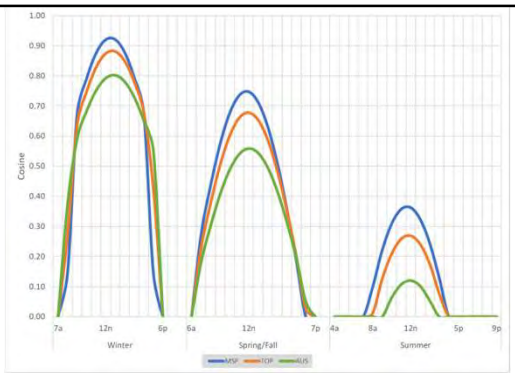
1 Million Energy Simulations
Doing More with Less

Jim Larsen
Cardinal Glass Industries

1

Today's Show is All About Trend Lines



2

Windows Matter

A Short Course
For the
11th Westford Symposium

3

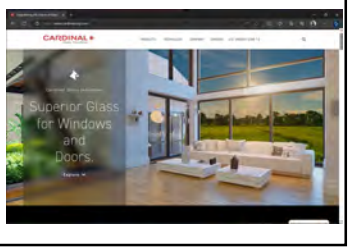
4

Who is Cardinal?

- OEM supplier to window manufacturer's

- We melt sand (float glass)
- Temper & laminate (safety glass)
- Low-E coatings
- Insulate (double & triple pane)

- 49 U.S. locations
- 10,000 employees



5


ORNL/TM-2022/XXX

Multi-variable Parametric Analysis of Prototype Building Energy Performance Using Current and Future Weather Scenarios For Data-Driven Market Transformation Support

OAK RIDGE NATIONAL LABORATORY

Brett Blass
Jim Lutsens
Ben Edwards
Chris Mathis
Joshua New

June 2022

OAK RIDGE National Laboratory

Variables Considered:

- 5 Building types
- 2006, 2018, +15% UA over 2018
- Base air tightness, -50%
- Slab-on-Grade foundation
- 15 locations (6 primary)
- Local/seasonal fuel costs
- Gas furnace, heat pump, High Eff options
- Equal, 50/50 front/back: N/S & E/W
- 4 Window-to-Wall area ratios (WR)
- 9 windows (trend analysis)

500,000 simulations!

6

Two Analyses: 1,000,000 Simulations

ENERGY STAR Windows

1. Single family house
2. 2006 vintage
3. 2006 air tightness
4. 4 foundations
5. 132 locations
6. Nat'l average fuel cost
7. 4 HVAC @ federal minimum
8. Equal windows on 4 sides
9. 15% WWR
10. 313 windows (no trend analysis)

Cardinal/ORNL

1. 5 Building types
2. 2006, 2018, +15% UA over 2018
3. Base air tightness, -50%
4. Slab-on-Grade foundation
5. 6 primary
6. Local/seasonal fuel costs
7. Gas furnace, heat pump, High Eff options
8. Equal, 50:50 front & back (N/S & E/W)
9. 3 or 4 Window-to-Wall area ratios
10. 9 windows (trend analysis)

7

First Things: Glass & Window 101

8

Windows Affect Building 24*7*365

1. Winter night insulation (lower U-Factor) reduces heating load and improves cold weather occupant comfort
2. Winter day solar gains offset heat losses, **but** these gains are highly orientation dependent and don't change the nighttime response
3. Solar gains in the "swing seasons" can lead to overheat where cooling wasn't normally required
4. Solar gains in the summer can be 50% of more of the cooling load; huge impact on peak load, AC equipment sizing, and occupant comfort

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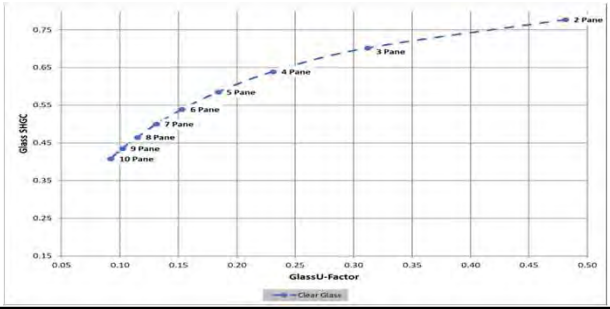
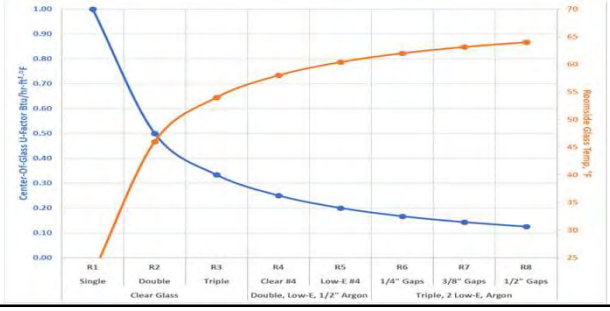
Rule of Panes



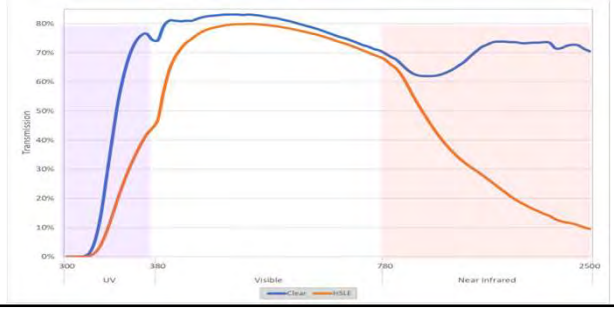
10

R-Value improves Comfort



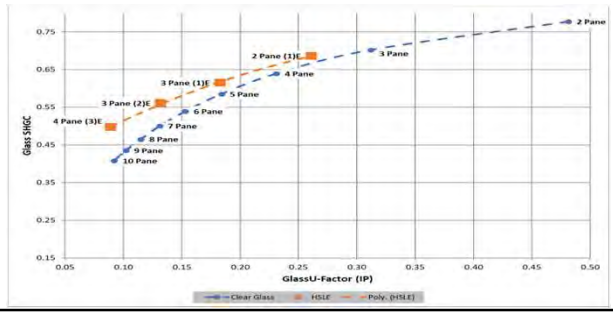
11

Clear (uncoated) Glass versus Low-E



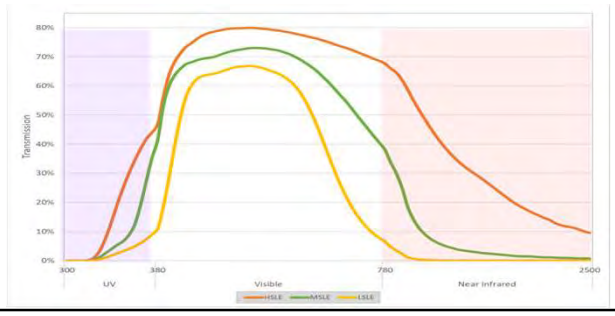
12

Low-E Coating Displaces Layers



13

High, Medium, Low Solar Gain Low-E



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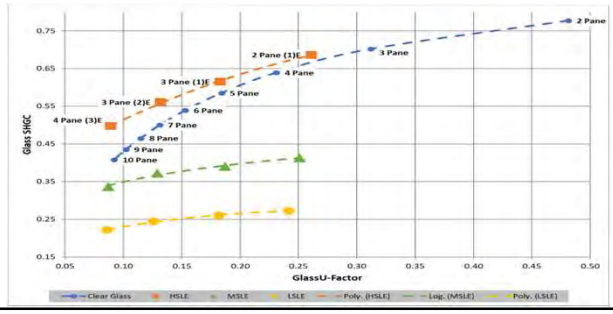
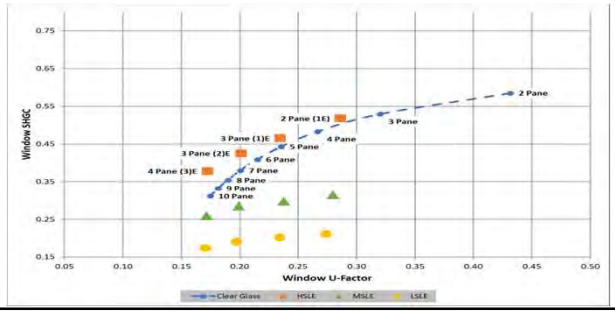
Multiple Solar Heat Gain Choices with Low-E



15

Don't Forget the Frame Effect



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Be Sure to Use Rated Windows

17

www.nfrc.org

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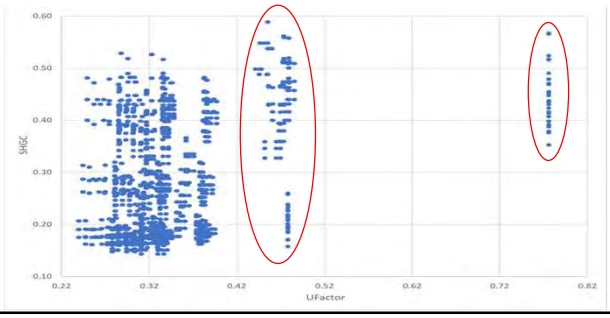
(1) Product Line: 7,446 Glass Options



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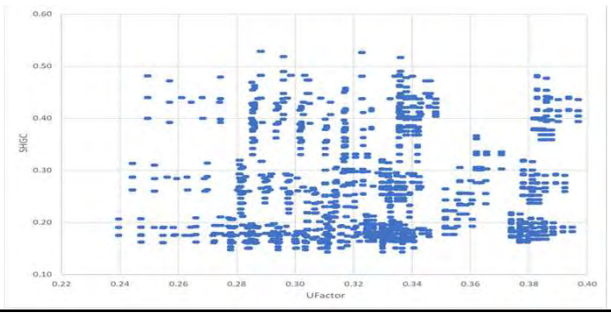
Filter to Low-E Glass (~3,400 options)



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Grid Bars

GRID CODES

Code	Description
G	Grids between the glass
N	No Grids
S	Simulated Divided Lites
T	True Divided Lites

GRID SIZE CODES

Code	Description
	Blank for no grids
0.75	Grids less than 1"
1.5	Grids greater than or equal to 1"

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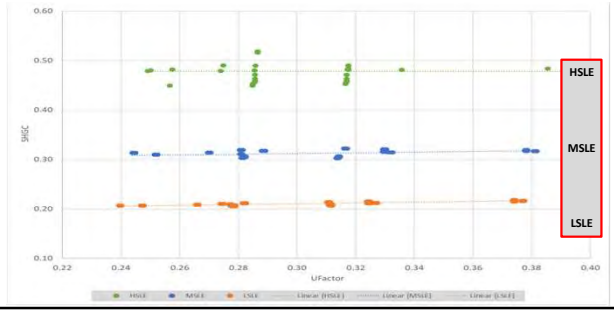
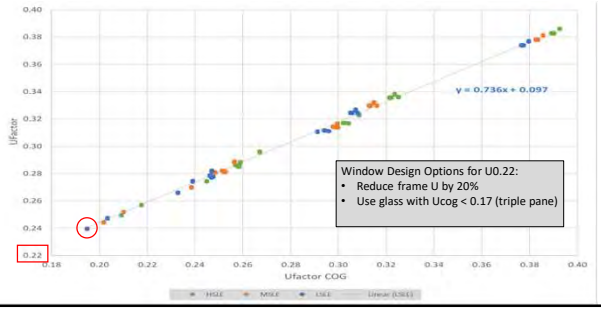
Simplify to Low-E without Grids



22

Uwindow vs. Uglass (COG)



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Simplify the Windows First

ENERGY STAR Windows
1. Single family house
2. 2006 vintage
3. 2006 air tightness
4. 4 foundations
5. 132 locations
6. Nat'l average fuel cost
7. 4 HVAC @ federal minimum
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1. 5 Building types
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9. 3 or 4 Window-to-Wall area ratios
10. 9 windows (trend analysis)

24

2-Parameter Linear Regression Analysis (LINEST)

- Credit LBNL for (first) use in 2008 ENERGY STAR Windows analysis
- Excel outputs formula in the form: Y = **± m2***SHGC + **m1***U + **b**
  - Y = energy, dollars, or carbon
    - -adding Heat & Cool together must account for energy source (e.g. gas heat vs. electric cool)
  - **± m2** = regression coefficient for window SHGC
  - **m1** = regression coefficient for window U-Factor
  - **b** = "opaque" building

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Window Regression Research

- Started with (21) U-Factors in increments of 0.1 W/m²·°C from Usi=3.0 to Usi=1.0 (2p Clr to 2p w/low-E to 3p w/2E)
- (21) SHGC from 0.1 to 0.5 in increments of 0.02
- 441 options
- Slightly better "fit" with bi-quadratic versus linear regression
- Validated 3U * 3S represents full matrix of options

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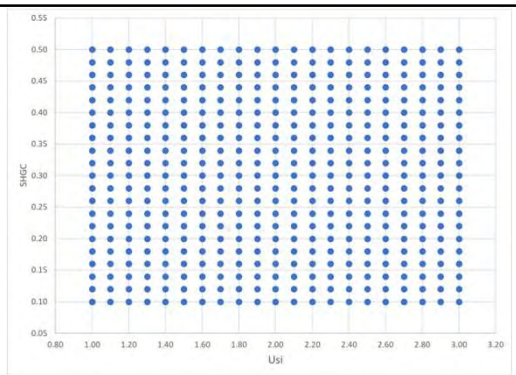
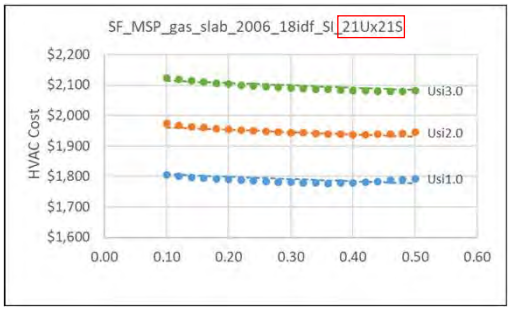


27

Linear: $$ = -75*SHGC + 154*Usi + 1,661



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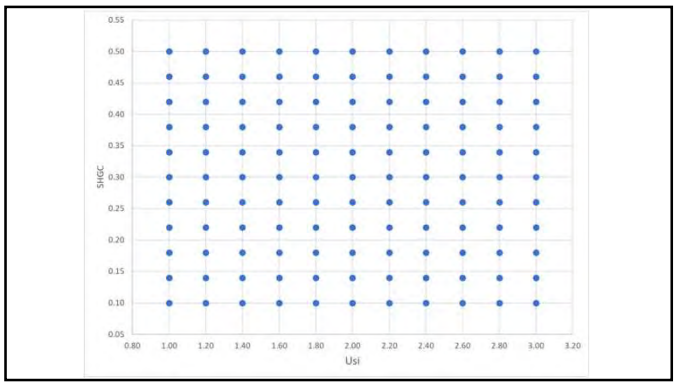

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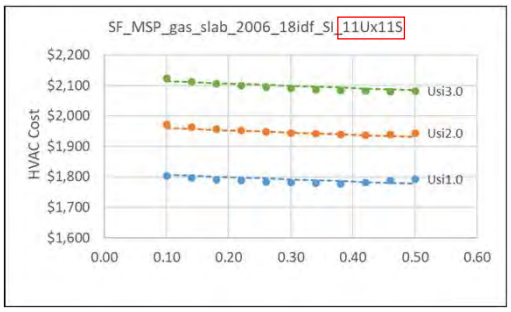
$$ = -74*SHGC + 154*Usi + 1,661



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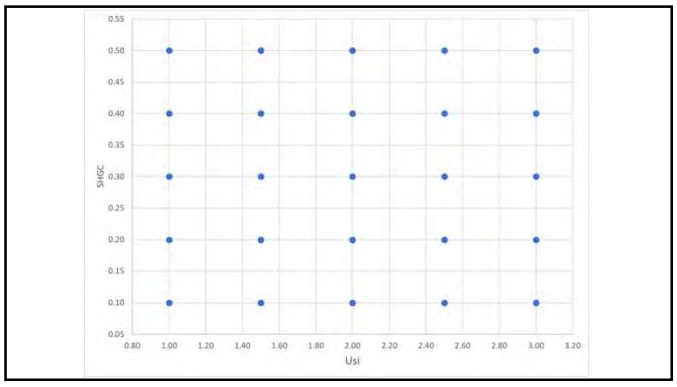
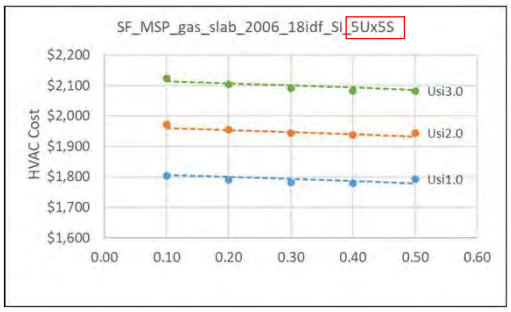


31

$$ = -72*SHGC + 154*Usi+ 1,661



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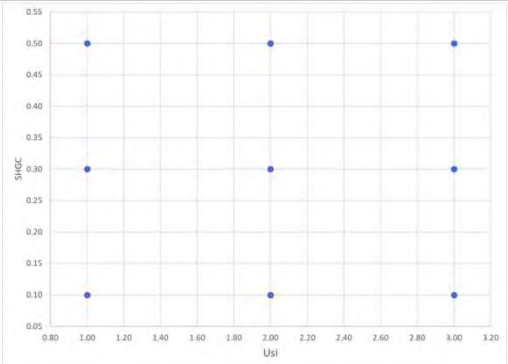
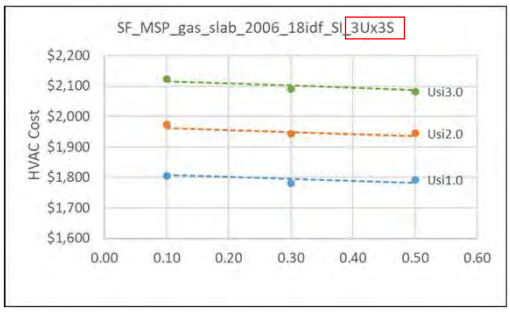


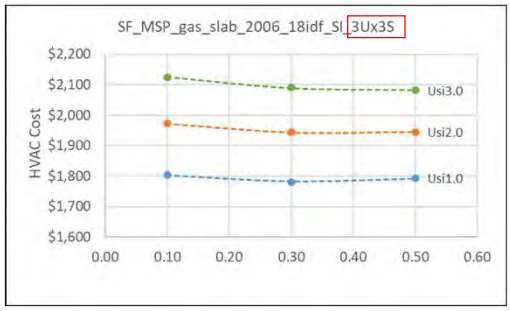
33

$$ = -68*SHGC + 153*Usi + 1,663



34

$$ = +380*SHGC² - 219*SHGC - 8.0*Usi²+ 198*Usi + 1,636



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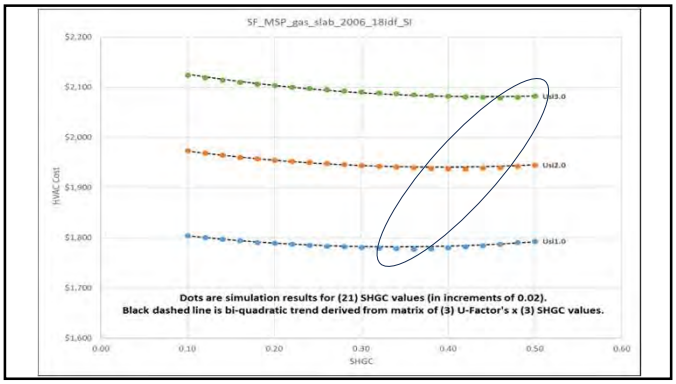

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Attribute Important to Window Energy Analysis?

ENERGY STAR Windows
1. Single family house

Cardinal/ORNL
1. 5 Building types

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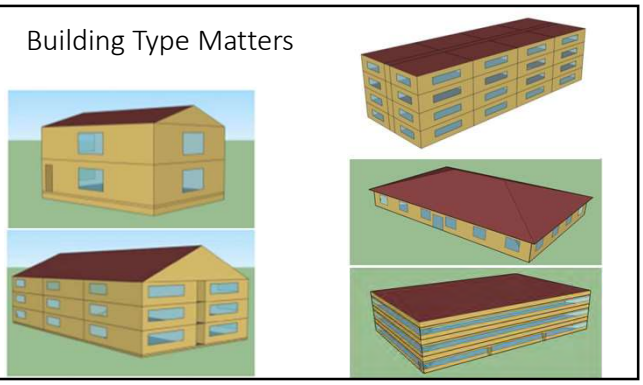
Building Type Matters



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Attribute Important to Window Energy Analysis?

ENERGY STAR Windows
~~1. Single family house~~
2. 2006 vintage

Cardinal/ORNL
~~1. 5 Building types~~
2. 2006, 2018, +15% UA over 2018

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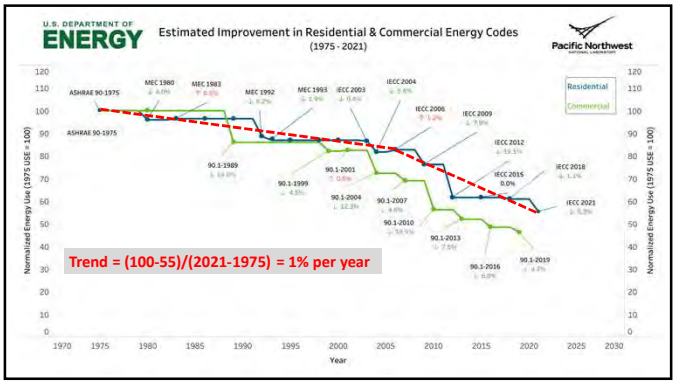

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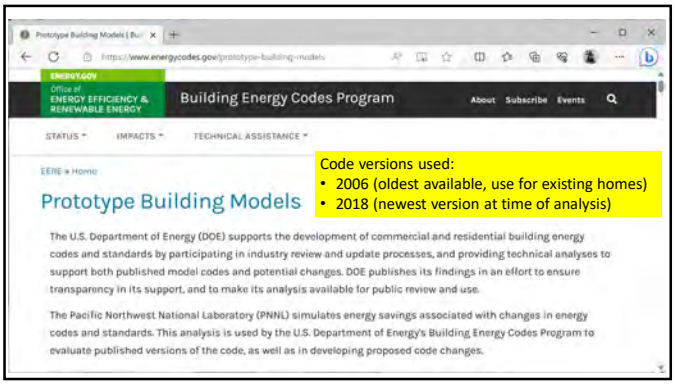

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Attribute Important to Window Energy Analysis?

ENERGY STAR Windows	Cardinal/ORNL
~~1. Single family house~~	~~1. 5 Building types~~
~~2. 2006 vintage~~	~~2. 2006, 2018, +15% UA over 2018~~
3. 2006 air tightness	3. Base air tightness, -50%

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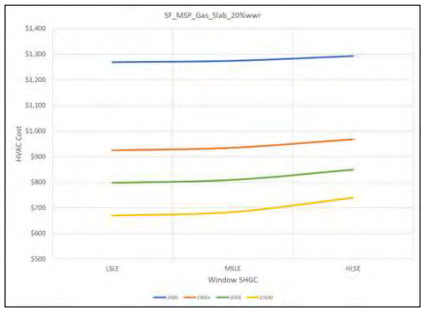
- Air leakage affects building energy costs
- Small change to window trends
- Newer air-tight building sensitive to solar overheat? (bottom line)



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Attribute Important to Window Energy Analysis?

ENERGY STAR Windows	Cardinal/ORNL
~~1. Single family house~~	~~1. 5 Building types~~
~~2. 2006 vintage~~	~~2. 2006, 2018, +15% UA over 2018~~
~~3. 2006 air tightness~~	~~3. Base air tightness, -50%~~
4. 4 foundations	4. Slab on Grade

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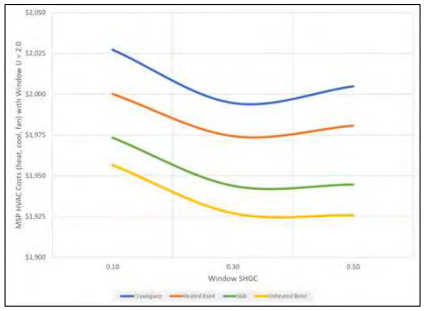
Foundation effects:

- Equipment in or outside of thermal envelope
- Change in conditioned volume (heated basement)
- Does not change window trends



45

Simplify to Slab for all Buildings?

Existing Homes

- About 1/3 each for basement, crawlspace, and slab-on-grade

New Construction

- 50% slab-on-grade
- 25% each for crawlspace and basement

Shift in type due to geographics of home construction or change in building practices?

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Attribute Important to Window Energy Analysis?

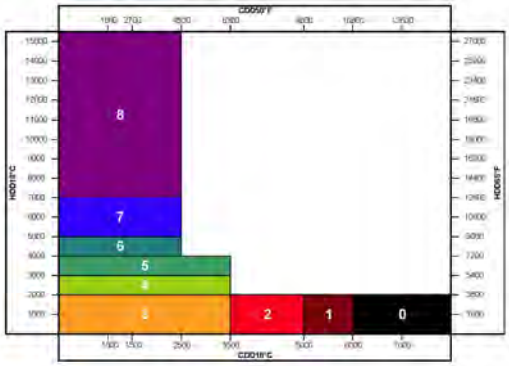
ENERGY STAR Windows

1. ~~Single family house~~
2. ~~2006 vintage~~
3. ~~2006 air tightness~~
4. ~~4 foundations~~
5. 132 locations

Cardinal/ORNL

1. ~~5 Building types~~
2. ~~2006, 2018, +15% UA over 2018~~
3. ~~Base air tightness, -50%~~
4. ~~Slab on Grade~~
5. 6 primary locations

47



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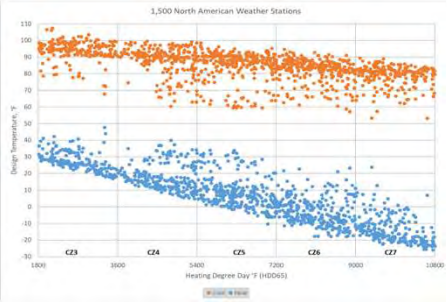
1% Design Temperature Conditions



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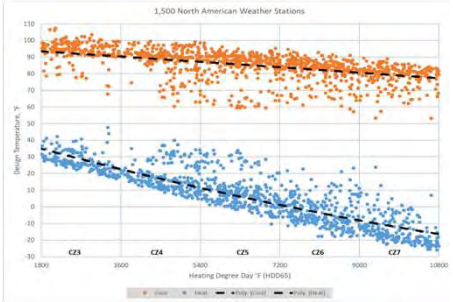
Design Temp vs. Degree Day Trendline



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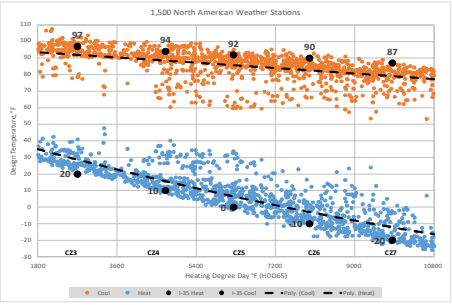
Representative Cities



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10°F Heat ΔT per zone, 2°F Cool ΔT per zone

Climate Zone	Heating Design	Cooling Design
7 (DLH)	-20°F (-25°C)	87°F (31°C)
6 (MSP)	-10°F (-20°C)	90°F (32°C)
5 (DSM)	0°F (-15°C)	92°F (33°C)
4 (TOP)	10°F (-10°C)	94°F (34°C)
3 (OKC)	20°F (-5°C)	97°F (35°C)
2 (AUS)	30°F (0°C)	98°F (36°C)

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I-35 Climate Analysis

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Attribute Important to Window Energy Analysis?

ENERGY STAR Windows

1. ~~Single family house~~
2. ~~2006 vintage~~
3. ~~2006 air tightness~~
4. ~~4 foundations~~
5. ~~132 locations~~
6. Nat'l average fuel costs

Cardinal/ORNL

1. ~~5 Building types~~
2. ~~2006, 2018, +15% UA over 2018~~
3. ~~Base air tightness, -50%~~
4. ~~Slab on Grade~~
5. ~~6 primary locations~~
6. Local/seasonal fuel costs

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How to add Heat and Cool together?

- Heat and Cool are often different fuels with different costs (gas heat vs. electric cool)
- Different equipment efficiencies; AFUE vs. SEER
- Different seasonal efficiencies (and capacities!) with heat pumps; HSPF vs. SEER
- Seasonal fuel rates?

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Heating and Cooling Energy

1. Site
   - Output of energy simulation analysis/building measurement
2. Source
   - With the wide range of electricity sources; does this still have value?
3. Dollars
   - Consumer signal; captures cost of fuel and infrastructure to deliver energy
4. Carbon
   - Environmental signal

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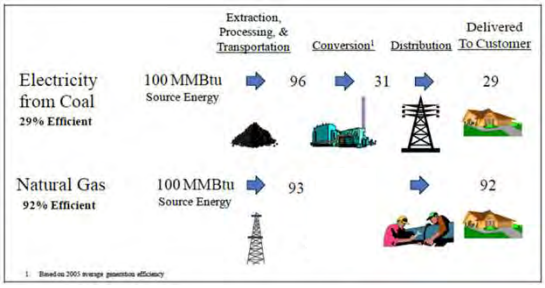
Site versus Source Energy



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Cost is the recognized measure in the national energy code.

SECTION R405
TOTAL BUILDING PERFORMANCE

R405.1 Scope. This section establishes criteria for compliance using total building performance analysis. Such analysis shall include heating, cooling, mechanical ventilation and service water-heating energy only.

R405.2 Performance-based compliance. Compliance based on total building performance requires that a *proposed design* meets all of the following:

1. The requirements of the sections indicated within Table R405.2.
2. The building thermal envelope greater than or equal to levels of efficiency and solar heat gain coefficients in Table R402.1.1 or R402.1.3 of the 2009 *International Energy Conservation Code*.
3. An annual energy cost that is less than or equal to the annual energy cost of the *standard reference design*. Energy prices shall be taken from a source *approved* by the *code official*, such as the Department of Energy, Energy Information Administration's State Energy Data System Prices and Expenditures reports. Code officials shall be permitted to require time-of-use pricing in energy cost calculations.

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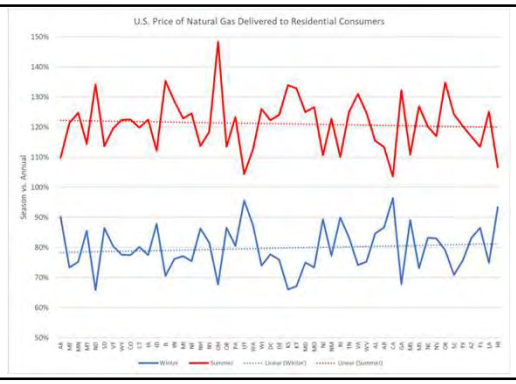

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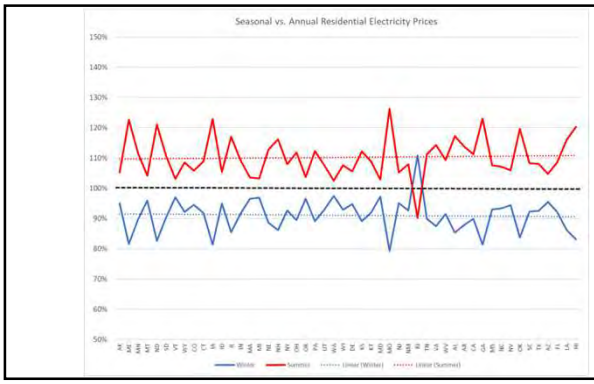

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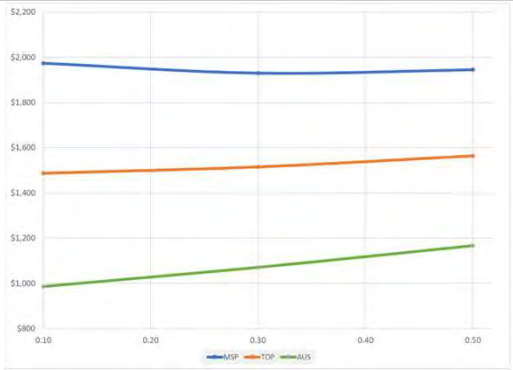
HVAC Costs vs. SHGC and Climate Zone



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Attribute Important to Window Energy Analysis?

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7. 4 HVAC @ federal minimums	7. Gas furnace, heat pump, High Eff options

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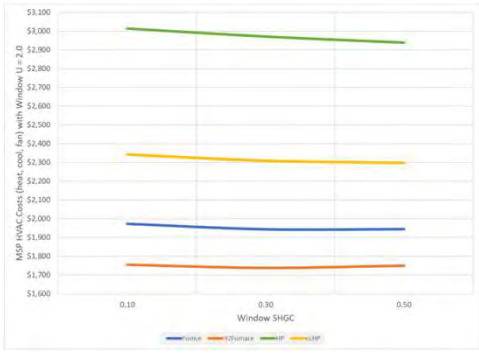
Big Changes with HVAC Type and COP



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~~5. 132 locations~~	~~5. 6 primary locations~~
~~6. Nat'l average fuel costs~~	~~6. Local/seasonal fuel costs~~
~~7. 4 HVAC @ federal minimums~~	~~7. Gas furnace, heat pump, High Eff options~~
8. Equal windows on 4 sides	8. Equal, 50:50 front & back, N/S & E/W

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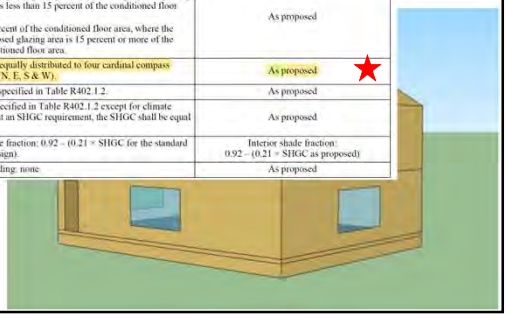
TABLE R405.4.2(1)
SPECIFICATIONS FOR THE STANDARD REFERENCE AND PROPOSED DESIGNS

BUILDING COMPONENT	STANDARD REFERENCE DESIGN	PROPOSED DESIGN
Vertical fenestration other than opaque doors	Total area[b] = (a) The proposed glazing area, where the proposed glazing area is less than 15 percent of the conditioned floor area. (b) 15 percent of the conditioned floor area, where the proposed glazing area is 15 percent or more of the conditioned floor area.	As proposed
	Orientation: equally distributed to four cardinal compass orientations (N, E, S & W).	As proposed ★
	U-factor: as specified in Table R402.1.2.	As proposed
	SHGC: as specified in Table R402.1.2 except for climate zones without an SHGC requirement, the SHGC shall be equal to 0.40.	As proposed
	Interior shade fraction: 0.92 – (0.21 × SHGC for the standard reference design).	Interior shade fraction: 0.92 – (0.21 × SHGC as proposed)
	External shading: none	As proposed



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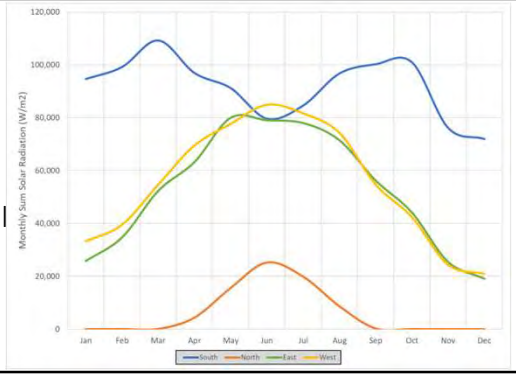
Solar Gain on Vertical Wall



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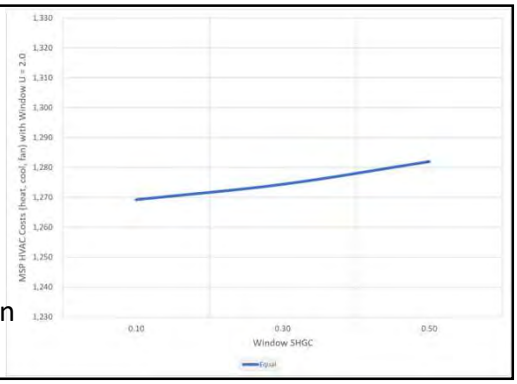
Energy Costs w/SHGC at U=0.34 "Equal" Distribution



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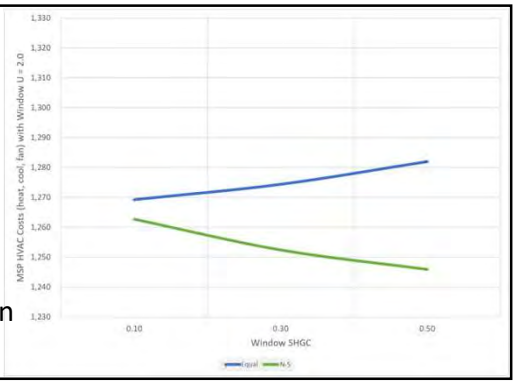
Energy Costs w/SHGC at U=0.34 "N-S" Distribution



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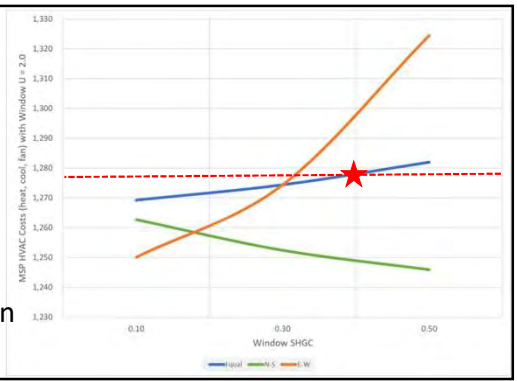
Energy Costs w/SHGC at U=0.34 E-W Distribution



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Attribute Important to Window Energy Analysis?

ENERGY STAR Windows	Cardinal/ORNL
~~1. Single family house~~	~~1. 5 Building types~~
~~2. 2006 vintage~~	~~2. 2006, 2018, +15% UA over 2018~~
~~3. 2006 air tightness~~	~~3. Base air tightness, -50%~~
~~4. 4 foundations~~	~~4. Slab-on-Grade foundation~~
~~5. 132 locations~~	~~5. 15 locations (6 primary)~~
~~6. Nat'l average fuel cost~~	~~6. Local/seasonal fuel costs~~
~~7. 4 HVAC @ federal minimum~~	~~7. Gas furnace, heat pump, High Eff options~~
~~8. Equal windows on 4 sides~~	~~8. Equal, 50:50 front & back: N/S & E/W~~
9. 15% WWR	9. 4 Window-to-Wall area ratios (WR)

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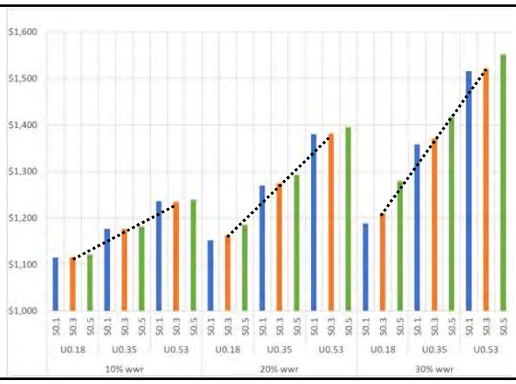
3 Areas
*
3 U
*
3 SHGC



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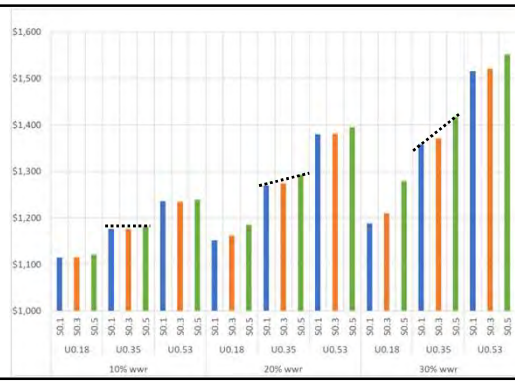
3 Areas
*
3 U
*
3 SHGC



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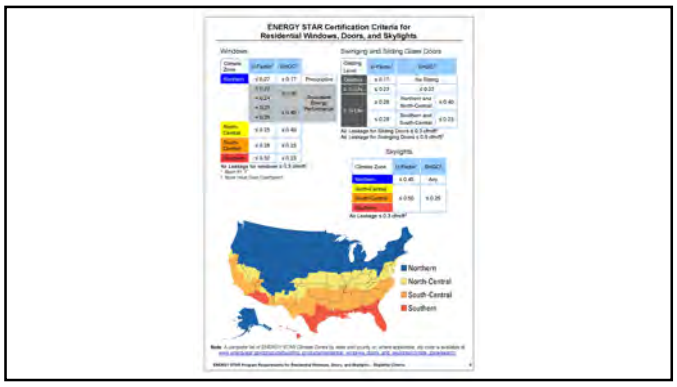

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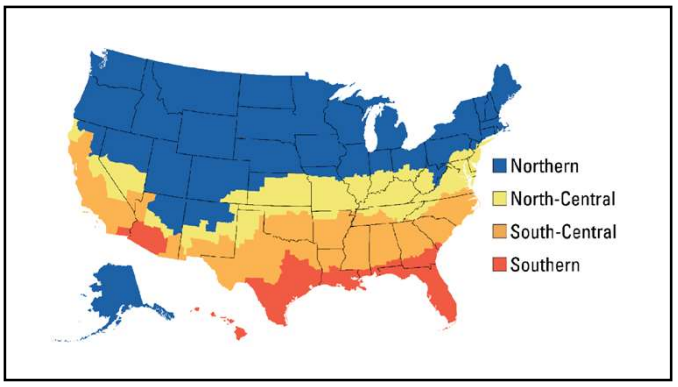

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Windows

Climate Zone	U-Factor[1]	SHGC[2]	
Northern	≤ 0.22	≥ 0.17	Prescriptive
	= 0.23	≥ 0.35	Equivalent Energy Performance
	= 0.24		
	= 0.25	≥ 0.40	
	= 0.26		
North-Central	≤ 0.25	≤ 0.40	
South-Central	≤ 0.28	≤ 0.23	
Southern	≤ 0.32	≤ 0.23	

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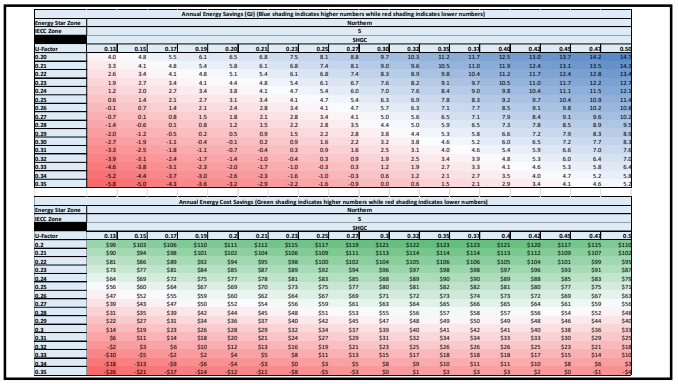

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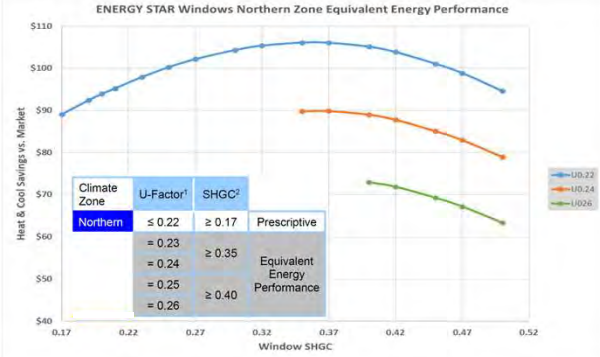

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My Key Messages

- Simplified window regression allows for more in-depth building analysis
- Orientation matters!
- Future buildings (improved UA) reduces the benefit of "free" solar gain
- Electrification & Decarbonization requires "Cold-Climate" heat pumps
- Need more analysis on future weather (climate change) versus building design
- This style of "trend analysis" supports all building analysis. Could be extended to comparisons of various energy modeling programs.

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Thank you
ALL!

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