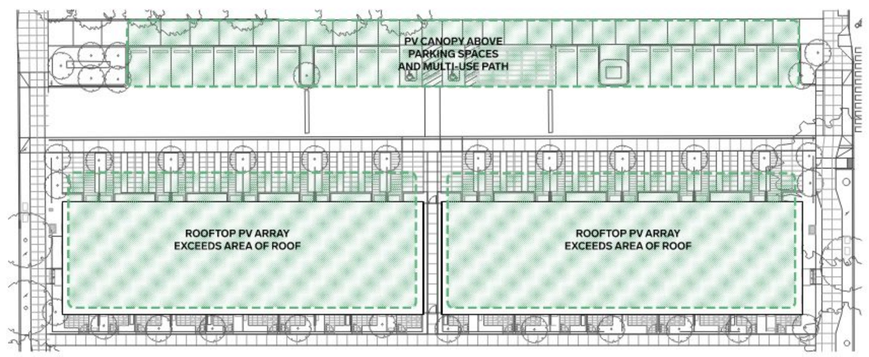
Embodied CO2 vs Operating Emissions

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% energy vs code minimum
- Smaller PV array to reach NZE
- Possible to be energy positive on smaller projects
- Improved comfort
- More resilient to extreme weather events
- Better indoor air quality
- Increased durability
- Reduced mechanical system sizes

Passive House Envelope

- Reduced operational CO2 between 7% - 14% annually
- Increased embodied CO2e 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

LEVER ARCHITECTURE

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

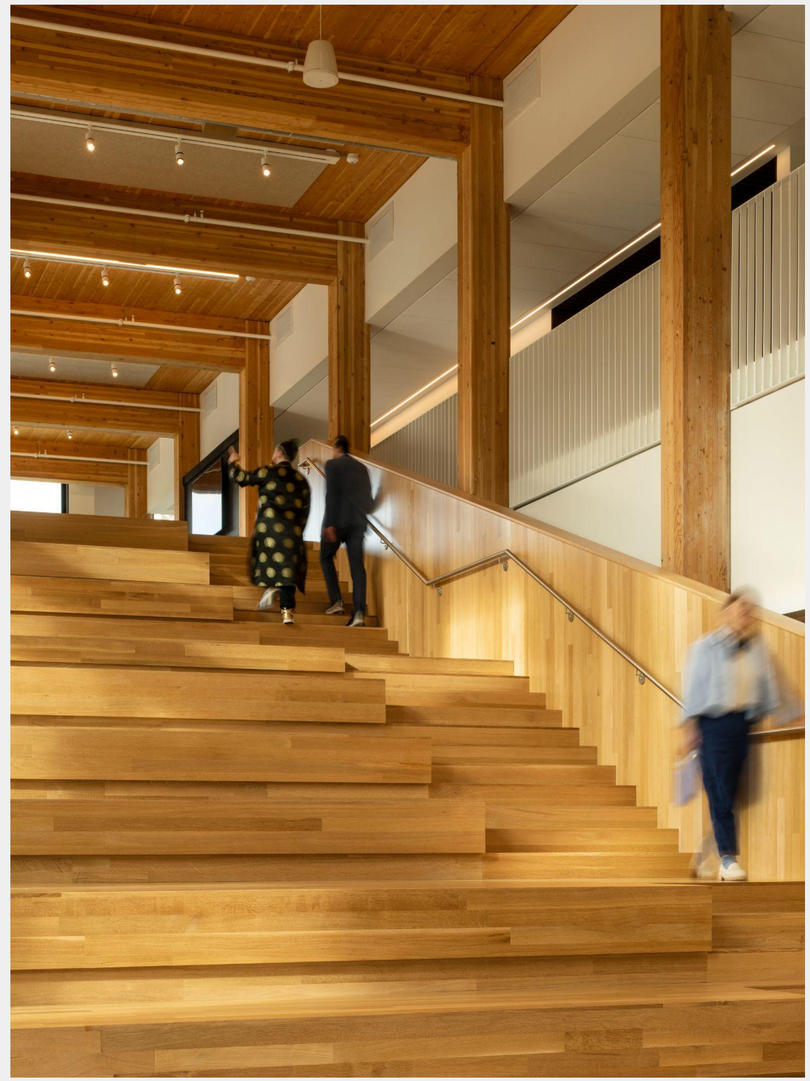
Stick frame exterior walls to maximize cavity insulation

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

LEVER ARCHITECTURE

How to Create Low Carbon Buildings

Conclusions

Carbon modeling is in its infancy with many uncertainties

Data accuracy is challenging when comparing wood buildings

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

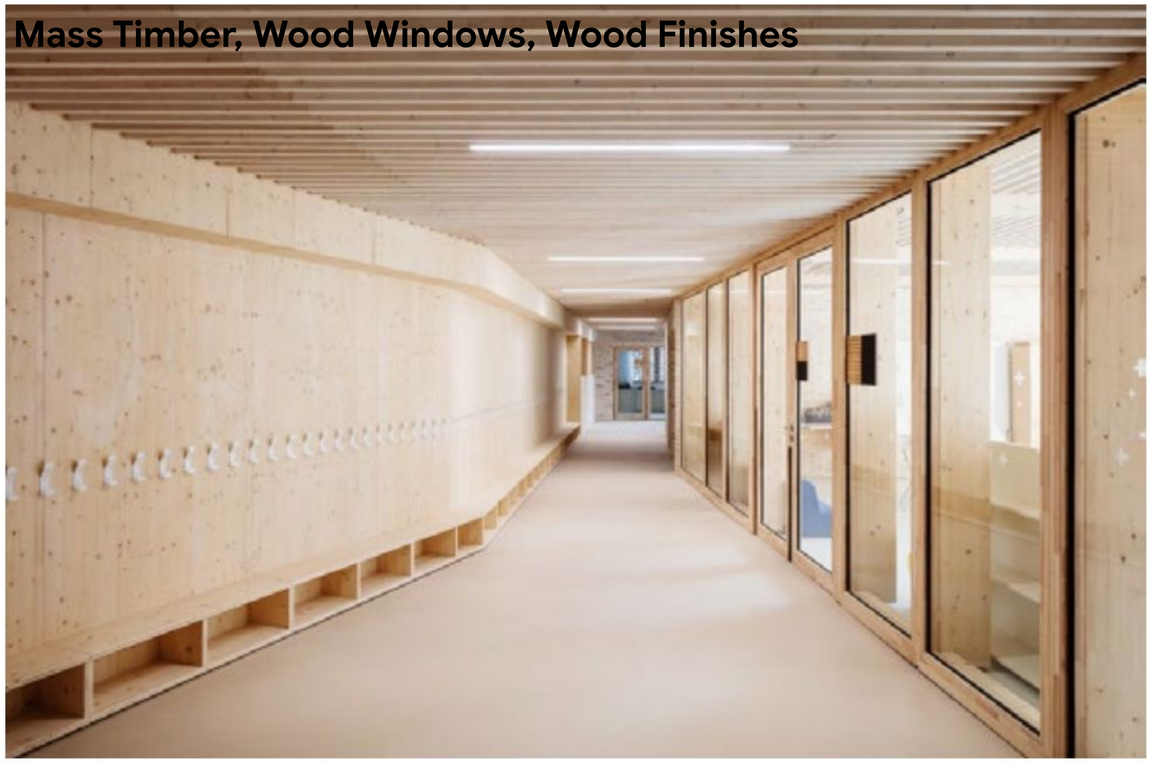
A Bio-based Case Study

Jeanne d’arc Nursey School in Paris France

Wood Clad Exterior

Passive House Certified

Mass Timber, Wood Windows, Wood Finishes



MT, Straw Panels, Wood Fiber

Wood Windows

Atelier Desmichelle Architecture + La Architectures

Thank you

Jeff Stern
Senior Associate
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jstern@leverarchitecture.com