Center for Energy and Environment

Energy Savings with Window Retrofits

Presentation to

Energy Design Conference & Expo

Duluth, MN

February 25, 2014

Agenda

- Background
- Introduction: What are window retrofits?
- A peak at the results
- Determining energy savings
- Residential building results
  - Residential total energy use profile
- Commercial building results
  - DOE standard buildings
  - Total energy use profiles
- Opportunities for market transformation
- Other products not included in the study

Project Background

- Minnesota Department of Commerce, Division of Energy Resources 2012 Conservation Applied Research and Development (CARD) project
  - "Window Retrofit Technologies for Increased Energy Efficiency without Replacement"
  - Determine cost-effectiveness
  - Must create persistent savings
  - Assumes energy performance of many windows can be improved prior to the time they need to be replaced

The Project Team

- Center for Energy and Environment
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  - Chris Plum
  - Christie Traczyk
- Center for Sustainable Building Research
  - John Carmody
  - Kerry Haglund

About CEE

About CSBR

Introduction: What are window retrofits?

- Anything added to an existing window
  - Blinds
  - Shades
  - Curtains
  - Shutters
  - Awnings
  - Screens
  - Exterior storm windows
  - Interior storm windows (panels)
  - Window films
  - New products
    - Electrochromic inserts
    - Solar films

Technologies in our scope

- Window panels
  - Also called “Interior Storm Windows,” always save energy
- Window films
  - Primarily save cooling energy
  - Many products available, a few were found to save energy
  - The lower solar heat gain (tinted windows) often increases heating needs in winter, due to loss of warming sun
- Excluded technologies that require manual intervention and new higher cost technologies
  - Blinds, curtains, shades and shutters
  - Electrochromic windows, solar window films

Background of this project

- Explore the potential for energy savings
- Focus is window panels and window films
- Residential and commercial uses
- Literature review
- Current product review
- Industry and building owner survey
- Modeling of technologies to determine cost-benefit
  - RESFEN, COMFEN, and ENERGY PLUS
- Suggest strategies for implementation

Baseline: Current MN window stock

- Double pane glazing was 45% of all windows in 1980, is now 97%.
- In 2005 56% of all new windows had a low-e coating
- Windows are typically replaced every 40 years
- There are over 2 million housing units in MN, 24% are apartments
- There are over 120,000 commercial buildings in MN
- Over 800,000 windows are installed annually (2.5%)
- Approximately 2/3 of window area is for residential windows

Window films

www.efficientwindowcoverings.org/understanding-window-coverings/applied-film

Free Hotmail XcelEnergy Bookmarks

NFRC's Window Film Energy Performance Label

Overall Thermal Performance

For a specific application, users can assess the amount of solar heat gain through a window with film based on the solar heat gain coefficient (SHGC) and visible transmittance (VT) rating listed on the film's National Fenestration Rating Council (NFRC) label (see page 1). Window films were the first—and so far only—window attachment option to be rated by the NFRC.

Key Benefits

- Reduce solar heat gain through windows (many different films are available with widely varying solar heat gain rejection properties)
- Reduce heat loss when low-e coating is applied as the innermost exposed layer of the film
- Reduce glare and eye strain (some films are designed specifically for these benefits)
- Block UV very effectively (95-99.9%)
- Provide privacy (films with high reflectance or "mirroring")
- Enhance security and safety (some films designed specifically for these benefits)
- No operation or maintenance

The window on the left has no film; the window on the right does. How much a film alters the appearance of the window (inside and out) depends on a number of variables and is difficult to generalize because there are currently so many different films

from the outside.

When to consider this retrofit—Window conditions

- ✓ Existing window single-glazed
- ✓ Existing window double-glazed, no low-e*
- ✓ Existing window double-glazed with low-e

* Applying a non-low-e surface film to a low-e window makes the most sense

Recommended Installer

- ✓ Do it Yourself
- Carpenter
- ✓ Manufacturer or supplier

Once applied, films are treated and maintained just like the original glass. Today's state-of-the-art films are more scratch and UV-resistant.

Photo: Eastman Chemical Company

Complementary Options

Compatible with any window attachment but work best with:

- Exterior storm windows
- Window unit air sealing

Operation

www.efficentwindowcoverings.org

Window panels

Interior glass window panels are heavier than plastic but more durable (although they can be broken), less likely to be scratched during cleaning, and available with low-emissivity (low-e) coatings that increase thermal insulation for improved energy efficiency and thermal comfort.

Terminology

The attachments described in this fact sheet are often called "interior storm windows," but that's a misleading term, since they really don't offer any storm protection. Here, we will refer to them as interior window panels.

Tracked interior window panels are just like exterior storms, but permanently installed on the inside of the window. With integral screens, they adjust for ventilation. Made of glass, they are durable, clean easily, and are available with low-e coatings.

Photo: BuildingGreen

Overall Thermal Performance

Interior window panels, when properly installed and deployed, bring a window's performance close to that of a double-paned clear window, by reducing air leakage and increasing thermal insulation. Interior glass window panels with low-e coatings bring a window's overall thermal performance close to the performance of a new double-paned low-e window.

When existing windows suffer from air leakage, a tight-fitting

When To Consider

- Historic codes, covenants, or condominium association rules preclude installation of exterior storm windows.
- Additional insulation needed for windows on upper floor where installation of exterior storm windows is difficult.
- Renters are reluctant to invest in more permanent window treatments, such as exterior low-e storm windows.
- Existing windows are leaky.
- Climate is moderate or cold and additional window insulation during heating season is desirable.
- Climate is hot, and interior window panel with solar heat gain control coating reduces need for interior cooling in warm season.
- Window egress is not an issue.

When to consider this retrofit—Ownership

✓	Homeowner
✓	Apartment Renter - Long Term
	Apartment Renter - Short Term
✓	Live in a Condo
✓	Live in a Historical District

When to consider this retrofit—Window conditions

✓	Existing window single-glazed
✓	Existing window double-glazed, no low-e*
	Existing window double-glazed with low-e

*low-emissivity coating

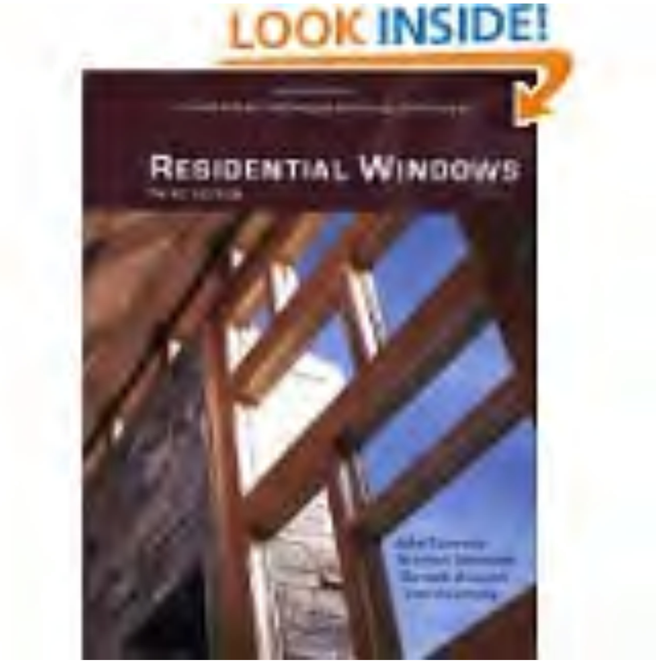
Recommended Installer

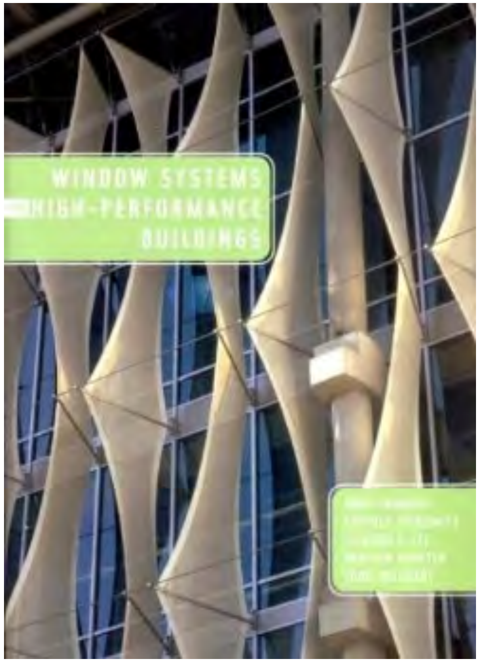
✓	Do it yourself
✓	Carpenter
	Manufacturer or supplier

Complementary Options

Literature Review

- Hundreds of articles are available
- Our team includes experts conversant in all of them





More Background on Windows

- The Impact of Window Energy Efficiency and How to Make Smart Choices
  - Webinar by John Carmody and Kerry Haglund available at http://mncee.org/Innovation-Exchange/Events-And-Webinars/The-Impact-of-Window-Energy-Efficiency-and-How-to-/

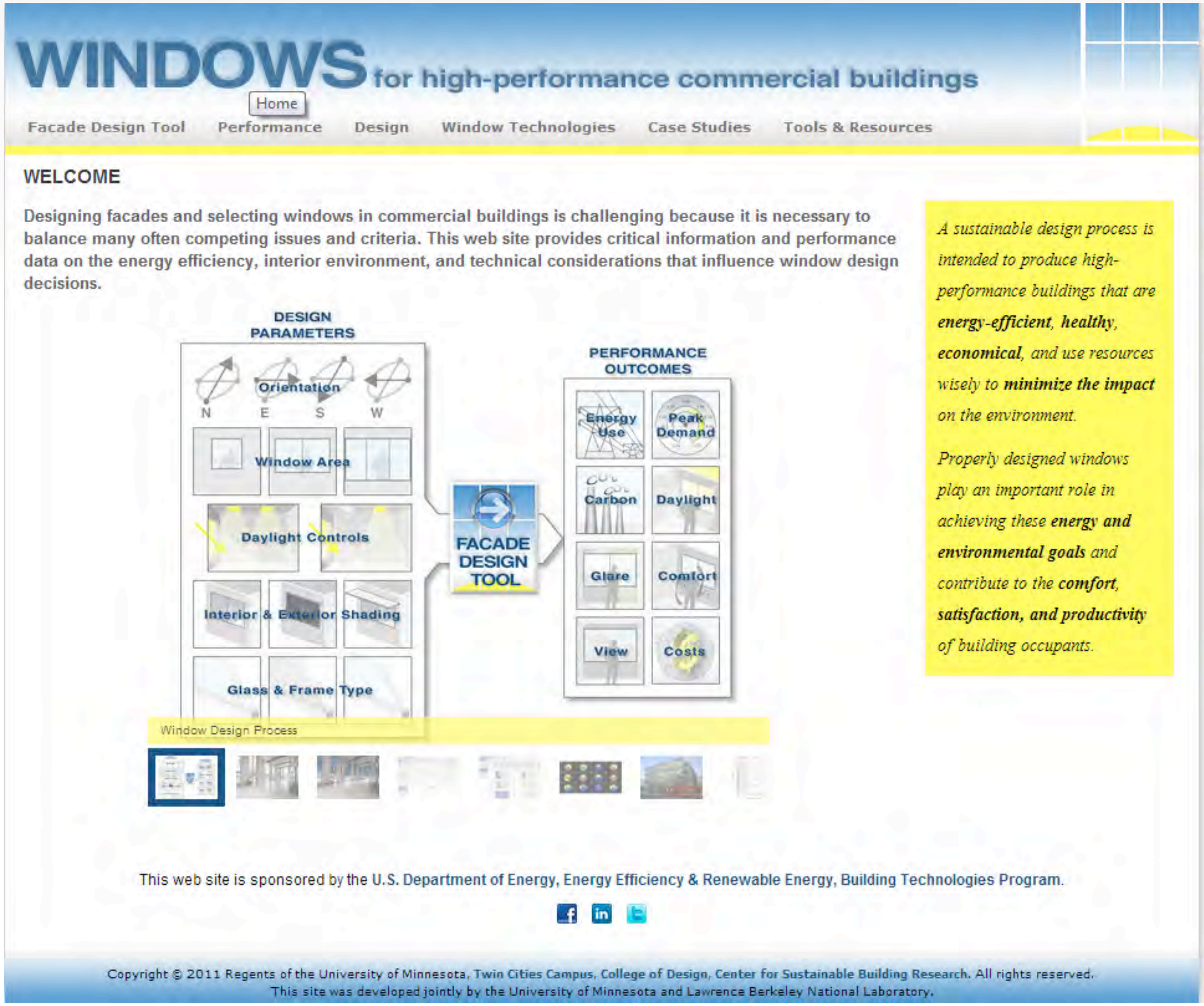
- Course offered at the University of Minnesota's Center for Sustainable Building Research

http://www.csbr.umn.edu/research/aia2030training.html

Web based tools exist for new construction

- CSBR is an active participant in all of these
- Commercial Windows
  - http://www.commercialwindows.org/
  - Joint development effort of University of Minnesota's Center for Sustainable Building Research, Lawrence Berkeley National Laboratory and Building America
- Efficient Windows (Residential)
  - http://www.efficientwindows.org/
- Efficient Window Coverings (Residential and Commercial)
  - http://www.efficientwindowcoverings.org/

http://www.commercialwindows.org/



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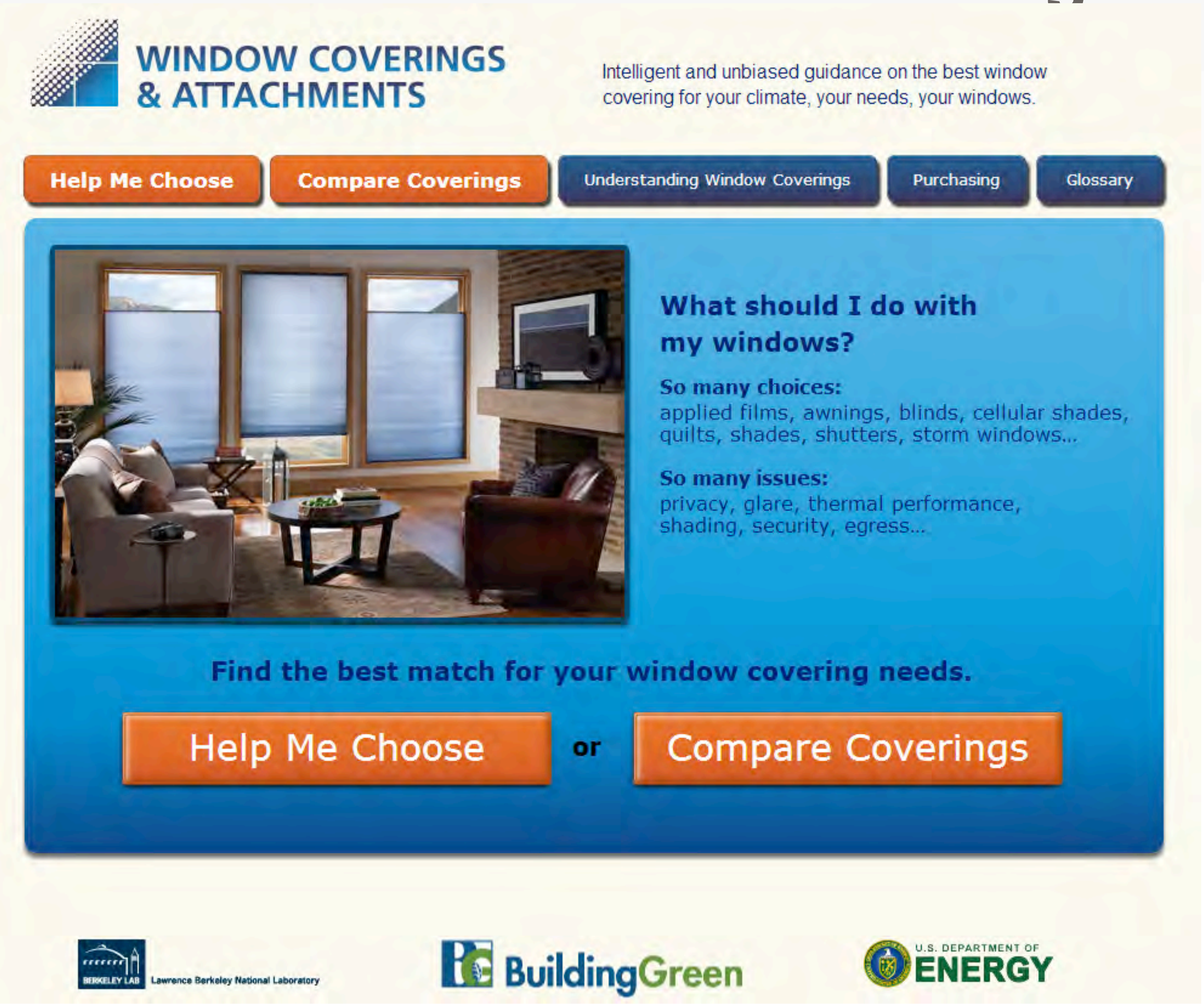
http://www.efficientwindows.org/

http://www.efficientwindowcoverings.org/



A peak at the results

- ❖ Adding a panel (inside or outside) to an existing window saves the same amount of energy as upgrading to a new window with one more pane
  - But costs much less
  - Turns a double pane window into a triple pane one
  - For buildings with single pane glass, results will be even better
- ❖ More heating, less cooling than other parts of the US
  - Winter sun helps more than summer sun hurts
- ❖ Low-e coatings (films or on a panel) that keep heat from passing through window can increase energy use in some cases
  - Keeps solar heat out when it is desirable

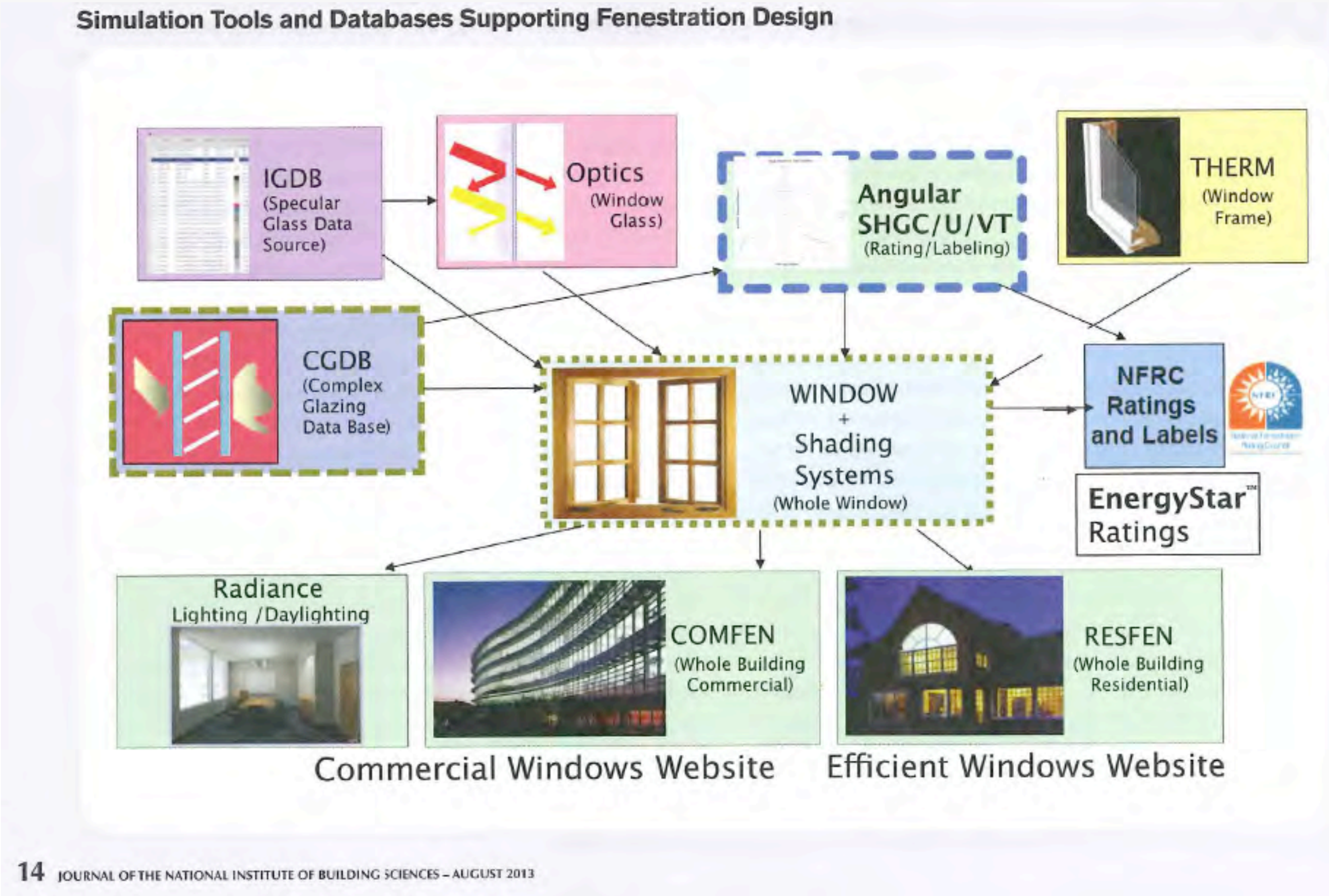
Determining energy savings

- ❖ Energy Modeling is used
  - Established methods
  - Standard buildings
  - Representative of 2/3 of the state's building stock
- ❖ Change the windows but leave everything else the same
- ❖ Model output is energy used by heating, cooling, lighting, hot water, plugs loads, fans, pumps and motors

Energy Modeling

- Levels of modeling
  - Components
  - Assemblies
  - Room
  - Whole Building
- How our modeling software fits best practices
  (Journal of National Institute of Building Sciences)

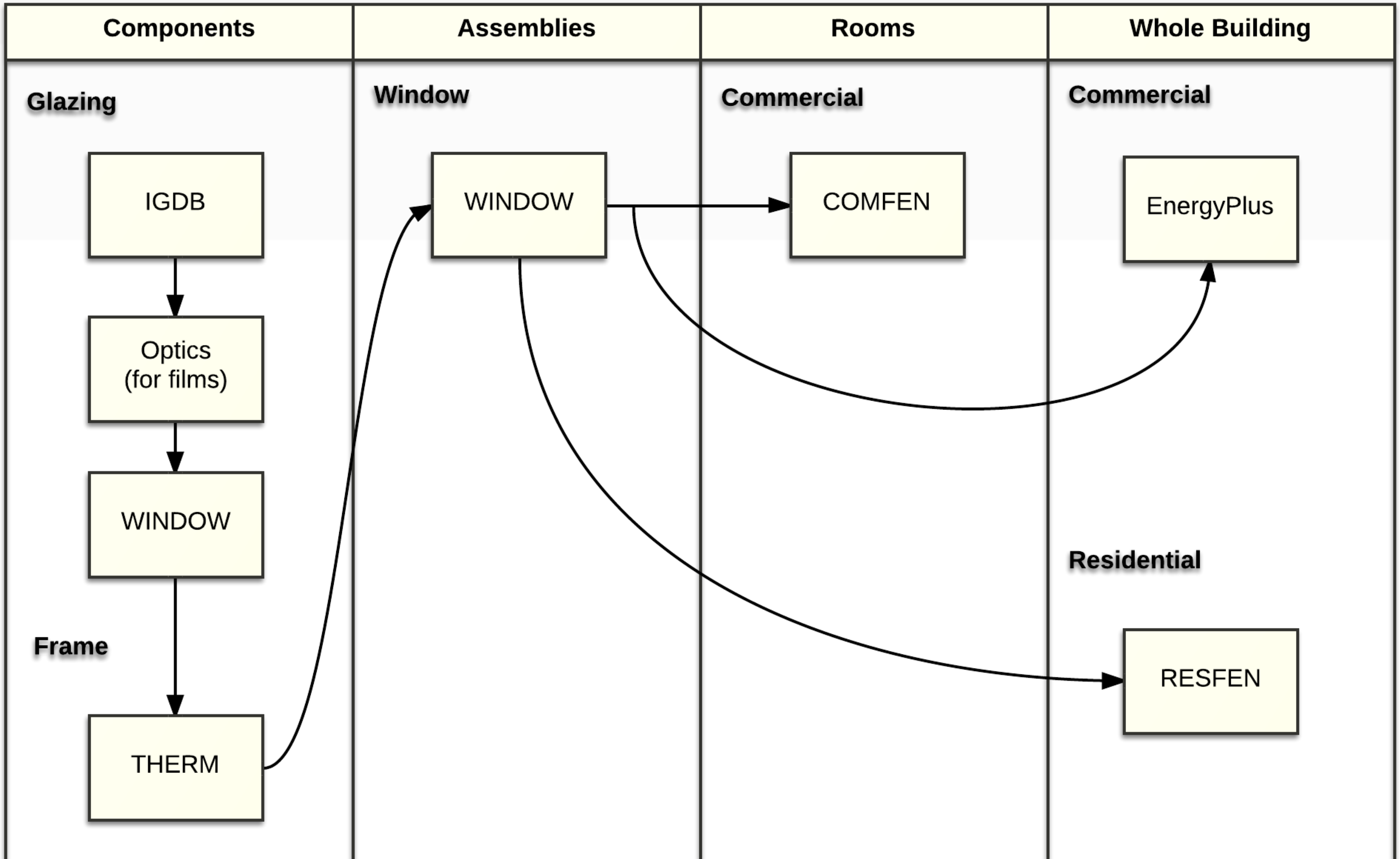
Energy Modeling



Energy Modeling

- Levels of modeling
  - Components
  - Assemblies
  - Room
  - Whole Building
- How our modeling software fits best practices (Journal of National Institute of Building Sciences)
- Our use of modeling software

Energy Modeling



Energy Modeling

- Levels of modeling
  - Components
    - Frame [THERM]
      - Get U-value for frame components
    - Glazing [WINDOW]
      - Get U-value for glazing unit
  - Assemblies
    - Frame and Glazing becomes Window [WINDOW]
      - Get total window U-value, SHGC, and Visual Transmittance in accordance with NFRC

Energy Modeling

- Levels of modeling (continued)
  - Room [COMFEN]
    - Frame and Glazing into wall in room
      - Get fenestration annual energy use
  - Whole Building (Commercial) [EnergyPlus]
    - Window properties into all windows in the building
      - Get entire building annual energy use
  - Whole Building (Residential) [RESFEN]
    - Window properties into all windows in the building
      - Get entire building annual energy use

Energy Modeling

- Energy Modeling so far
  - NFRC Class on WINDOW, THERM, Optics
  - Modeled 350 runs with COMFEN
    - Storefront window system
    - Runs
      - Full scale U-values (0.25-1.0)
      - Full scale SHGC (0.2-0.8)
      - Full scale VT (0.2-0.8)
      - Full scale WWR (5-55%)

Energy Modeling

❖ Energy Modeling so far

- Modeled ~4,000 runs with EnergyPlus
  - Building types

Large Office	Primary School	Midrise Apartment
Small Office	Secondary School	Stripmall

  - Building construction dates

Pre 1980	1980-2004	Post 2004 (NC)

  - Building Window to Wall Ratio
    - + Only used default so far

Energy Modeling

❖ Energy Modeling for this project

- Modeled ~4,000 runs with EnergyPlus
  - Specific product runs:
    - Solar blocking window film
    - Interior panel with clear acrylic
    - Interior panel with LowE acrylic
  - Other runs:
    - Full scale U-values (0.25-1.25)
    - Full scale SHGC (0.1-0.9)
    - Full scale VT (0.1-0.9)
- Modeled a variety of residential buildings with RESFEN
  - Validated the published research of DOE/PNNL

Residential building results

- Houses are “envelope driven” so window improvements will save energy
  - Assuming installation is done properly
- Clear window panels create ‘triple pane’ windows
  - Lower cost than a window replacement
- Adding a low e coating (either with an applied film or on the window panel) usually improves performance

Residential total energy use profile

- Over half of the typical home's energy is for heating and cooling
- Highly dependent on occupant behavior
  - Thermostat set point and setback
  - Use of curtains or shades
- Highly dependent on the local environment
  - Shading from trees
  - Protection from wind
  - Orientation of windows (where are south and west?)

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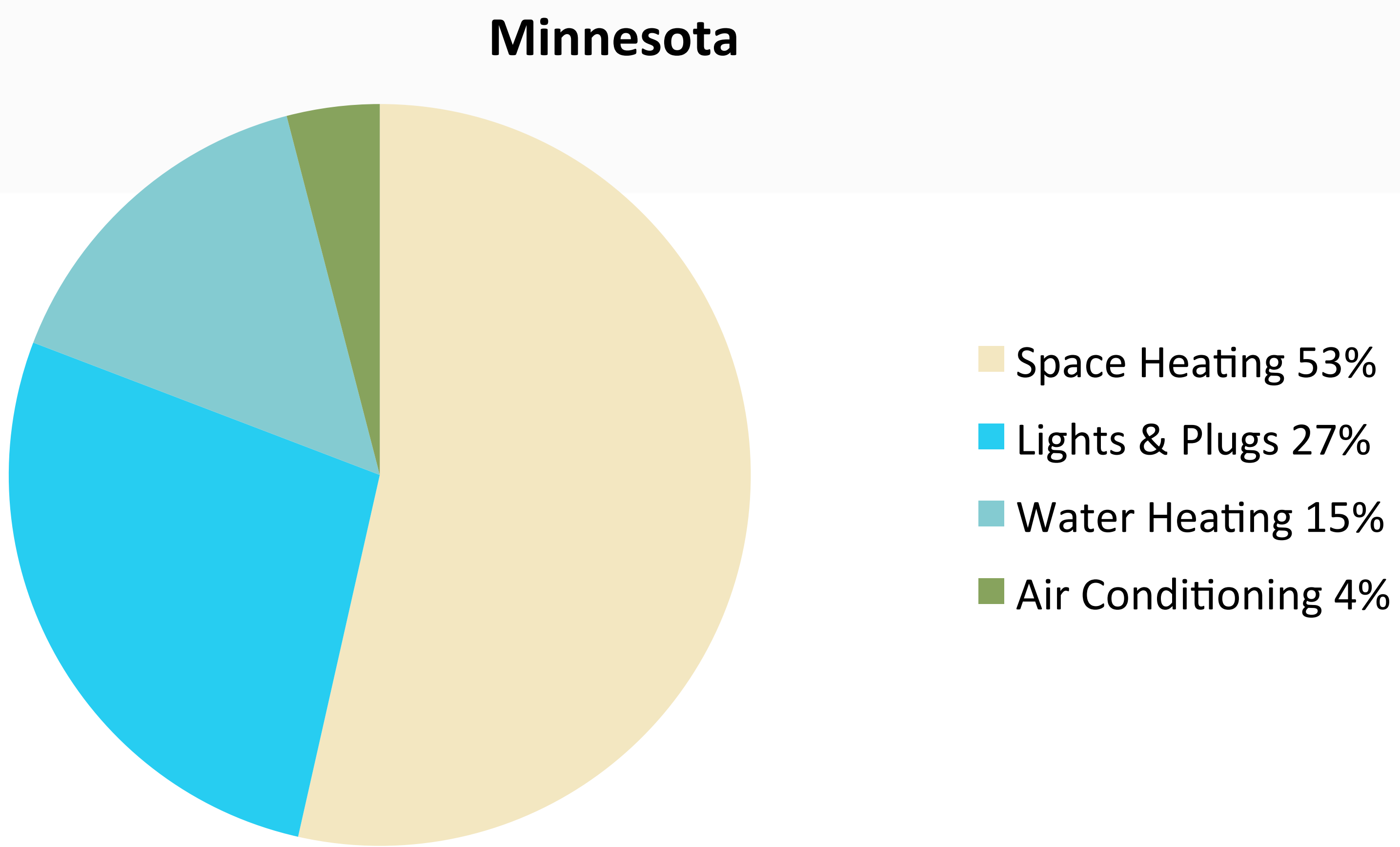
Where does energy go in a house?



Our Typical Minnesota House

- 2,000 sq ft, with 255 sq ft of windows
- 25’ x 40’ footprint
- 8 ft wall height
- 17 windows
  - 3’x5’ each
  - Evenly distributed around the house
- 2 stories (includes “basement”)
- Wall area above ground 1,700 sq. ft. (15% window/wall ratio)
- Wall area below ground 500 sq. ft.

Simple model of heat loss ("Manual J")

Heat loss depends on:

- U value = U
- Surface area = A
- Temperature across the surface = ΔT
- We looked at both code and observed values
  - Roof R-40 (code) or R-20 (typical)
  - Walls R-13 (code) or R-10 (typical good)
  - Basement: used heat loss based on research work (~R-30)
  - Windows: Published values (R-2 to R-4)

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Building Science: Heat loss = $u*A*\Delta T$

Building Assembly	2007 Building Code	Typical House
Roof	R-40 (.025)	R-19 (.05)
Walls (above ground)	R-14 (.07)	R-10 (.10)
Walls (below ground)		R-10 (.10)
Basement floor		R-30 (.03)
Double clear window	R-2 (.50)	R-2 (.50)
Triple pane	R-3 (.33)	R-3 (.33)

R Values followed by U value in parentheses (U = 1/R), each has an appropriate use

Typical Minnesota House

- 48% of heat loss through walls (excluding windows)
- 32% of heat lost through windows
- 12% of heat lost through ceiling
- 8% of heat lost through basement floor

2004 ASHRAE 90.1, adopted by Minnesota in 2007
(Window and wall improvements)

- 40% of heat loss through frame walls (R-19 from R-10)
- 37% of heat lost through windows (u=.35 from .50)
- 10% of heat lost through ceiling (R-40)
- 12% of heat lost through basement floor (R-30)

Window heat loss per sq. ft. (Simplified)

❖ Assumes 65 degree "balance point"

	Duluth	Minneapolis
Heating Degree Days	9,724	7,876
Energy per sq ft of window area (Double clear, u = 0.50)	1.30 Th	1.05 Th
Cooling Degree Days	225	700
Energy per sq ft of window area (Double clear, u = 0.50)	0.06 Th	0.19 Th

❖ HDD*24 hrs/day*U/(100,000btu/Th*0.90)

- For 90% furnace efficiency

Solar Heat Gain Coefficient

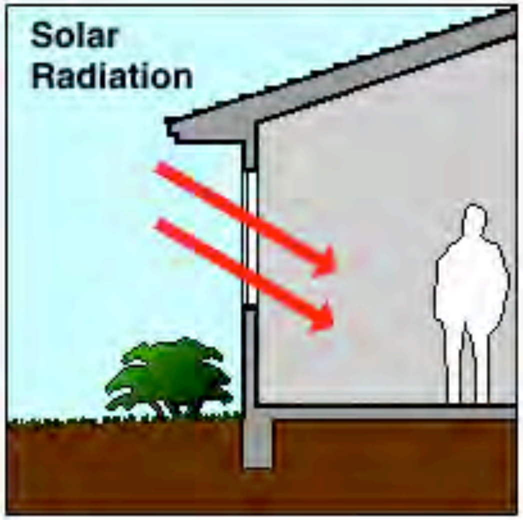
Efficient Windows *Collaborative*

New Construction Windows | Replacement Windows | Understanding Windo

Measuring Performance: Solar Heat Gain Coefficient (SHGC)

The SHGC is the fraction of incident solar radiation admitted through a window, both directly transmitted and absorbed and subsequently released inward. SHGC is expressed as a number between 0 and 1. The lower a window's solar heat gain coefficient, the less solar heat it transmits.

The nationally recognized rating method by the National Fenestration Rating Council (NFRC) is for the whole window, including the effects of the frame. Alternately, the center-of-glass SHGC is sometimes referenced, which describes the effect of the glazing alone. Whole window SHGC is lower than glass-only SHGC, and is generally below 0.8.

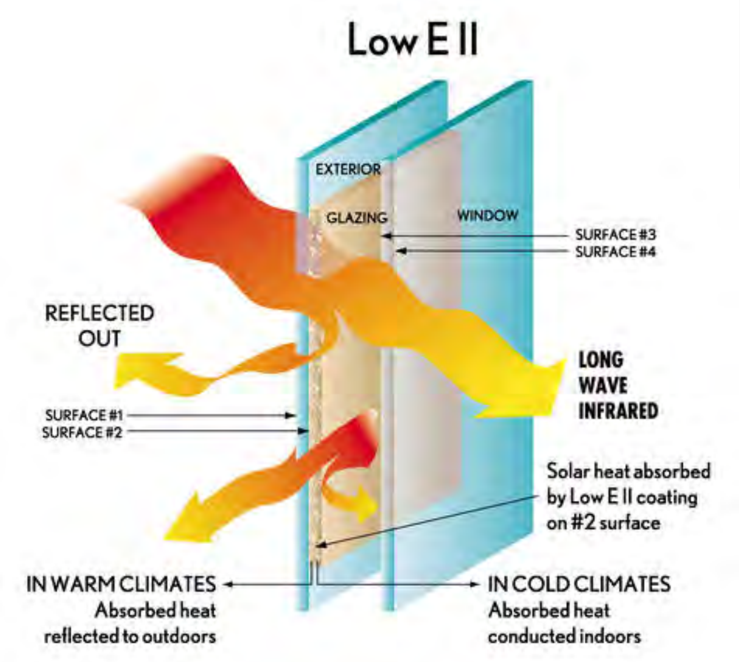


Why is a SHGC important?

Solar heat gain can provide free heat in the winter but can also lead to overheating in the summer. How to best balance solar heat gain with an appropriate SHGC depends upon the climate, orientation, shading conditions and other factors. **ENERGY STAR** provides simplified guidance on recommended SHGC values for your climate; additionally, the **Window Selection Tool** compares average simulated energy costs for your location based on various window types.

Low-emissivity coating

- A thin metal oxide film that reflects infra-red radiation
- On the inside of the window "keeps heat in"
  - Northern states
- On the outside of the window "keeps heat out"
  - Southern states, and the majority of the US
  - This generally does not save energy in Minnesota



Whole House Heating Savings for Complete Retrofit (in Therms per year)

	Minneapolis	Duluth
Triple Pane low-e Window	118	145
Low-e film	59	73
Exterior storm	86	106
Interior low-e panel	118	145

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Reference Values for Window Retrofits

Wood 2 pane DH	Storm	U value	SHGC
	None	.51	.57
	Clear, exterior	.34	.49
	Clear, interior	.32	.51
10 to 13% savings MSP or DLH	Low-e, exterior	.28	.42
	Low-e, interior	.26	.47
Al frame 2 pane DH			
	None	.51	.58
	Clear, exterior	.45	.51
	Clear, interior	.41	.52
16 to 18% savings MSP or DLH	Low-e, exterior	.36	.44
	Low-e, interior	.32	.47

From: "Database of Low-e Storm Window Energy Performance across US Climate Zones"
K.A. Cort and T.D. Culp, September 2013, DOE/PNNL

We will define SHGC and Low-e

Cost Comparison

Window	Materials	Labor	Energy Saving
New Triple Pane Window	$450-$1000	$5 (DIY) or $300-$500	7% (13% of heating energy)
New Double Pane Window	$300-$700	$5 (DIY) or $300-$500	0% (Base case)
Exterior Clear Storm Window	$80	$2 (DIY) or $50-$60	5%
Interior low-E Window Panel	$110	$2 (DIY) or $50-$60	7%
Low E Window Film	$10 -$25	$5 (DIY) or $50-$100	4%

Based on a Typical 3'x 5' Window, retail cost at building supply centers

Effect of the cost of different fuels

- Electricity at 8 cents/kWh costs $24 per million BTU
- Natural gas at 80 cents/Th costs $8 per million BTU

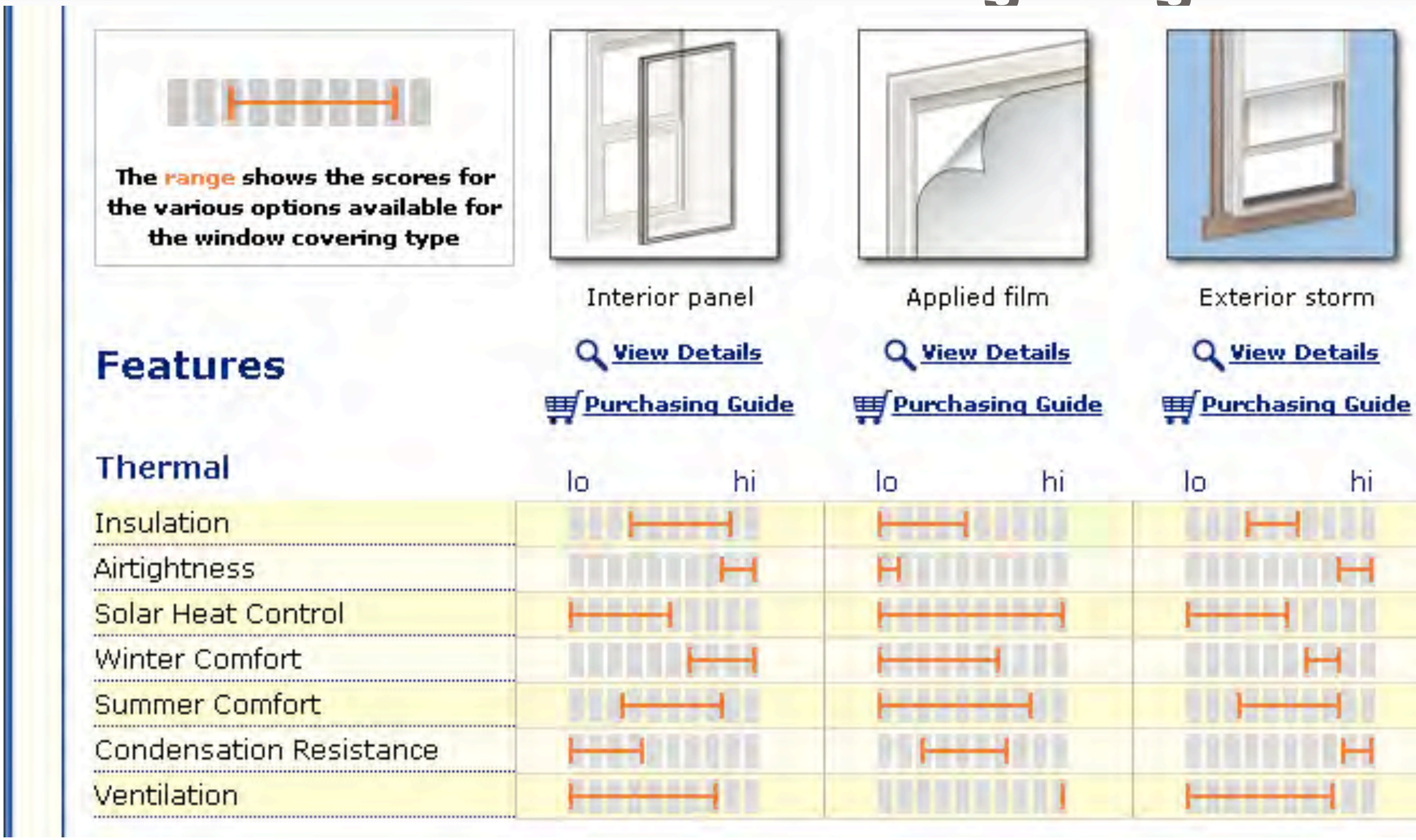
- Decreasing cooling by 1 million BTU (electric) while increasing heating by 2 million BTU's uses more energy (1 million BTU's) but saves money ($8)

- Our project is based on total energy savings

Cost Benefits of Residential Window Retrofits (for 225 sq ft of window)

Dollars Saved/Year	Minneapolis	Duluth
Exterior Clear Storm Window	$10	$12
Interior low-E Window Panel	$14	$17
Low E Window Film	$8	$10
Payback (Years)	**Minneapolis**	**Duluth**
Exterior Clear Storm Window	8-14	7-12
Interior low-E Window Panel	8-12	6-10
Low E Window Film	2-14	1.5-12

Consumer information can be found at www.efficientwindowcoverings.org



Commercial building results

- Based on buildings “constructed to code”
- Energy savings of up to 10% per year
- Economics are affected by the fact that the “equalized” cost of energy from natural gas is 1/3 the cost of electricity
  - There are cases that use more energy but save money (because today gas heat is less expensive than electric cooling)

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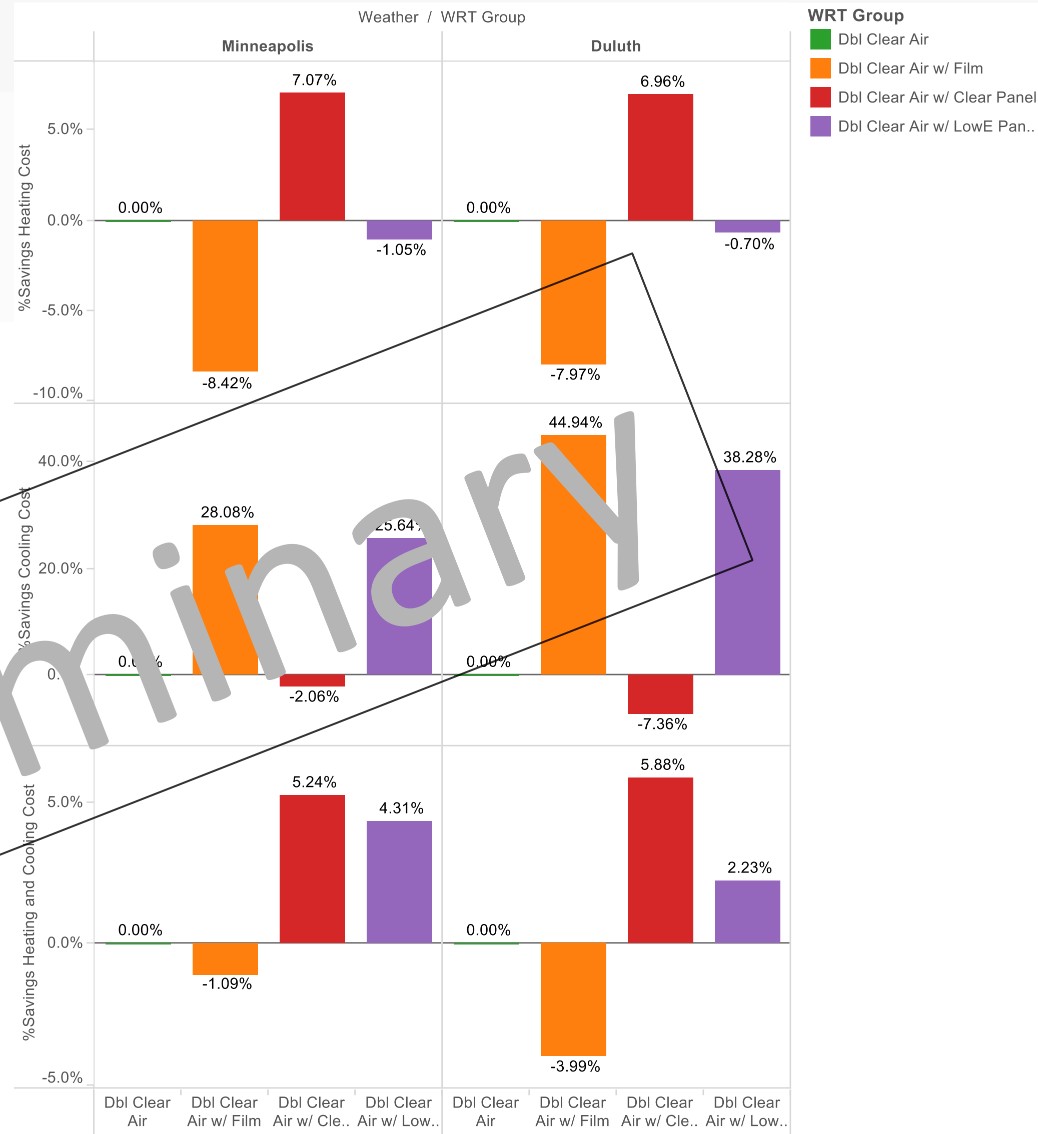
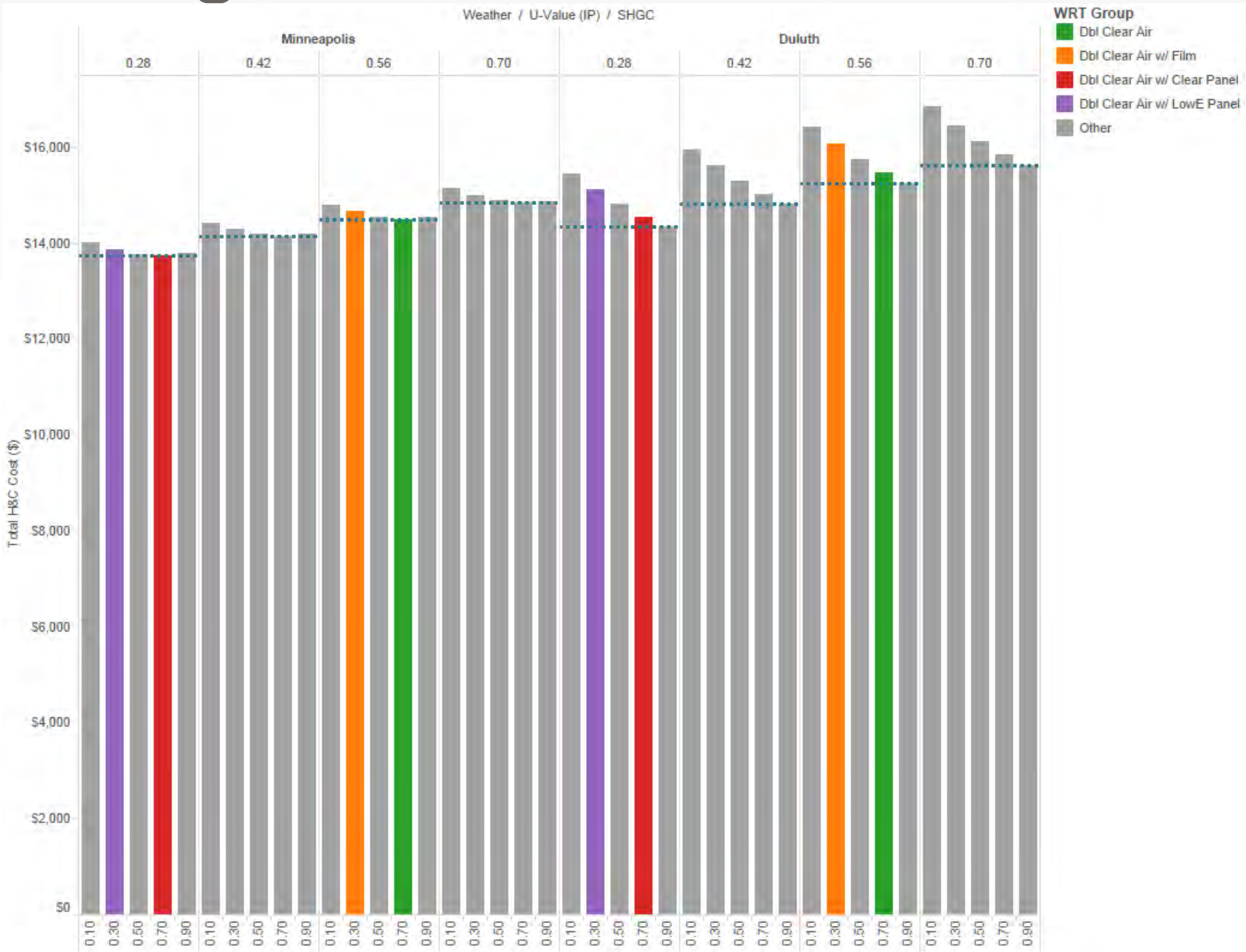
Energy Modeling

- Sample Results from EnergyPlus



Energy Modeling

- Sample full range results from EnergyPlus



DOE standard buildings

- Based on the Commercial Building Energy Consumption Survey of 2003
- Created sixteen building models that represent about 2/3 of the commercial building stock in the US
- Allows energy modelers to compare their results
- Includes three vintages
  - Pre-1980
  - Post 1980
  - Current Code (ASHRAE 90.1-2004)
- Primary purpose is to study design, not retrofit, so we had to make some adjustments
  - For example, it assumes that if you reduce the need for heat, you replace the heating system with a smaller one.

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Total energy use profiles of standard buildings

Buildings in Duluth	Sq ft	EUI	% E for H+C
Small Office	5,500	80.4	36%
Large Office	498,588	67.0	39%
Strip Mall	22,500	175.9	58%
Primary School	73,960	95.3	53%
Secondary School	210,887	109.7	67%
Midrise Apartment	33,740	96.2	74%

Large Office Buildings

Building Characteristics

- 498,588 square feet
  - 250 ft. x 166 ft.
- 12 stories
- 13 feet between floors
- 9 foot interior ceilings
- 38% glazing fraction
- 53,441 square feet of window area

Large Office Buildings

- Energy Saving Comparisons (Shown as % annual savings compared to double pane, clear glass window)

Heating and Cooling Energy	Duluth	Minneapolis
Add Clear Panel	9.5%	8.2%
Add Low-e Panel	8.7%	8.4%
Add Best Low-e Film	6.9%	6.9%
Add Tinted Film	-0.8%	0.3%

Large Office Buildings

- Annual Savings

Dollars per square foot	Duluth	Minneapolis
Add Clear Panel		
Add Low-e Panel		
Add Low-e Film		

Payback (years)	Duluth	Minneapolis
Add Clear Panel		
Add Low-e Panel		
Add Low-e Film		

Small Office Buildings

Building Characteristics

- 5,500 square feet
  - 91 ft. x 61 ft.
- 1 story
- 10 foot interior ceiling
- 21% glazing fraction
- 642 square feet of window area

Small Office Buildings

- Energy Comparisons (Shown as kBtu/sq ft annual savings compared to double pane, clear glass window)

Heating and Cooling Energy	Duluth	Minneapolis
Add Clear Panel	4.6%	3.8%
Add Low-e Panel	0.9%	1.1%
Add Best Low-e Film	0	0.2%
Add Tinted Film	-3.9%	-3.1%

Small Office Buildings

- Annual Savings

Dollars per square foot	Duluth	Minneapolis
Add Clear Panel		
Add Low-e Panel		
Add Low-e Film		

Payback (years)	Duluth	Minneapolis
Add Clear Panel		
Add Low-e Panel		
Add Low-e Film		

Strip Malls

Building Characteristics

- ❖ 22,500 square feet
- ❖ 1 story
- ❖ 17 foot interior ceiling
- ❖ 11% glazing fraction
- ❖ 1,339 square feet of window area

Strip Malls

- Energy Comparisons (Shown as kBtu/sq ft annual heating and cooling savings compared to double pane, clear glass window)

Heating and Cooling Energy	Duluth	Minneapolis
Add Clear Panel	1.2%	1.1%
Add Low-e Panel	-0.2%	-0.2%
Add Best Low-e Film	-0.5%	-0.4%
Add Tinted Film	-1.5%	-1.3%

Preliminary

Strip Mall

- Annual Savings

Dollars per square foot	Duluth	Minneapolis
Add Clear Panel		
Add Low-e Panel		
Add Low-e Film		

Payback (years)	Duluth	Minneapolis
Add Clear Panel		
Add Low-e Panel		
Add Low-e Film		

Primary Schools

Building Characteristics

- 73,960 square feet
- 1 story
- 13 foot interior ceiling
- 35% glazing fraction
- 9,463 square feet of window area

Primary Schools

❖ Energy Comparisons (Shown as kBtu/sq ft annual savings compared to double pane, clear glass window)

Heating and Cooling Energy	Duluth	Minneapolis
Add Clear Panel	5.4%	4.4%
Add Low-e Panel	8.9%	10.0%
Add Best Low-e Film	[illegible].6	9.3%
Add Tinted Film	2.[illegible]%	5.7%

Primary School

- Annual Savings

Dollars per square foot	Duluth	Minneapolis
Add Clear Panel		
Add Low-e Panel		
Add Low-e Film		

Payback (years)	Duluth	Minneapolis
Add Clear Panel		
Add Low-e Panel		
Add Low-e Film		

Secondary Schools

Building Characteristics

- ❖ 210,887 square feet
- ❖ 2 stories
- ❖ 13 feet between floors
- ❖ 13 foot interior ceilings
- ❖ 32.7% glazing fraction
- ❖ 21,009 square feet of window area

Secondary Schools

- Energy Comparisons (Shown as kBtu/sq ft annual savings compared to double pane, clear glass window)

Heating and Cooling Energy	Duluth	Minneapolis
Add Clear Panel	4.0%	4.4%
Add Low-e Panel	6.5%	10.0%
Add Best Low-e Film	[illegible].6	6.0%
Add Tinted Film	1.[illegible]%	2.9%

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Secondary School

- Annual Savings

Dollars per square foot	Duluth	Minneapolis
Add Clear Panel		
Add Low-e Panel		
Add Low-e Film		

Dollars per building	Duluth	Minneapolis
Add Clear Panel		
Add Low-e Panel		
Add Low-e Film		

Multifamily (Midrise)

Building Characteristics

- 33,742 square feet
  - 152 ft x 55 ft
- 4 stories
- 10 feet between floors
- 8 foot interior ceilings
- 15% glazing fraction
- 2,490 square feet of window area

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Multifamily (Midrise)

Heating and Cooling Energy	Duluth	Minneapolis
Add Clear Panel	4.3%	4.0%
Add Low-e Panel	0%	0.4%
Add Best Low-e Film	-0.90	-0.5%
Add Tinted Film	-4.5%	-3.7%

Multifamily Apartments

- Annual Savings

Dollars per square foot	Duluth	Minneapolis
Add Clear Panel		
Add Low-e Panel		
Add Low-e Film		

Payback	Duluth	Minneapolis
Add Clear Panel		
Add Low-e Panel		
Add Low-e Film		

Effect of Date of Construction

- ❖ Heat loss through windows is not changed
- ❖ As other building components get better, percentage loss through windows can become greater
- ❖ Advances in glazing, primarily coatings with variable transmission by radiation wavelength, result in commercial windows that can be "net energy positive" in well designed buildings
- ❖ Our project assumes windows will be replaced every 40 years, but the rest of the building envelope may not have been upgraded

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Energy Saved per Square Foot of Window

	Duluth	Minneapolis
Base energy/sq ft of window (kbtu)	130 kbtu/sq ft (heating)	105 kbtu/sq ft (heating)
Average savings kbtu/sq ft	17.7	20.2
Average total % Savings	2.3%	2.6%
Average Heating Savings	12.1	12.1
Average Cooling Savings	5.6	8.1

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Cost benefit estimates

Preliminary

Opportunities for market transformation

- Education
- Product certification (Energy Star)
- Utility rebates
- Contractor incentives
- Building codes
- Builder education

Other products not included in the study

- ❖ Electrochromic windows
- ❖ Interior shutters
- ❖ Solar film on window surface
- ❖ Honeycomb shades

- ❖ Not technologically mature or require behavioral change for persistent savings

Questions?

- Special thanks to:
- Our collaborators at the Center for Sustainable Building Research, John Carmody and Kerry Haglund
- The Minnesota Department of Commerce, Division of Energy Resources. Mary Sue Lobenstein, Program Administrator
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