CARDINAL Glass Industries

Beyond ENERGY STAR Windows to Carbon Savings

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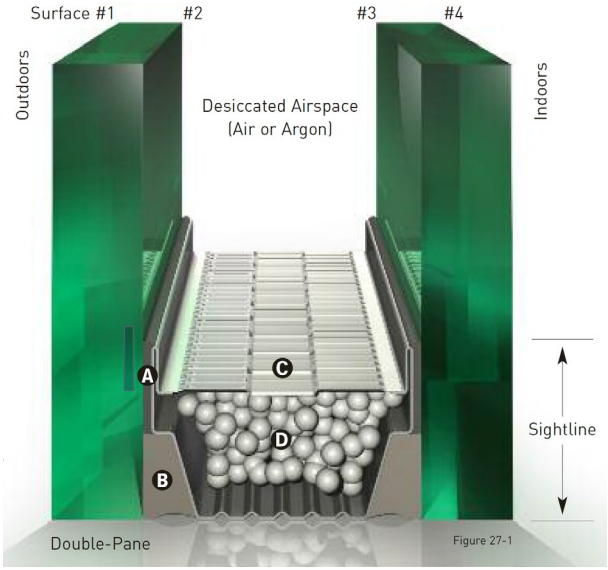
Glass is Energy Intensive

- Melt sand to make clear glass
- Sputter silver to make low-E
- Temper glass for safety glazing
- Fabricate into insulating glass units

- What's the payback
  for Improvements?



Window Energy Ratings

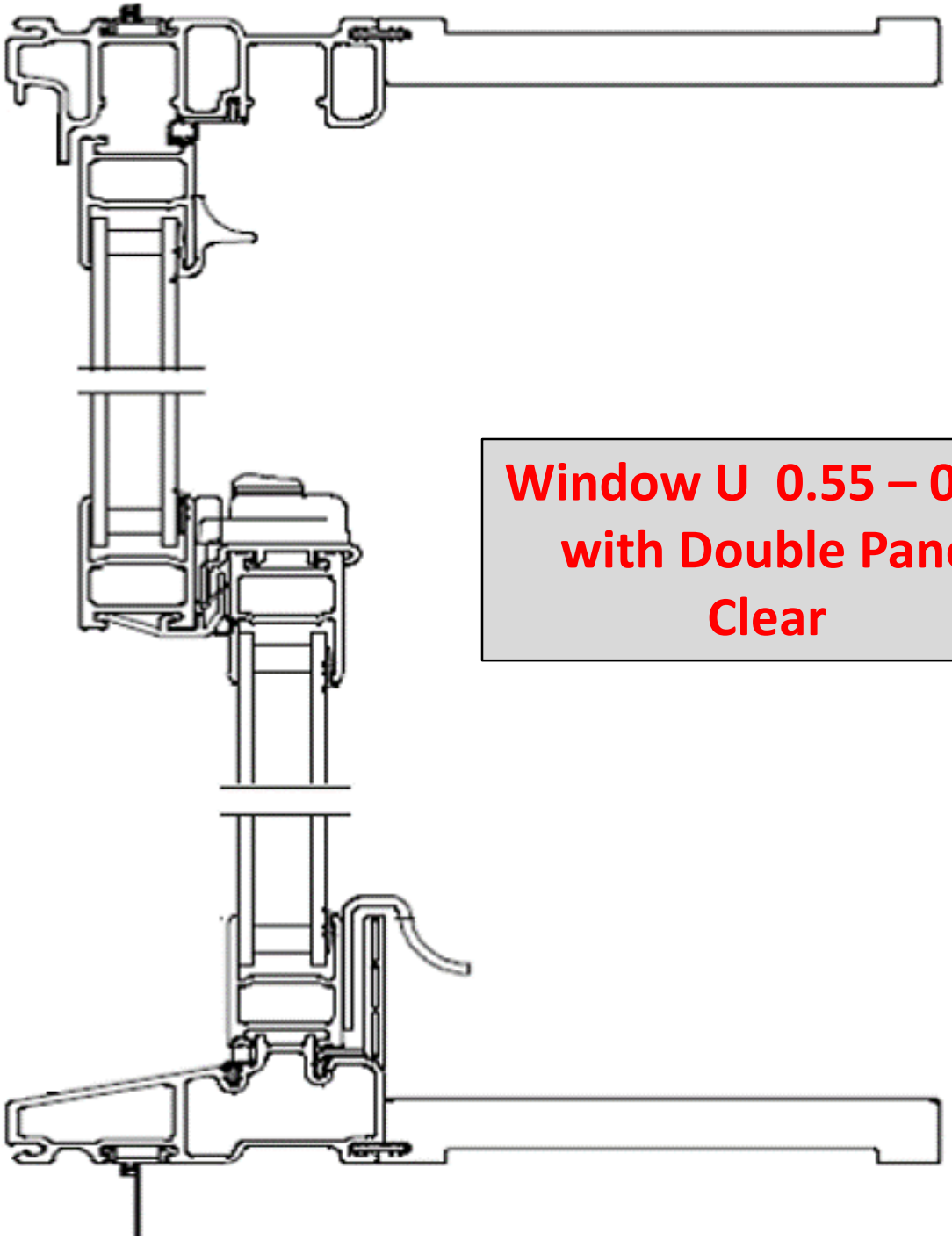
Windows from 30 Years Ago

South: R1

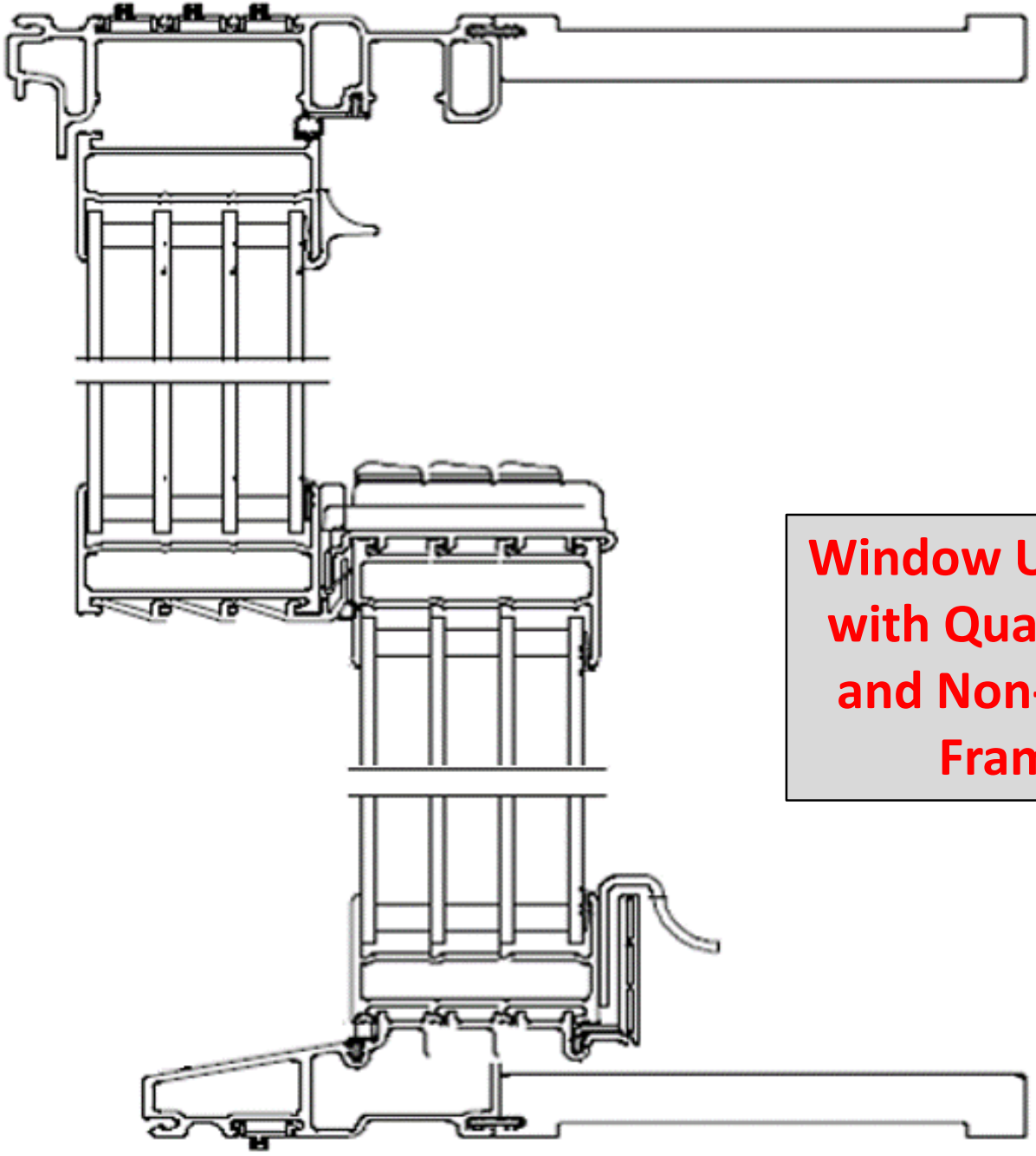
- Aluminum Frames
- Single Pane (clear or tinted)

North: R2

- Non-Metal Frames (wood, vinyl)
- Double Pane (IG or single + storm)



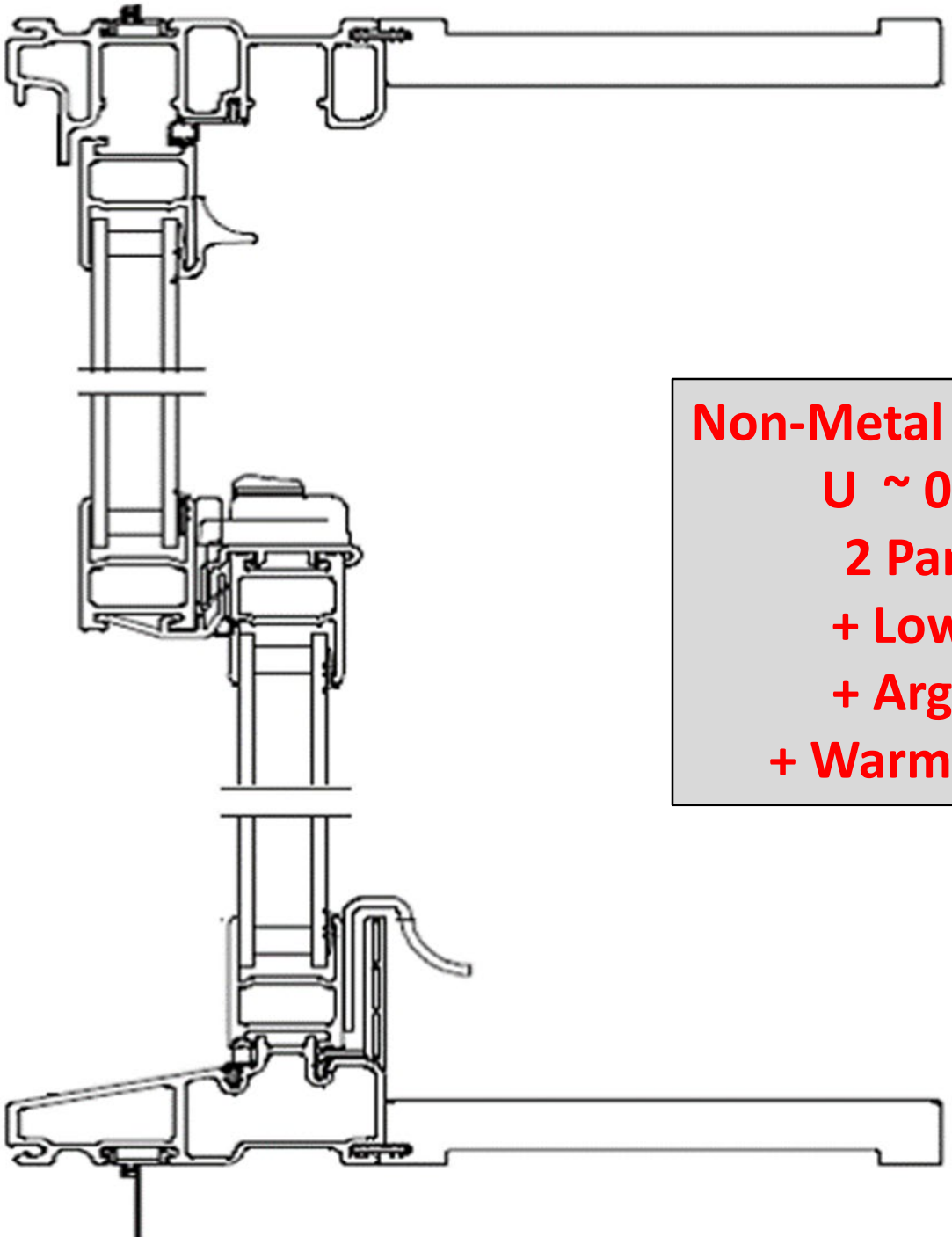
Window U 0.55 – 0.80 with Double Pane Clear



Window U ~ 0.35 with Quad Pane and Non-Metal Frame

Low-E Glass Introduced Mid-1980's

- Triple pane insulating value in a double pane package
- Low-E + Argon = Quad pane performance
- High solar gain (HS)
- Used mostly in the north (heating dominated climates)

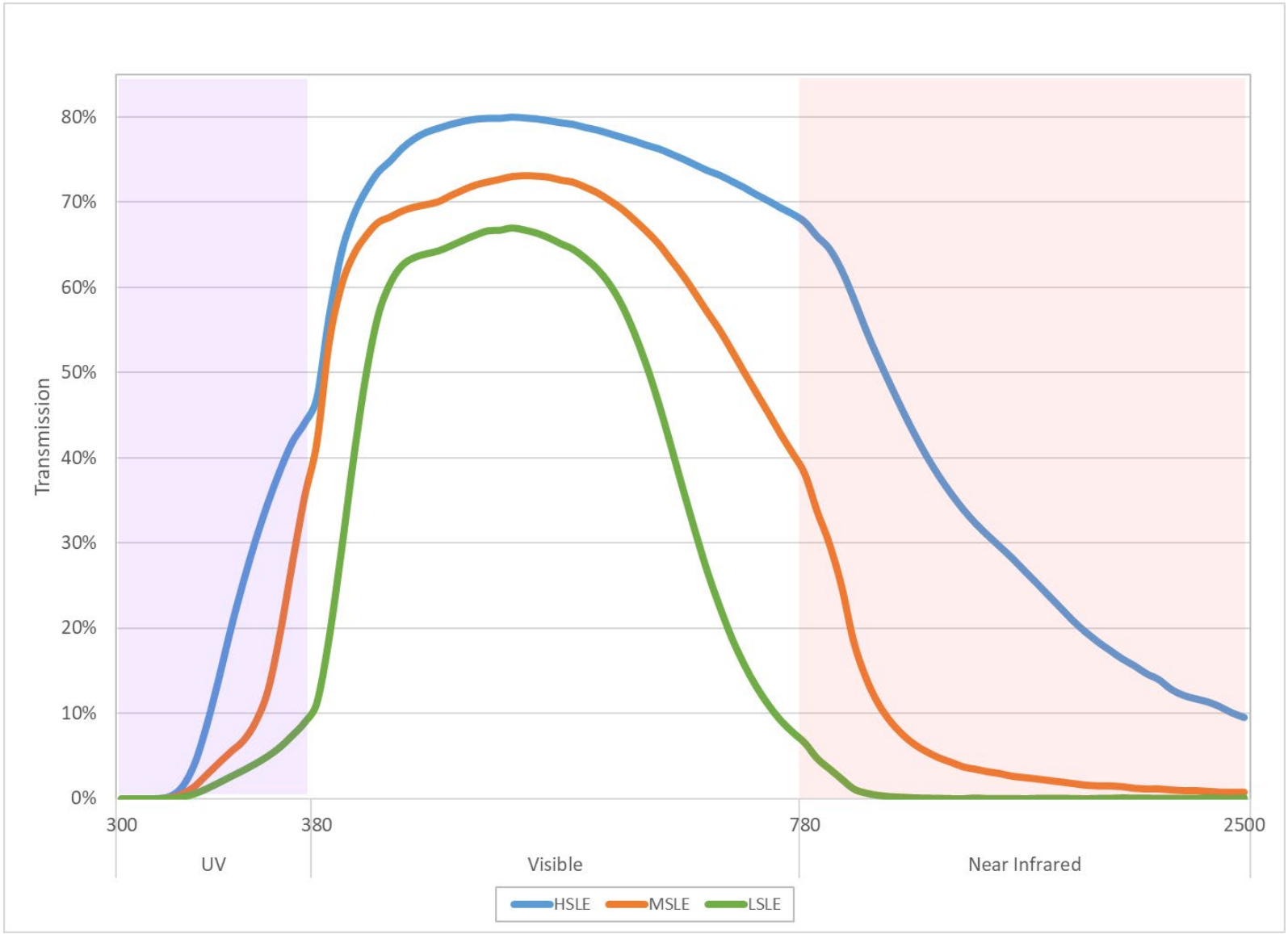


Non-Metal Window
U ~ 0.30
2 Pane
+ Low-E
+ Argon
+ Warm Edge

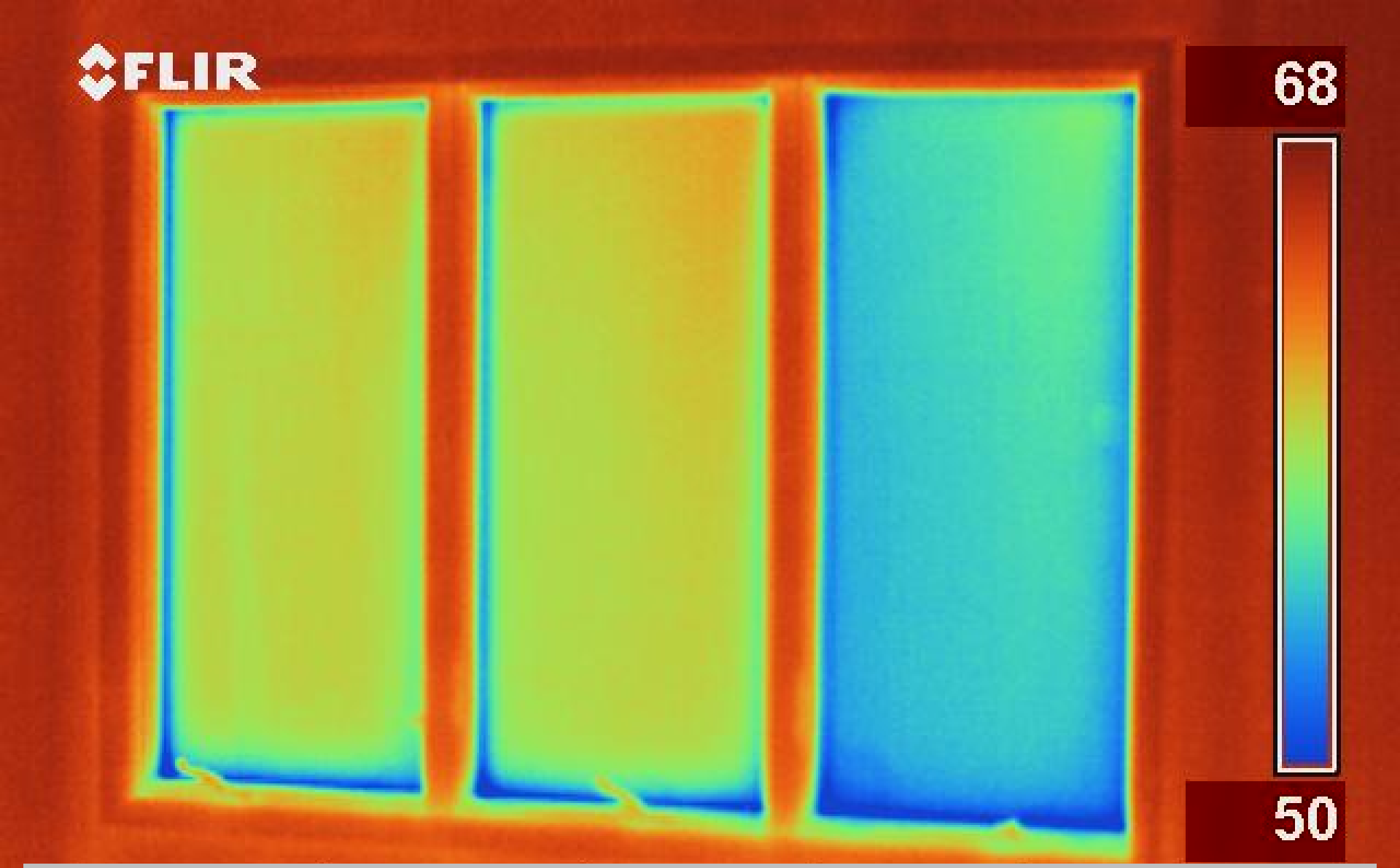
“Clear” Low-E Options Today

- High Solar Gain (window SHGC ~0.50)
  - HS
- Medium Solar Gain (window SHGC ~0.30)
  - MS
- Low Solar Gain (window SHGC ~0.20)
  - LS

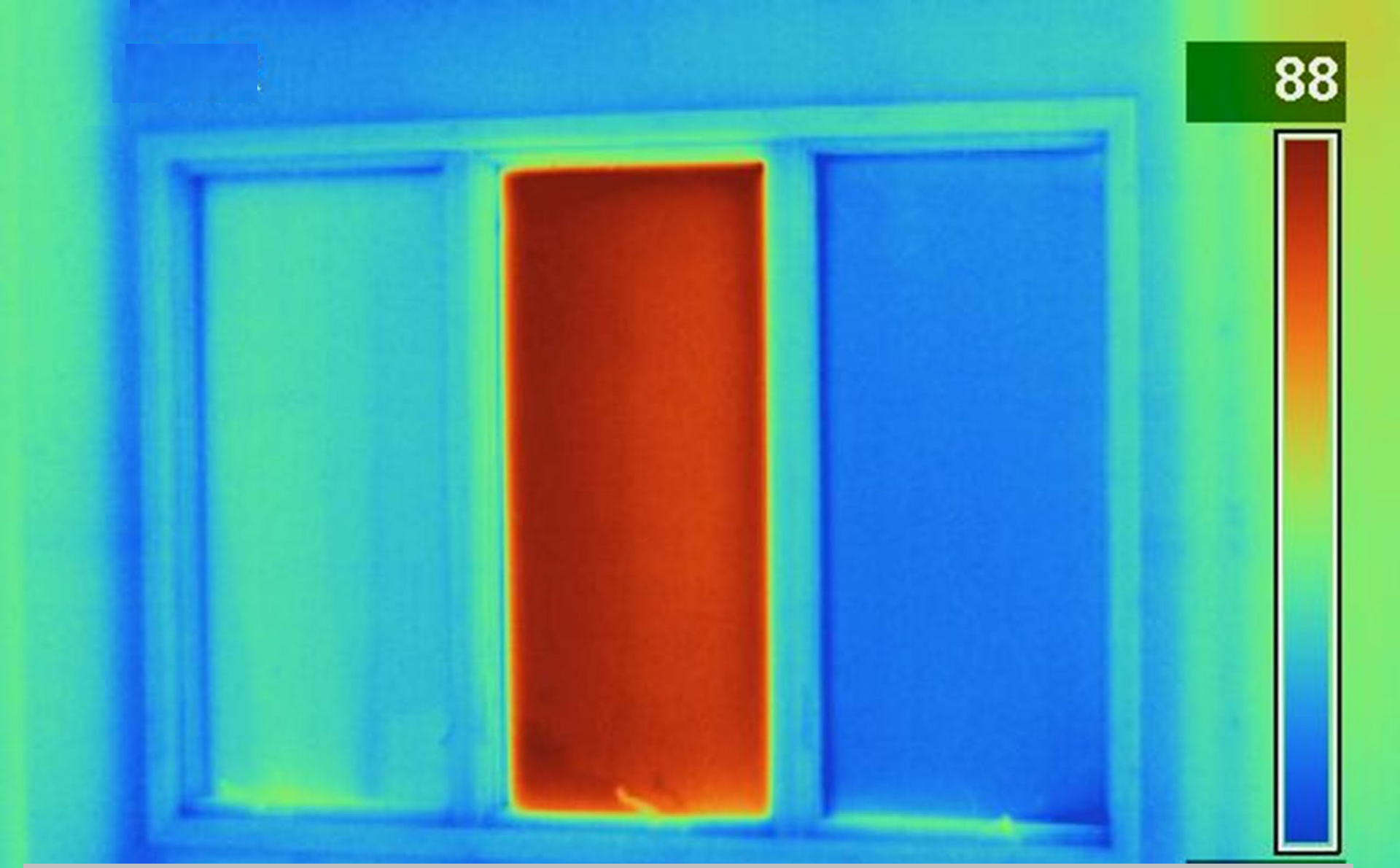
Spectrally Selective Low-E



| Low-E | Clear Glass
Medium Solar | High Solar



Low-E units are warm on winter night. Clear glass is cool.



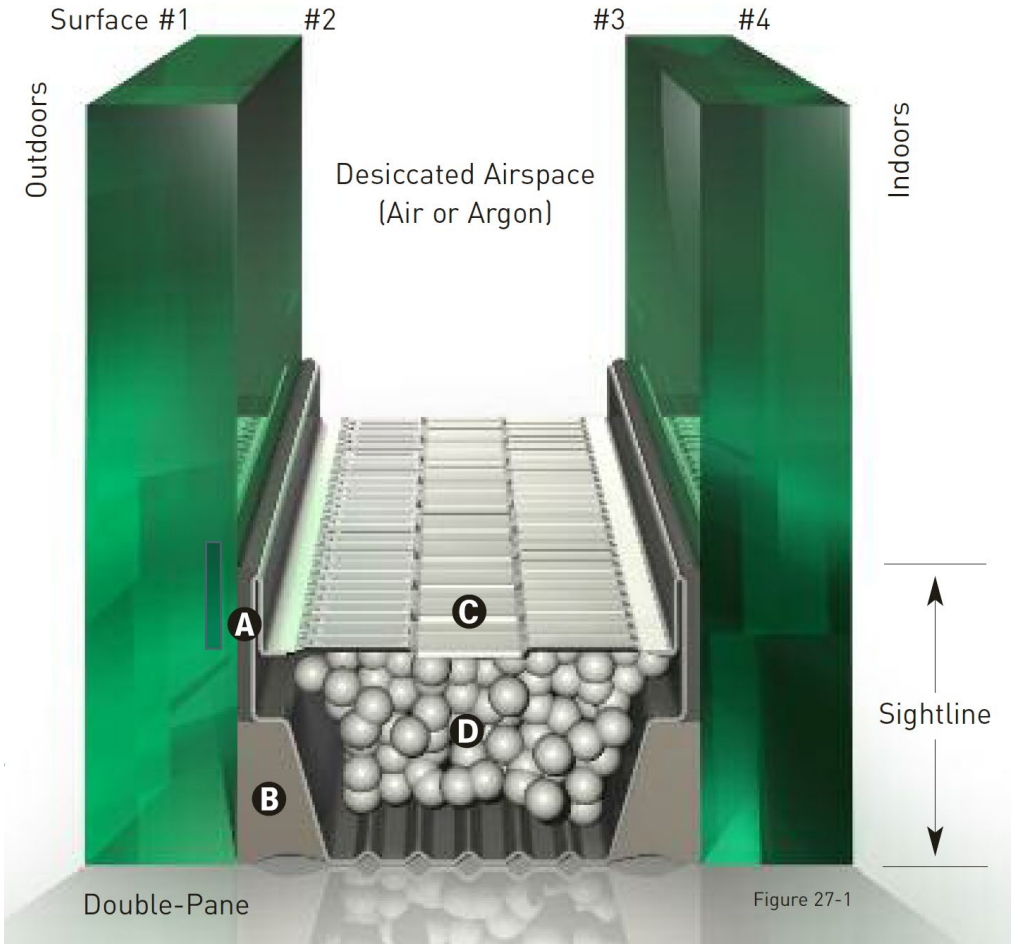
MSLE HSLE Clear 2-Pane

Roomside Glass Temperatures on Winter Day

Next Gen U-Factor Options

- Add 2nd low-E to roomside surface of double pane unit with low-E in cavity
  - Glass improves from R4 to R5
  - 10% reduction in window U

R5 Glass: Low-E #2 and #4

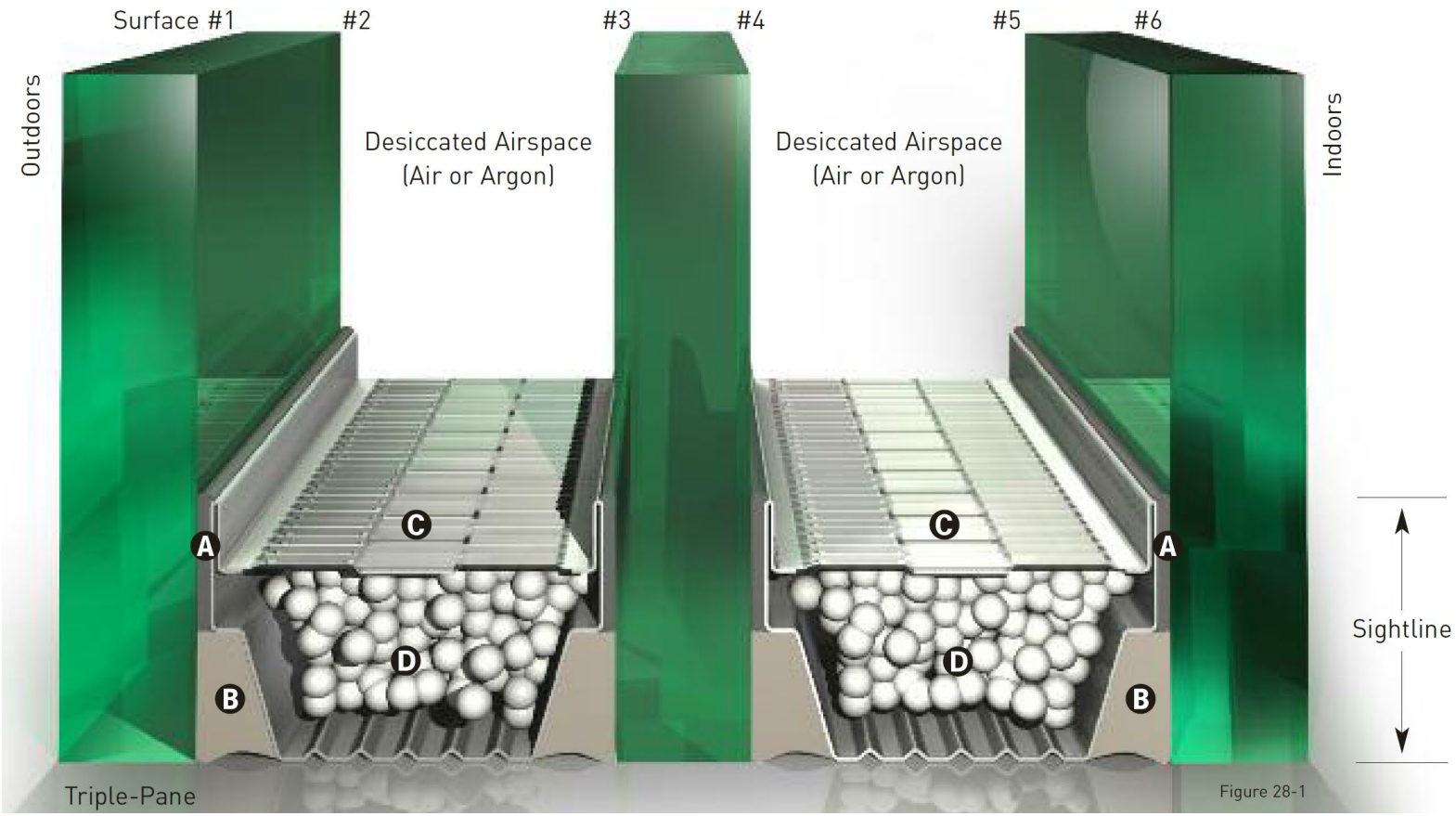


Next Gen U-Factor Options

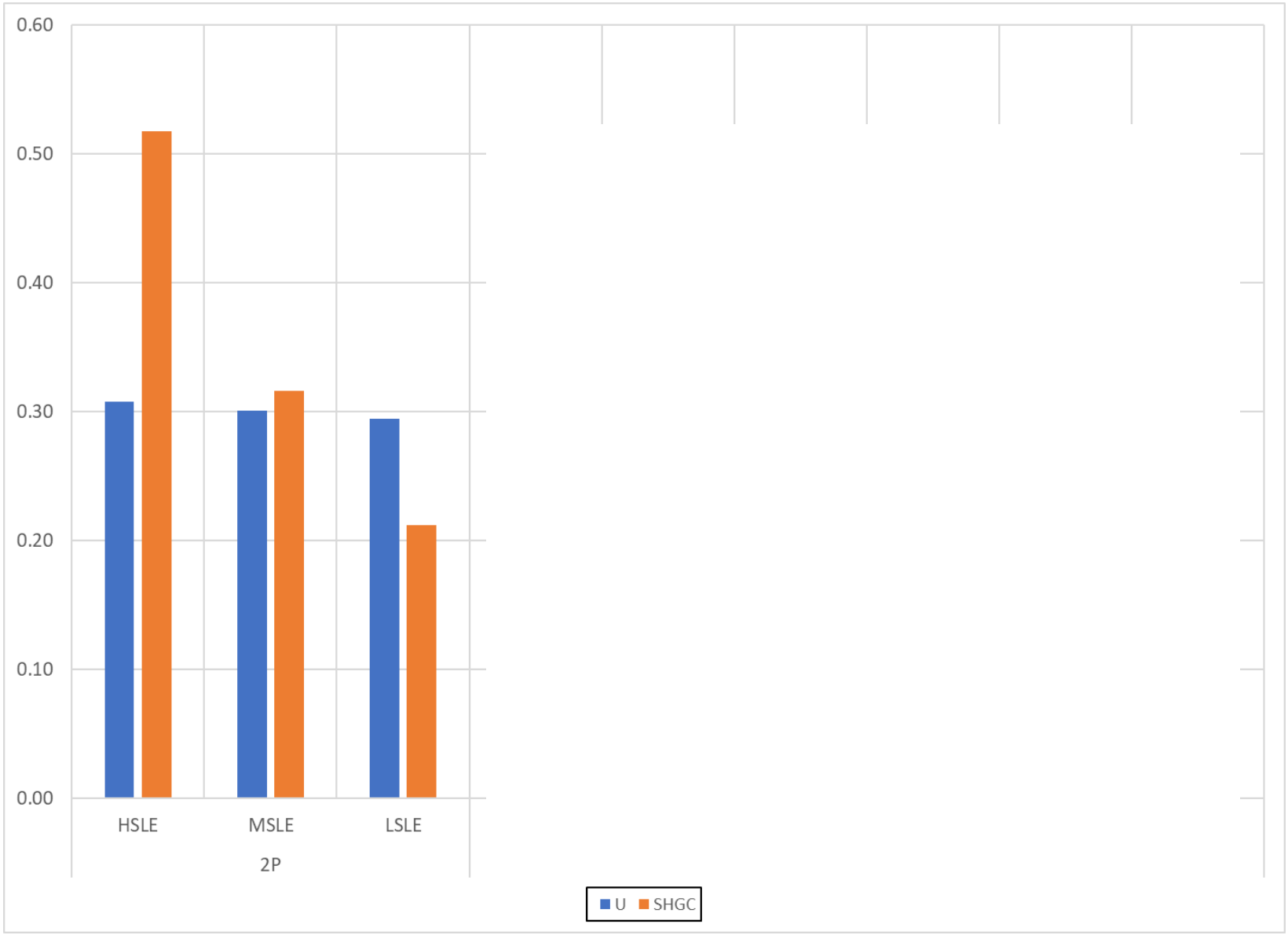
- Add 2nd low-E to roomside surface of double pane unit with low-E in cavity
  - Glass improves from R4 to R5
  - 10% reduction in window U

- Triple pane with low-E in each gap
  - 30% reduction in window U

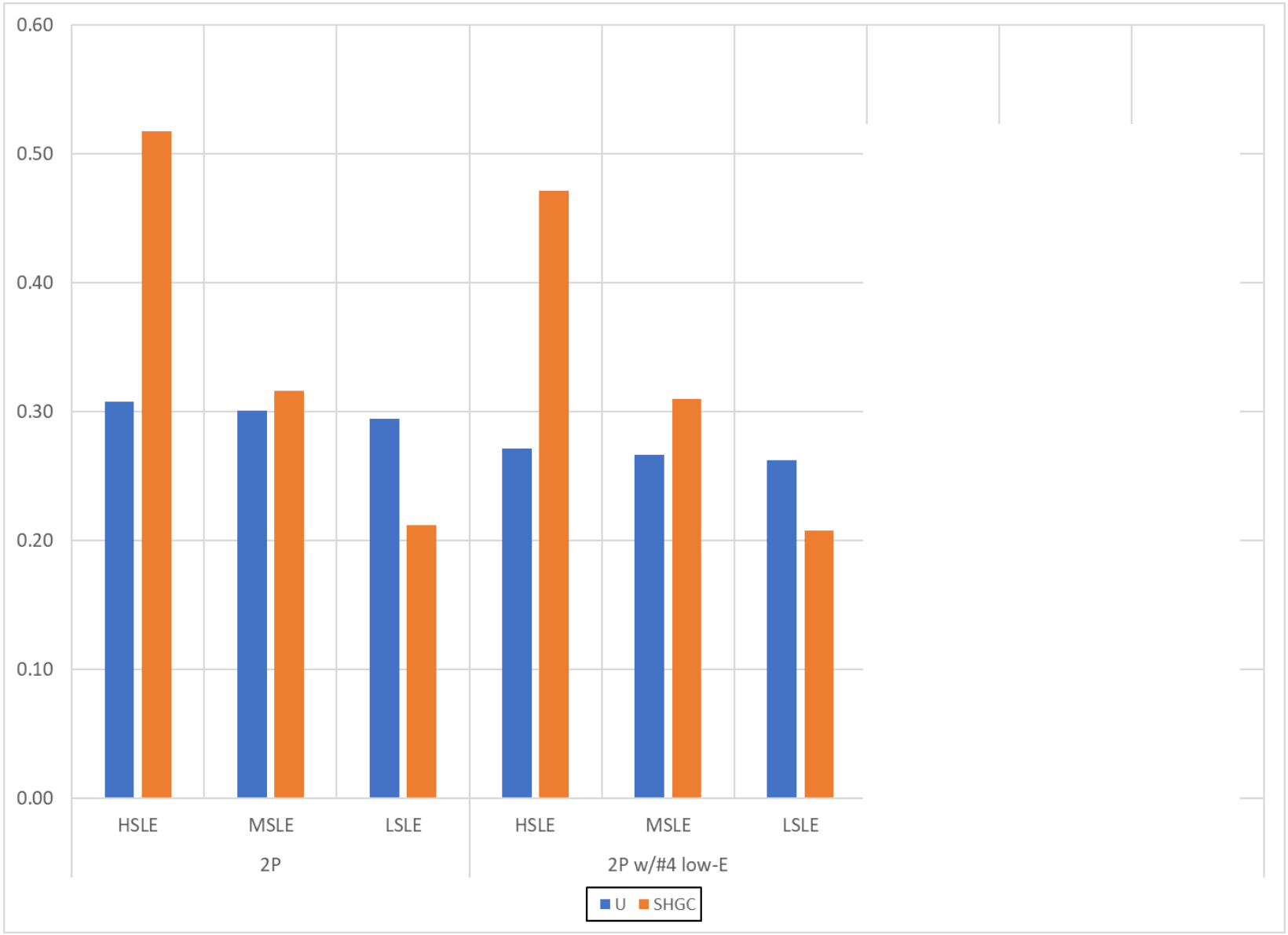
R8 Glass: Low-E #2 and #5



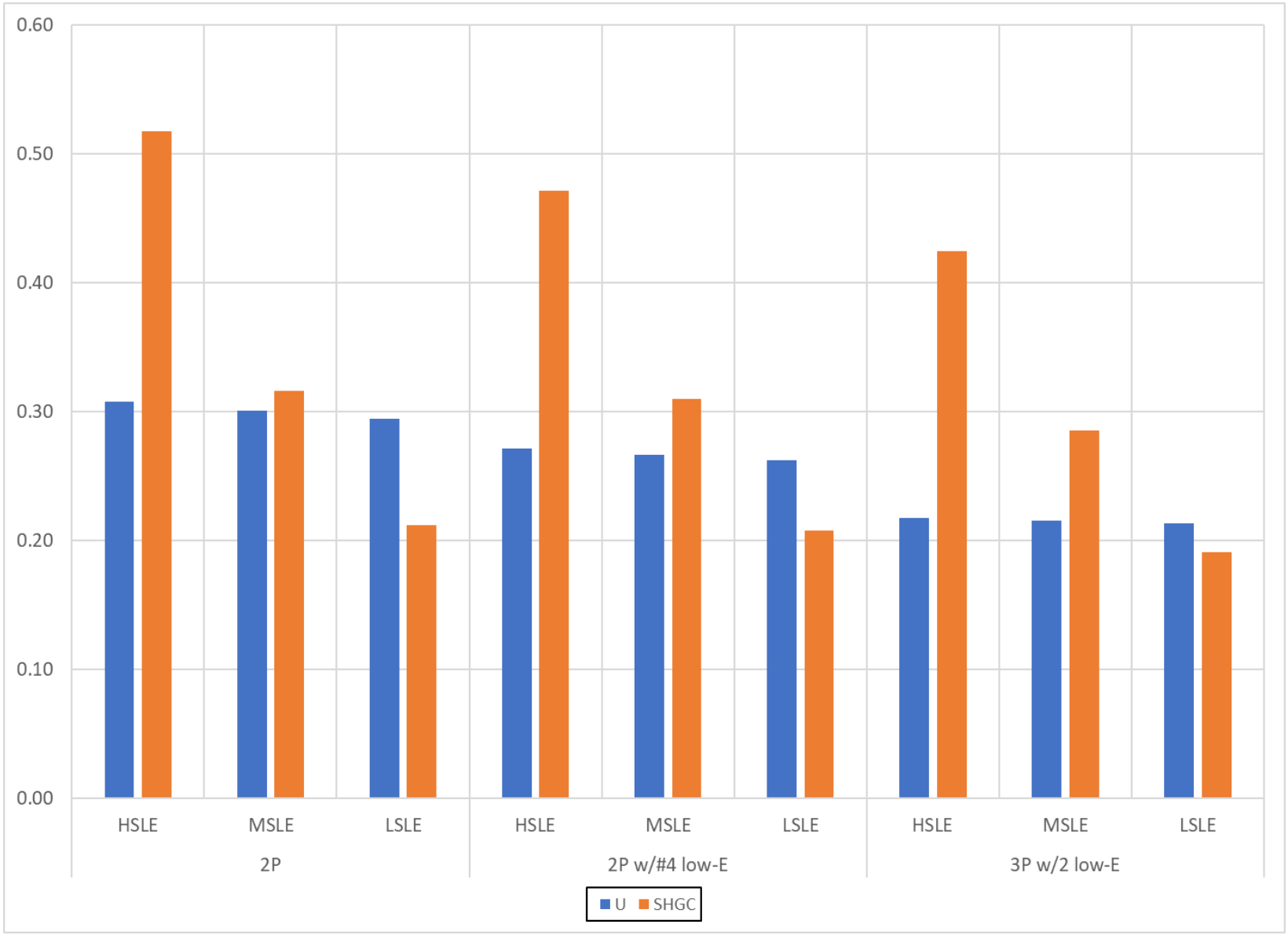
Today's Low-E Windows



Add 4th Surface Low-E: -10% ΔU



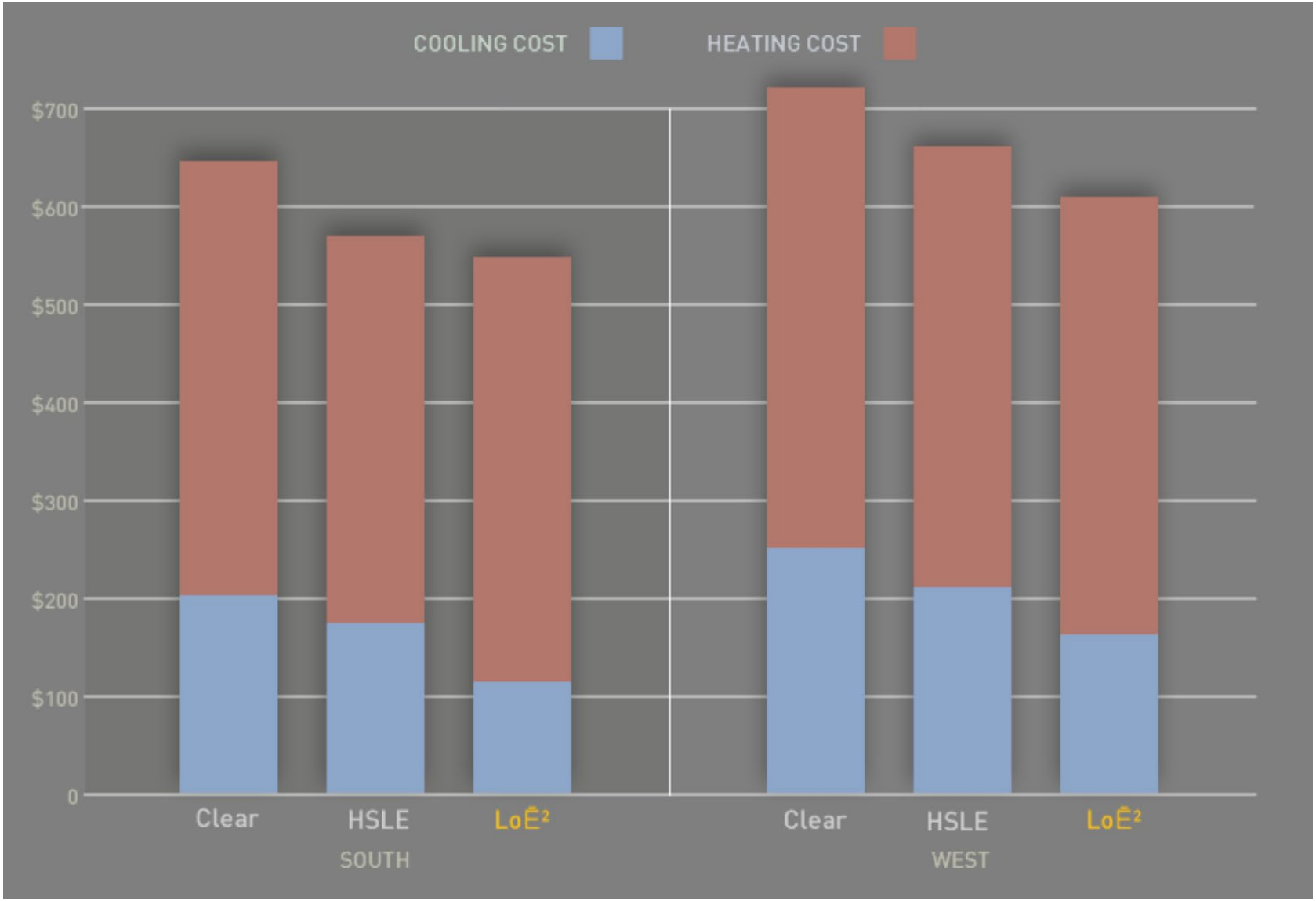
Move to Triple Pane: -30% ΔU



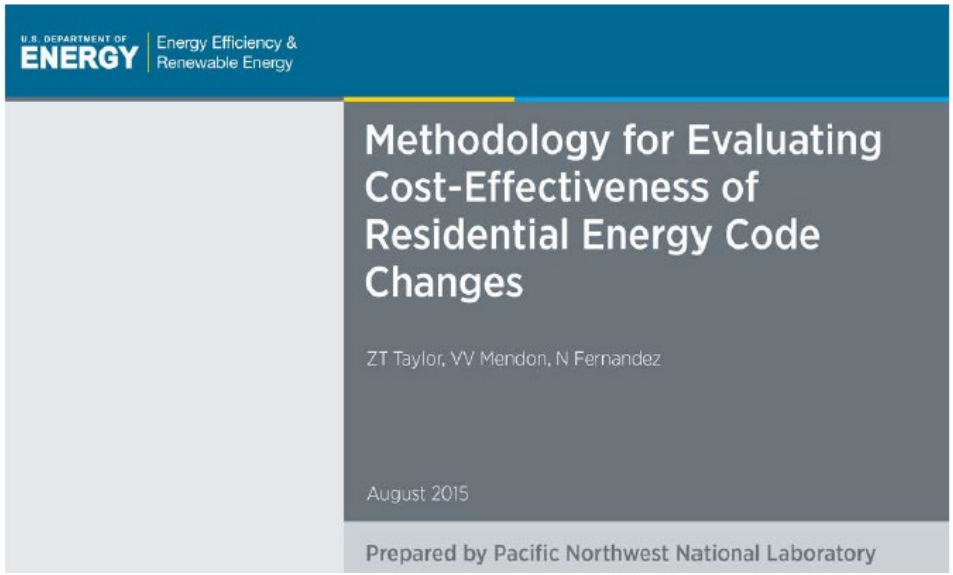
National Home Energy Analysis

BIG rabbit hole!

Real World Tests Match Energy Plus

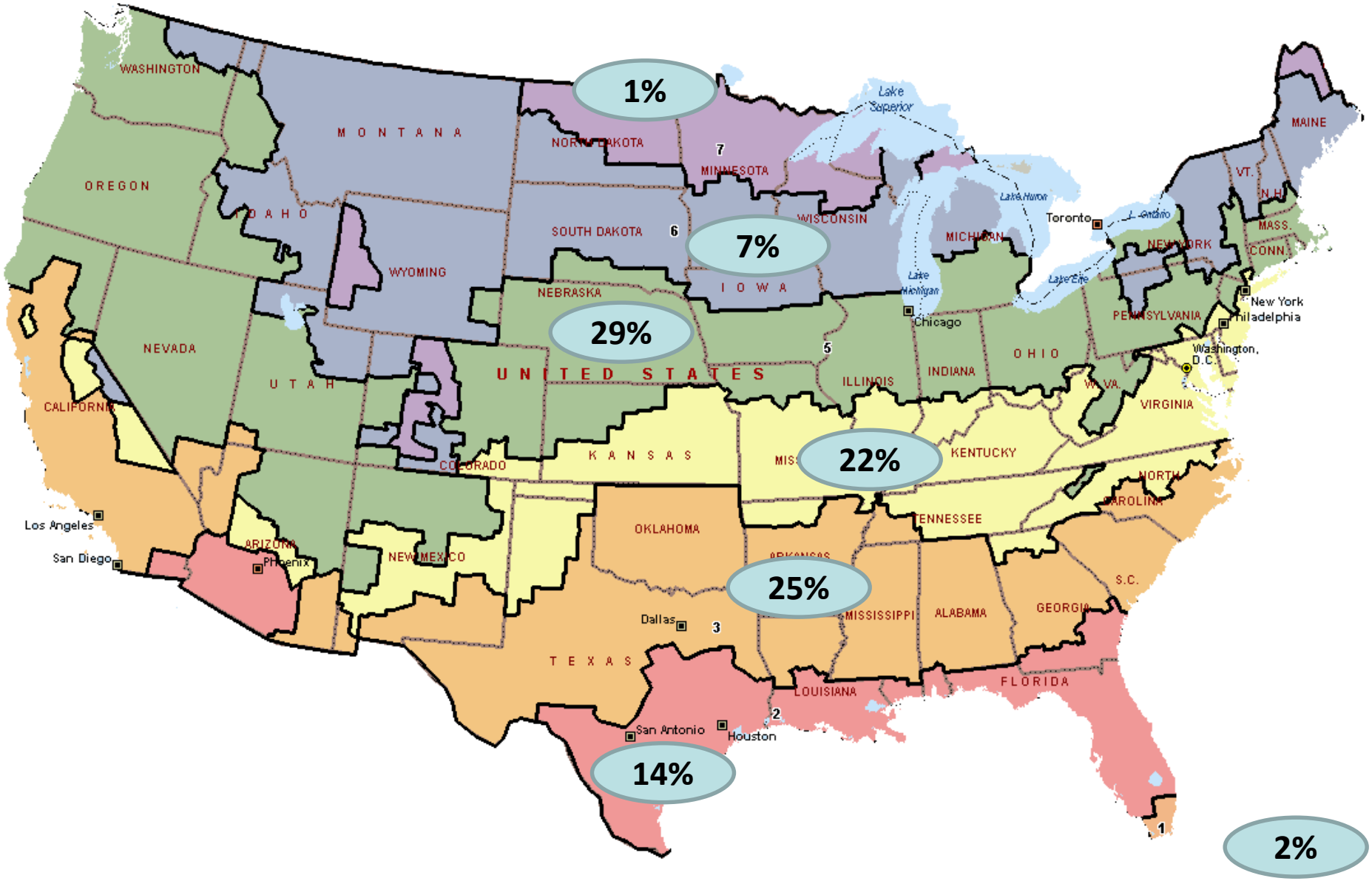


Start with PNNL Code Determination

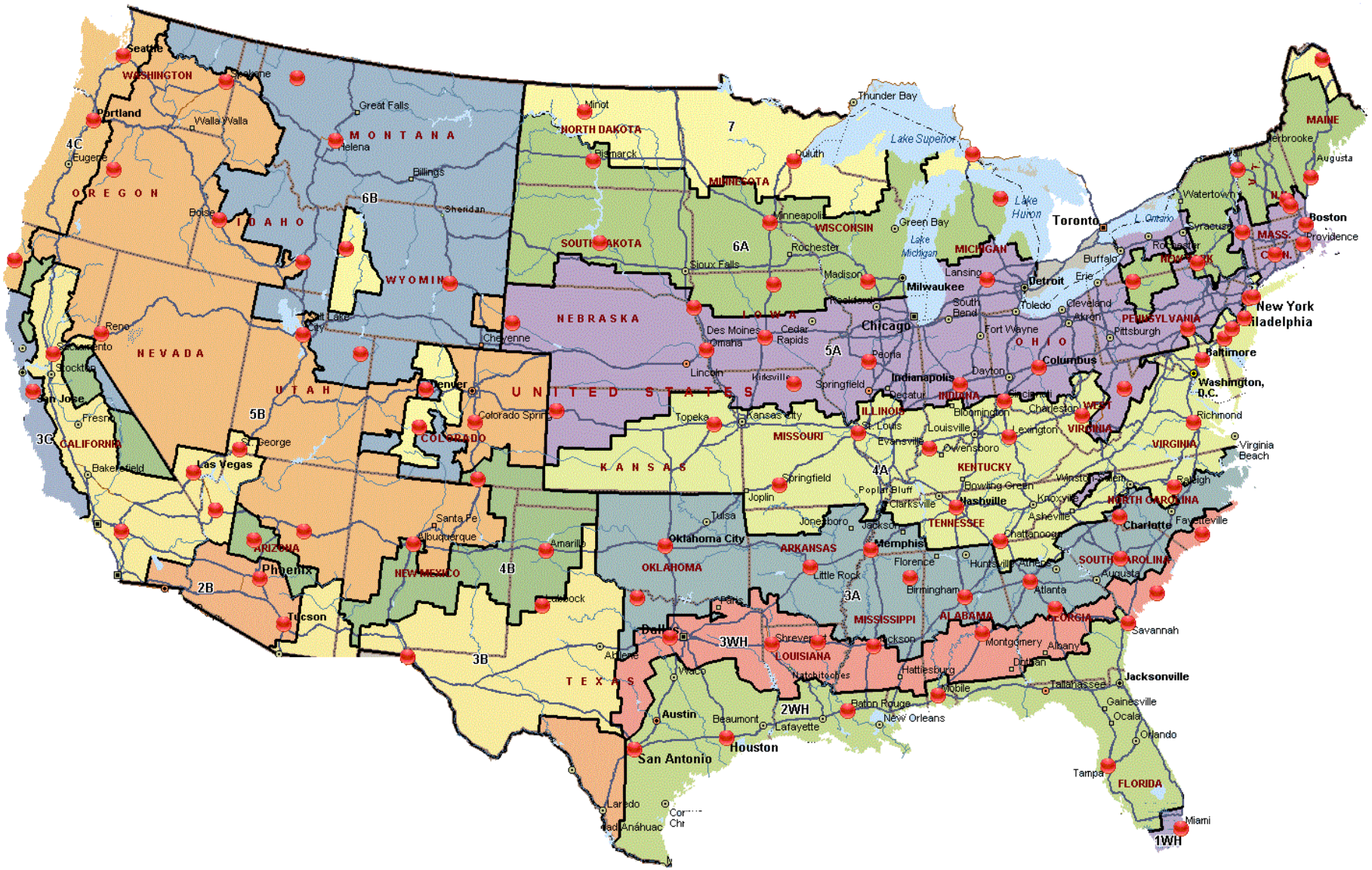


- Energy Plus program
- TMY3 weather data
- Heat, Cool, and Fan energy
- Population weighting

135,000,000 Existing Houses



118 Climate Groupings



Use LBNL Window Regression Analysis

- Routine used since 2001 Energy Star Windows analysis
- Linear regression of multiple window U & SHGC (interactions of heat loss and solar gain)

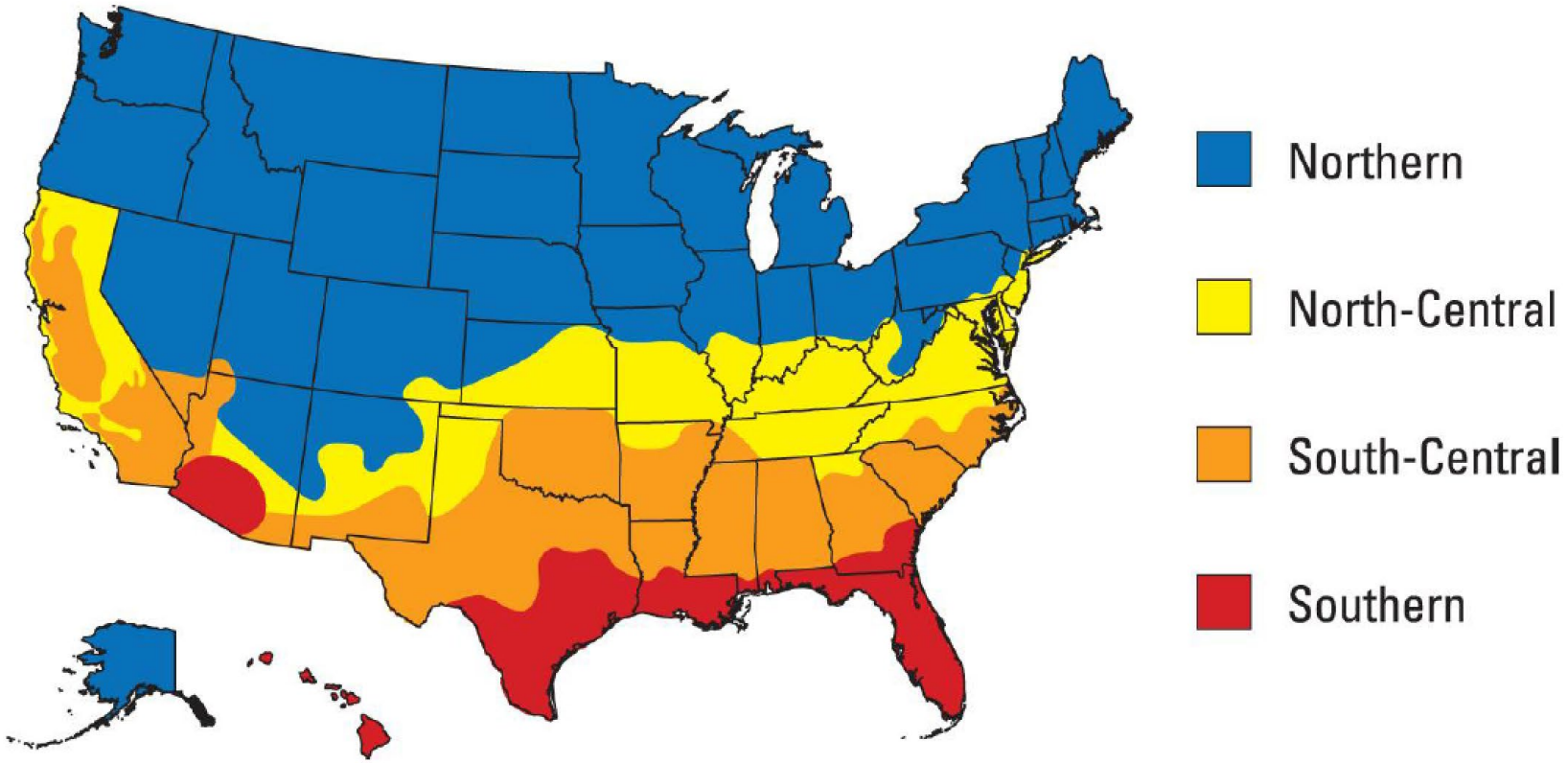
2 Parameter Linear Regression

Multiple parameter form in LINEST function:

Y = **b** + **m1***U-Factor + **m2***SHGC

- **Y** = Energy (heat, cool, total)
- Opaque Building Load = **b**
- Window Conductance = **m1** *U-Factor
- Solar Effect = **m2** * SHGC

Energy Star Windows



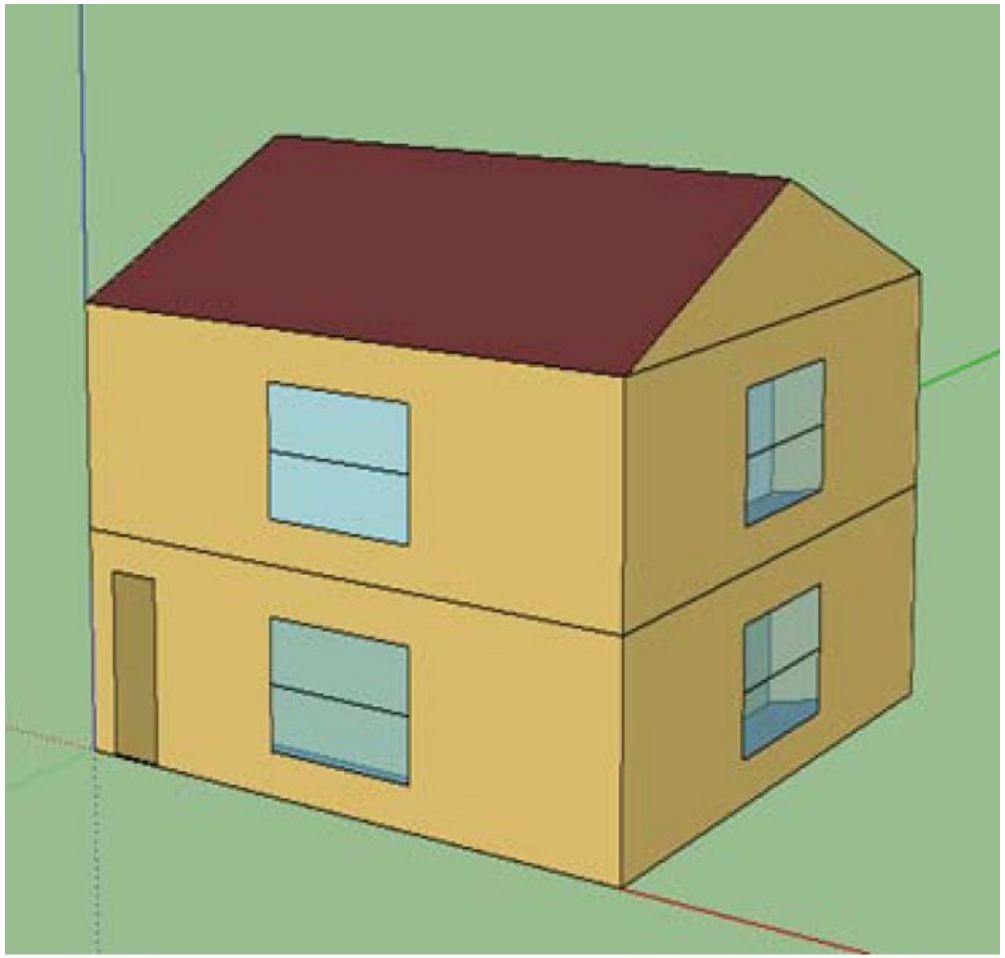
Note: A complete list of ENERGY STAR Climate Zones by state and county or, where applicable, zip code is available at https://www.energystar.gov/index.cfm?fuseaction=windows_doors.search_climate.

Energy Star Requirements by Zone

Windows

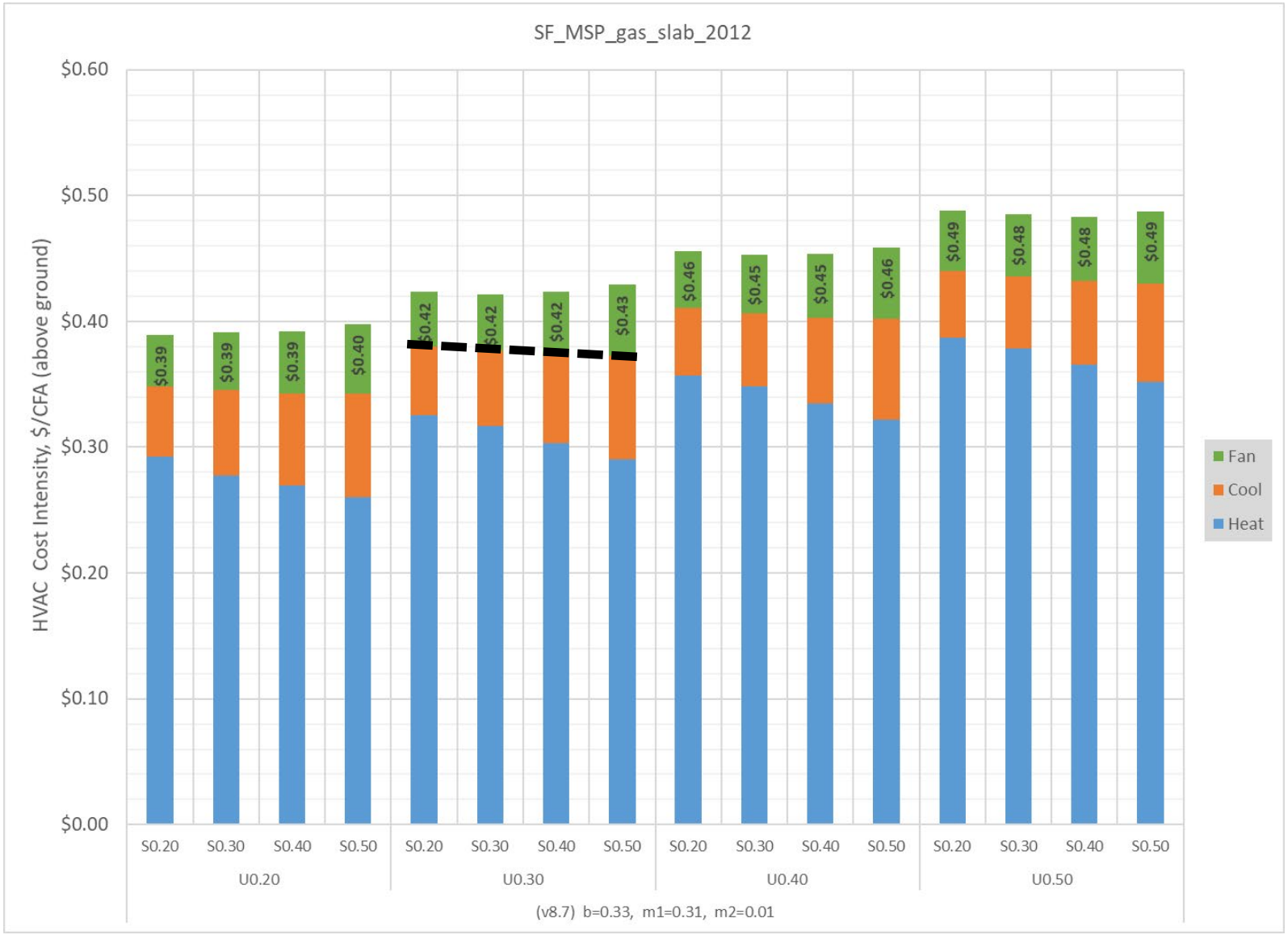
Climate Zone	U-Factor[1]	SHGC[2]	
Northern*	≤ 0.27	Any	Prescriptive
	= 0.28	≥ 0.32	Equivalent Energy Performance
	= 0.29	≥ 0.37	
	= 0.30	≥ 0.42	
North-Central	≤ 0.30	≤ 0.40	
South-Central	≤ 0.30	≤ 0.25	
Southern	≤ 0.40	≤ 0.25	

Lazy Modeling (my terminology)

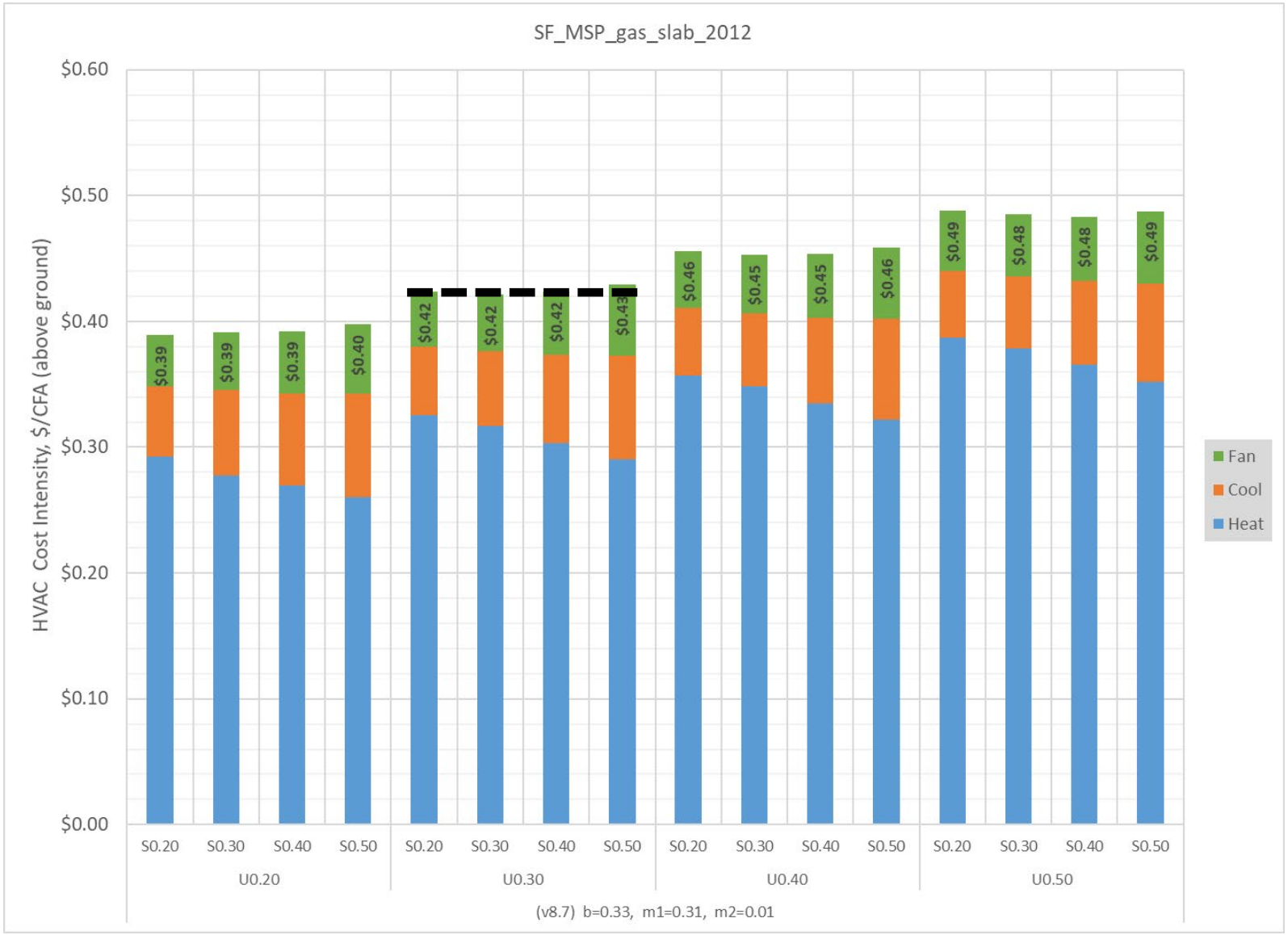


Use Equal Distribution of Windows to Represent “Average” of Asymmetric Window Configurations

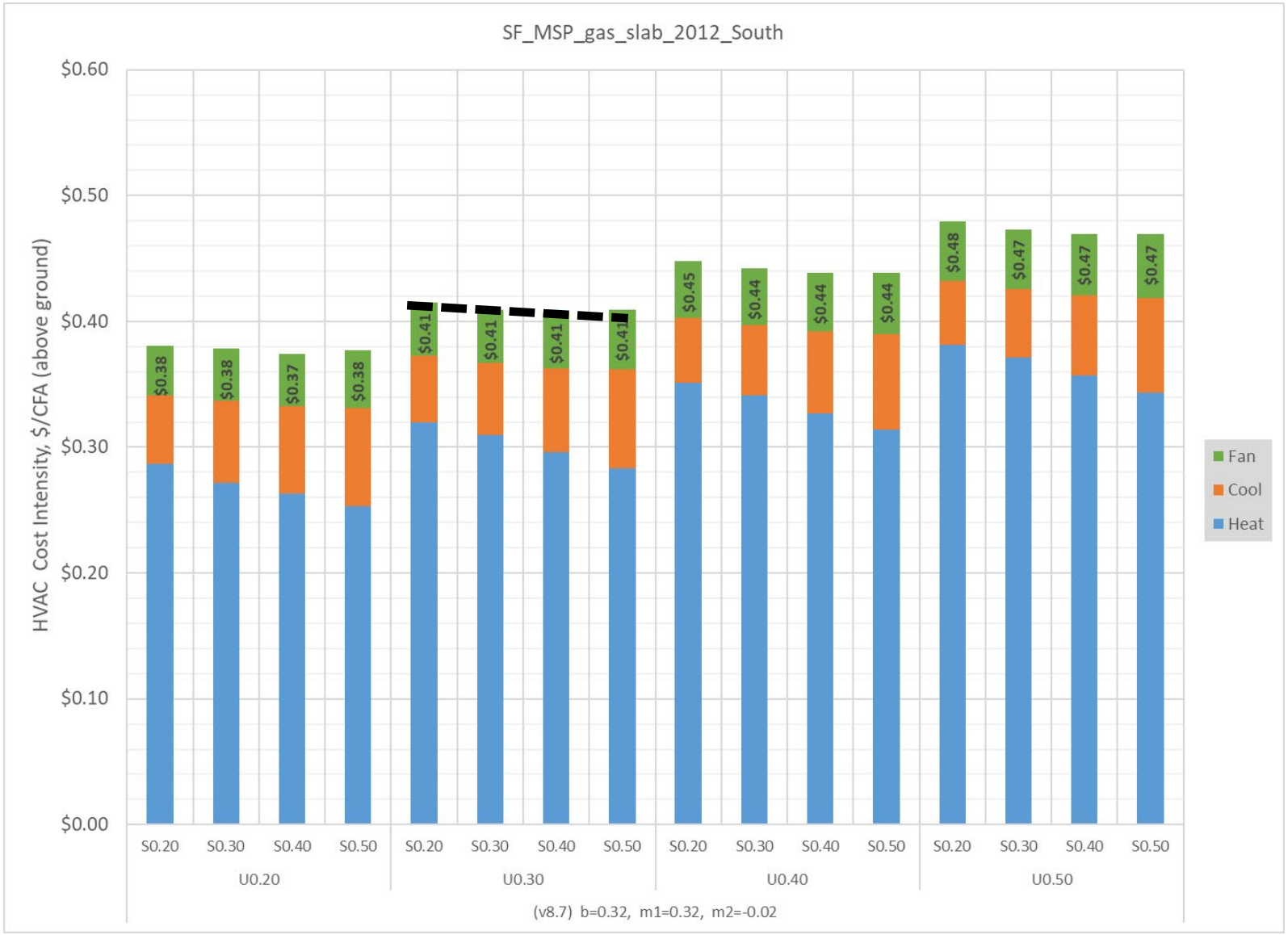
Equal Distribution w/o Fan



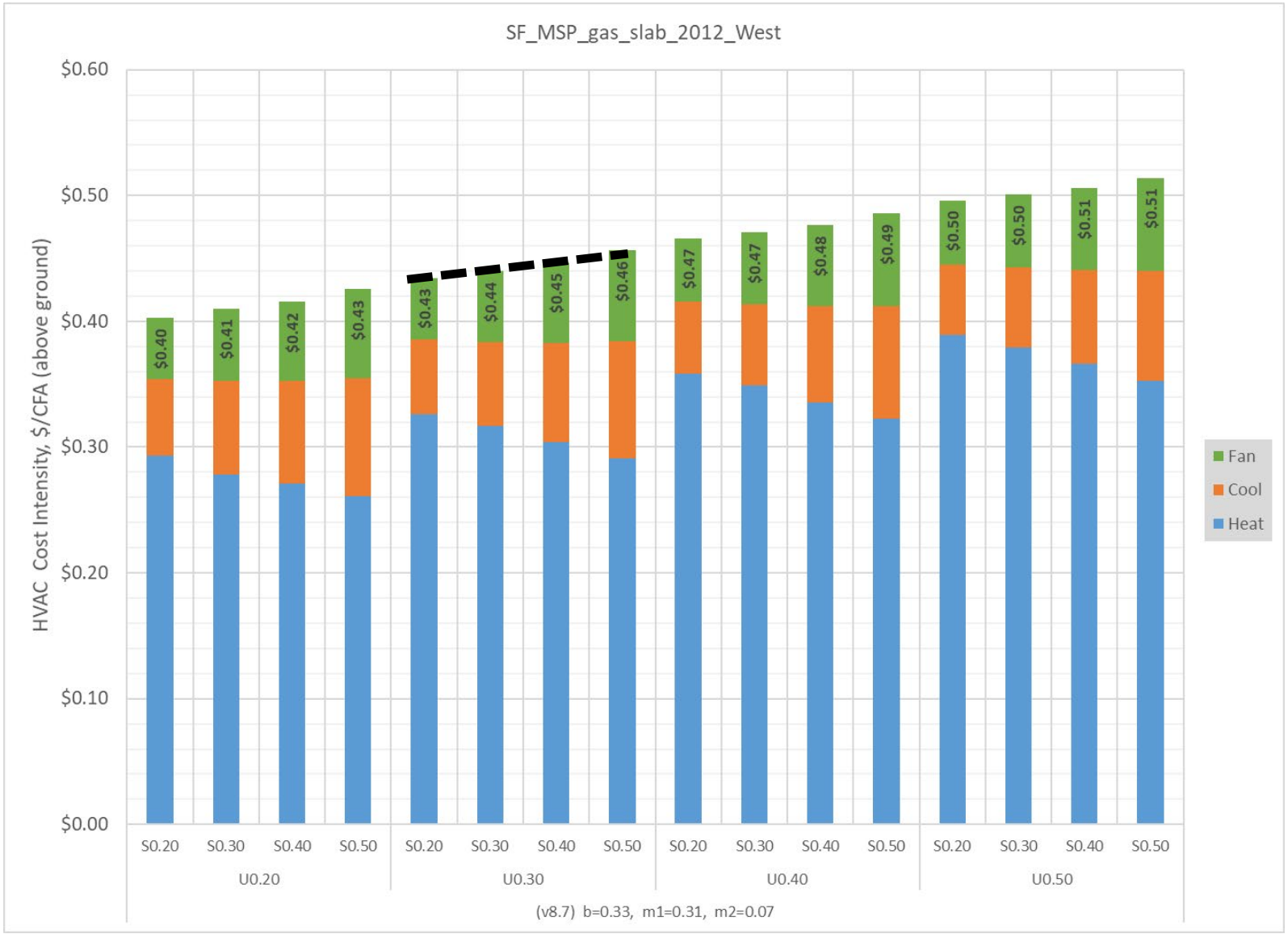
Equal + Fan = Solar Neutral



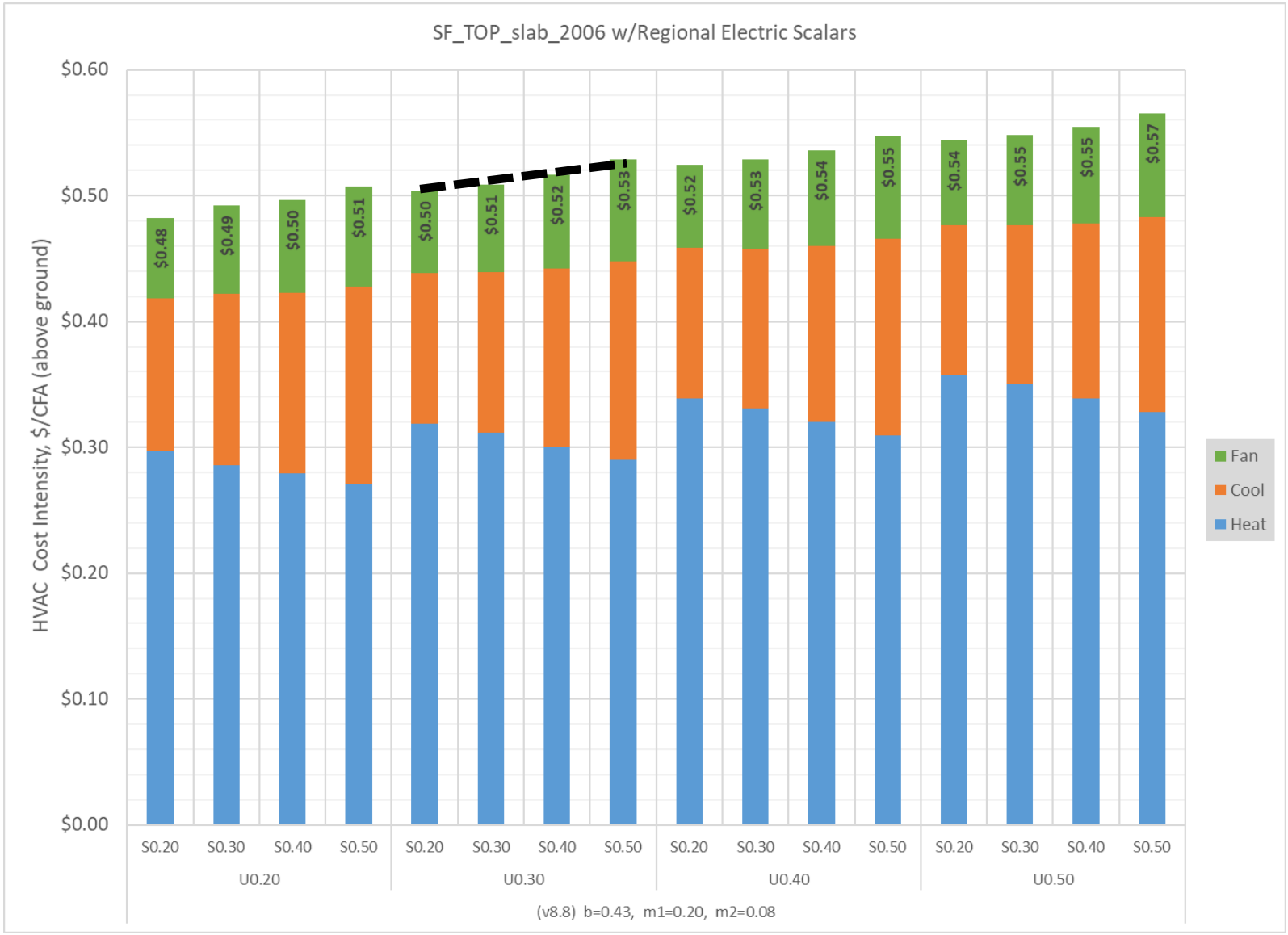
South Facing = Passive Benefit



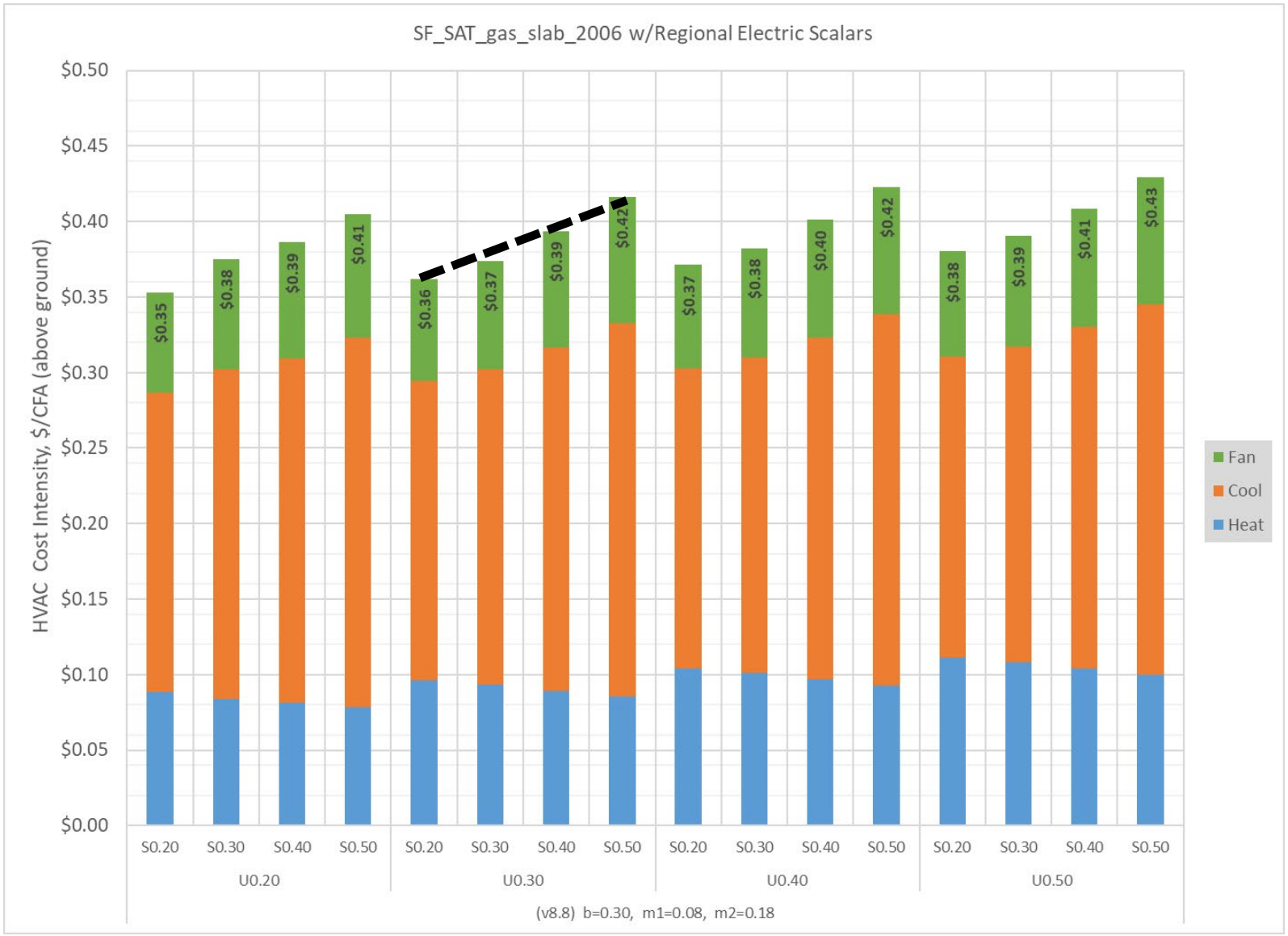
West Facing = Solar Penalty



Climate Zone 4



Climate Zone 2



Carbon Translation from Energy

- EPA eGrid
- State level energy costs
- State level CO2 emissions
- Updated annually
- Costs and emissions don't correlate well
  - Public utility commissions?

2016 coal = ½ of 2005

- Replaced with natural gas

Carbon Dioxide Equivalent: CO_2e

- Global Warming Potentials for pollutants 100 years lifetime
  - Carbon Dioxide (CO2) GWP = 1
  - Methane (CH4) GWP = 28
  - Nitrous Oxide (N2O) GWP = 265

- Emissions data comes from EPA eGRID

Source Energy

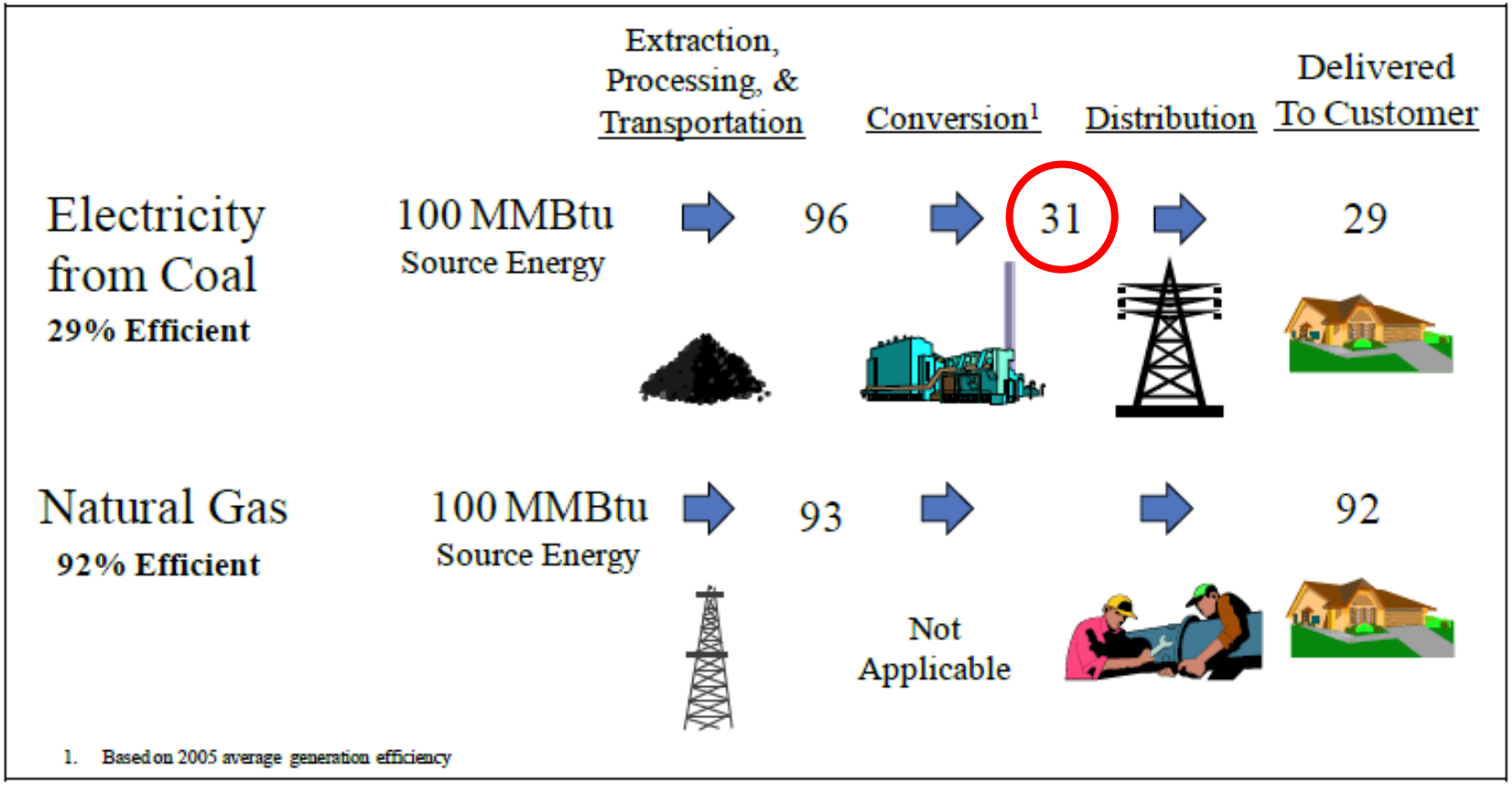


Figure 4 Comparison of Source Efficiencies Delivered to Customers (%)

Source: CMIC Source Energy and Emissions Analysis Tool (www.cmictootls.com)

10 Year History on Electrical Fuel Mix

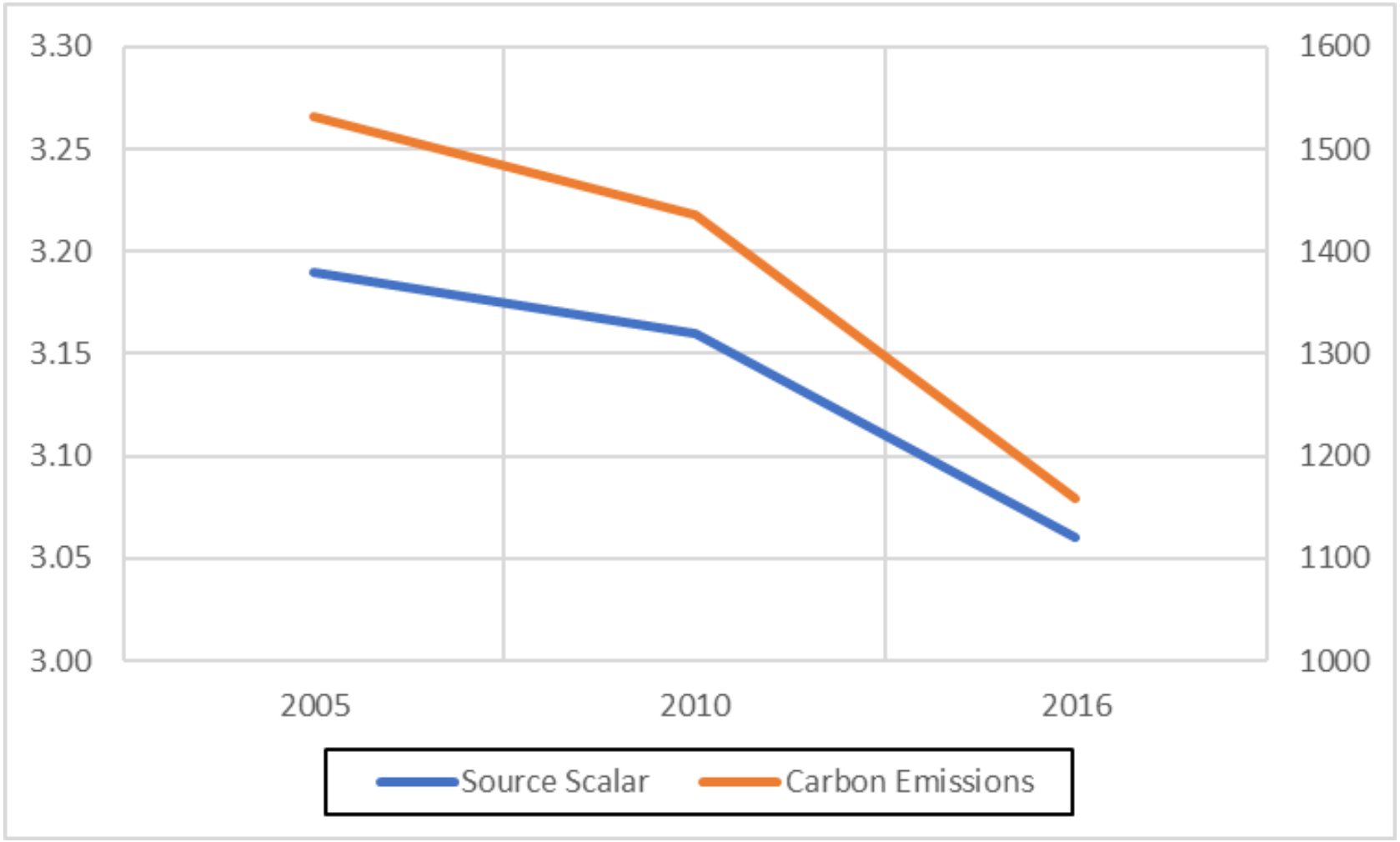
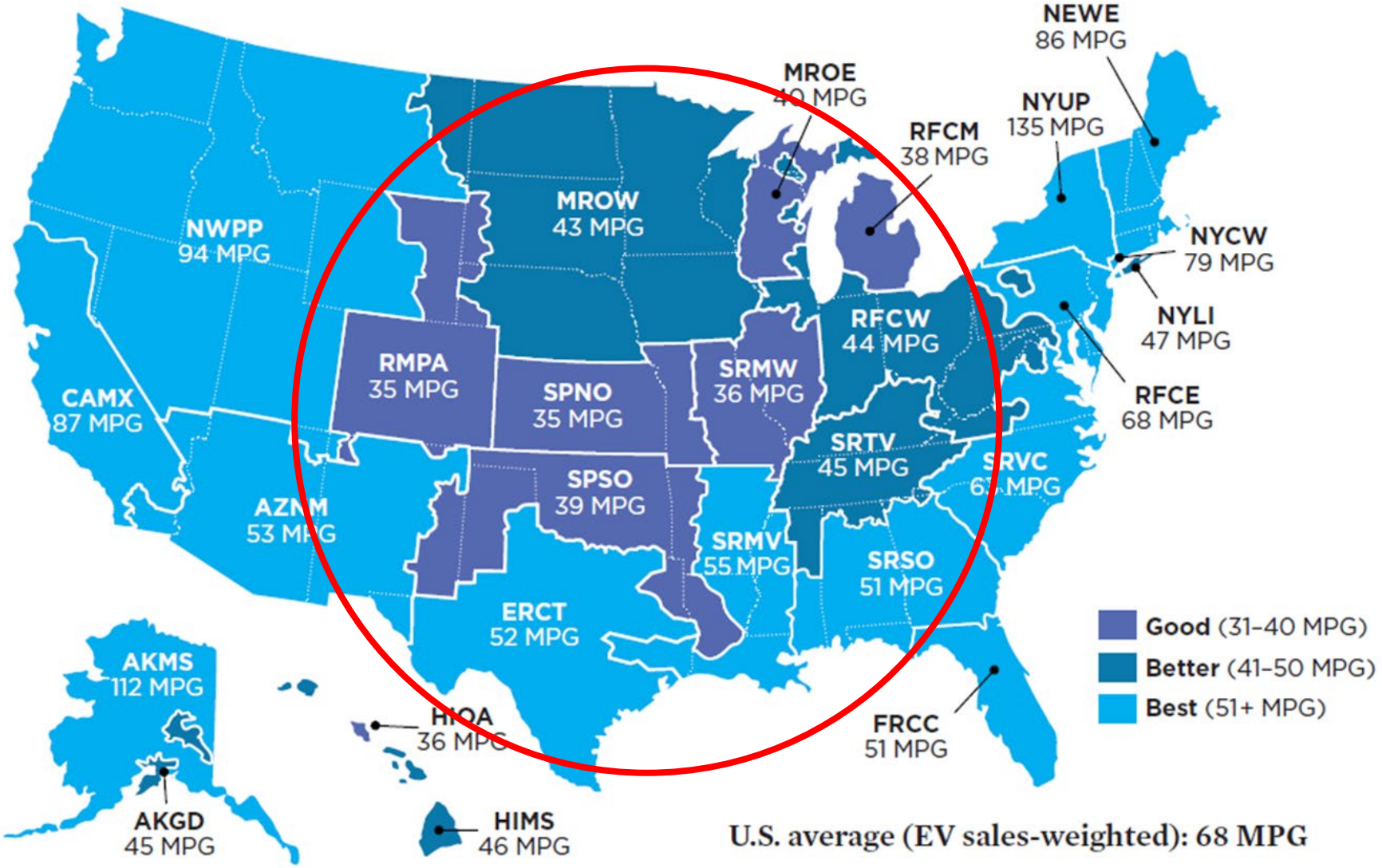


FIGURE ES-1. **Electric Vehicle Global Warming Pollution Ratings and Gasoline Vehicle Emissions Equivalents by Electricity Grid Region**



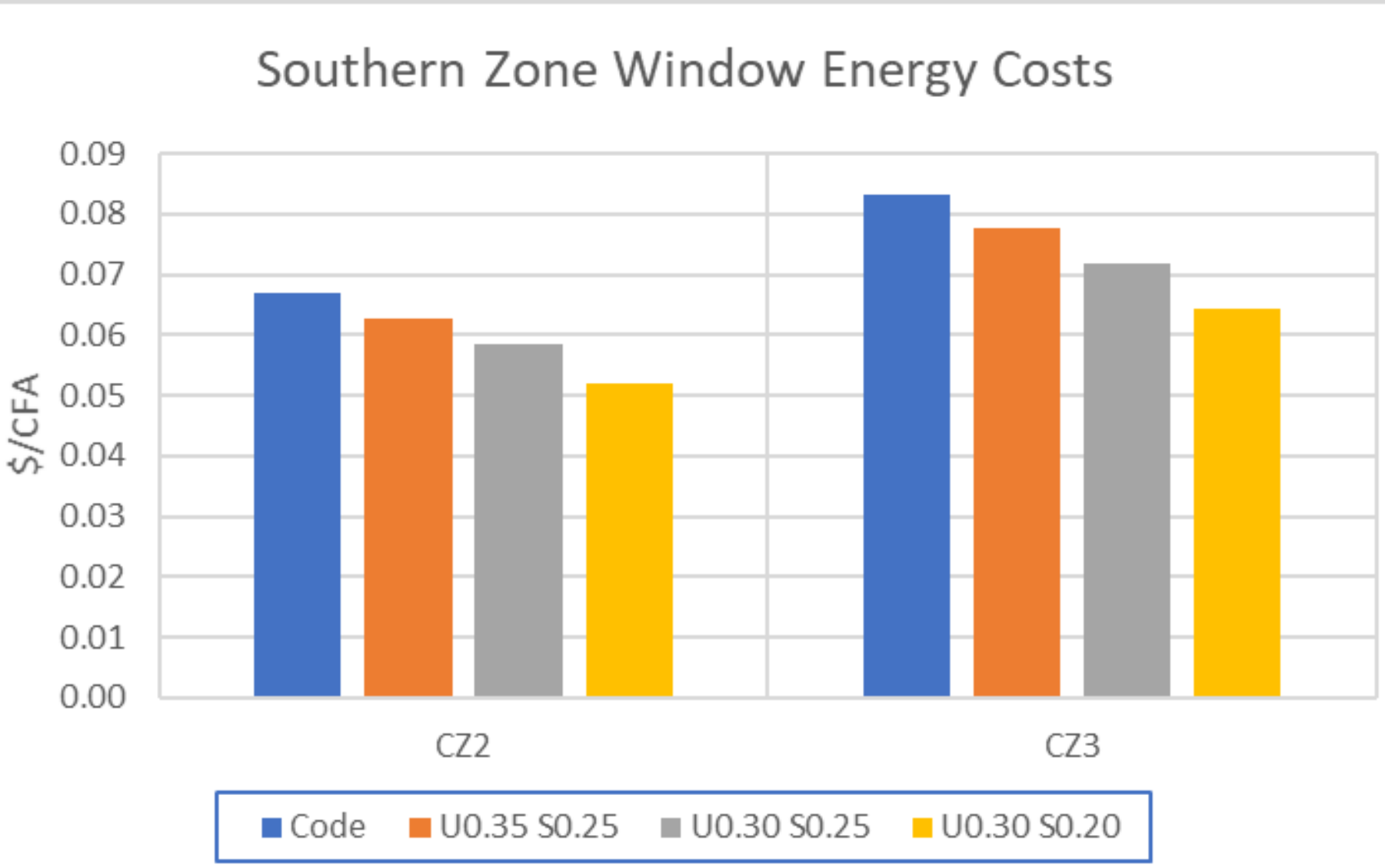
Note: The MPG (miles per gallon) value listed for each region is the combined city/highway fuel economy rating of a gasoline vehicle that would have global warming emissions equivalent to driving an EV. Regional global warming emissions ratings are based on 2012 power plant data in the EPA's eGRID 2015 database (the most recent version). Comparisons include gasoline and electricity fuel production emissions. The 68 MPG U.S. average is a sales-weighted average based on where EVs were sold in 2014.

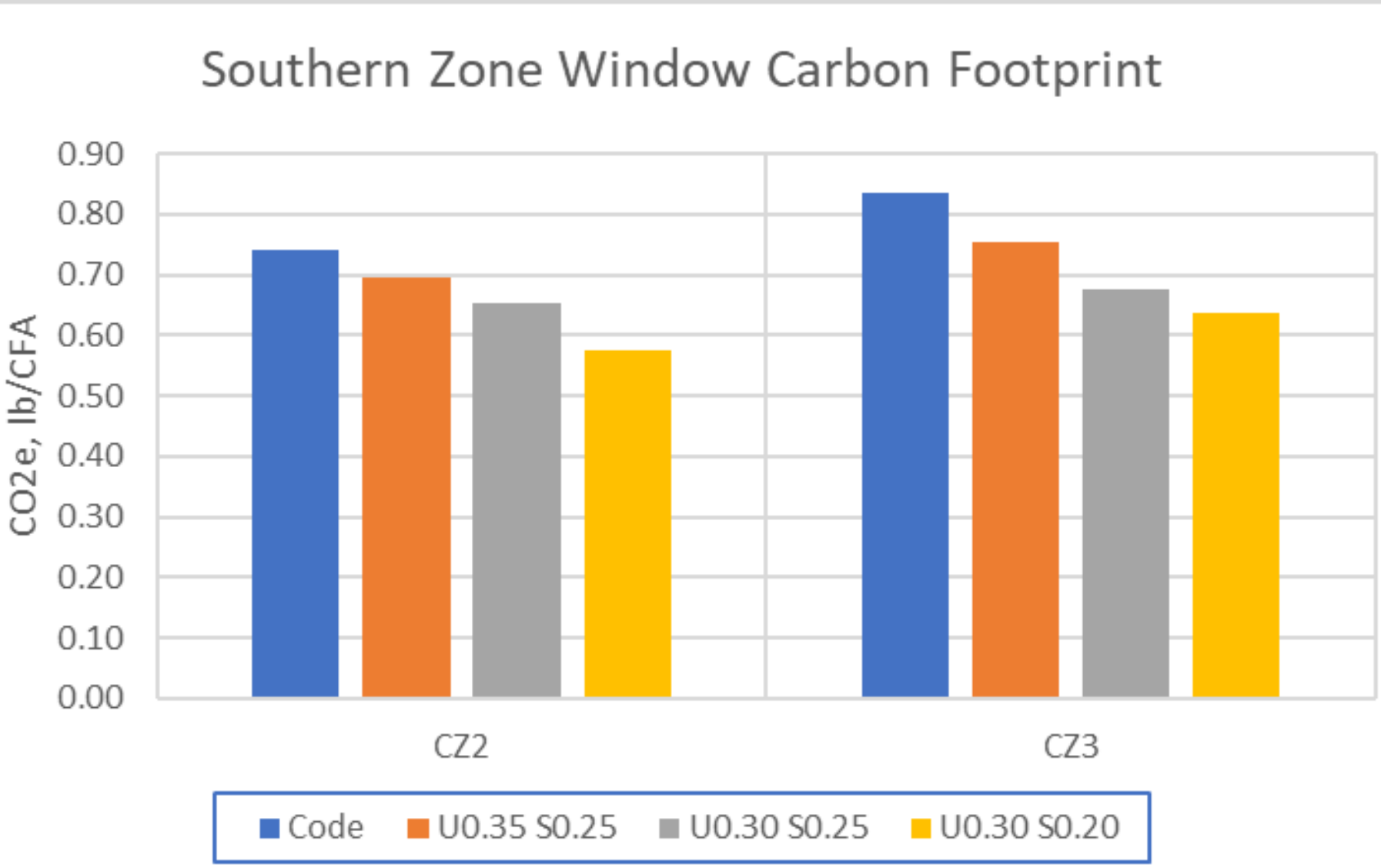
SOURCE: EPA 2015C; IHS 2015.

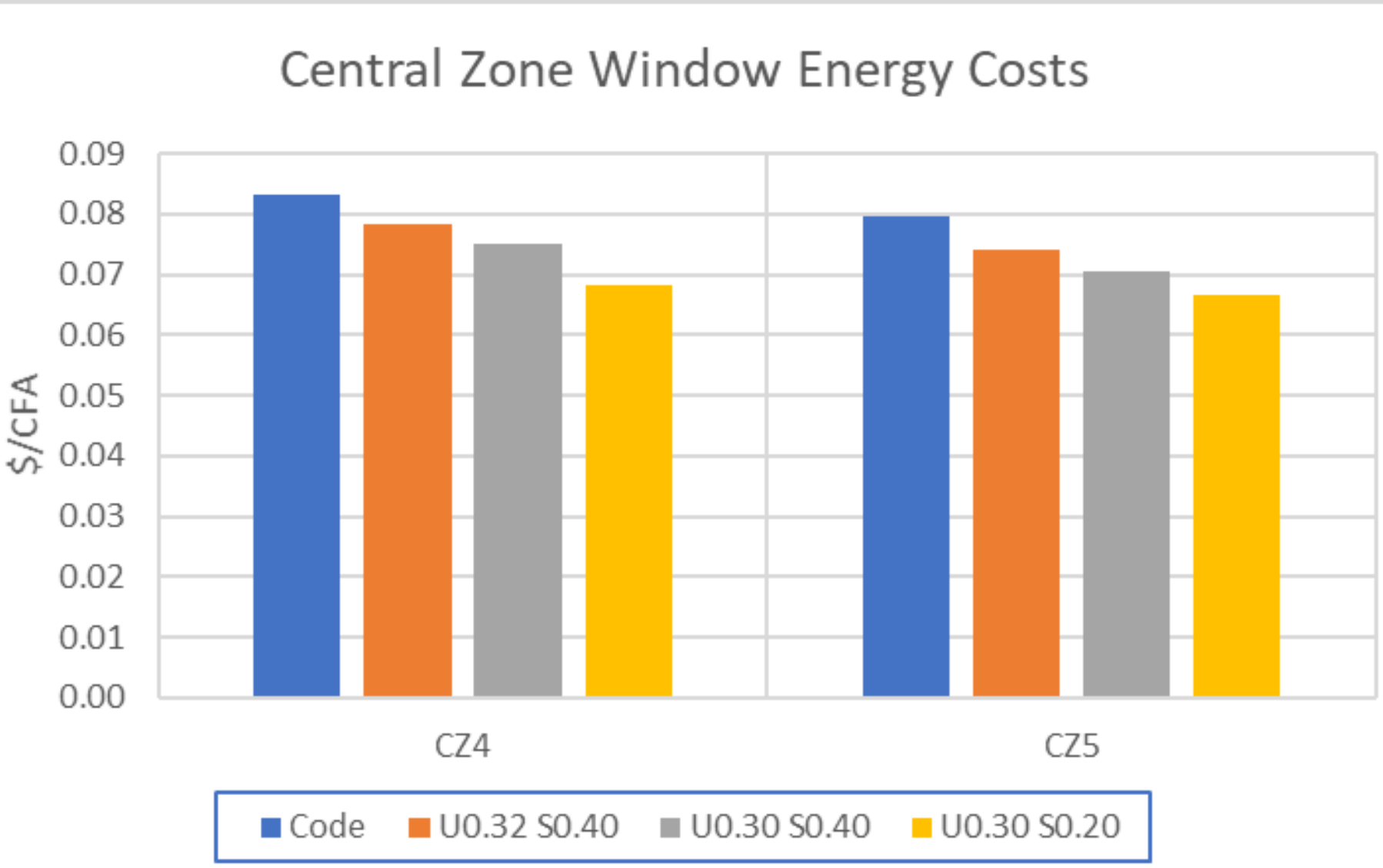
Nat'l Totals (yellow = passive)

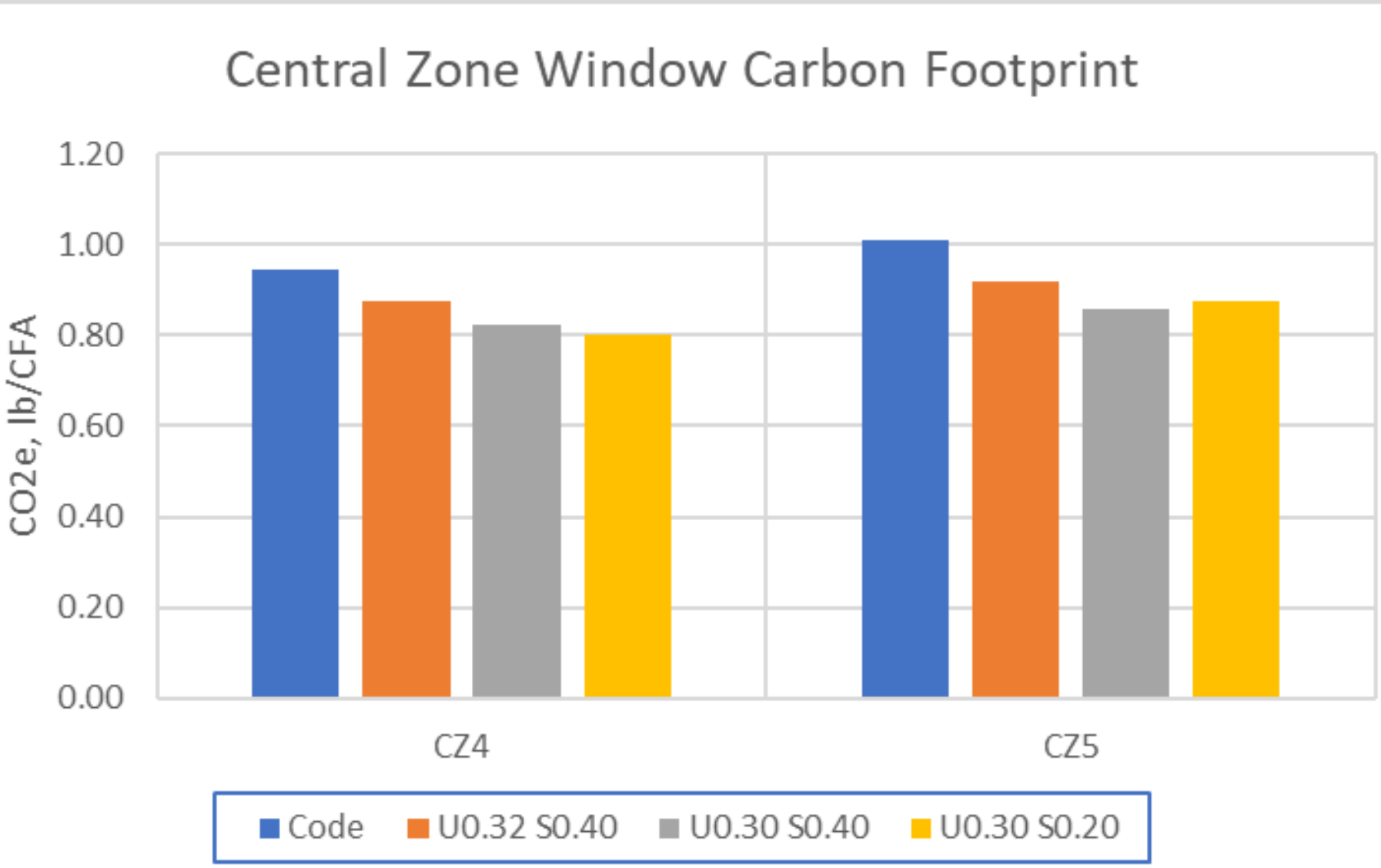
Weighted Zone Coefficients using Regional Electric Fuel Mix

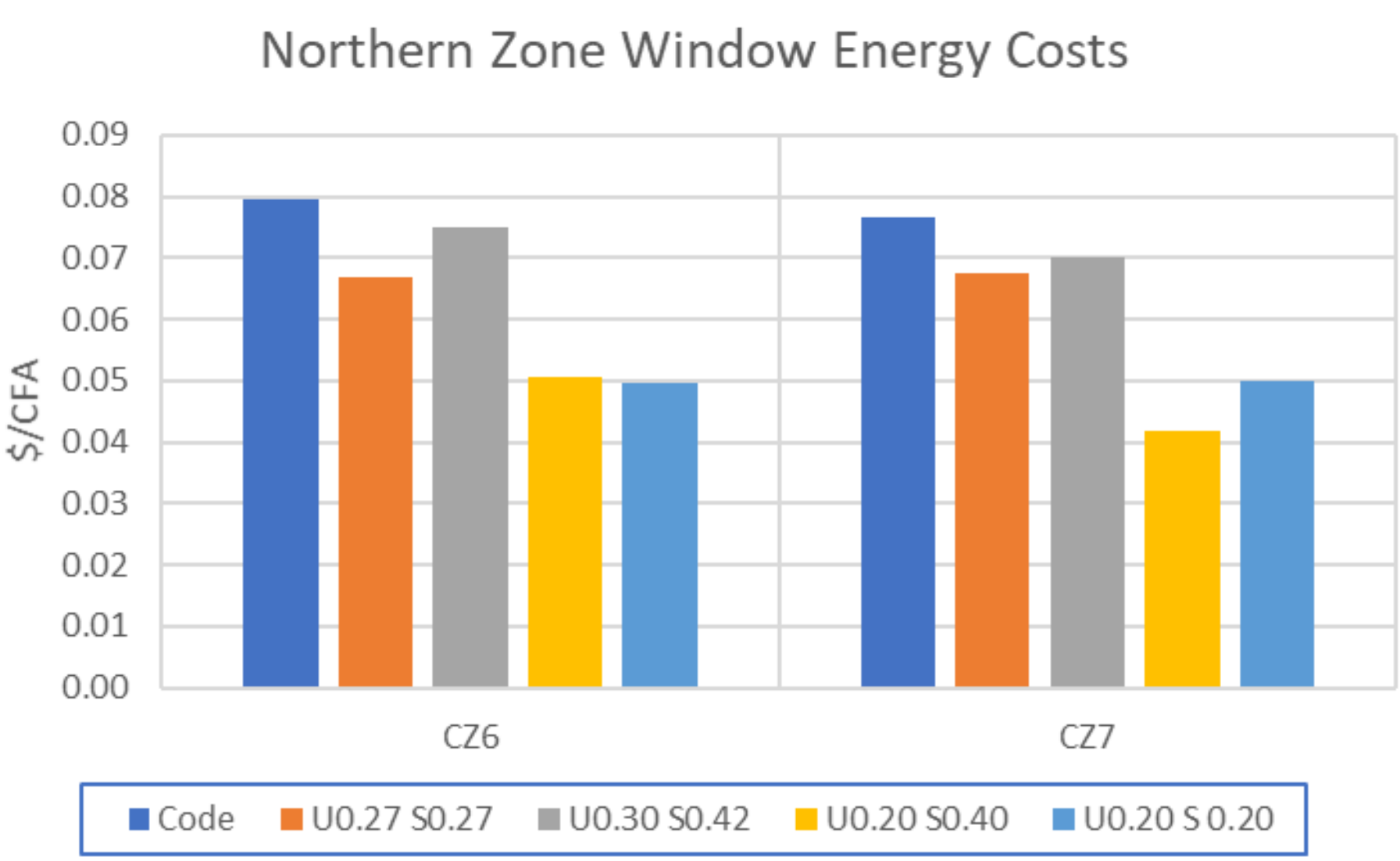
IECC Zone	U.S. Housing Fraction	Dollars			Carbon		
		b	m1	m2	b	m1	m2
1	2%	0.39	0.00	0.33	3.62	-0.01	3.12
2	14%	0.32	0.08	0.16	3.64	0.89	1.78
3	25%	0.30	0.11	0.18	3.20	1.60	0.90
4	22%	0.39	0.19	0.07	5.17	2.78	0.27
5	29%	0.37	0.21	0.04	5.57	3.55	-0.18
6	7%	0.46	0.28	0.00	7.08	4.61	-0.73
7	1%	0.51	0.34	-0.04	8.44	5.68	-1.07
8	0%	0.89	0.50	-0.01	11.99	7.06	-1.19
	U.S.	0.36	0.17	0.10	4.73	2.56	0.47

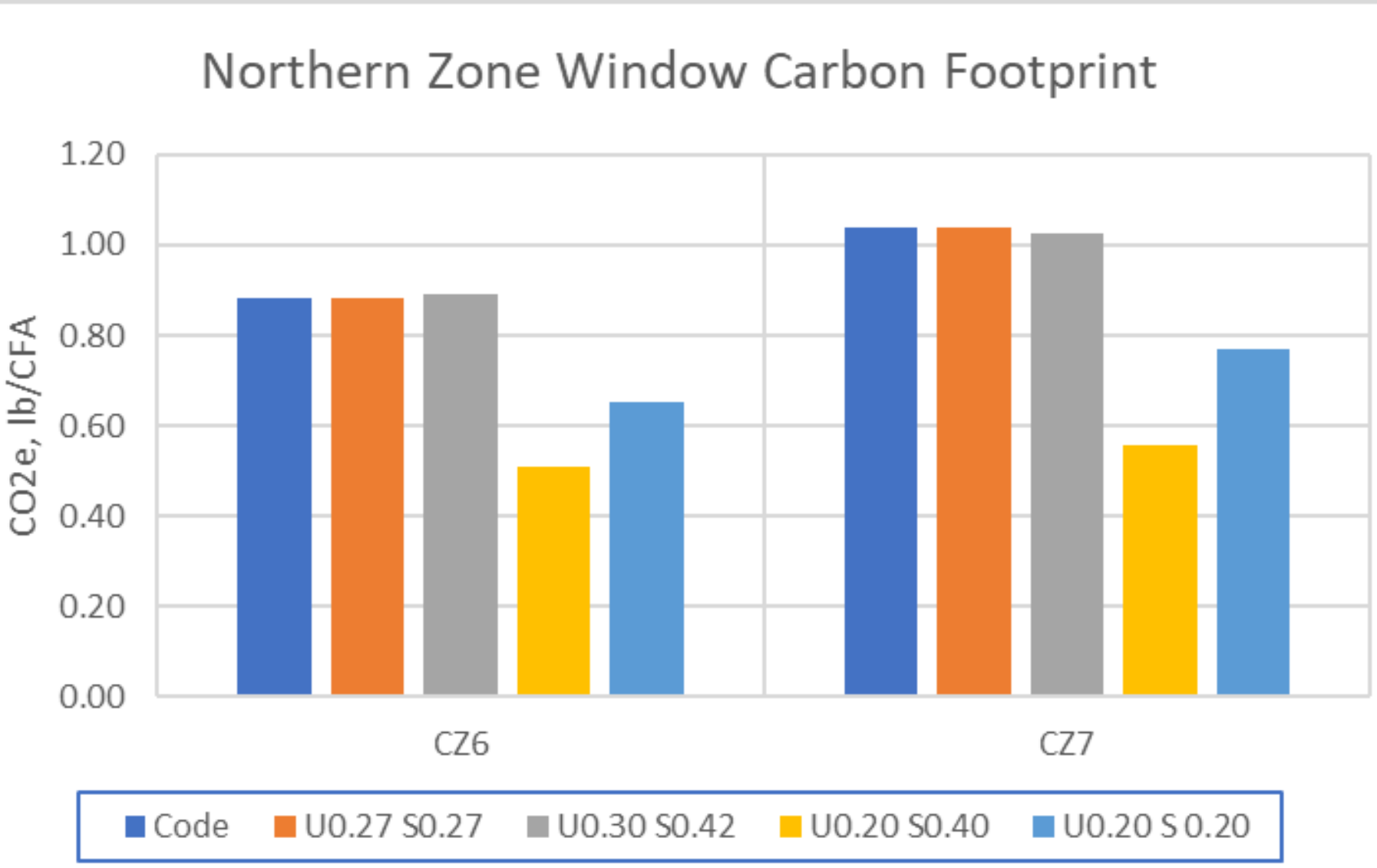

Southern Zone Window Energy Costs
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
$/CFA
CZ2
CZ3
Code
U0.35 S0.25
U0.30 S0.25
U0.30 S0.20


Southern Zone Window Carbon Footprint
CO2e, lb/CFA
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
CZ2
CZ3
Code
U0.35 S0.25
U0.30 S0.25
U0.30 S0.20


Central Zone Window Energy Costs
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
$/CFA
CZ4
CZ5
Code
U0.32 S0.40
U0.30 S0.40
U0.30 S0.20


Central Zone Window Carbon Footprint
CO2e, lb/CFA
1.20
1.00
0.80
0.60
0.40
0.20
0.00
CZ4
CZ5
Code
U0.32 S0.40
U0.30 S0.40
U0.30 S0.20


Northern Zone Window Energy Costs
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
$/CFA
CZ6
CZ7
Code
U0.27 S0.27
U0.30 S0.42
U0.20 S0.40
U0.20 S 0.20


Northern Zone Window Carbon Footprint
1.20
1.00
0.80
0.60
0.40
0.20
0.00
CO2e, lb/CFA
CZ6
CZ7
Code
U0.27 S0.27
U0.30 S0.42
U0.20 S0.40
U0.20 S 0.20

Conclusions

- Source energy is changing quickly (fuel mix)
- Climate Zone 5 should drop out of the Northern Energy Star Widnows grouping and merge into the Central
- More analysis to come!