BUILDINGENERGY BOSTON

Lowering Total Carbon Emissions in a Dorm: Strategies for Design and Construction

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Northeast Sustainable Energy Association (NESEA) | March 20, 2024

The Putney School New Dorms

Lowering Total Carbon Emissions in a Dorm:

Strategies for Design and Construction

Bill Maclay, Maclay Architects, Founding Principal
Catherine Earley, Vermont Integrated Architects
Andrew M. Shapiro, Energy Balance, Inc
Jacob Deva Racusin, New Frameworks

The Putney School New Dorms:
AIA Learning Objectives

1. **Lowering Embodied Carbon**
   Define embodied carbon and identify strategies that the design team used to lower embodied carbon emissions in the project.

2. **Lowering Operational Carbon**
   Define operational carbon emissions and how they are different from operational energy, and identify strategies that the design team used to lower operational carbon emissions in the project.

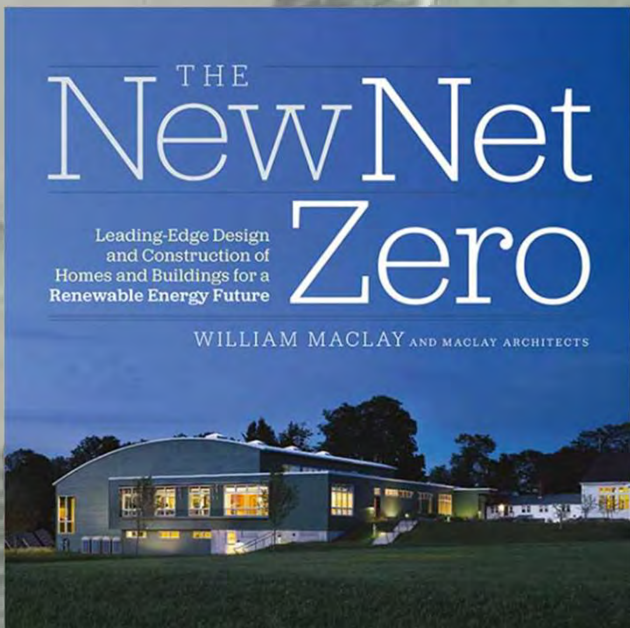
3. **Tools & Methods**
   Identify the analysis tools and methodology used to evaluate the total carbon impact of the project.

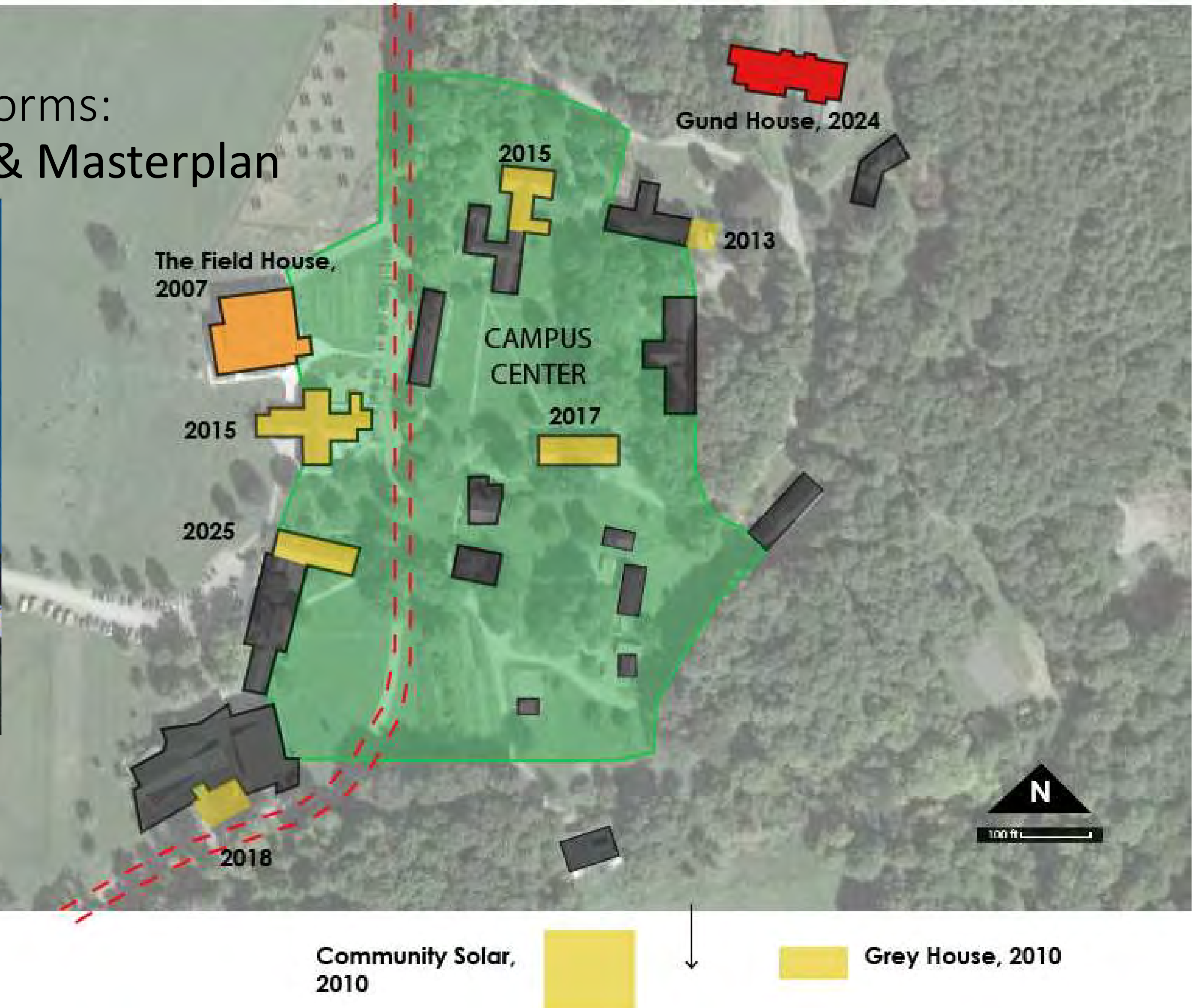
4. **Lessons Learned**
   Apply lessons learned from the project team during design and construction to the participants' professional experience.

The Putney School New Dorms:
Structure of Presentation

1. The building and context
2. Operational Energy and CO2e Modeling (3 options)
3. Embodied CO2e in Materials (3 options)
4. Total carbon picture (3 options)
5. Lessons Learned
6. Questions?

The Putney School New Dorms:
Net Zero Buildings, Plans & Masterplan






Hepper House
Gund House

The Putney School New Dorms:
Cedar Siding

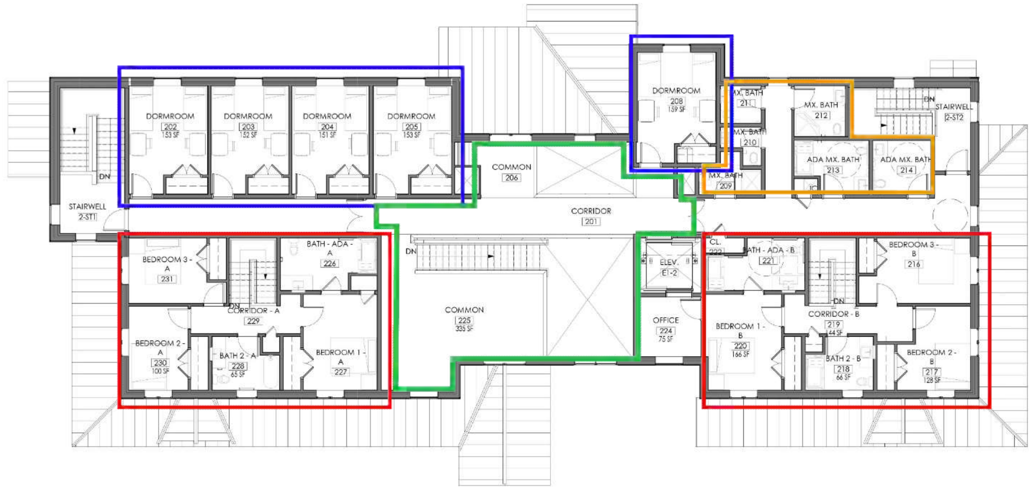
Gund House

Hepper House

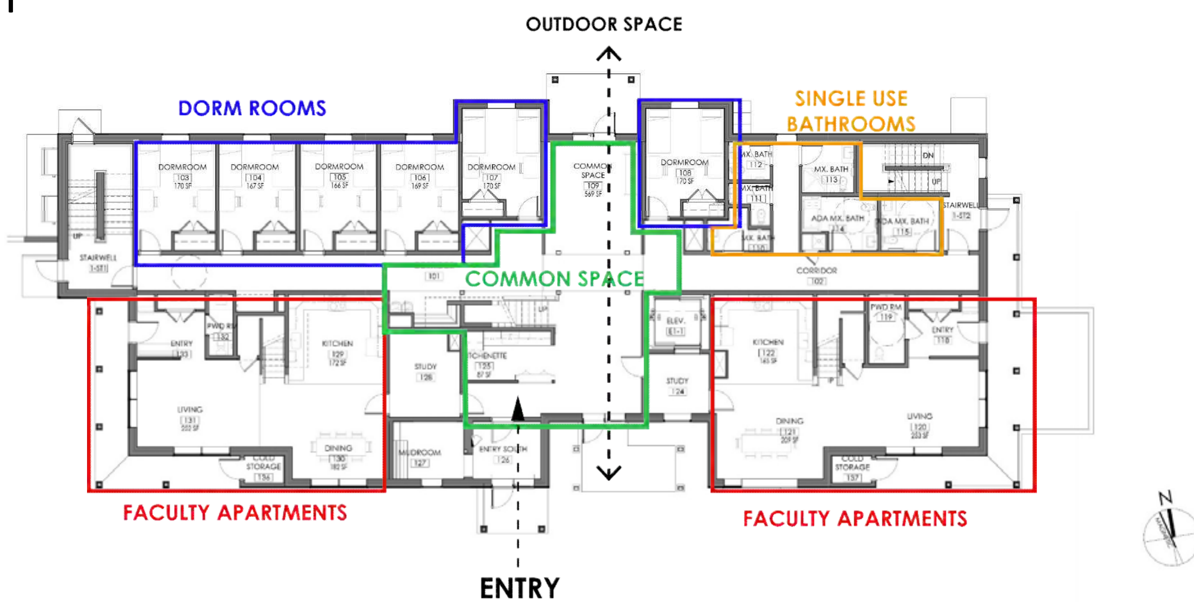
The Putney School New Dorms:
Two Buildings, Small Differences

Gund House

Hepper House



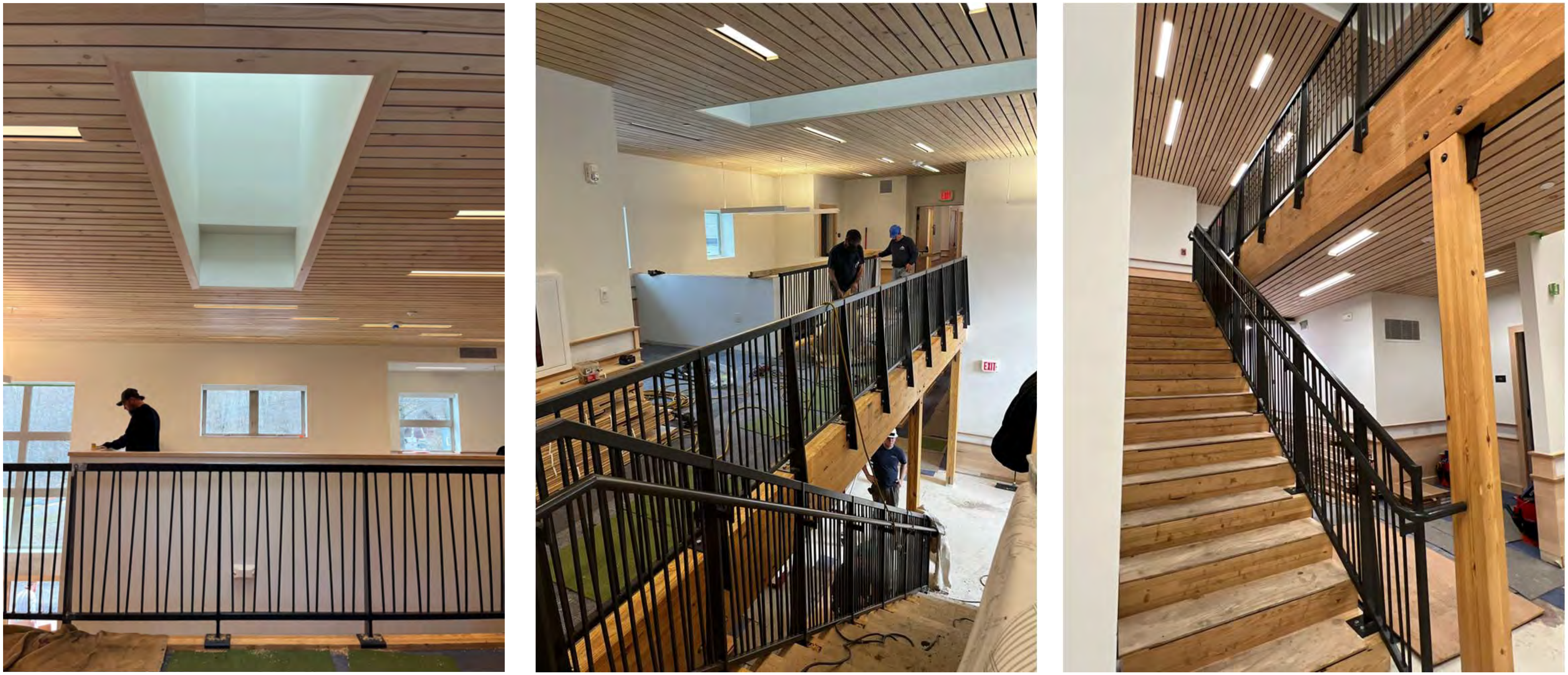
Second Floor Plan



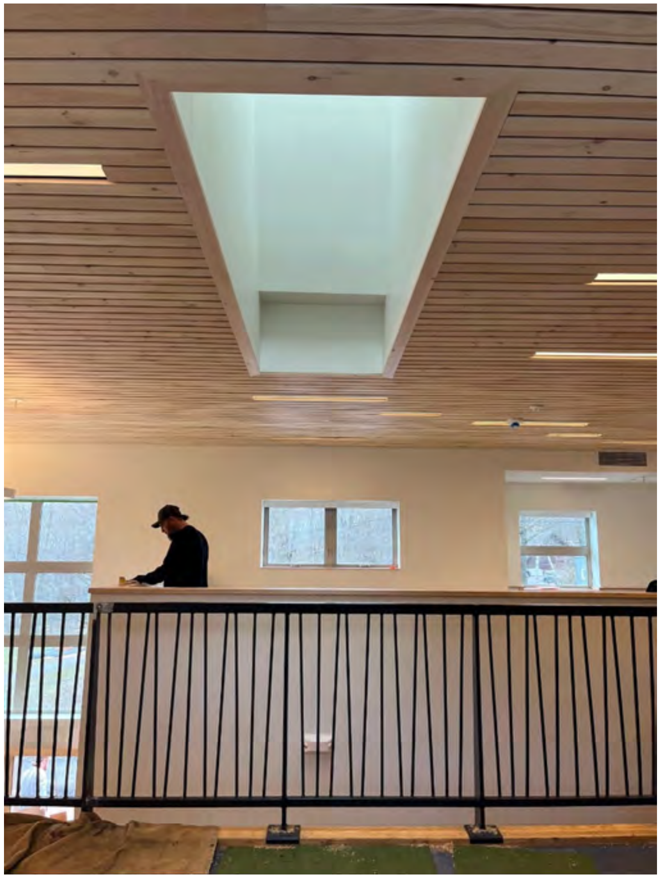
First Floor Plan

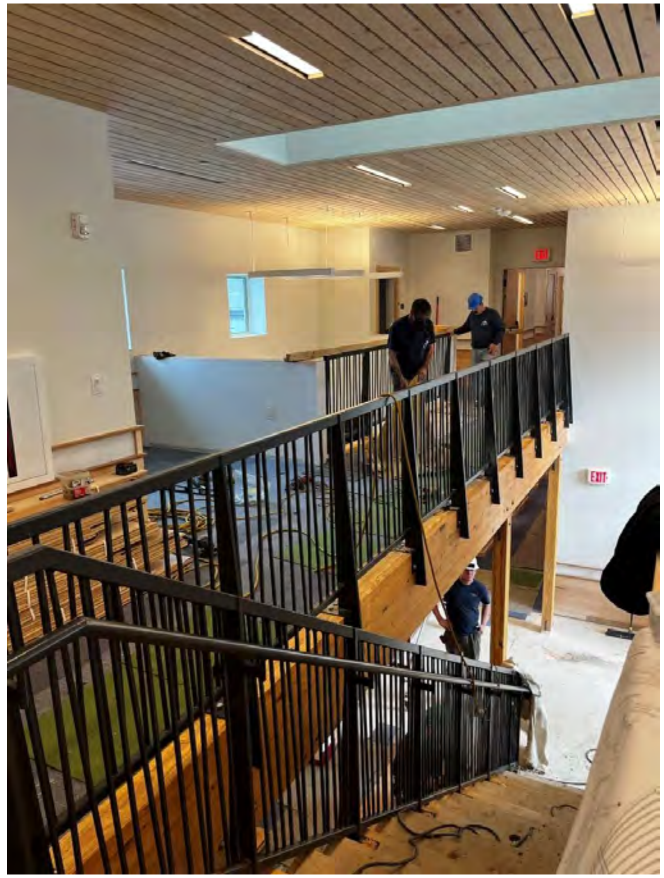
The Putney School New Dorms:
Embodied Carbon – Material Considerations

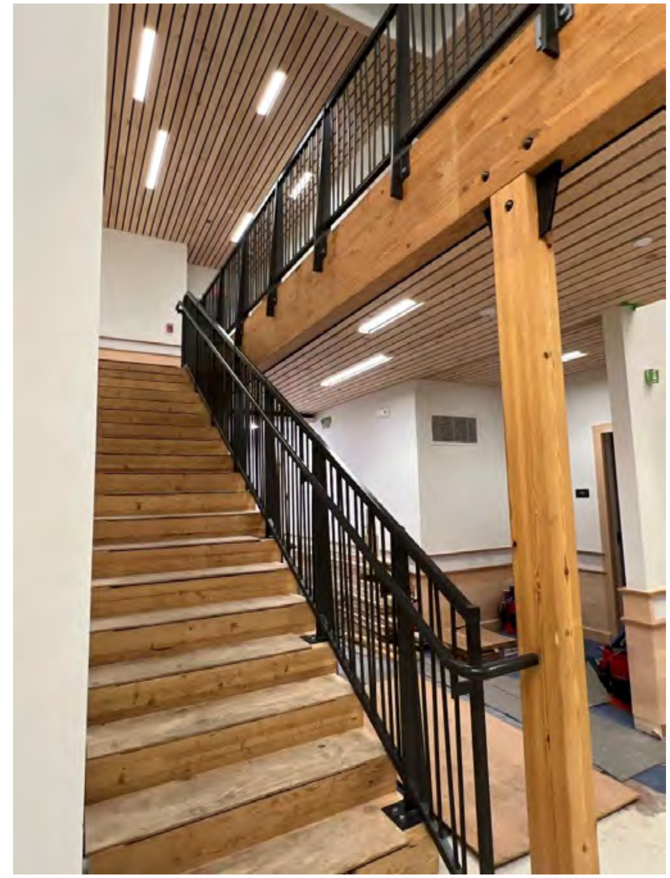
Original interior rendering:



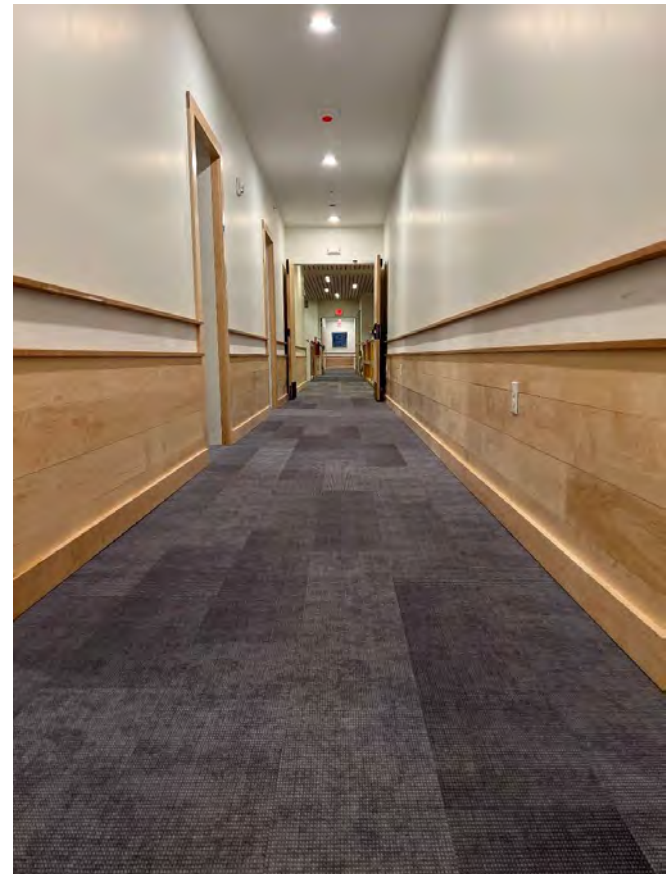
Double-height common space for students







Double-height common space for students



Wood accents anticipating student involvement

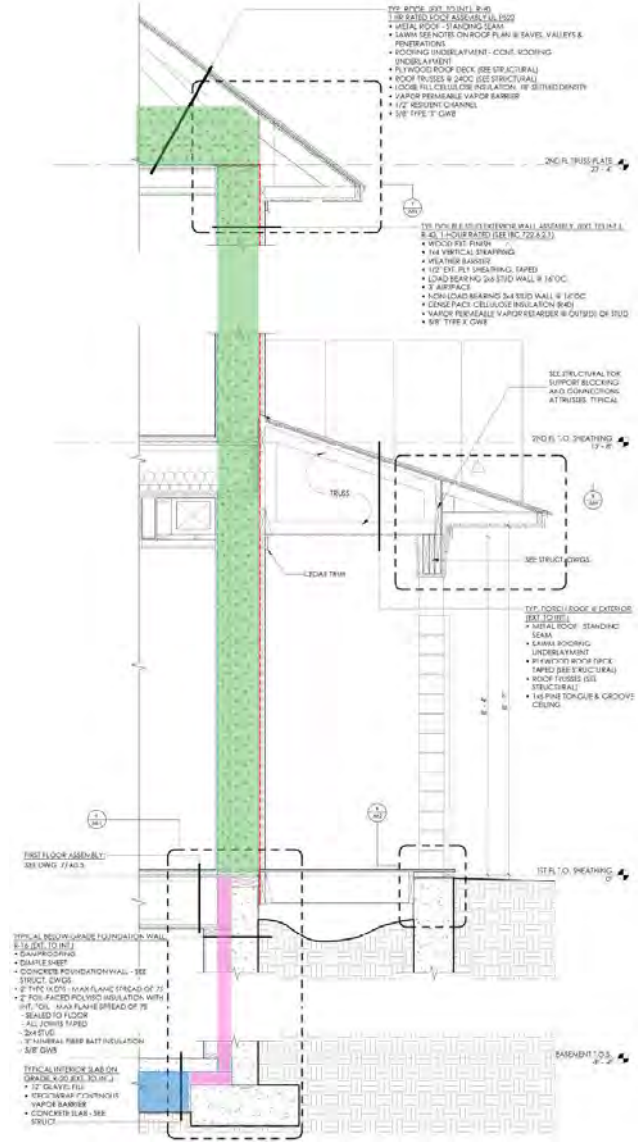
The Putney School New Dorms:
Embodied Carbon & Insulation

18” of Blown Cellulose
R-60

12” of Wet Spray Cellulose
R-40

4” of EPS + Polyiso
R-16

12” of Glavel
R-20



The Putney School New Dorms:
Embodied Carbon & Concrete

TABLE 1. CONCRETE MIXTURES

PROVIDE BID PRICE FOR BOTH TABLE 1 AND TABLE 2 MIX OPTIONS

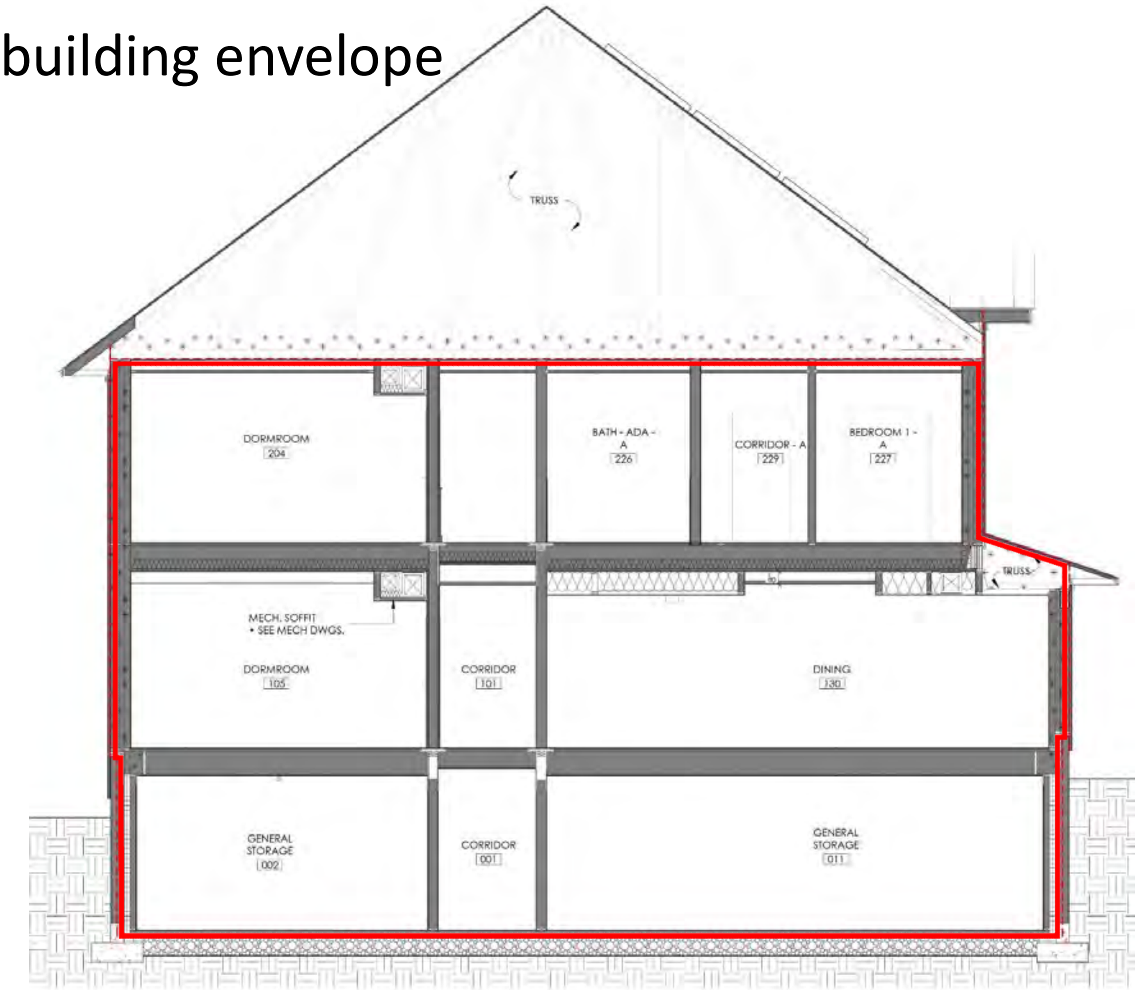
CONCRETE USAGE	MIN. COMPRESSIVE STRENGTH (f'_c)	CONCRETE TYPE	EXPOSURE CLASSES	MAX. W/CM RATIO	PERMISSIBLE AIR CONTENT	REQUIRED CEMENT REPLACEMENT	MAX. AGGREGATE SIZE	ADDITIONAL REMARKS
FOOTINGS	3,000 psi AT 56 DAYS	NWC	C0, F0	N/A	N/A	**25% - 70%**	1-1/2"	
WALLS, COLUMNS AND PIERS	4,000 psi AT 28 DAYS	NWC	C1, F1	0.45	4.5% ±1.5%	**20% - 50%**	1-1/2"	
INTERIOR SLAB-ON-GRADE	4,000 psi AT 28 DAYS	NWC	C0, F0	0.50	N/A	**0 - 25%**	1"	
EXTERIOR SLAB-ON-GRADE	5,000 psi AT 56 DAYS	NWC	C2, F2	0.40	5.5% ±1.5%	**15 - 25%**	1-1/2"	

NOTES:

1. ALL CONCRETE SHALL BE CONSIDERED TO BE IN EXPOSURE CLASS F0, S0, P0 AND C0 ACCORDING TO ACI 318-08 UNLESS NOTED OTHERWISE IN TABLE ABOVE, IN NOTES BELOW OR ELSEWHERE ON THE STRUCTURAL DRAWINGS.
2. CONCRETE NOTED ABOVE OR ON PLAN AS EXPOSURE CLASS F1, F2, S1, S2, S3, P1, C1 OR C2 SHALL BE PROPORTIONED TO COMPLY WITH ACI 318-08 TABLES 4.3.1, 4.4.1 AND 4.4.2 IN ADDITION TO THE NOTATIONS IN THE REQUIREMENTS FOR VARIOUS EXPOSURE CLASSES RELATIVE TO CEMENT TYPE, AIR ENTRAINMENT REQUIREMENTS, CHLORIDE ION LIMITS AND POZZOLAN LIMITS.
3. FOR SLAB, COORDINATE AND PROVIDE MIX DESIGNS MEETING MAXIMUM CEMENT CONTENT FOR AGGREGATE SIZE TO COMPLY WITH TABLE 8.4.1B OF ACI 302-15.

The Putney School New Dorms:
Lowering Operational Emissions at building envelope

Final blower door test of 0.035 CFM50 /SF of Envelope (6 sides)



The Putney School New Dorms:
Continuous Air Barrier

The Putney School New Dorms –
Energy and CO2e Modeling

Three options analyzed:

1. Code building baseline, 2020 CBES
2. Baseline net zero ready building – Net zero ready performance built as if embodied CO2e was NOT considered
3. Lower embodied carbon net zero ready – Building as built

The Putney School New Dorms –

Operational Energy and CO2e Modeling

Building Enclosure	Code building baseline, CBES	Baseline Net Zero Ready Building	Lower Embodied Carbon Net Zero Ready
Windows	Low-e R-3.0, U-.33 windows, vinyl, SHGC-0.37	Triple-glazed vinyl windows; U=0.20; SHGC=0.21	Triple-glazed vinyl windows; U=0.20; SHGC=0.21

The Putney School New Dorms –

Operational Energy and CO2e Modeling

Building Enclosure	Code building baseline, CBES	Baseline Net Zero Ready Building	Lower Embodied Carbon Net Zero Ready
Doors	U - 0.37, R-2.7, metal insulated, wood/glass front doors	U - 0.3, R-3.3, metal insulated, wood/glass front doors	U - 0.3, R-3.3, metal insulated, wood/glass front doors

The Putney School New Dorms –

Operational Energy and CO2e Modeling

Building Enclosure	Code building baseline, CBES	Baseline Net Zero Ready Building	Lower Embodied Carbon Net Zero Ready
Concrete	100% cement in all uses	100% cement in all uses	Footings, 50% slag replacement of cement; walls, columns and piers, 19.6% replacement; interior slabs 0%; exterior slabs 20% replacement

The Putney School New Dorms –

Operational Energy and CO2e Modeling

Building Enclosure	Code building baseline, CBES	Baseline Net Zero Ready Building	Lower Embodied Carbon Net Zero Ready
Insulation	Basement Walls, 3" XPS foam; f-factor 0.41	Basement Walls, 2" XPS foam + 2" foil-faced PI + empty 2x4 cavity -- R-23, f-factor 0.16	Basement Walls, 2" XPS foam + 2" foil-faced PI + empty 2x4 cavity -- R-23, f-factor 0.16
	No subslab insulation	R-20 sub-slab XPS insulation, on 7" crushed stone.	R-R-20 Glavel under basement slab, except over footings, where there will be 4" EPS
	Walls: R-21 fiberglass cavity insulation in 2x6 16" OC, interior polyethylene membrane + R-7.5 XPS continuous	Walls: R-21 mineral fiber cavity insulation in 2x6 16" OC, interior polyethylene membrane + R-15 XPS continuous	Walls: R-40 double stud wall with cellulose, Intello+ variable vapor retarder interior membrane
	Attic R-49 fiberglass batts	Attic R-80 mineral fiber batts	Attic R-80 loose fill cellulose

The Putney School New Dorms –

Operational Energy and CO2e Modeling

Building Enclosure	Code building baseline, 2020 CBES	Baseline Net Zero Ready Building	Lower Embodied Carbon Net Zero Ready
Cladding	Fiber cement siding	Fiber cement siding	Locally milled Eastern Cedar, NY state
Cladding finish	3 coats water-based paint	3 coats water-based paint	3 coats oil-based semi-transparent stain
Roofing	standing seam metal	standing seam metal	standing seam metal

The Putney School New Dorms –

Operational Energy and CO2e Modeling

Building Enclosure	Code building baseline, 2020 CBES	Baseline Net Zero Ready Building	Lower Embodied Carbon Net Zero Ready
Interior partitions	cold formed steel studs	cold formed steel studs	wood studs
gypsum board	typical	typical	1. Stairwell Glass Mat: DensArmor Plus – 5/8” 2. MR Board: 5/8” 3. Gold Bond Shaftliner XP: 1” 4. Durock Cement Board: – ½”
Interior finishes	commercially available wainscoting	commercially available wainscoting	Locally milled wainscoting, NY state

The Putney School New Dorms –

Operational Energy and CO2e Modeling

Building Enclosure	Code building baseline, 2020 CBES	Baseline Net Zero Ready Building	Lower Embodied Carbon Net Zero Ready
Air leakage rate	0.3 ACH50	.05 cfm50/sq.ft. shell, 6 sides	.05 cfm50/sq.ft. shell, 6 sides
Enclosure Commissioning	No	Yes	Yes

Achieved 0.035 cfm50/sq.ft. shell – 6 sides!

The Putney School New Dorms –

Operational Energy and CO2e Modeling

Mechanicals	Code building baseline, 2020 CBES	Baseline Net Zero Ready Building	Lower Embodied Casrbon Net Zero Ready
Ventilation	1200 cfm total, 50% enthalpy recovery; 66% sensible recovery,	1200 cfm total, 50% enthalpy recovery; 66% sensible recovery,	1200 cfm total, 50% enthalpy recovery; 66% sensible recovery,
Heat	propane 90 AFUE boiler at 85% seasonal efficiency, fan coils	ASHP annual heat COP 2.3,	ASHP annual heat COP 2.3,
Cooling	Split system AC with coils in ductwork	Split system AC with coils in ductwork	ASHP cooling
Setpoint	70F heating 72F cooling Basement conditioned	70F heating 72F cooling Basement conditioned	70F heating 72F cooling Basement conditioned

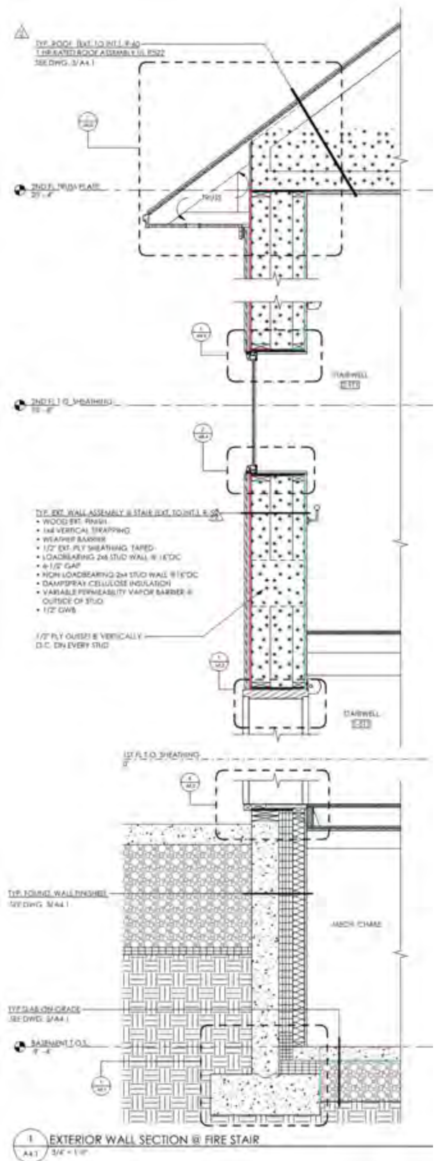
The Putney School New Dorms –

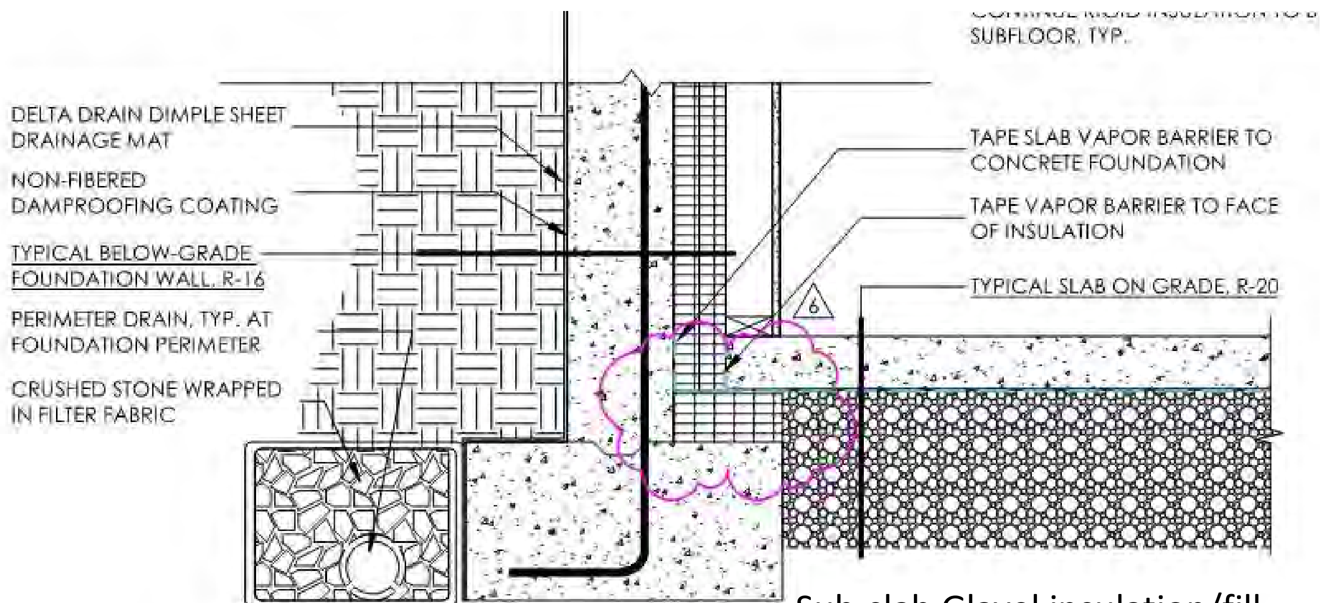
Operational Energy and CO2e Modeling

Mechanicals	Code building baseline, 2020 CBES	Baseline Net Zero Ready Building	Lower Embodied Casrbon Net Zero Ready
Hot Water	From boiler, 75% efficient delivery plus recirc loop losses	Solar hot water, backup with heat pump, with drainwater heat recovery on dorm showers, resistance electric top-up	Solar hot water, backup with heat pump, with drainwater heat recovery on dorm showers, resistance electric top-up
Metering?	None	EGauge	EGauge
MEP Commissioning	No	Yes	Yes

The Putney School New Dorms –

Building Enclosure

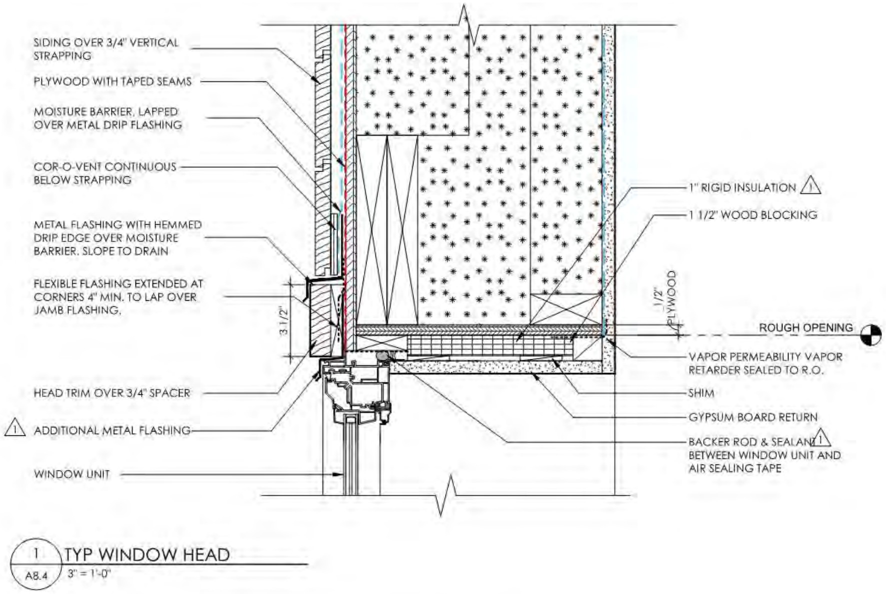


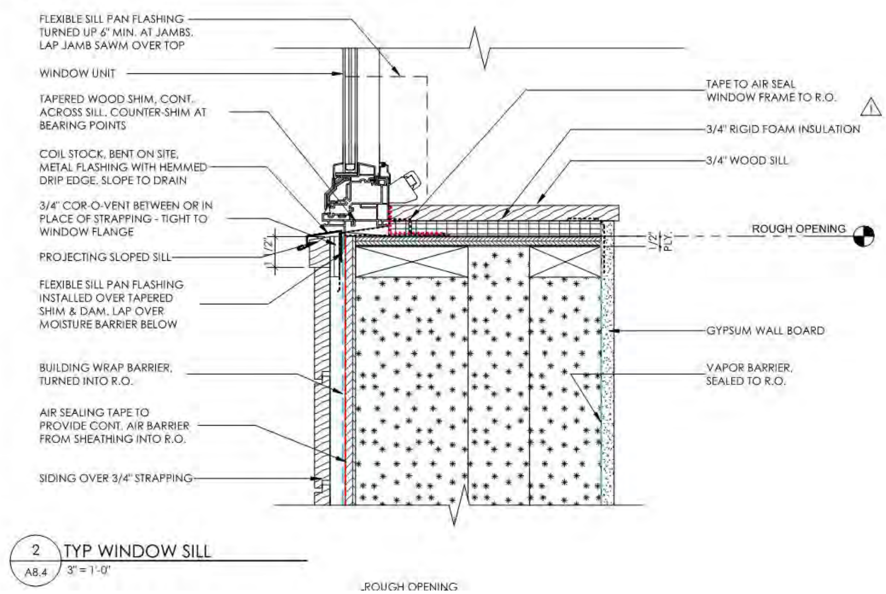


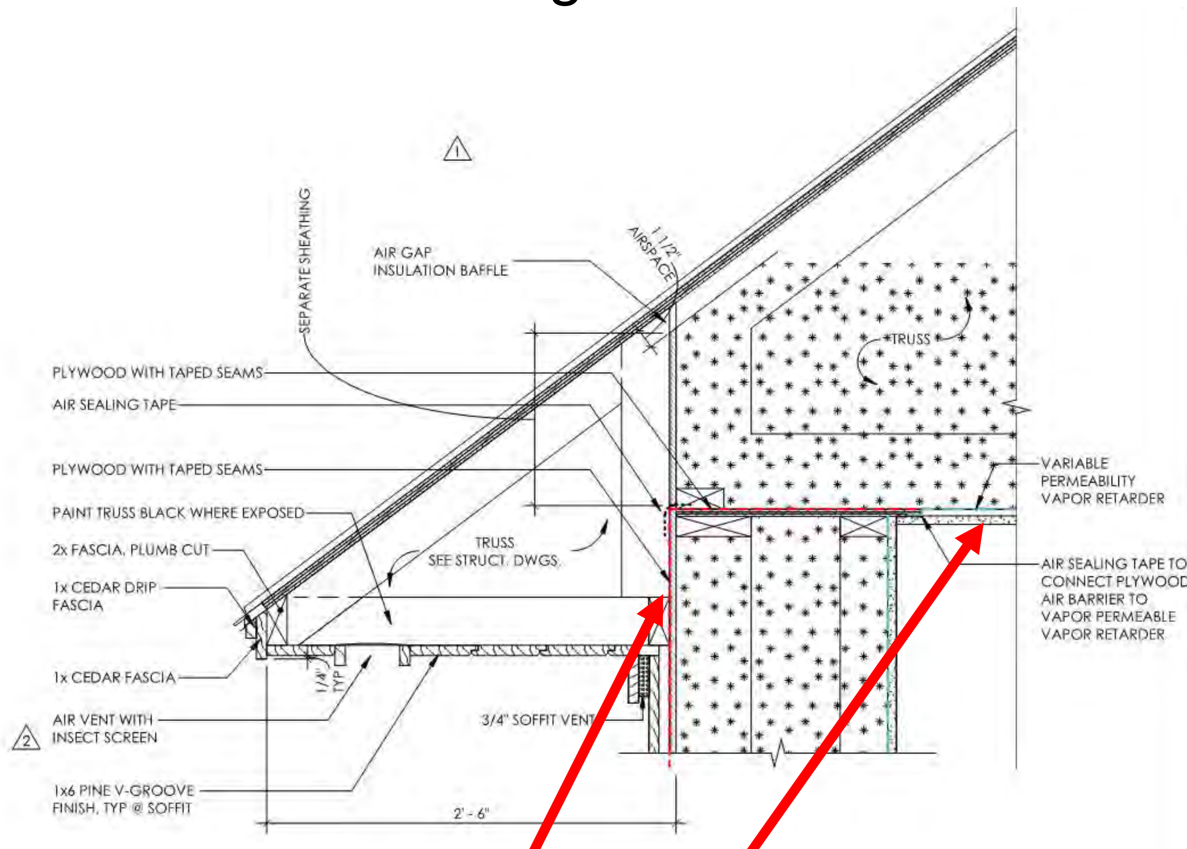
Sub-slab Glavel insulation/fill

The Putney School New Dorms –

Building Enclosure





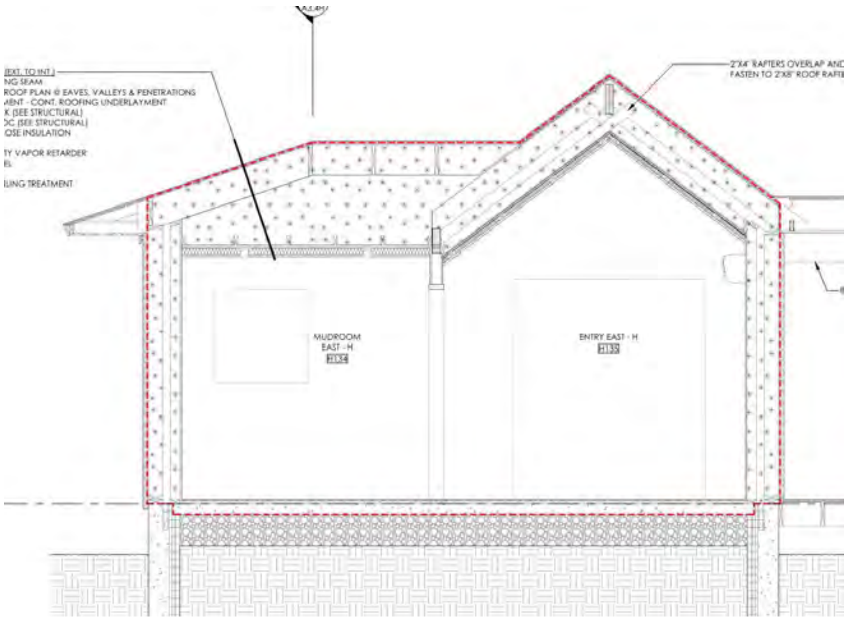


Air barrier moves from outside to inside

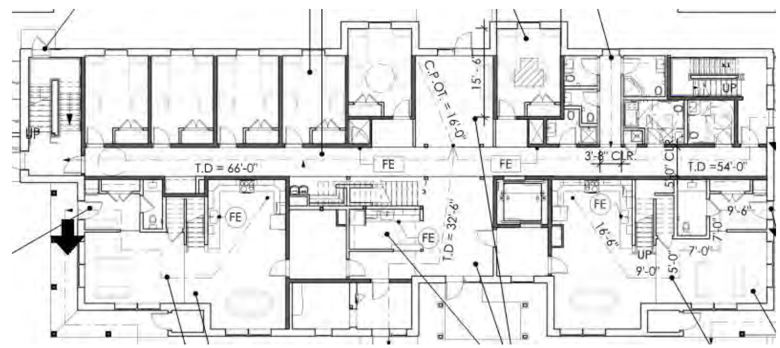
Uplift and deflection of 40 ft trusses required complex detailing

The Putney School New Dorms –

Building Enclosure



Building floorplan complexity increases cost of achieving a high performance enclosure



First floor has 22 corners; second floor has fewer corners

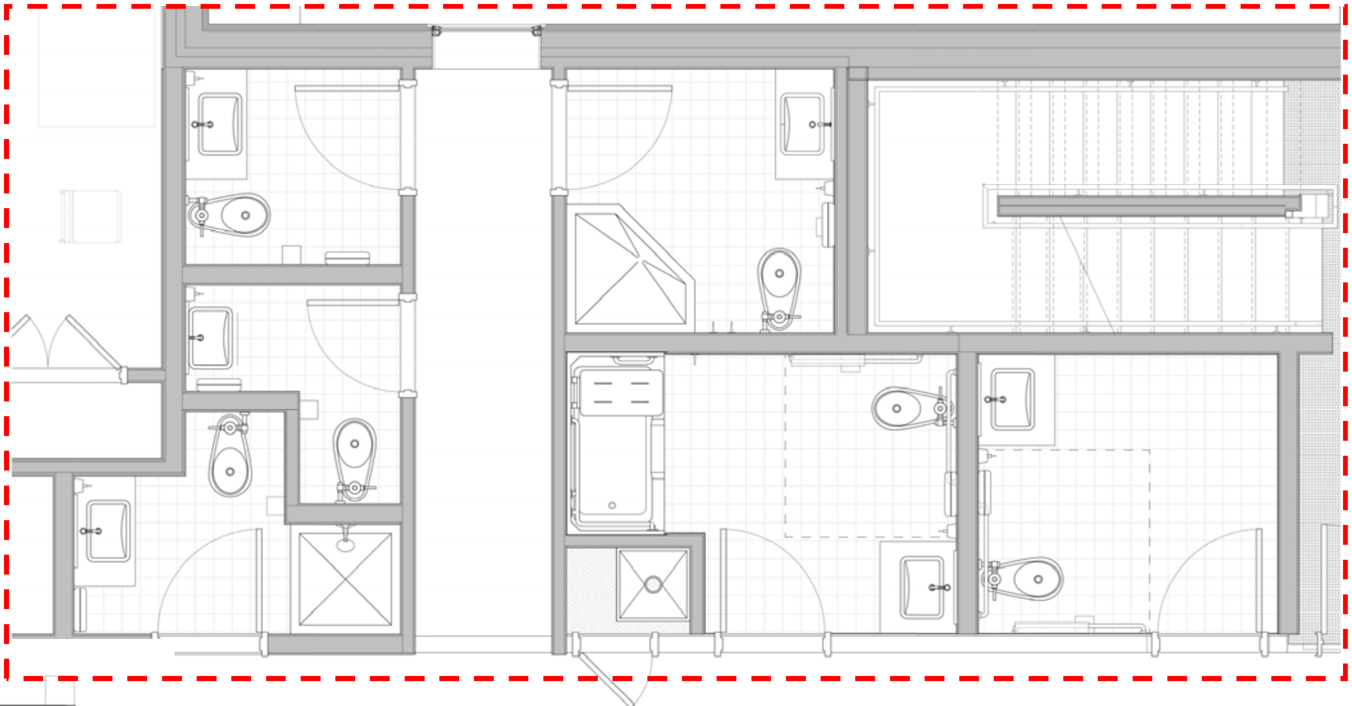
The Putney School New Dorms –

Operational Energy and CO2e Modeling

Hot Water	From boiler, 75% efficient delivery plus recirc loop losses	Solar hot water, backup with heat pump, with drainwater heat recovery on dorm showers, resistance electric top-up	Solar hot water, backup with heat pump, with drainwater heat recovery on dorm showers, resistance electric top-up
MEP Commissioning	No	Yes	Yes
Lighting	100% LED	100% LED	100% LED

Drainwater heat recovery system captures about 50% of heat going down the drain

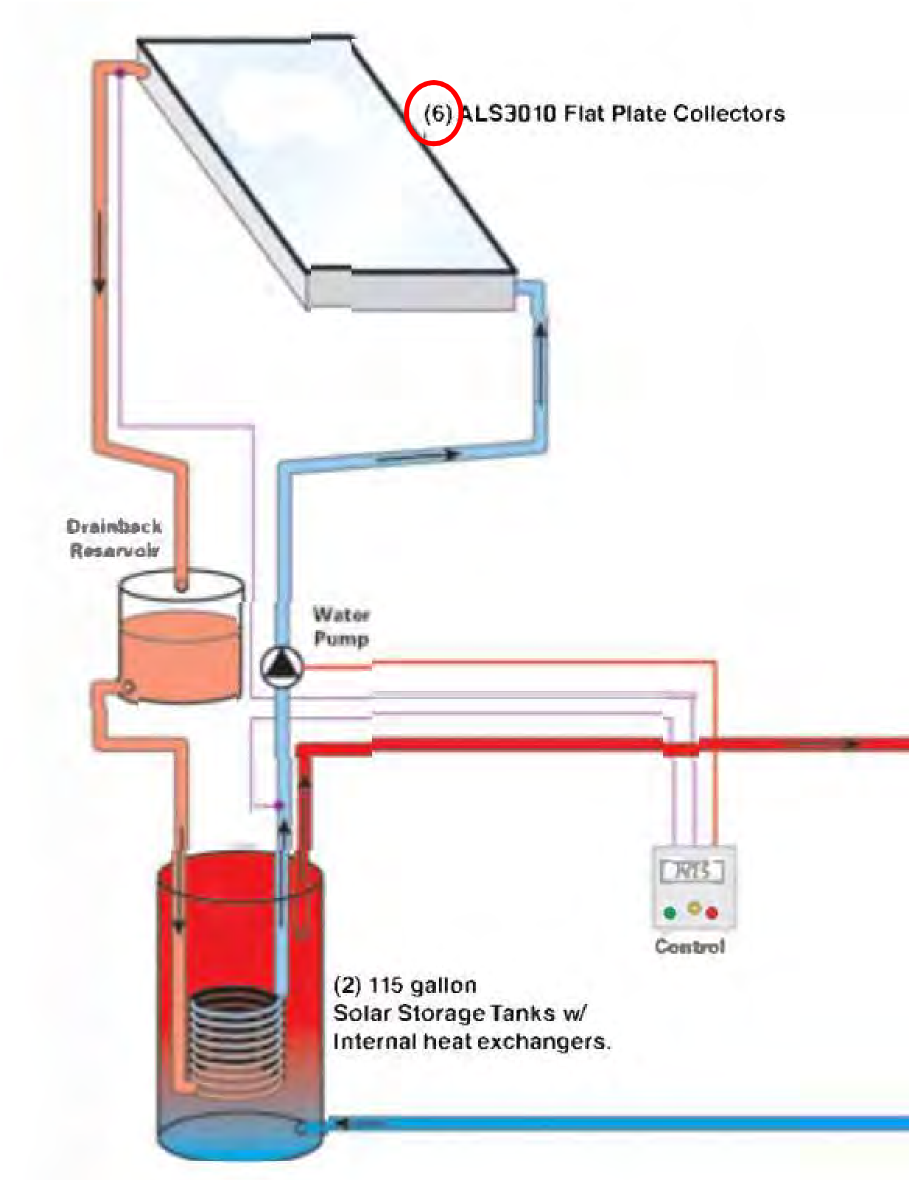
Ganged bathrooms allow shower drainwater heat recovery from dorm room showers – two floors similar dorm room showers <u>and</u> avoids need for recirc hot water system



Closed Loop Drain-Back Solar Hot Water

Buildings are to be used in summer!

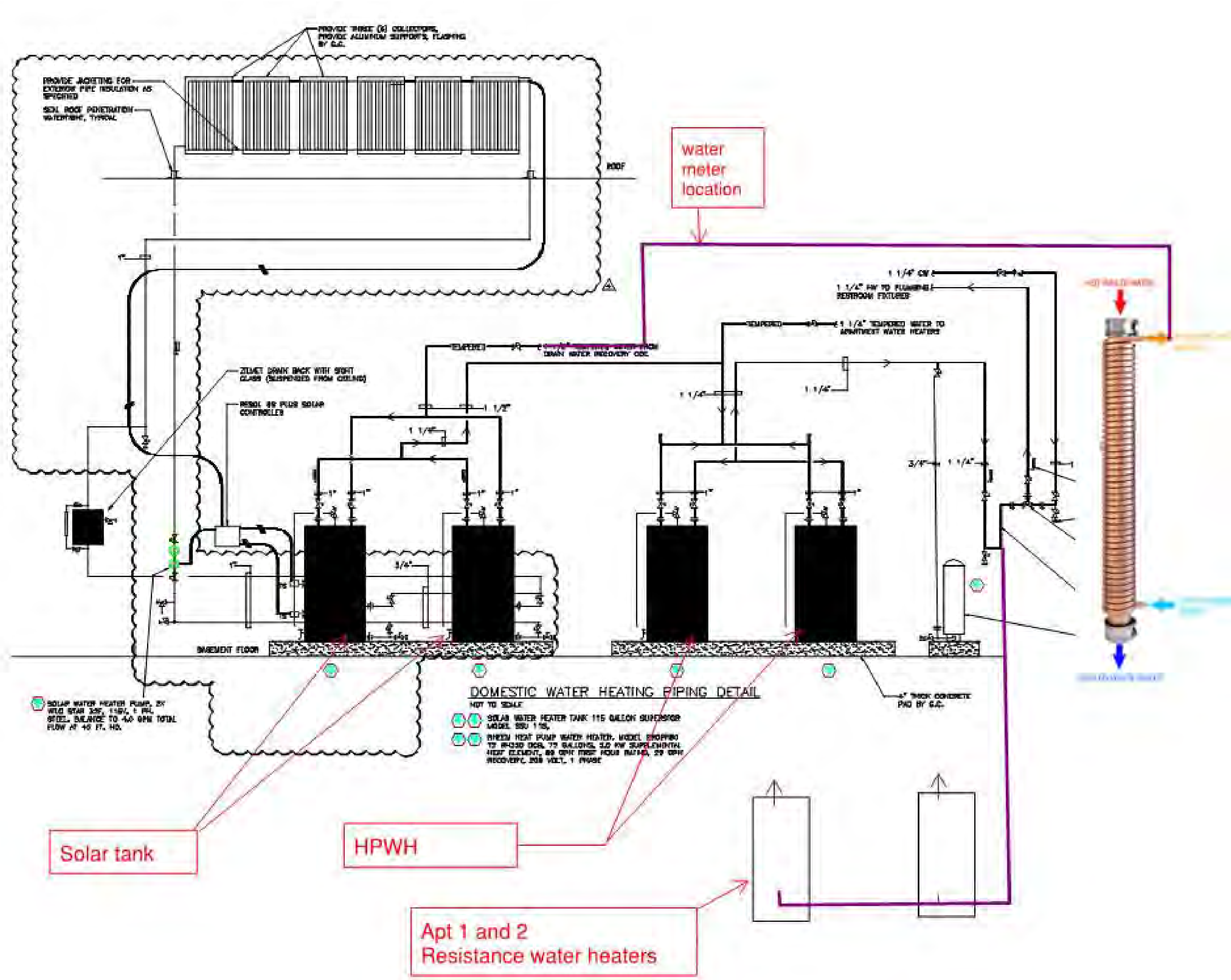
1. Near zero pressure in system
2. Collectors empty except when heating
3. Stainless tanks, copper piping
4. Very long antifreeze life
5. Very long system life
6. Modeled 50% savings of 15 MWh/year load



>>> Hot water out

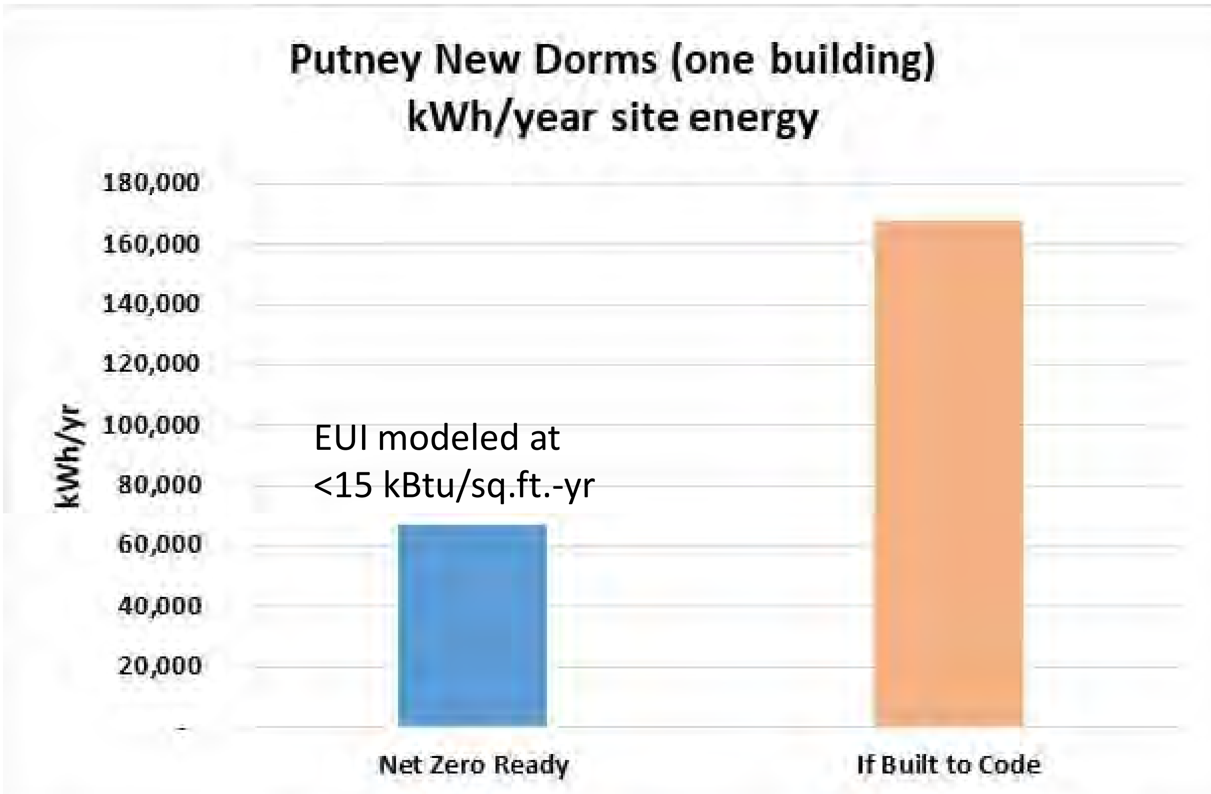
<<< Cold water in

Hot water system



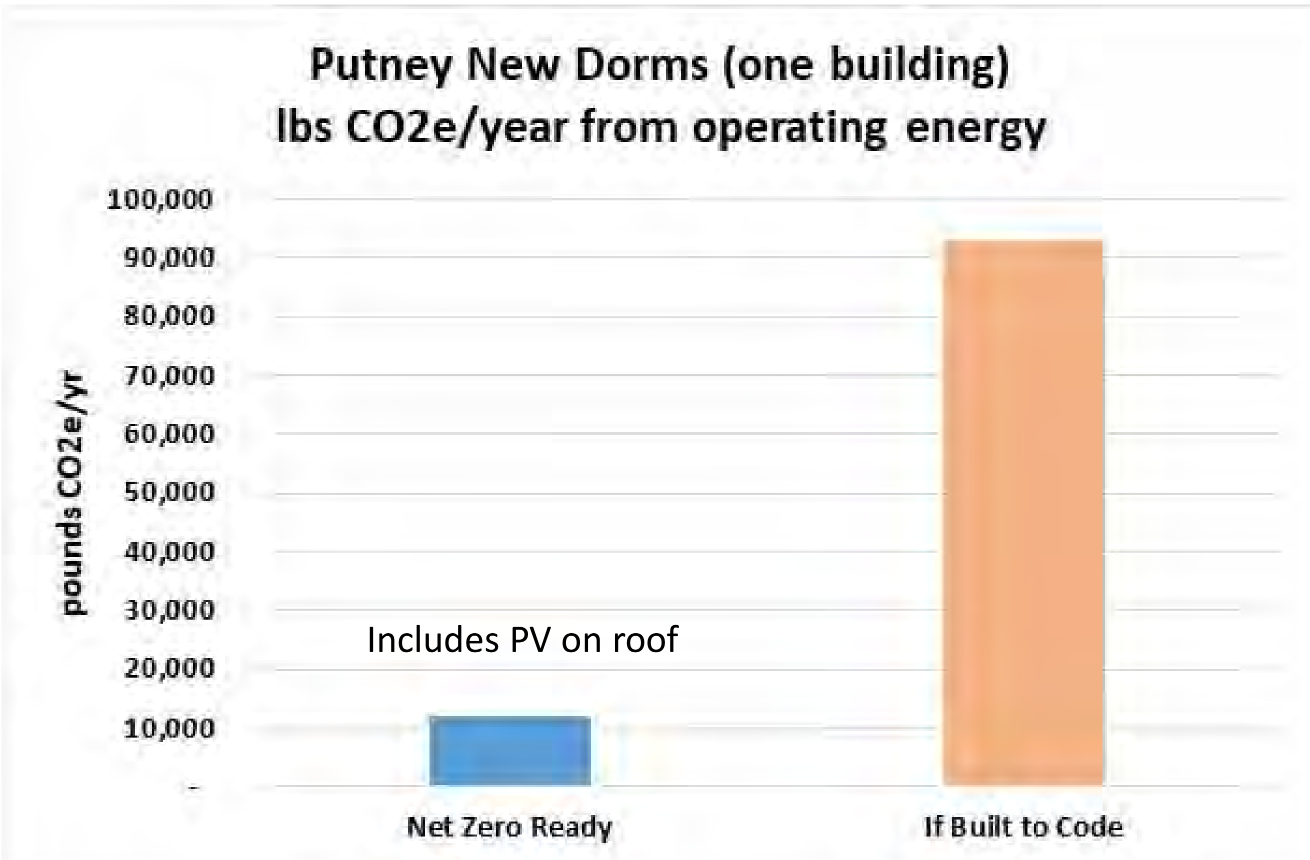
The Putney School New Dorms –

Operational Energy - Modeled



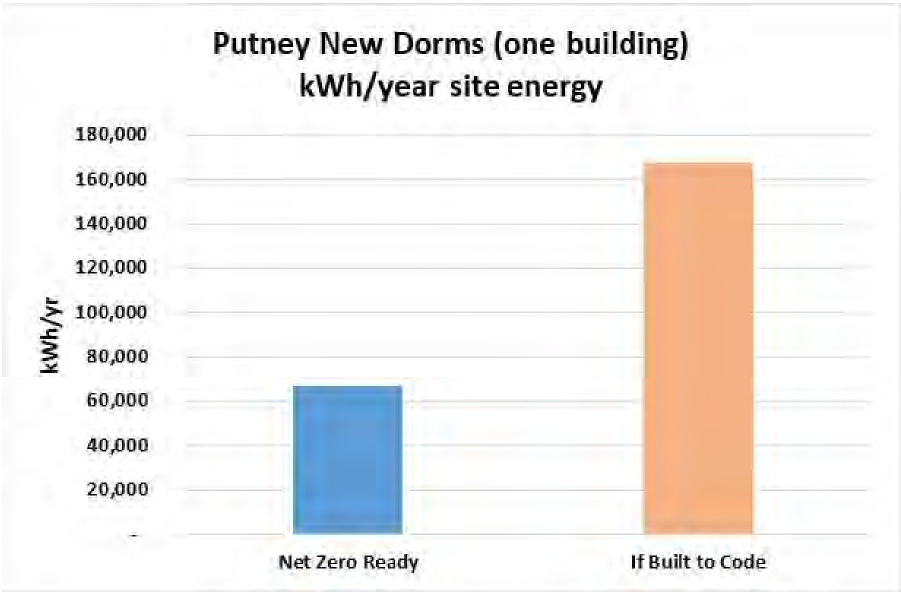
The Putney School New Dorms –

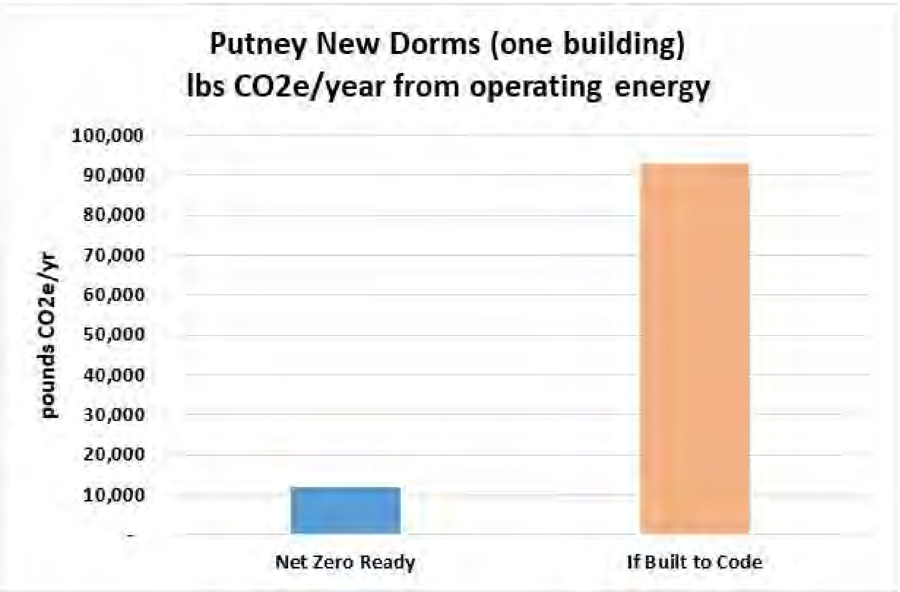
Operational Energy CO2e Emissions - Modeled



The Putney School New Dorms –

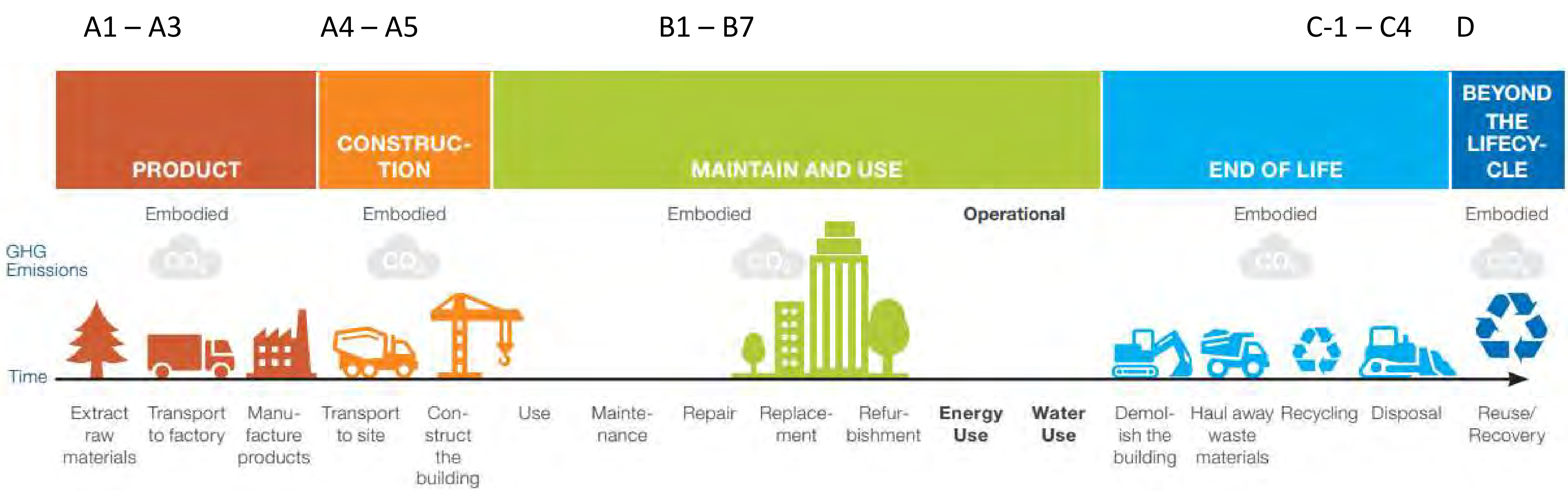
Operational Energy CO2e Emissions



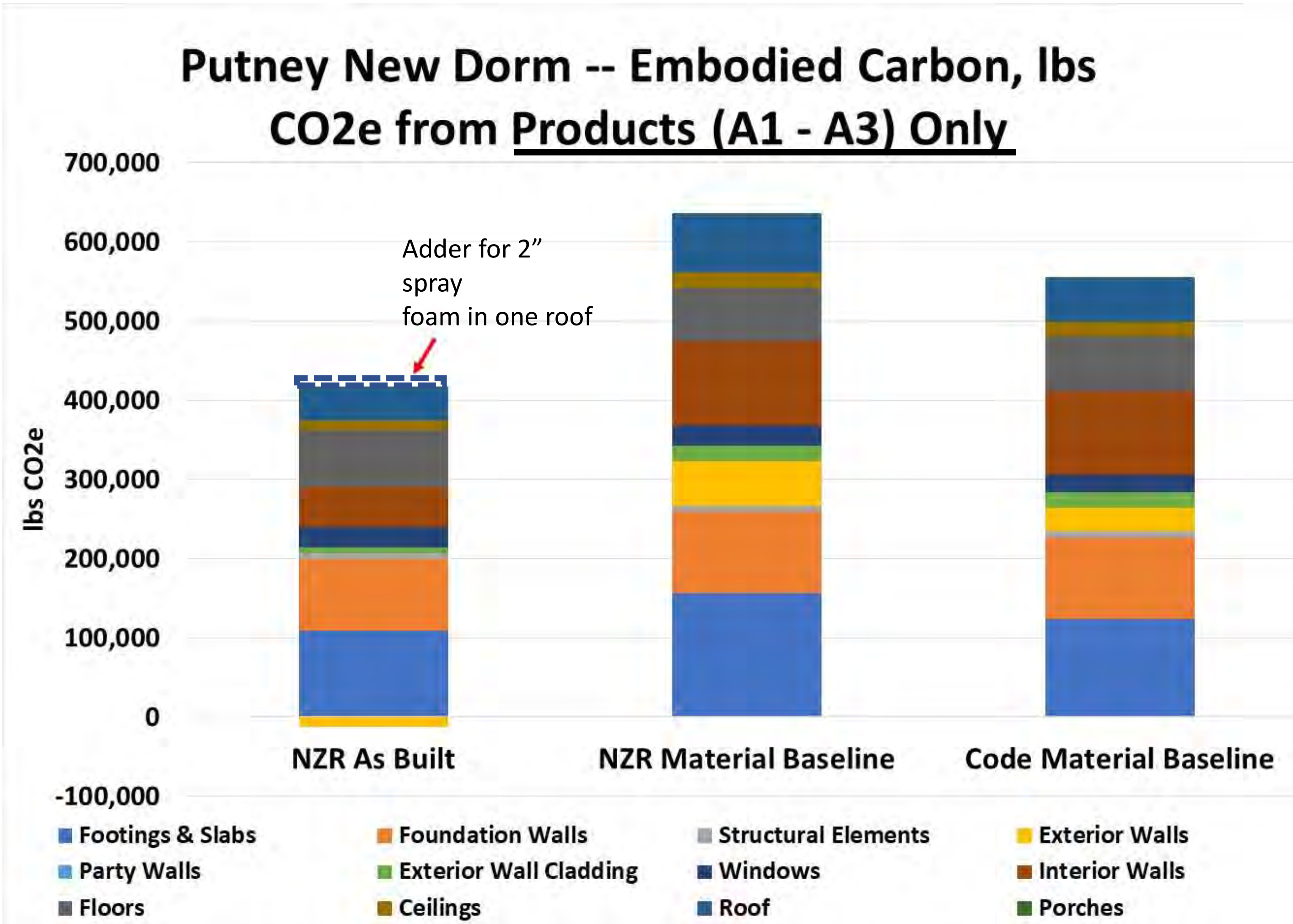


The Putney School New Dorms –

Embodied Energy CO2e Emissions --- Life Cycle Assessment

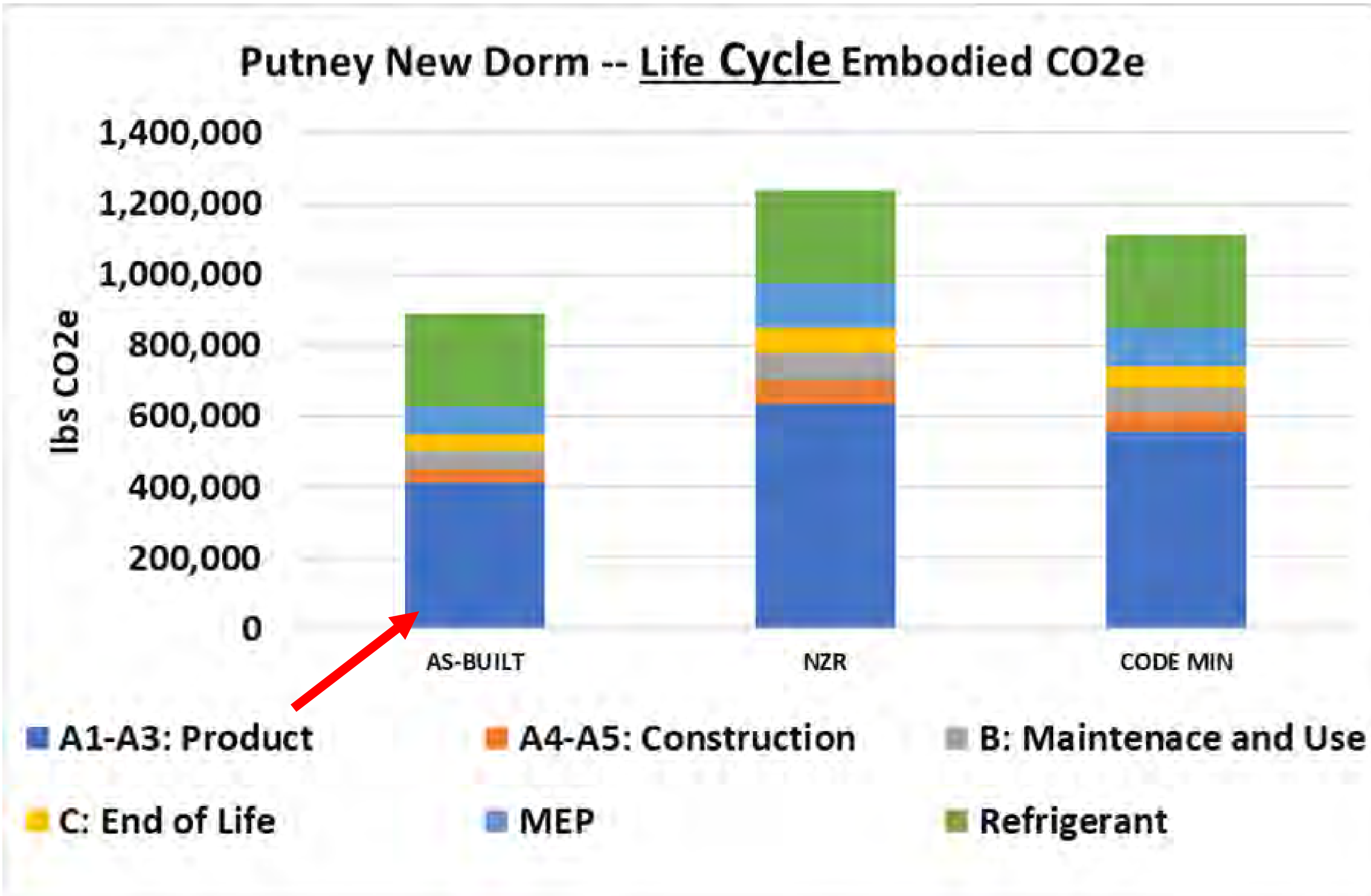


The Putney School New Dorm – Embodied CO2e Emissions - BEAM



The Putney School New Dorms –

Embodied Energy CO2e Emissions --- Life Cycle Assessment



The Putney School New Dorms –

The BIG PICTURE

What is the atmospheric CO2e over time?

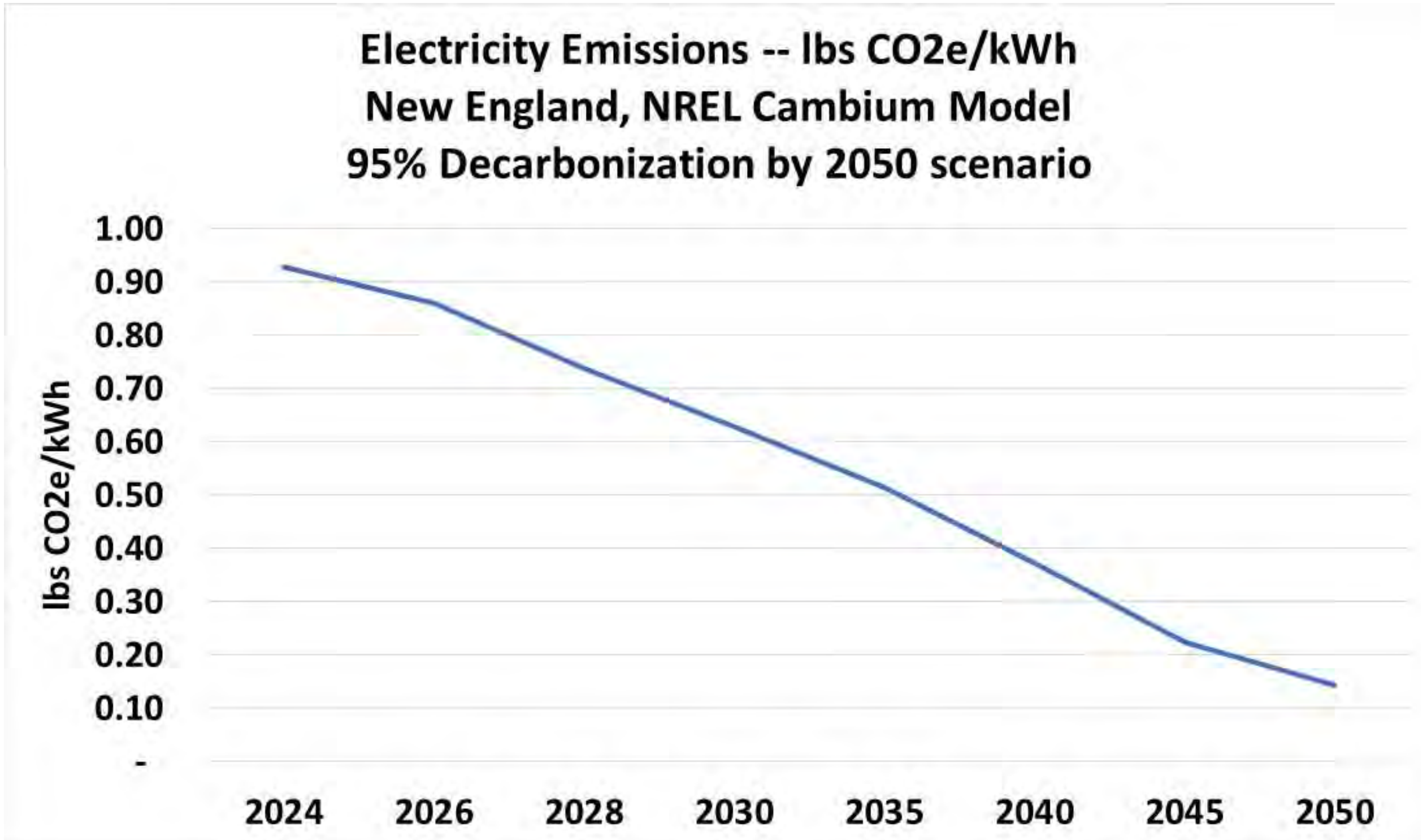
Electric Grid Emissions Expected to Reduce Over Time

and

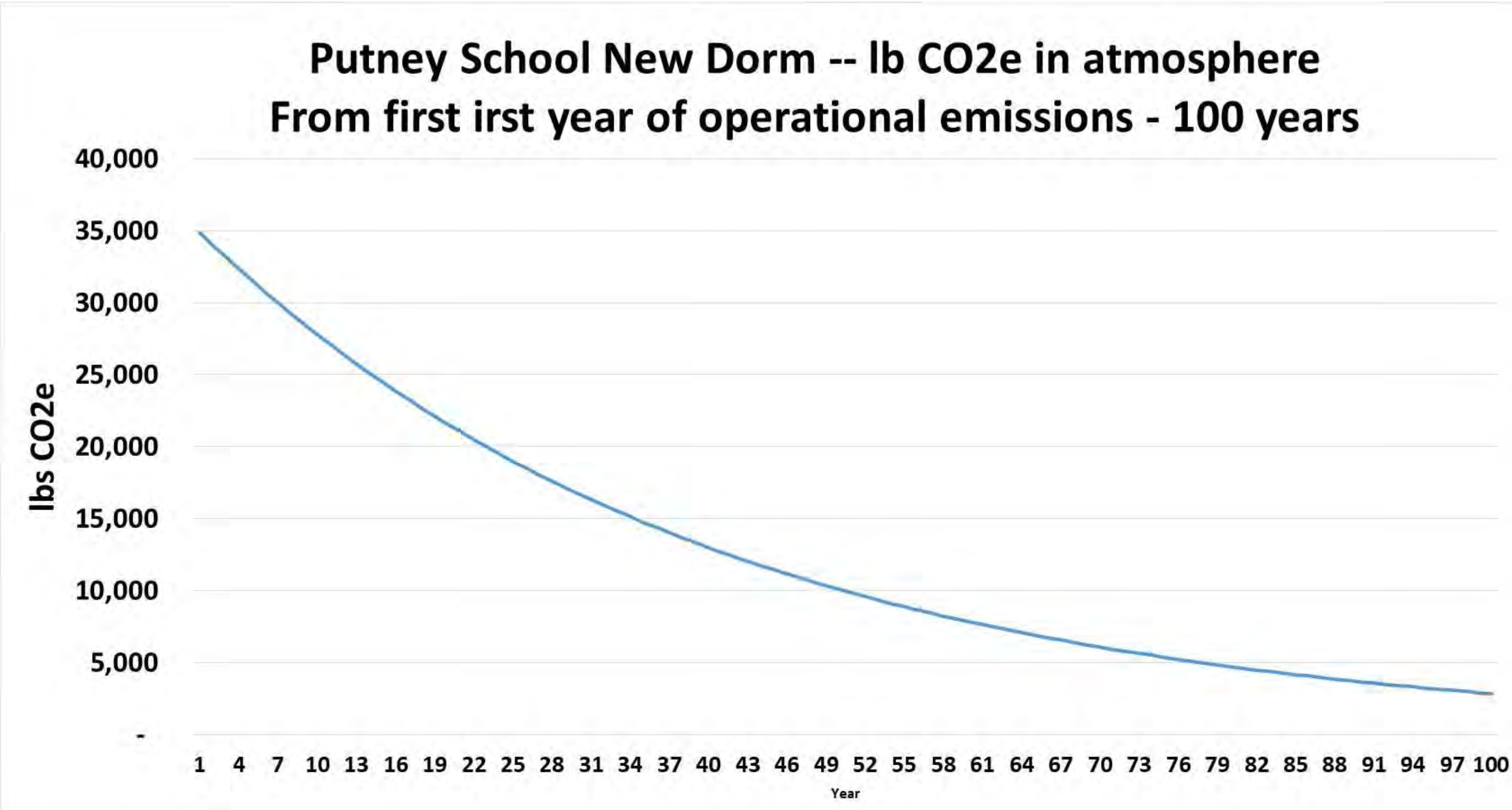
Persistence of CO2 in the atmosphere

The Putney School New Dorms –

Grid Electricity CO2e Emissions Over Time – NREL Cambium Model

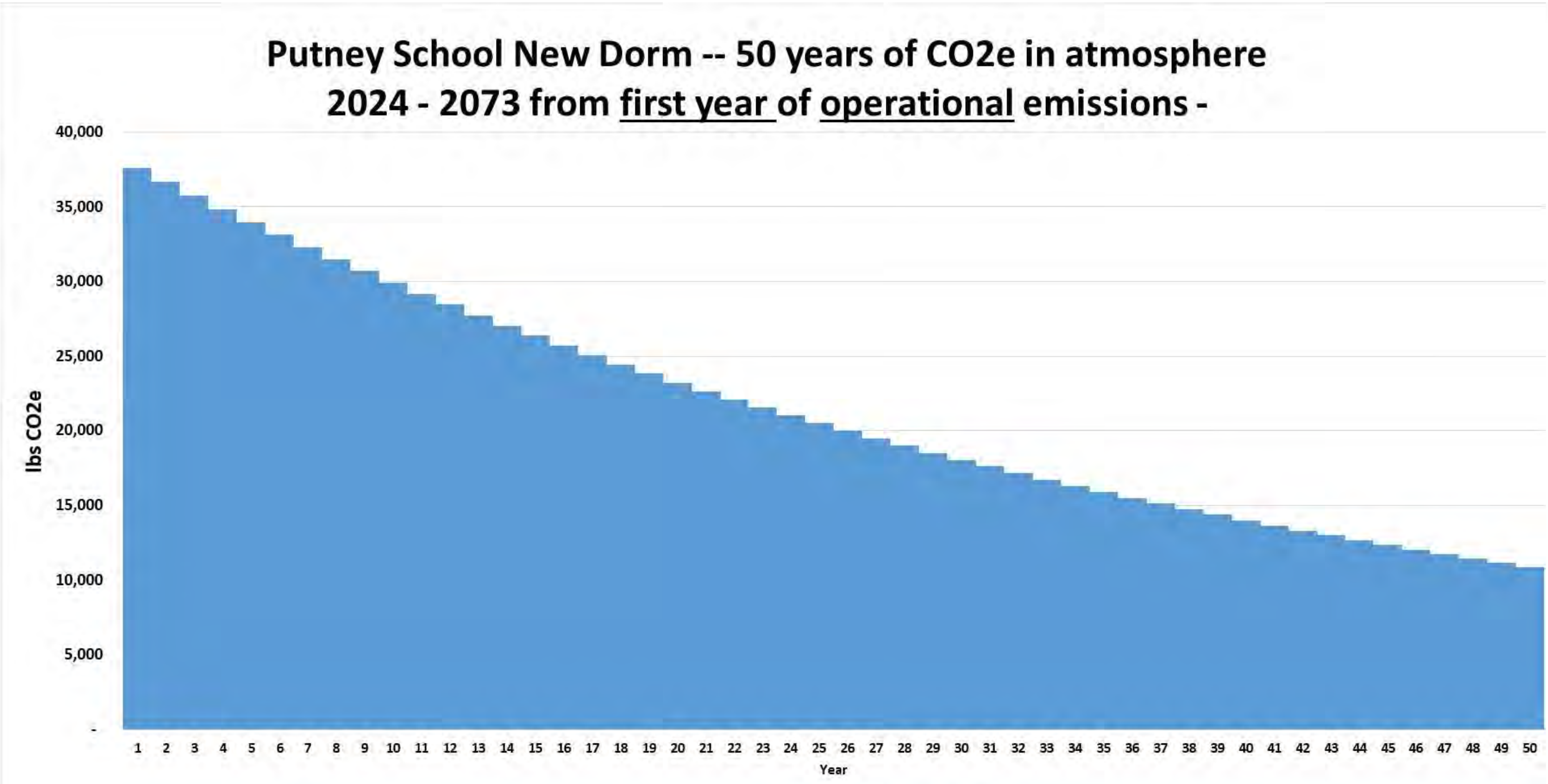


The Putney School New Dorm – CO2e Emissions --- Persistence in Atmosphere

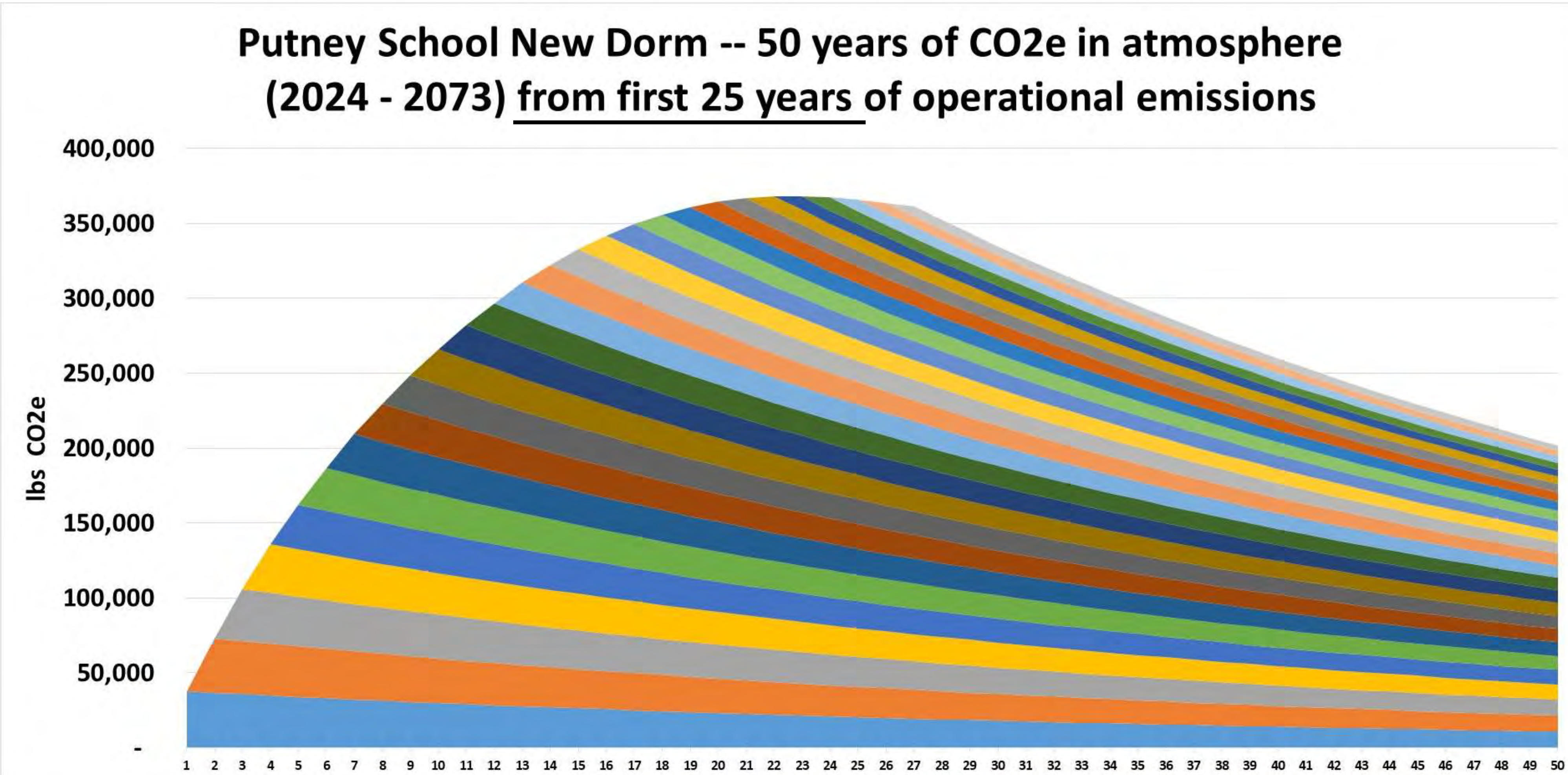


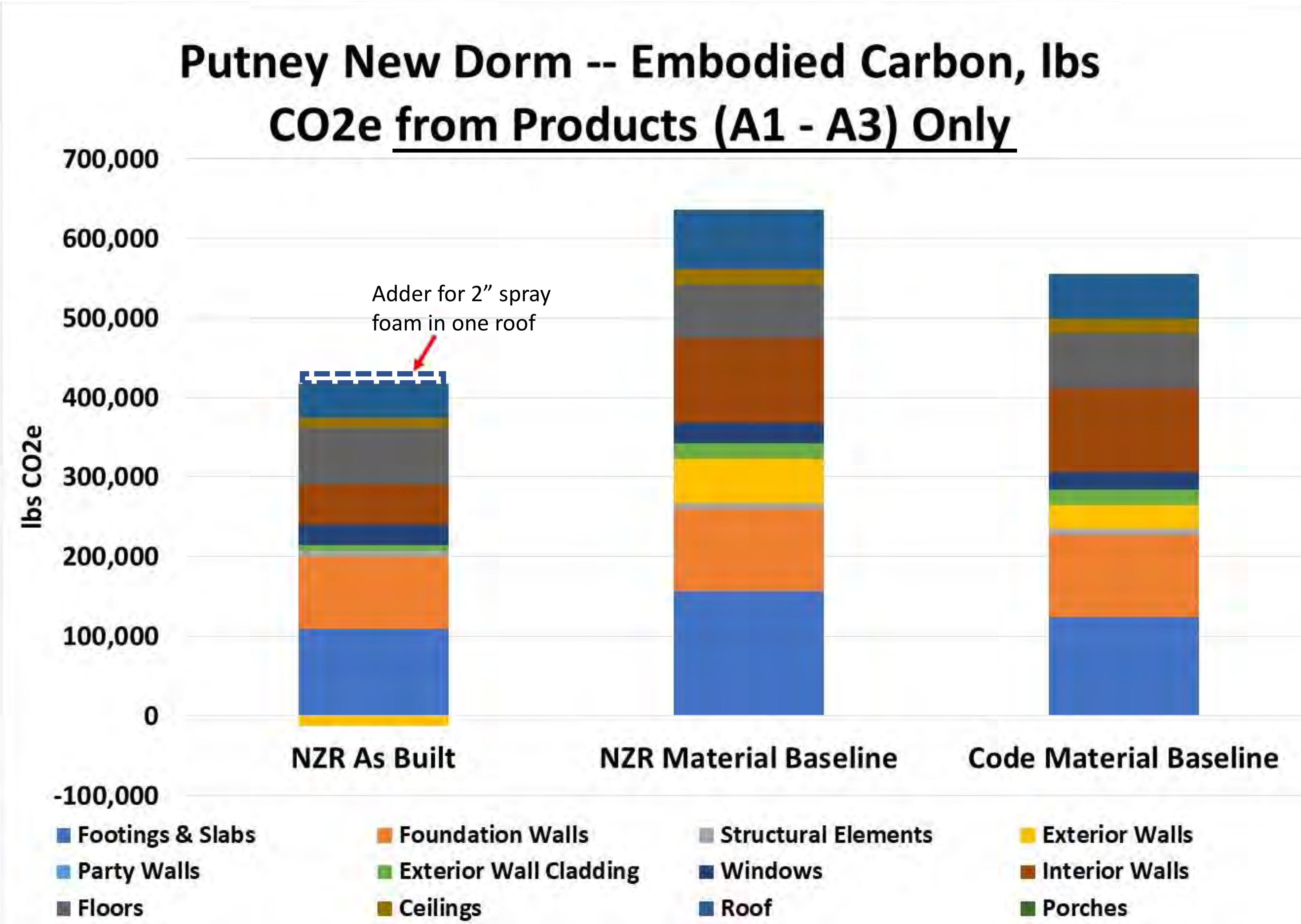
The Putney School New Dorms –

CO2e Emissions --- Persistence in Atmosphere

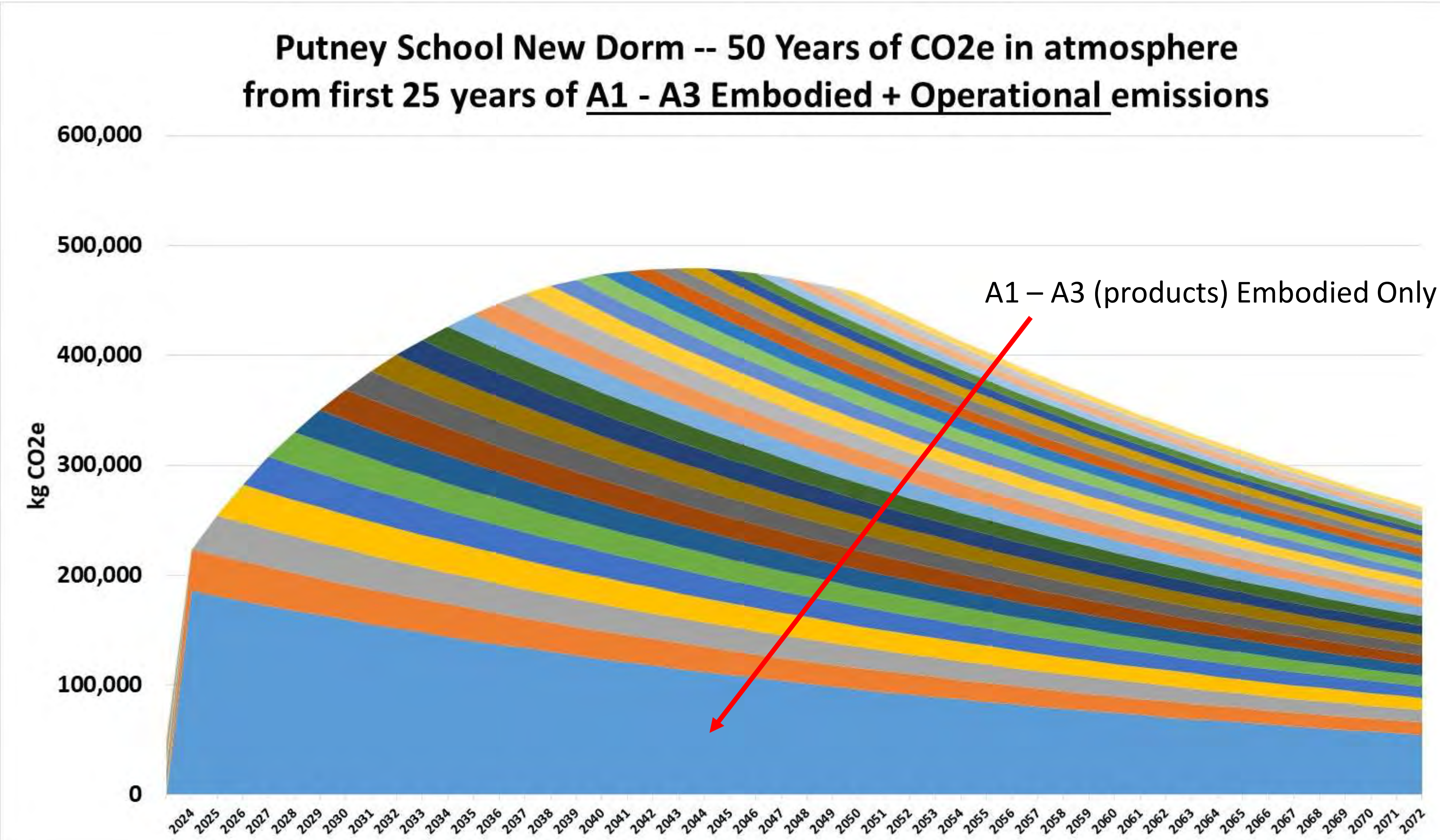


The Putney School New Dorm – CO2e Emissions --- Persistence in Atmosphere





Putney New Dorm -- Embodied Carbon, lbs CO2e from Products (A1 - A3) Only
700,000
600,000
500,000
400,000
300,000
200,000
100,000
0
-100,000
lbs CO2e
Adder for 2" spray foam in one roof
NZR As Built
NZR Material Baseline
Code Material Baseline
Footings & Slabs
Foundation Walls
Structural Elements
Exterior Walls
Party Walls
Exterior Wall Cladding
Windows
Interior Walls
Floors
Ceilings
Roof
Porches


Putney School New Dorm -- 50 Years of CO2e in atmosphere
from first 25 years of A1 - A3 Embodied + Operational emissions
600,000
500,000
400,000
300,000
200,000
100,000
0
kg CO2e
A1 – A3 (products) Embodied Only
2024
2025
2026
2027
2028
2029
2030
2031
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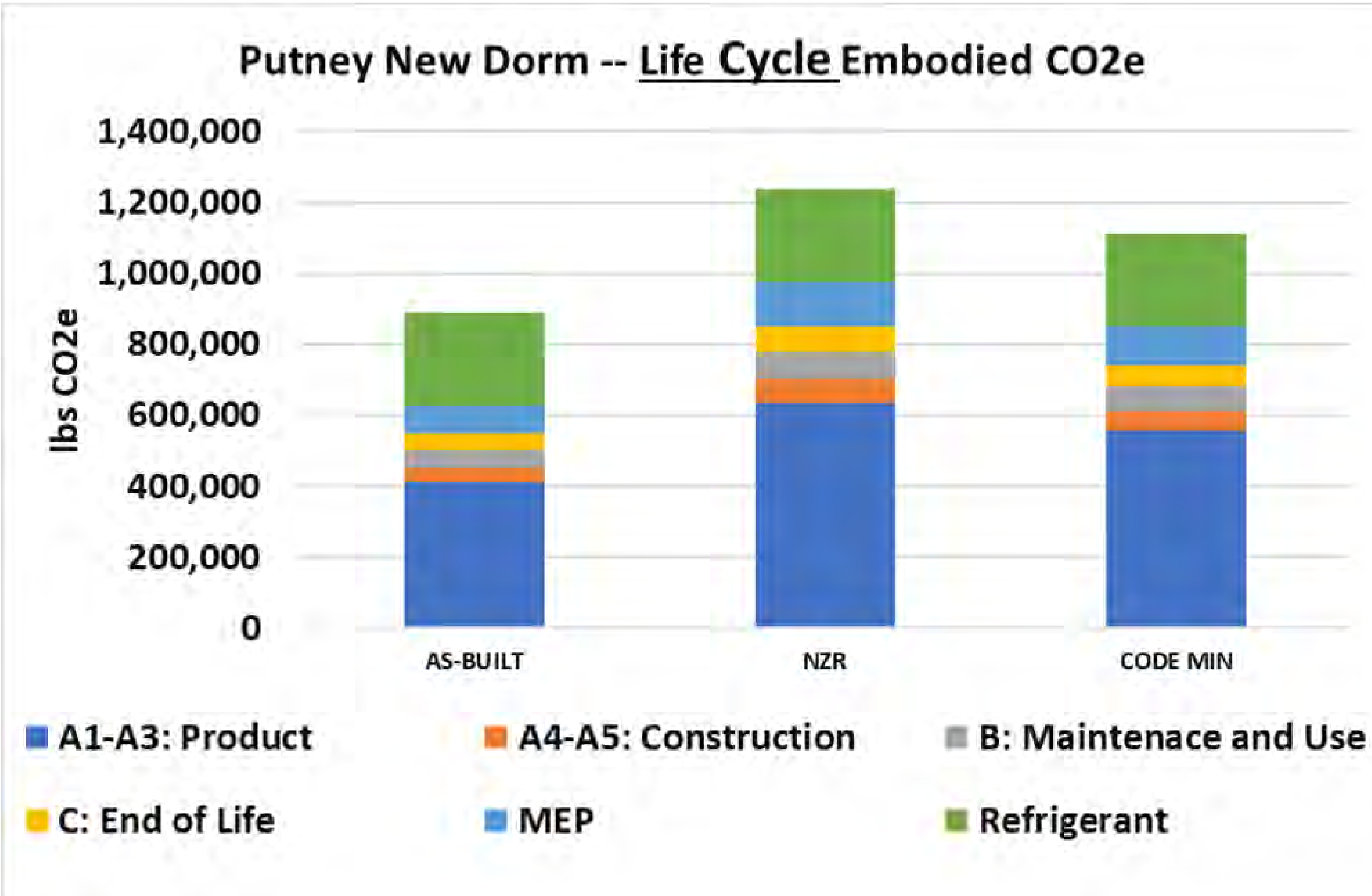
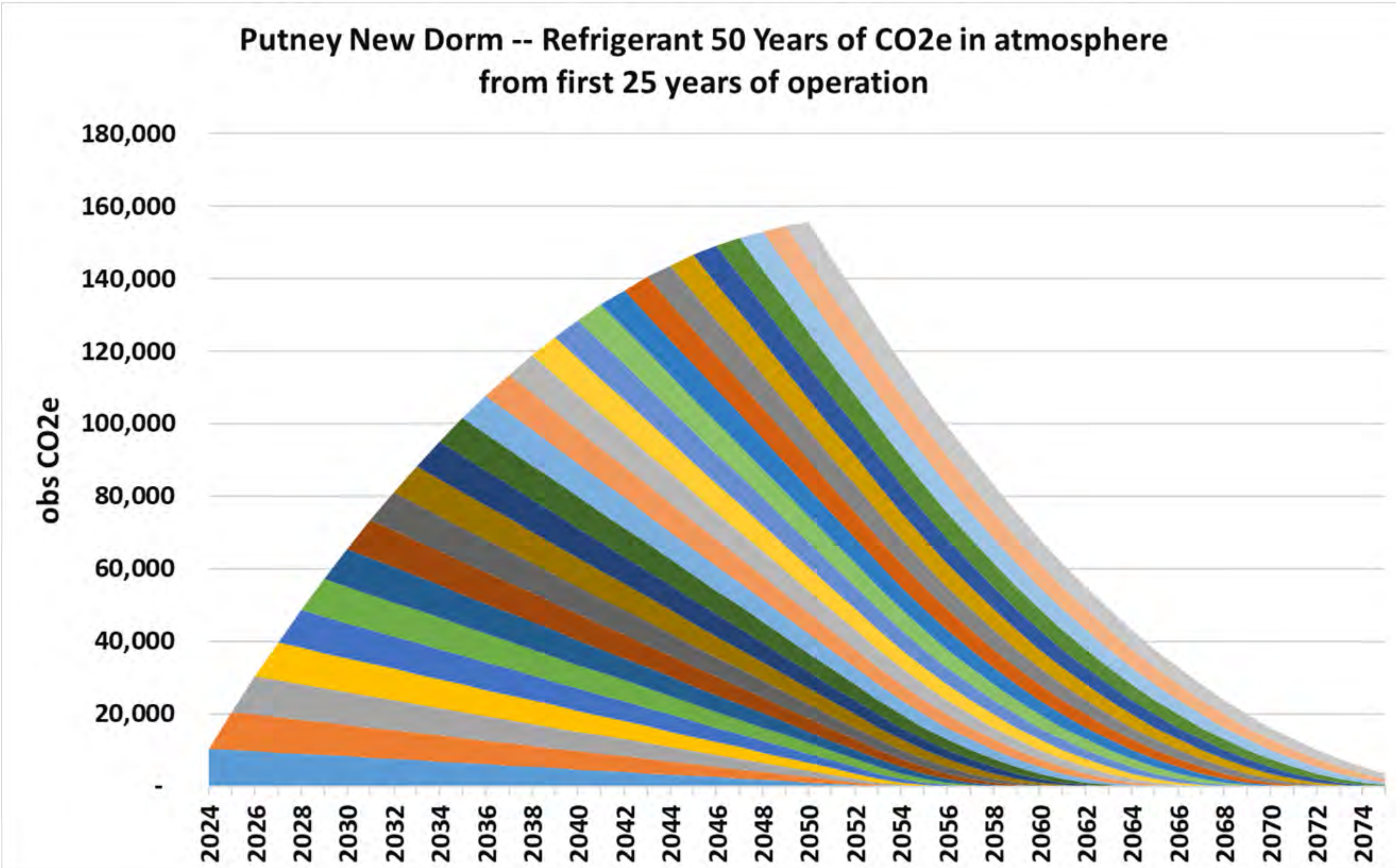
The Putney School New Dorm





Putney New Dorm -- Refrigerant 50 Years of CO2e in atmosphere
from first 25 years of operation
obs CO2e
180,000
160,000
140,000
120,000
100,000
80,000
60,000
40,000
20,000
-
2024
2026
2028
2030
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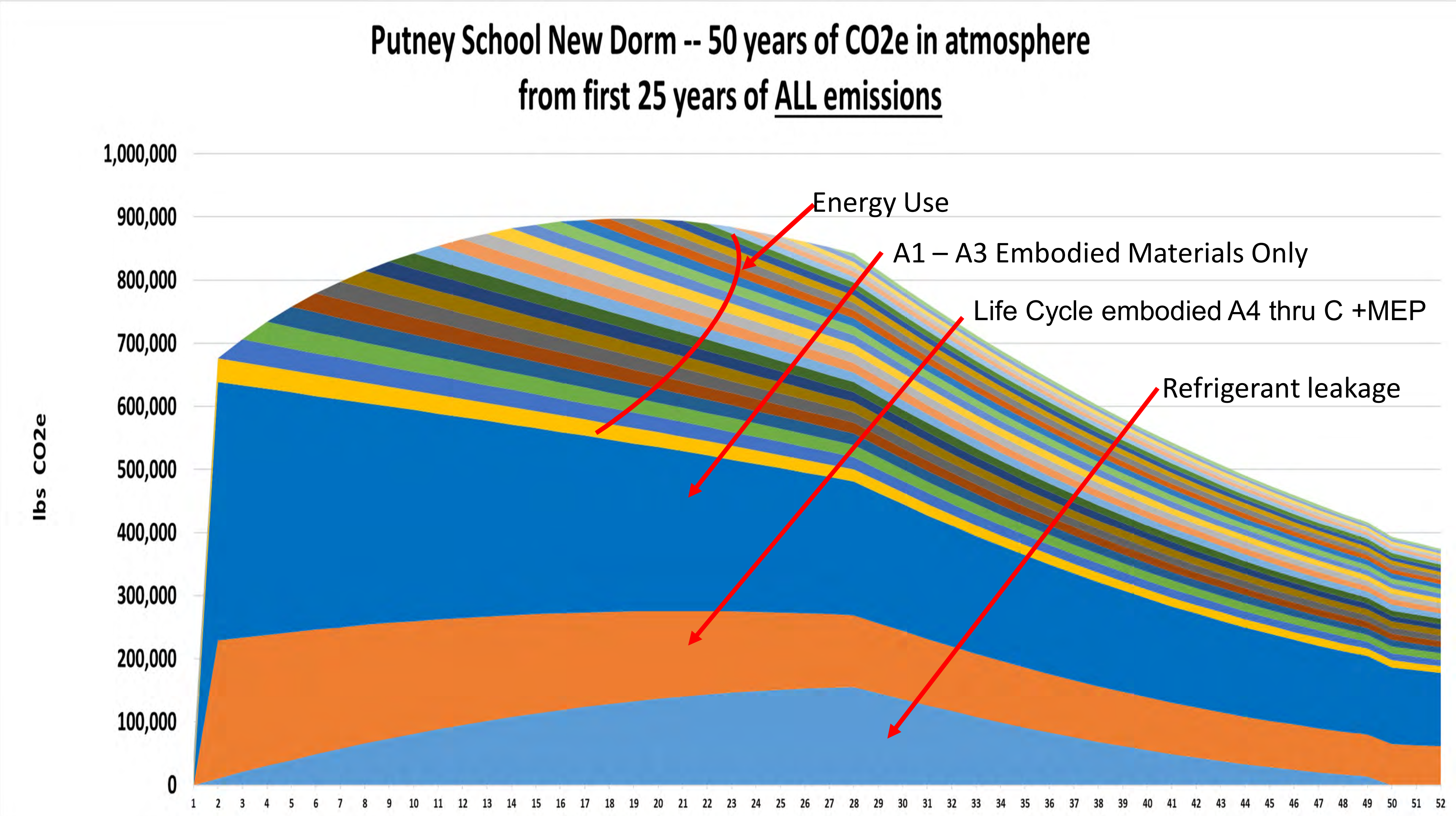

Putney School New Dorm -- 50 years of CO2e in atmosphere
from first 25 years of ALL emissions
lbs CO2e
1,000,000
900,000
800,000
700,000
600,000
500,000
400,000
300,000
200,000
100,000
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52
Energy Use
A1 – A3 Embodied Materials Only
Life Cycle embodied A4 thru C +MEP
Refrigerant leakage

The Putney School New Dorms –

Lessons Learned -- Critical Items

- Active commitment of owner, design team and builder
- Early engagement allows strategy to turn into design, specs and details
- Lots of corners and roofs make it much more difficult to achieve a good enclosure

The Putney School New Dorms –

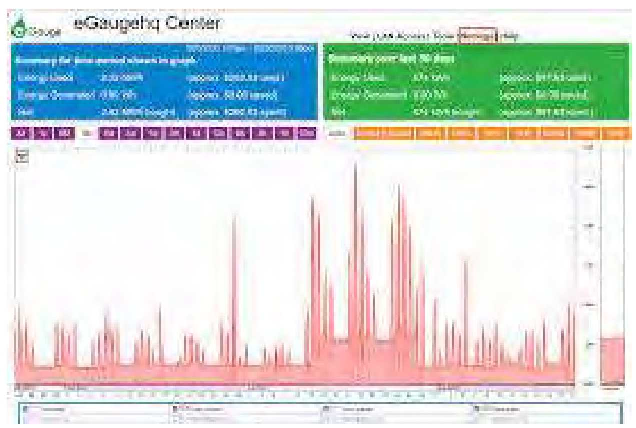
Lessons Learned -- Critical Items

- Cement substitutes in concrete difficult to achieve and can have uncertainty in supply
- Building enclosure commissioning – including periodic testing of enclosure
- Show up more often! Preconstruction meeting needs to be followed by same for each sub just before they begin their piece of the work
- Moisture management during construction!

The Putney School New Dorms –

Lessons Learned -- Critical Items

- ReArch CM attention to detail AND problem solving was excellent
- Skilled, can-do air sealing and insulation subcontractor (Murphy's CellTech)
- Building enclosure commissioning and MEP commissioning (BECx and Cx) with EGauge monitoring system

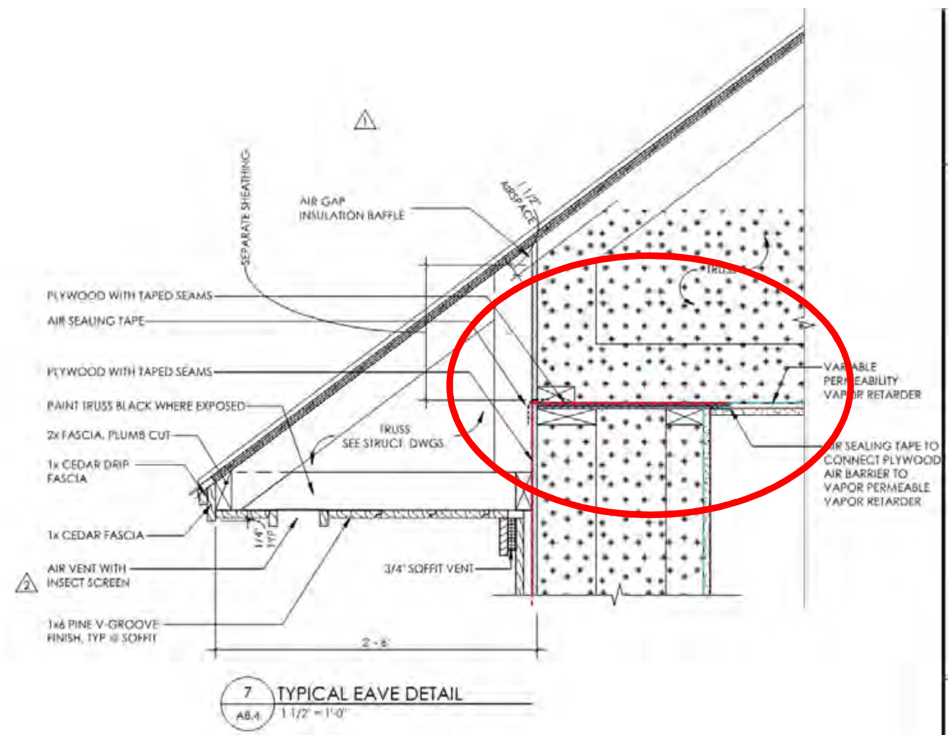


The Putney School New Dorms –

Lessons Learned – Pinch Points in the Process

- Complex enclosure areas required on-site head-scratching sessions with CM, framers, insulation and and air sealing contractor, enclosure commissioner

- Cement substitutes availability hard to predict – hold the line: Pre-plan, schedule. SCM landscape is shifting; e.g. ground glass

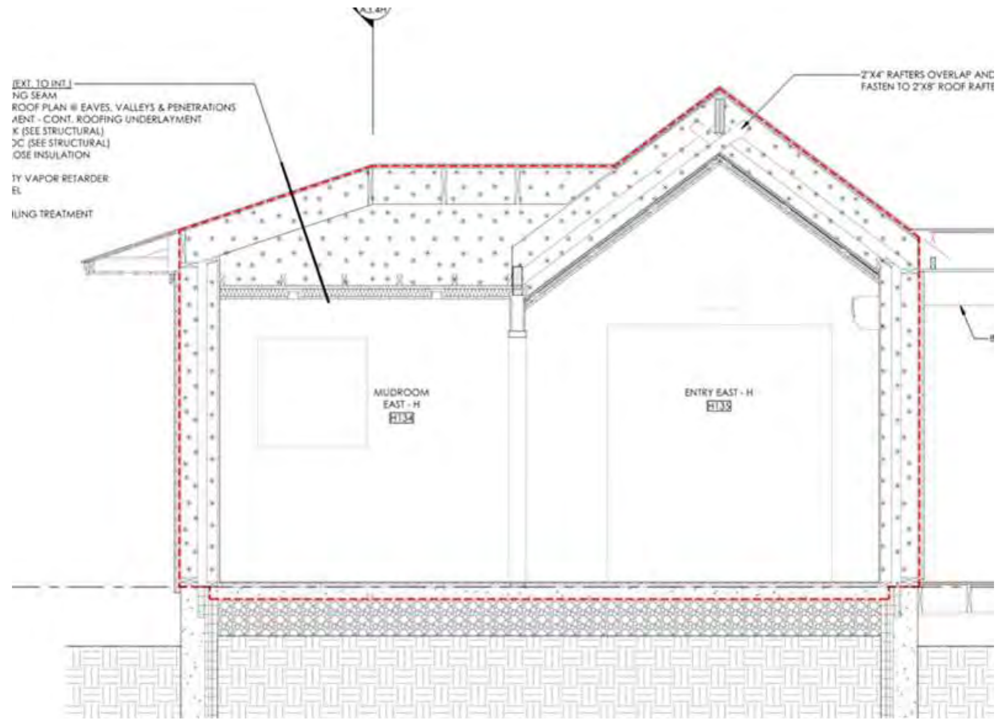


The Putney School New Dorms –

Lessons Learned – Pinch Points in the Process

- An eagle eye on submittals is critical. For example, low embodied gypsum board not in submittal but was easy: same cost, lighter weight and half the embodied energy. But not available for fire rated gypsum board

- Incomplete design prior to construction increases stress on process



The Putney School New Dorms – **Lessons Learned – Pinch Points**

- Top of exterior wall detail -- Attic air-sealing detail
- Truss uplift/partition wall/air barrier problem solving