



# Carbon and Energy Impacts of Roof Insulation: The Whole[-Life] Story

# Elizabeth Grant, PhD, AIA

Building & Roofing Science Research Lead, GAF



# Benjamin Meyer, AIA, NCARB, LEED AP

Building Enclosure Business Director, Siplast



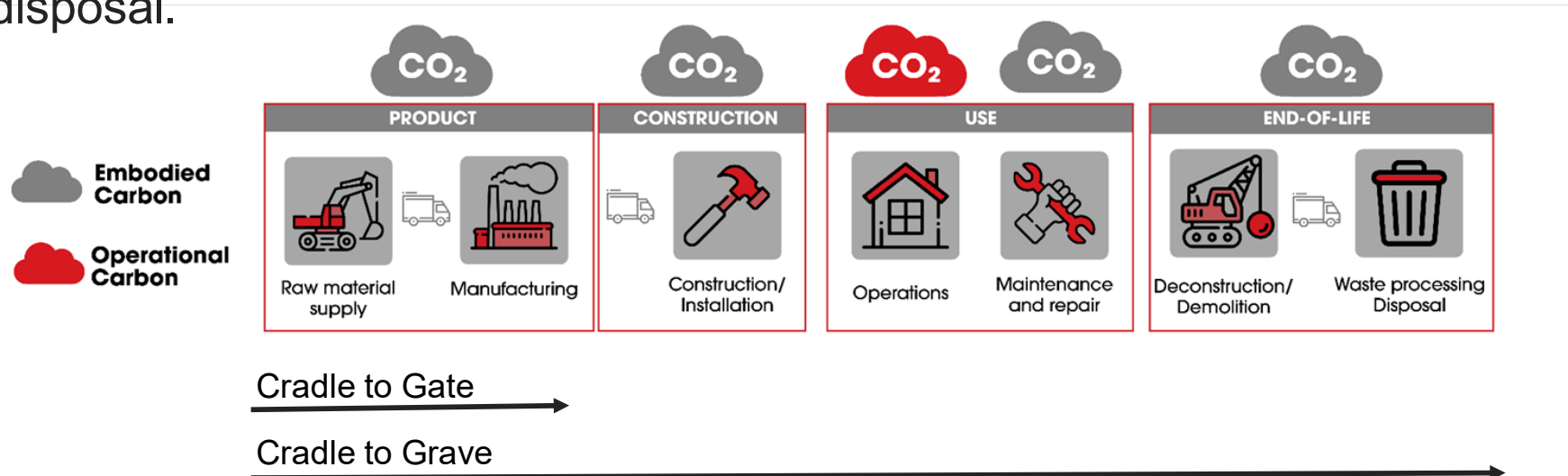
# Whole-Life Carbon

# Whole-Life Carbon

Whole Life Carbon = Embodied Carbon + Operational Carbon

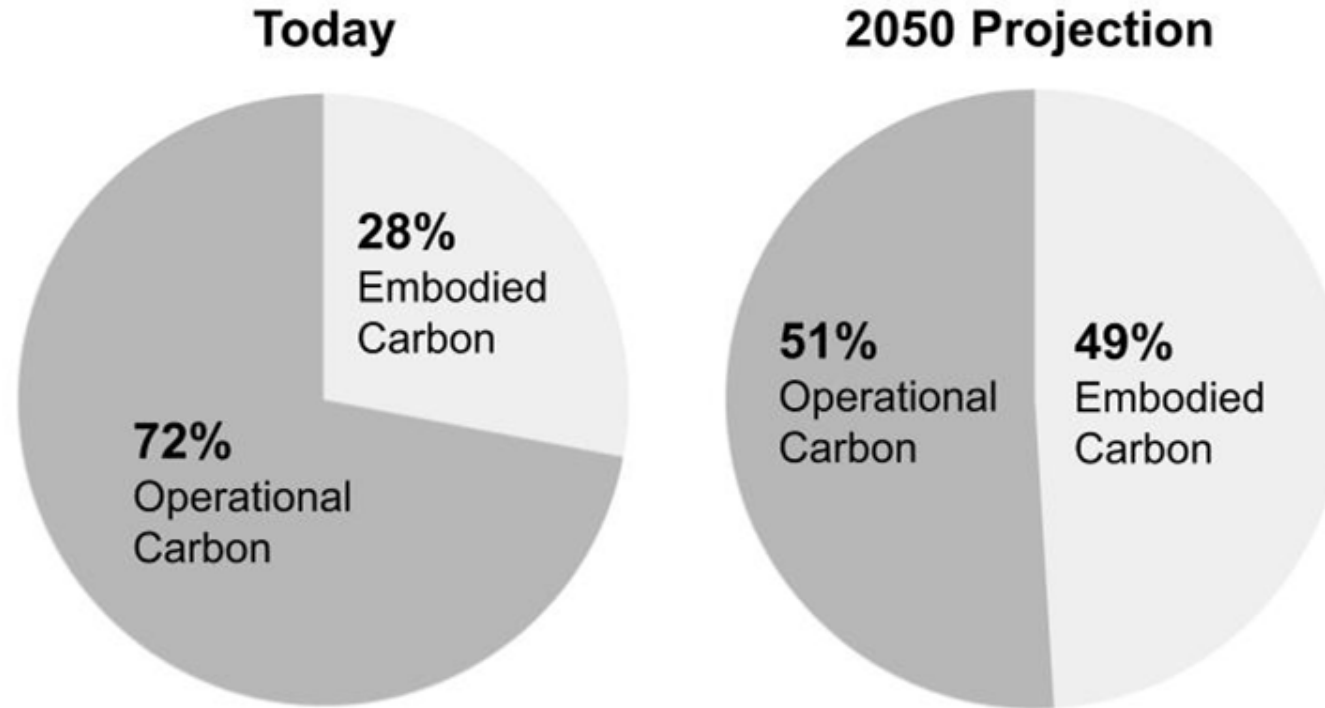
Embodied carbon: greenhouse gas emissions from supply of raw materials, manufacturing, transport, construction/installation, maintenance and repair, deconstruction/demolition and waste processing/disposal.

Operational carbon: the greenhouse gas emissions due to the in-use phase of a building, such as energy consumption.



# Whole-Life Carbon

Today and in the Future






**“Insulation occupies the unique position at the intersection of embodied and operational carbon emissions for a building. Insulation is the only building material that directly offsets operational emissions. It can be said to pay back its embodied carbon debt with avoided emissions during the building’s lifetime.”**

*Embodied Carbon 101: Envelope*, Boston Society for Architecture





# Roof Insulation LCA Example

# Roof Insulation LCA Example



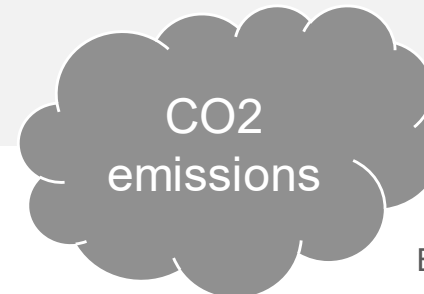
Kg of CO<sub>2</sub>e



Energy Generation  
Manufacturing  
Disposable Goods  
Durable Goods  
Transportation  
Installation



**Your flight**  
No durable good  
created



Reduce Emissions



# Roof Insulation LCA Example



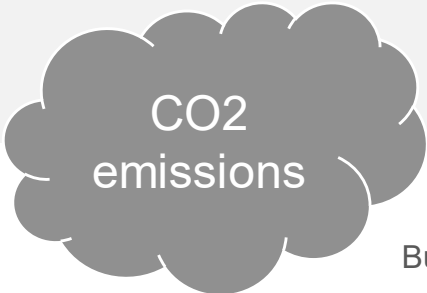
Kg of CO2e



Energy Generation  
Manufacturing  
Disposable Goods  
Durable Goods  
Transportation  
Installation



**Wallpaper**  
Product **without**  
use-phase  
benefits



Reduce Emissions  
**Extend Useful Life**  
**Increase Performance**  
**Consider 3 Rs**

# Roof Insulation LCA Example



Kg of CO2e

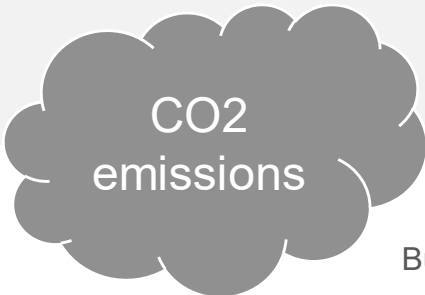


Energy Generation  
Manufacturing  
Disposable Goods  
Durable Goods  
Transportation  
Installation



## Insulation

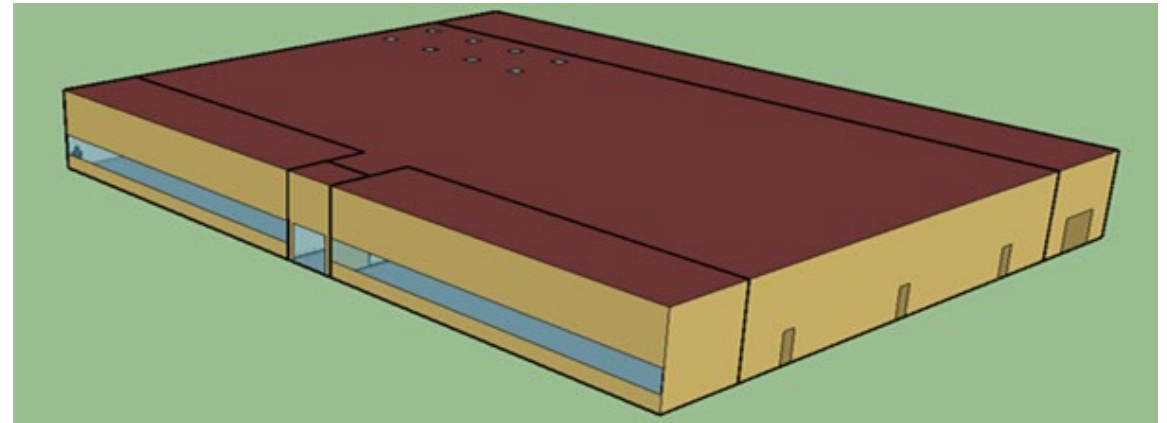
Product **with** use-  
phase benefits



**Give Operational  
CO2e Benefit**  
Reduce Emissions  
Extend Useful Life  
Increase  
Performance  
Consider 3 Rs

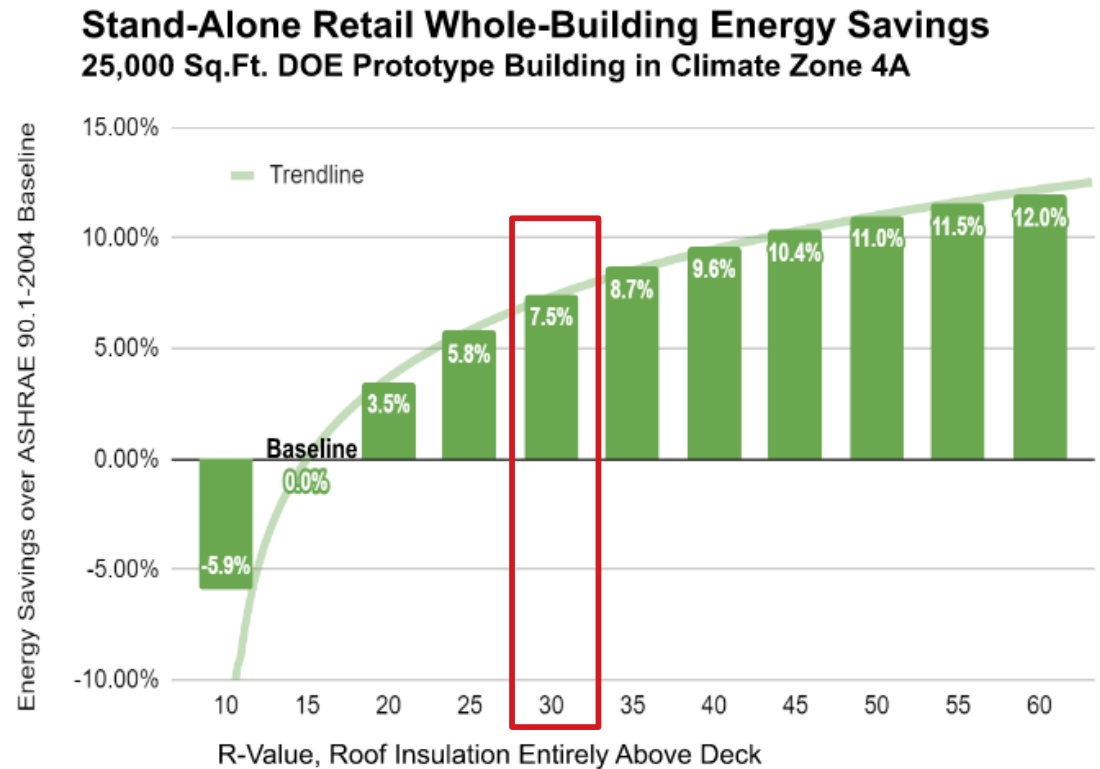
# Roof Insulation LCA Example

- Stand-alone retail, DOE prototype building, approx. 25,000 sq.ft. (178 ft. x 139 ft.)
- Climate Zone 4A
- Modeled to ASHRAE 90.1-2019
- ASHRAE 90.1-2004 insulation requirements as a baseline
- CO<sub>2</sub>e from DOE 2011 Buildings Energy Data Book
- Insulation embodied energy and carbon data from PIMA's industry-wide EPD



# Roof Insulation LCA Example

Look what happens when you compare operational energy savings for initial insulation levels beyond the R-15 assumed by the PIMA EPD!

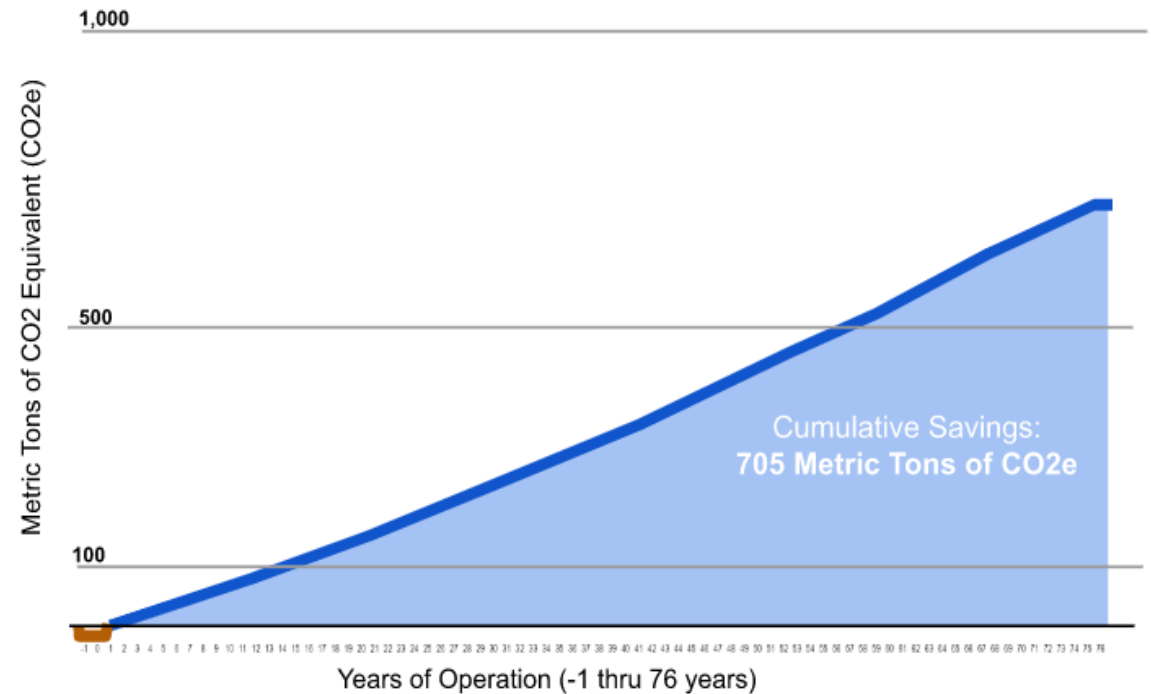


# Roof Insulation LCA Example

## Assumptions:

- 75-year building life
- Begins at R-30
- Increased every 20 years by R-10 (with roof replacement)
- Embodied carbon, replacement embodied carbon, and end-of-life disposal are taken into account.

**Cumulative Carbon Savings for Roof Insulation Over 75-Year Building Life**  
25,000 Sq.Ft. Stand-Alone Retail Building, Climate Zone 4A

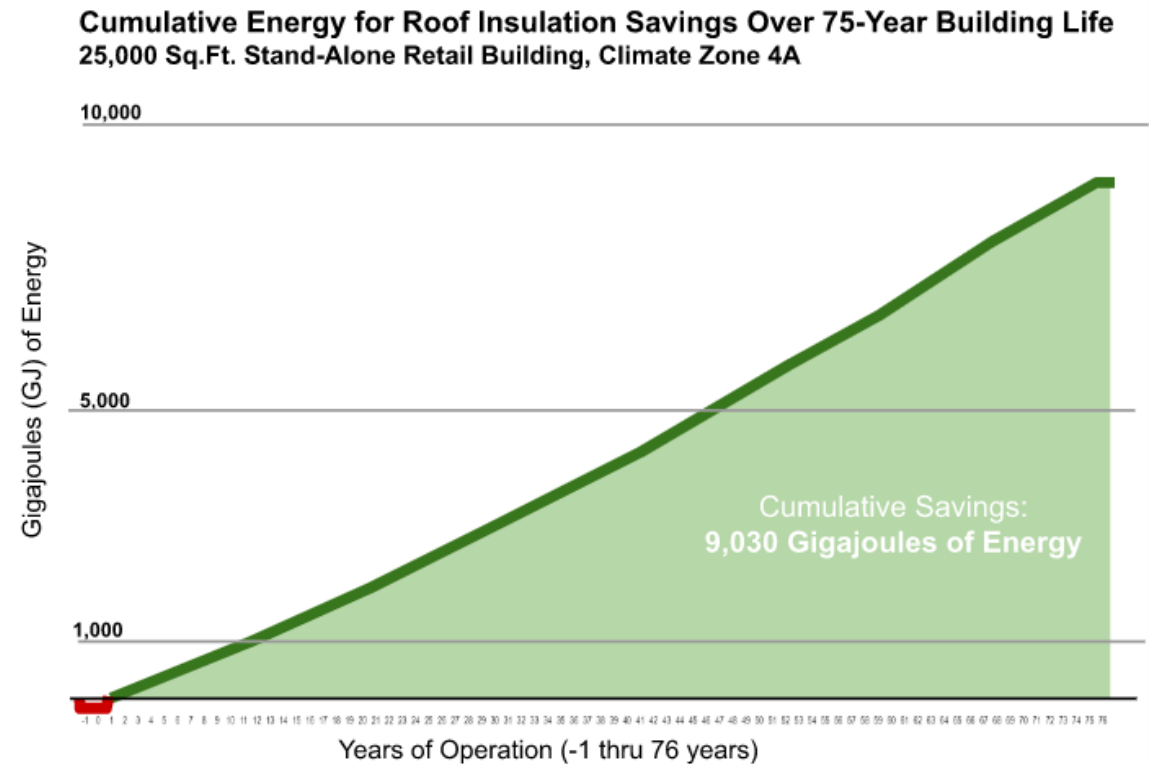




# Roof Insulation LCA Example

Energy savings track with carbon savings

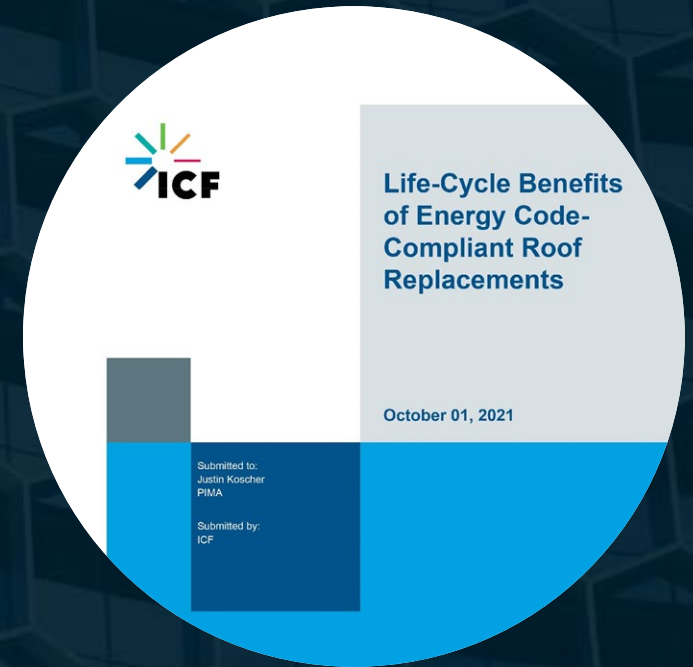
- Increase in embodied energy from R-15 to R-30 is 38.3 GJ
- Pays back in less than five months!



# 2021 PIMA Report

## Life-Cycle Benefits of Energy Code-Compliant Roof Replacements

by ICF, October 1, 2021



# 2021 PIMA Report: Methodology

## 4 Commercial Building Types in 5 Climate Zones

Table 1 – Building Energy Modeling Characteristics

DOE Commercial Building Types	DOE Model Vintage	Climate Zone	City Locations
Small Office	New Construction (2004)  Small office building model roof construction modified from “Typical Wood Joist Attic, Floor Insulation Only” to low-sloped roof with “Insulation Entirely Above Deck.”	2A Hot Humid	Tampa, FL (2A)
Stand-alone Retail		3A Warm Humid	Atlanta, GA (3A)
Primary School		4A Mixed Humid	New York City, NY (4A)
Strip Mall		5A Cool Humid	Chicago, IL (5A)
			Buffalo, NY (5A)
		6A Cold Humid	Montreal, Canada (6A)
			Rochester, MN (6A)

# 2021 PIMA Report: Methodology

## Baseline Roof Insulation

- Assumes R-Value of 12.5 for all buildings and climate zones, based on PIMA's research on typical buildings.

## Code-Compliant Roof Insulation

- Meets requirements of ASHRAE 90.1-2019/2021 IECC-C for each climate zone

Table 3 – Insulation Entirely Above Deck R-value and Incremental Thickness Increase

Climate Zone	Baseline Roof Insulation R-Value	Code-Compliant Roof Insulation R-Value	Incremental Roof Insulation Thickness Increase (in)
2A	12.5	25.0	2.2
3A	12.5	25.0	2.2
4A	12.5	30.0	3.1
5A	12.5	30.0	3.1
6A	12.5	30.0	3.1



# 2021 PIMA Report: Key Learnings

## Code-Compliant Roof Replacement Analysis Results



- Absolute energy savings are primarily driven by a reduction in natural gas use.
- Energy fuel type saved is generally a function of climate zone.
- Relative energy savings tend to be greater for larger buildings.



# 2021 PIMA Report: Key Learnings

## Life-Cycle Benefits of Code-Compliant Roof Replacements

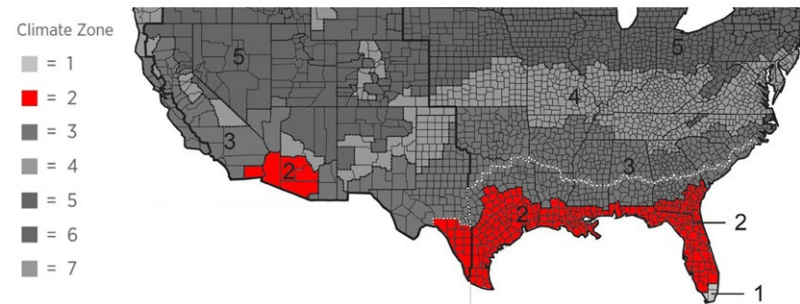


- Roof replacements are economical under various conditions.
- Roof replacements support transition to building electrification.
- Roof replacements support building performance standards and carbon reduction goals.





# 2021 PIMA Report: Key Learnings

## Results by Climate Zone

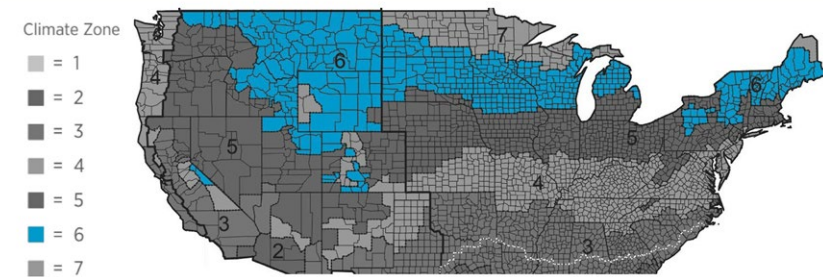
U.S. Climate Zone 2 – Hot Climates | Example City – Tampa, FL







### Potential Savings Estimates for Roof Replacements in Climate Zone 2 (R-25)

Building Type	Annual Total Energy Savings	Cumulative Total Energy Cost Savings	Cumulative Energy Cost Savings per SF	Cumulative Total CO <sub>2</sub> e per SF
Primary School 	3%	\$201,921	\$2.73	31.78 lbs.
Retail Store 	2%	\$44,088	\$1.77	19.44 lbs.
Strip Mall 	3%	\$61,333	\$2.73	29.54 lbs.
Small Office 	3%	\$9,456	\$2.73	18.16 lbs.

U.S. Climate Zone 6 - Cold Climates | Example City – Montréal Canada



### Potential Savings Estimates for Roof Replacements in Climate Zone 6 (R-30)

Building Type	Annual Total Energy Savings	Cumulative Total Energy Cost Savings	Cumulative Energy Cost Savings per SF	Cumulative Total CO <sub>2</sub> e per SF
Primary School 	12%	\$444,636	\$6.01	107.12 lbs.
Retail Store 	7%	\$79,890	\$3.20	56.87 lbs.
Strip Mall 	6%	\$89,447	\$3.97	64.01 lbs.
Small Office 	8%	\$23,518	\$4.27	53.61 lbs.

# Support for Carbon Investment Decisions





**Product Embodied Carbon**

**High**

**Reduce use**

Improve products and manufacturing to lower embodied values.

**Use strategically**

Improve products and manufacturing to lower embodied values.

**Reduce use**

Substitute for high embodied carbon alternatives with equal performance.

Use as a carbon sink if possible.

**Use *more*; maximize benefit**

Substitute for high embodied carbon alternatives with equal performance.

Use operational carbon savings to offset embodied carbon.

**Low**

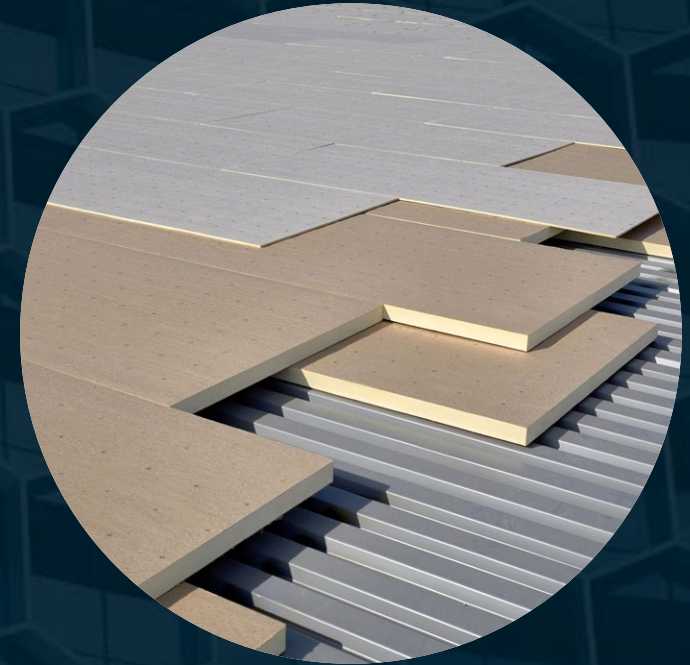
**Low**

**High**

**Operational Carbon Savings**

**We can consider product embodied carbon as a potential investment.**

**Design choices and product selection can have a significant impact on whole-life carbon targets for a building.**





# Thank You



Building & Roofing Science

Connect with us on

