Window Performance Basics

Keeping cool in summer, warm in winter, comfortable all the time,... and saving energy too

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Windows for Energy Smart Buildings

- Many factors affect the design and choice of windows for the Florida home.
- This presentation provides background information
Are windows just “holes in the insulation?”

Some are, but . . . “it ain’t necessarily so!”

- Good windows can out-perform opaque insulated walls, energy-wise.
- Windows provide much more than energy savings!
- A building is there to provide comfort and protection from the elements, not just to save energy.
- If energy can be saved too, that’s even better.

- We’ll start with some basics
- Then we’ll cover energy and economics
- And finish with a summary of window option recommendations
What are windows for?

- Views to the outdoors - visual connections to the natural world
- Illumination of the interior with natural daylight
- Acoustic connections to the outdoors
- Routes for emergency escape
- Protection from the discomforts of cold, heat, wind, and rain
- Do you see energy anywhere in this list?
Finding the Right Window

- It is more than just choosing a pretty window.
- We must also deal with the heat, the cold, as well as the glare and overheating of direct sunlight
  - The heat and cold: insulation and shading
  - The glare and overheating of direct sunlight: orientation and shading
- Other issues
  - Choice of window frame and glazing
  - To insulate or not?
  - Impact resistance?
  - Acoustic isolation?
  - Utility concerns
Dealing with the Sun

- **The Good**: Big windows provide a bright and open room with great views and good daylight illumination
- **The Bad**: Overheating, fading of furnishings, blocked views
- **The Ugly**: Killer glare from the sun, big energy bills, thermal discomfort
- **Three strategies for dealing with the sun**
  - Know where the sun is
  - Shape and orient the building properly relative to the sun
  - Shade the windows and walls properly
Factors affecting window options

• Which way the window faces
• How much it is shaded from the sun
• The importance ($-$value) of thermal comfort
• The importance ($-$value) of sound isolation
• The importance of impact protection
• New construction vs retrofit (replacement)
• Occupant preferences for style and color
• Electric utility company incentives
• Florida Building Code Compliance
Window Fundamentals

Subjects to be covered:

• Heat transfers (Radiation, Conduction, Convection)
• The path of the sun through the sky
• Orientation and shading
• Electromagnetic spectrum
• The solar spectrum
• Solar radiant heat gain, direct and diffuse
• Illumination — Daylighting, glare, electric lighting
• The “U-factor” — Conductive heat transfer
• Solar Heat Gain Coefficient (SHGC)
• Visible transmittance (VT)
Heat Transfer

The three modes of heat transfer

Radiation
Conduction
Convection
Heat Flows Through Windows

- Absorbed solar radiation conducted through the frame
- Directly transmitted solar radiation through the glazings (includes both light & heat)
- Reflected solar radiation
- Glazing-absorbed solar radiant heat
- Outward flowing fraction of glazing absorbed radiation
- Inward flowing fraction of glazing absorbed radiation
Heat Flows Through Windows

- Absorbed solar radiation conducted through the frame
- Directly transmitted solar radiation through the glazings (includes both light & heat)
- Glazing-absorbed solar radiant heat
- Reflected solar radiation
- Outward flowing fraction of glazing absorbed radiation
- Inward flowing fraction of glazing absorbed radiation
- Heat conducted through the glass
- Heat conducted through the frame
Insulated windows reduce conduction, convection, and radiation.

- Insulation reduces heat conduction through the frame.
- Coatings reduce radiation transfer.
- Insulating gas reduces conduction.
- Proper spacing minimizes convection.
- Insulation reduces heat conduction through the frame.
Knowing Where the Sun is

- Radiation from the sun is generally much stronger than that from the sky, except on hazy and partially overcast days.
- The sun moves through the sky in a known way each day.
- Radiation coming directly from the sun’s “disk” is called “direct beam radiation.”
- Orienting the building and its windows is important to maximize the benefits and minimize the problems produced by direct beam solar radiation.
- First we look at a generic drawing of the sun’s path through the sky on the summer and winter solstices.
- Then we consider how to orient a house properly relative to the sun’s positions in the sky.
SUMMER

Sun rises north of due east, 
sets north of due west, 
and is high in the sky at noon

Shade: 
overhang for noon 
east to northeast morning 
west to northwest afternoon

WINTER

Sun rises south of due east, 
sets south of due west, 
and is low in the sky at noon

Shade: southwest to west to 
protect west window on warm winter days
Orientation and shading

Minimize east and west exposure. Shade the facade.

Wide overhangs

Buffer East and West Exposures

Garage

Fence

Closet

Utility room
Exterior window shading strategies

- Bahama shutters
- Exterior roll blind
- Sarasota shutters
- Sun screen
- Slatted aluminum
- Venetian awning (east or west exposure)
- Porch
- Trellis & vines
- Hood awning
- Gambrel awning (for casement windows)
- Trees
- Solid aluminum awning
- Roller awning (self-storing)
The sun’s radiation covers a range of colors, and beyond.

This electromagnetic radiation has important features for the design and performance of windows in different climates.

We need to know a little more about the physics of solar radiation to fully understand the variety of window products now on the market.

We begin with the electromagnetic spectrum.
Breaking sunlight into its various colors

Sir Isaac Newton
1723

Glass prism

Invisible infrared

Invisible ultraviolet

Red 700 nm

Blue 400 nm

Green

Yellow

Orange
Electromagnetic Spectrum

Wave length

1pm
1nm
1μm
1mm
1m
1km

Cosmic rays
Gamma rays
X rays
UV
Visible spectrum
Solar spectrum
Microwaves
Radio

Sound frequencies

UV
320 nm
400 nm
450 nm
500 nm
550 nm
600 nm
650 nm
700 nm
750 nm
800 nm
900 nm
1000 nm
1100 nm
1200 nm
1300 nm
1400 nm
1500 nm
1600 nm
1700 nm
1800 nm
1900 nm
2000 nm
2100 nm
2200 nm
2300 nm
2400 nm
2500 nm
2600 nm
2700 nm
2800 nm
2900 nm
3000 nm
3100 nm
3200 nm
3300 nm
3400 nm
3500 nm

IR
Parts of the solar spectrum

**Solar spectrum**

**Human eye sensitivity** (Visible portion of the spectrum)

- **Ultraviolet (UV)**
- **Visible (VIS)**
- **Near Infrared (NIR)**
- **Far Infrared (FIR)**
Emission of Heat Radiation

- Warm objects emit radiation
- The hotter they are, the more they emit
- As their temperature increases, the spectral distribution shifts as well, as shown on the next slide
Warm Objects Emit Radiation

Blackbody radiation spectra from 80 to 35,000 deg Fahrenheit

- VIS
- NIR
- FIR

Spectral Exitance in W m⁻² nm⁻¹

Wavelength in micrometers

Room temperature
Why black body radiation is important

Warm panes radiate toward cold ones

The wavelengths are in the far IR spectral range

We can take advantage of this in designing the glass panes
Spectral Selectivity for Cold Climates

- Cold climate glass transmittance
- Room temperature surface emission spectrum
- Solar spectrum
- Human eye response

UV: 200 nm, 380 nm, 760 nm, 20 nm
VIS: 380 nm, 760 nm
NIR: 3.5 μm
FIR: 30 μm
Spectral Selectivity for Hot Climates

- **Wavelength**
  - **Hot climate transmittance**
  - **Cold climate transmittance**
  - **Room temperature surface emission spectrum**
  - **Solar spectrum**
  - **Human eye response**

- **Room temperature surfaces** emit invisible IR.

- **UV** (200 nm) - 380 nm - 760 nm, **VIS** (380 nm - 760 nm), **NIR** (3.5 μm), **FIR** (30 μm)

- **Visible light**
  - **Human eye response**

- **Ultra Violet**
  - **Invisible solar IR**

- **Invisible IR emitted by room temperature surfaces**

- **VIS NIR FIR**
  - **Visible light**
  - **Invisible solar IR**
Quantifying Heat Flows

Heat flux, $Q$ in W/m$^2$

- Incident solar irradiance: $E_0$
  - Reflected solar radiation: $R_s E_0$
  - Glazing-absorbed solar radiant heat: $A_s E_0 = Q_{absorbed}$
  - Outward flowing fraction of glazing absorbed radiation: $N_i A_s E_0 = Q_{inward}$
- Transmitted solar radiation: $T_s E_0 = Q_{direct}$
- Visible Transmittance: $VT$ (%)
- Glazing conduction heat transfer: $Q_g = U_g \times \text{Area} \times \Delta t$
- Frame conduction heat transfer: $Q_f = U_f \times \text{Area} \times \Delta t$
Performance Indices

- Reflected solar radiation: $R_s$
- Glazing-absorbed solar radiant heat: $T_s$
- Outward flowing fraction of glazing absorbed radiation: $N_i A_s$
- Visible Transmittance: $VT$
- U-factor: $U$

Solar Heat Gain Coefficient:

$$T_s + N_i A_s = \text{SHGC}$$

$$U = \frac{1}{\text{R-value}}$$

Primary Indices:

- VT
- U
<table>
<thead>
<tr>
<th>VT</th>
<th>Visible transmittance:</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Fraction of incident light transmitted</td>
</tr>
<tr>
<td>SHGC</td>
<td>Solar heat gain coefficient:</td>
</tr>
<tr>
<td></td>
<td>Fraction of incident solar radiation admitted as heat gain</td>
</tr>
<tr>
<td>LSG</td>
<td>Light-to-Solar Gain ratio:</td>
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<tr>
<td></td>
<td>Ratio of visible transmittance to solar heat gain coefficient</td>
</tr>
</tbody>
</table>

\[ LSG = \frac{VT}{SHGC} \]
Spectral Selectivity of Real Glazings

Spectral Transmittances of Various Window Glazings

- Clearplate
- Bluegreen #1
- Bluegreen #2
- Spectrally sel.-1
- Spectrally sel.-2
- Bronze coated

Lower VT, higher LSG

Similar IR spectra

VIS
VT and SHGC relationships for spectrally selective glazings

Visible transmittance

SHGC

Target for hot climate glazings

Single-pane clear glass

SHGC = 0.58

SHGC = 0.21

More heat than light

More light than heat

Target for hot climate glazings

Visible transmittance
Coatings and Tints

One can use

- High solar gain low-e coatings for cold climates
- Low solar gain low-e coatings for hot climates
- IR-absorbing glass for hot climates
- A variety of ways to coat and tint glass
Cold climate glazings
Admit and trap solar heat

One way to do the job

High solar gain low-e coating. Transmits solar, doesn’t emit FIR, so it keeps the heat inside where it is needed

Cold-climate low-e coated windows

Low-emissive configuration

FIR

Total solar spectrum

Insulated gas space (air, argon, krypton)

Cold Warm

1
Cold climate glazings
Admit and trap solar heat

Low-emissive configuration

Cold-climate low-e coated windows

Two ways to do the job

1. FIR not emitted
2. FIR reflected

Cold climate low-e coating.
Hot Climate Glazings
Admit visible, reject invisible solar

Hot-climate coated windows

One way to do it

By rejecting nearly half the incident solar radiation with reflection, the SHGC is nearly half as large

Solar near IR  Visible light

Hot-climate near-IR reflective coating
(Also called “hot-climate low-e coating"
(or a low-solar-gain low-e coating)
Hot Climate Glazings
Admit visible, reject invisible solar

Hot-climate coated windows

Two ways to do it

1. Hot-climate near-IR reflective coating
2. Cold-climate low-e coating

- Long-wavelength IR
- Solar near IR
- Visible light
- Solar near IR absorber

Hot
Cool
Absorptive
FIR
VIS

Warm
Reflective
Cool
VIS
Cold-climate low-e coated windows

A. Low-emissive configuration

B. High-reflective configuration

Hot-climate coated windows

C. Absorptive longwave conversion

D. Solar direct reflection

*Second pane optional in principle
Daylight Illumination

- Cool, natural daylight has good color rendering
- Daylight is healthy
- Daylighting can displace electric lighting
- Electric utility interactions
- The occupancy schedule is critical
  - Florida residential occupancies — are they different?
- Direct beam and diffuse daylight

Glare
- Disability glare
- Discomfort glare

Glare primer
Disability Glare

The mirror is used to show that if you can see the ceiling luminaire in it, then there is a veiling glare potential.

Light from the luminaire reflected from a magazine page will "veil" your view of the text and "disable" your ability to read.

This is called disability glare.
With discomfort glare, light from the side that is much brighter than the light from a visual task enters your eye. This light confuses the accommodation mechanisms, producing discomfort, headaches, and premature tiredness.
Direct Beam Solar Radiation

Can produce discomforting glare and localized overheating, as well as add to the air conditioning bill.
Avoiding Direct Beam
Orientation & Shading Strategies

- Minimize East and West Exposures
- Buffer East and West Exposures
- Wide overhangs
- Garage
- Fence
- Closet
- Utility room
Window Shading

Outdoors

Between the panes

Indoors
Exterior window shading strategies
Block solar gain before it reaches the window

- Bahama shutters
- Exterior roll blind
- Sarasota shutters
- Sun screen
- Slatted aluminum
- Venetian awning (east or west exposure)
- Porch
- Trellis & vines
- Hood awning
- Gambrel awning (for casement windows)
- Trees
- Solid aluminum awning
- Roller awning (self-storing)
When exterior shading is not permitted, desired, or possible

Use High-Performance Glazing Systems

- To minimize solar heat gain, use **hot-climate low-e coated** glazings with **high LSG ratio**

- Choose VT to fit the situation
  - **VT high** for north-facing, and exposures already shaded fairly well
  - **VT low** for east- and west-facing exposures inadequately shaded

- To reduce peak load, enhancing comfort and allowing smaller air conditioners, use **double pane** windows
  - **Impact resistant** for coastal zone
  - **Insulated frames** to reduce condensation and improve comfort further
Spectral Transmittances of Various Window Glazings

- Clear plate
- Bluegreen #1
- Bronze coated
- Bluegreen #2
- Spectrally sel. -1
- Spectrally sel. -2

High VT, low SHGC
Medium VT, lower SHGC
Low VT, lowest SHGC

Wavelength in nanometers

Transmittance

VIS
Window Energy Performance

- **Instantaneous** versus long term hourly performance
- For instantaneous perf., get the NFRC label information:
  
  U-factor       SHGC       VT

- But how do you know what are good values of these for your application?
- You need something to tell you about the long-term energy (and peak load) consequences of a given choice
- And you need a way to convert energy efficiency into economic information.
- Next comes some background information on energy computer programs and economic indicators
Hourly Building Energy Simulations

- **Building thermal properties**
  - Thermal mass & location
  - Wall, roof, & floor insulation
  - Infiltration models
  - Window SHGC & U-factors
  - HVAC efficiency data

- **Assumed internal heat loads**
  - Equipment
  - Humans & animals
  - Occupancy

- **Weather data** for each hour
  - Air temperature & humidity
  - Wind speed
  - Direct beam solar
  - Global horizontal solar

- **Loads** on HVAC system
  - Conduction through envelope
  - Internal loads
  - Fenestration Solar Gain

- **Other energy** consumed
  - Equipment
  - Electric lighting

- **Energy use** by energy type
  - Electric energy
  - Electric demand
  - Gas energy
  - Fuel oil

- **Costs of energy-efficiency**
  - Building envelope
  - HVAC system
  - Other features

- **Dollar costs** to operate the building each hour and for a year
  - Annual energy
  - Demand charges
  - Economic performance indicators
Window Energy Software

- RESFEN — Easier to run, and based on DOE-2, but you must be somewhat computer savvy to run it
- EnergyGauge USA — Requires licensing and training
- EnergyGauge FlaRes — Used mainly for code compliance
- Energy performance for a typical house can be determined at www.efficientwindows.org but this treats shading only minimally
- Sample results from DOE-2 on next slide
Example: DOE-2 Results for Miami -1

MIAMI – YEARLY ENERGY CONSUMPTION

WEST ORIENTATION

- No shade, No overhang
- No shade, With overhang
- With shade, No overhang

Lower is better

RELATIVE ENERGY USE (kWhr/ft²)

SHADING COEFFICIENT

(Note: Shading coefficient = 0.87 SHGC)

Single glazing, U = 1.3
Double glazing, U = 0.3 (Slightly less energy efficient)
Example: DOE-2 Results for Miami -2

Lower is better

MIAMI – PEAK COOLING LOAD

WEST ORIENTATION

Single glazing, $U = 1.3$

Double glazing, $U = 0.3$

RELATIVE PEAK LOAD (W/ft$^2$)

SHADING COEFFICIENT

No shade, No overhang
No shade, With overhang
With shade, No overhang
Example: DOE-2 Results for Miami

MIAMI – PEAK HEATING LOAD

WEST ORIENTATION

- Single glazing, $U = 1.3$
- Double glazing, $U = 0.3$

- No shade, No overhang
- No shade, With overhang
- With shade, No overhang

RELATIVE PEAK LOAD (W/ft$^2$)

SHADING COEFFICIENT
Conclusions from Miami Example

- U-factor is not that important for *annual* energy in South Florida
- Preventing solar gain is more important
- Thus low solar gain single pane, uninsulated windows would *appear* a good choice for Southern Florida
- At least one glass company offers “hard-coat” high LSG glass
- But there is more to the study than this.
- Further north, insulated windows become more attractive
- And there are other benefits of double pane windows:
  - Lowered Peak loads
  - Smaller, less expensive HVAC equipment
  - Acoustic isolation
  - Greater comfort and happiness
  - Motherhood and apple pie
What Can the Homeowner Do to Get Energy Performance Information?

- Use State Building Code energy provisions — Minimal
- Insist on NFRC ratings — Instantaneous values only, but still important to know that the numbers are correct
- Obtain Green Home Certification — Great environmentally, but modest incentive for window energy
- Use only Energy Star windows — Good but not best
- Information customized for your home, use RESFEN: http://windows.lbl.gov/software/resfen/resfen.html
Where to find these resources
Florida Building Commission

www.floridabuilding.org/bc/default.asp

Florida Building Code Online

View The Florida Building Code Online at SBCCI's website:

http://www.sbcci.org/floridacodes.htm

Similar sites can be found for many other states in the U.S.
National Fenestration Rating Council

NFRC.org
How to Select an Energy Efficient Window

1. Look for the Energy Star
   Look for a product that qualifies for the Energy Star in the Northern, Central, or Southern Climate Zone. To distinguish between Energy Star products, go to Step 2.

2. Look for Energy Efficient Window Properties on the NFRC Label
   The key window properties are U-factor, Solar Heat Gain Coefficient (SHGC), and Visible Transmittance (VT). The NFRC label provides the only reliable way to determine the window properties and to compare products. For typical cost savings from efficient windows in specific locations, go to Step 3.

3. Compare Annual Energy Costs for a Typical House
   Compare the annual energy use for different window options for a typical 2000-square-foot house in your state or region.
Energy Star

http://www.energystar.gov/products/windows/

Energy Star Homes
must meet a performance standard:
Have a HERS energy rating of 86 or above

Energy Star Windows
must meet a prescriptive standard:
In the hot climate zone:

<table>
<thead>
<tr>
<th></th>
<th>Windows &amp; Doors</th>
<th>Skylights</th>
</tr>
</thead>
<tbody>
<tr>
<td>U-Factor</td>
<td>0.75 or below</td>
<td>0.75 or below</td>
</tr>
<tr>
<td>Maximum Solar Heat Gain</td>
<td>0.40 or below</td>
<td>0.40 or below</td>
</tr>
</tbody>
</table>

Climatic Zones

Energy Star Homes
must meet a performance standard:
Have a HERS energy rating of 86 or above

Energy Star Windows
must meet a prescriptive standard:
In the hot climate zone:
None of the previous web sites offers much guidance on selecting window shading. The next one at least gives credit for tree shading.
Florida Green Home Certification

Florida Green Building Coalition, Inc., www.floridagreenbuilding.org

- Green Home Standard Certification based on a points rating
- “Green Home Designation Standard Checklist” publication
- Checklist includes points for Energy, Water, Site, Health, Materials, Disaster Mitigation, and a General category
- For new homes each category has a minimum number of points. The sum of the minimums (default case) is 160.
- Total points requirement is 200.
- More points are required if the minimum cannot be met in a category
- Window points are given for daylighting, east and west tree shading, and exceeding the Florida Energy Code HERS rating of 80
Window Selection Advice
To Double-pane or not?

- For energy savings only, double pane is generally not needed in hot climates
- In this case it is more important to put your money into preventing solar gain —
  
  **On the other hand:**

- The highest LSG glass is only available in double pane
- Double pane is more comfortable
- Double pane allows smaller A/C, saving dollars
- Double pane gives better acoustic isolation
- The electric utility might *pay you* to use double pane (if you ask them nicely)
- Double pane is important for cold climates
Guidance for the Average Building Owner

- **Purchase the best window you can afford for your situation, considering:**
  - Direction the window faces
  - Degree of existing shading of that window

- **Shade east- and west-facing windows from direct sunlight**
  - Trees
  - Trellis vines
  - Shrubs and plants
  - Awnings and shade screens
  - Shutters

- **Use double-pane glass and insulated frames to**
  - Maintain thermal comfort
  - Reduce peak A/C size required
  - Save energy and electricity costs
  - Protect against possible future peak demand charges
Conclusions - 1

- Our goals should be to
  - Disconnect from fossil fuel use to the greatest extent possible.
  - Install very high performance windows, (and very well insulated walls, ceilings, and floors)
- A home in the U.S. can drastically reduce its energy requirements and be more comfortable and enjoyable as well.
- If you are not yet ready to disconnect from your utility, at least strive for maximum fossil energy use efficiency.
Designing buildings *down* to a minimal energy code
- Is a failed opportunity for slowing the growth of energy demand
- Ignores comfort, produces more pollution, contributes to global warming
- In some cases is not cost-effective even in the traditional economic sense

Designing *up* to greater energy efficiency is a patriotic act—a commitment to the future of humanity and of the Earth.
- It leads to higher quality homes, that are more comfortable and have lower energy bills.
- It reduces pollution, lessens global warming, reduces dependence on foreign oil.
- It directly contributes to a sustainable future.

Better homes attract more customers, permit higher prices, and lead to greater profits for sellers.
Window Recommendations in Summary

- **All windows**: Insist on high-LSG glazings and double-pane, insulated windows throughout the house—for energy savings, comfort, reduced peak load, and smaller A/C capacity (and cost).

- **North-facing**: Use a side-wall, or a deep window reveal to block low rising and setting sun on hot summer days

- **South-facing**: Use a modest overhang if you like winter sun
  Use a wide overhang to avoid sun year round
  High-LSG glazings are especially important if shading’s inadequate

- **East- and West-facing**, a menu of choices:
  - For hot climates:
    - Dense tree shading where possible
    - Awning shade
    - Exterior shade screen
    - Exterior roller shutters
    - Highest-LSG glazing system, VT between 0.2 and 0.4
    - Interior reflective operable shade
  
  - For cold climates:
    - Well-insulated multiple pane windows with insulated frames

- **Laminated glass for impact resistance if exterior shade is not enough for this**
Additional Information & Resources

- For more information continue exploring our windows web site:  www.fsec.ucf.edu/bldg/active/fen/

- For information about the energy crisis:  www.dieoff.org


- www.thefutureofhumanity.org