Passive House Windows

From Design to Install

3C-REN

The Passive House Network

3C-REN: Tri-County Regional Energy Network

- Three counties working together to improve energy efficiency in the region
- Services for –
  - **Building Professionals:** industry events, training, and energy code compliance support
  - **Households:** free and discounted home upgrades
- Funded by ratepayer dollars that 3C-REN returns to the region

3C-REN ENERGY CODE CONNECT

- Serves all building professionals
- Three services –
  - **Energy Code Coach**
  - **Training and Support**
  - **Regional Forums**
- Makes the Energy Code easy to follow

Energy Code Coach:
3c-ren.org/codes
805.781.1201

Event Registration:
3c-ren.org/events

3C-REN BUILDING PERFORMANCE TRAINING

- Serves current and prospective building professionals
- Expert instruction:
  - **Technical skills**
  - **Soft skills**
- Helps workers to thrive in an evolving industry

Event Registration:
3c-ren.org/events

HOME ENERGY SAVINGS

Multifamily (5+ units)

- No cost technical assistance
- Rebates up to $750/apartment plus additional rebates for specialty measures like heat pumps

Single Family (up to 4 units)

- Sign up to participate!
- Get paid for the metered energy savings of your customers

Enrollment:
3C-REN.org/contractor-participation

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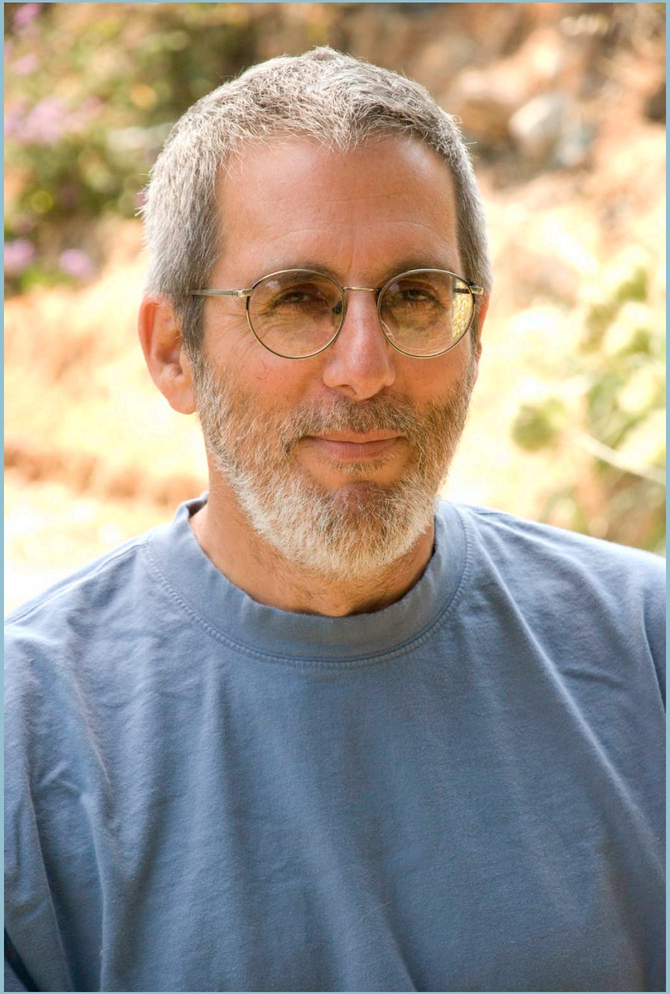

Meet the Trainer

Steve Mann

Certified Passive House Designer/ Tradesperson / Building Certifier

Principal / Home Energy Services

Trainer / PHN

Presentation Outline

1. Introduction to PH Windows
2. How to Design and Detail Passive House Windows

   -BREAK

3. Calculating Passive House Windows
4. How to Install Passive House Windows


Ryall Sheridan Architects

Section 1: Introduction to Passive House Windows

Why Windows Matter

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Why Windows Matter?

- Comfort
- Daylight
- Aesthetics
- Performance
- Energy Efficiency
- Energy Capture
- Ventilation
- Egress


Levenson Park Slope, BK

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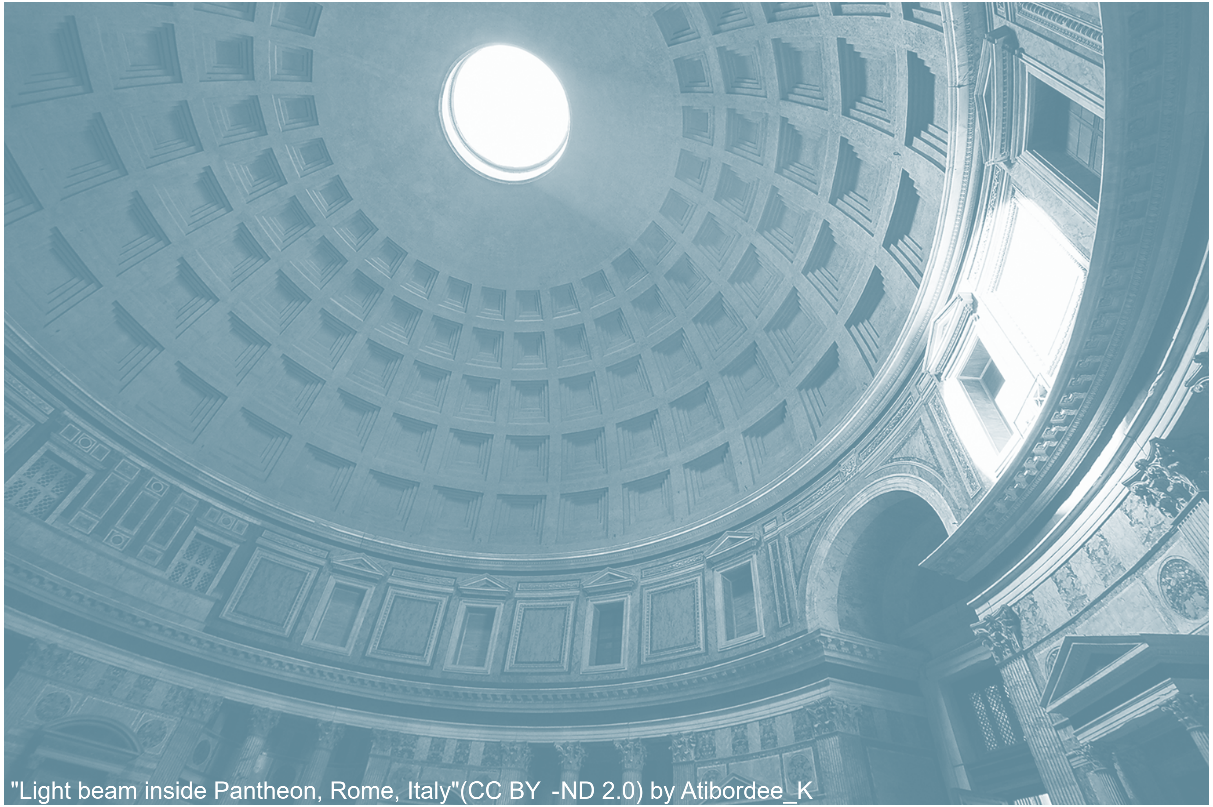
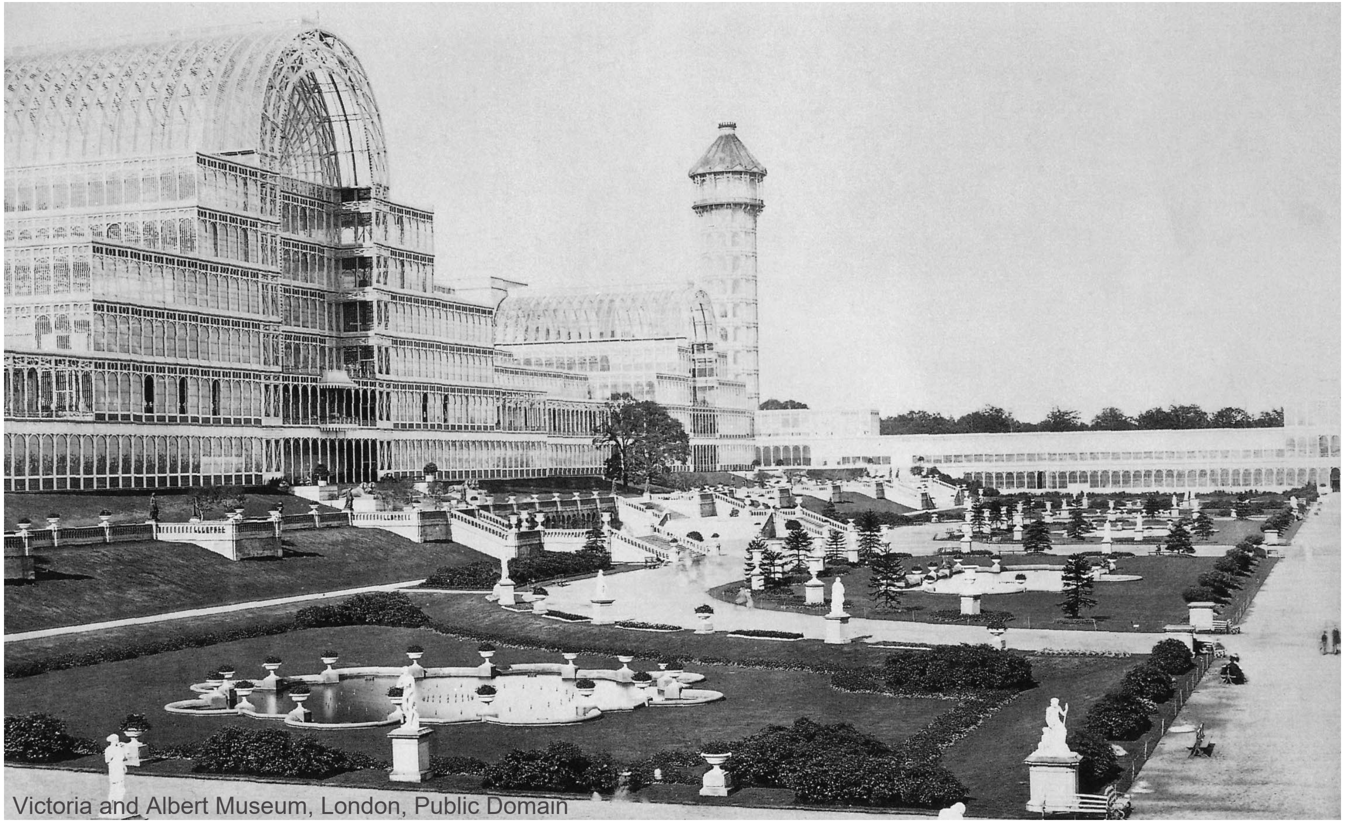
A Brief History of Fenestration



"Light beam inside Pantheon, Rome, Italy"(CC BY -ND 2.0) by Atibordee_K

Crystal Palace: 1851, Joseph Paxton

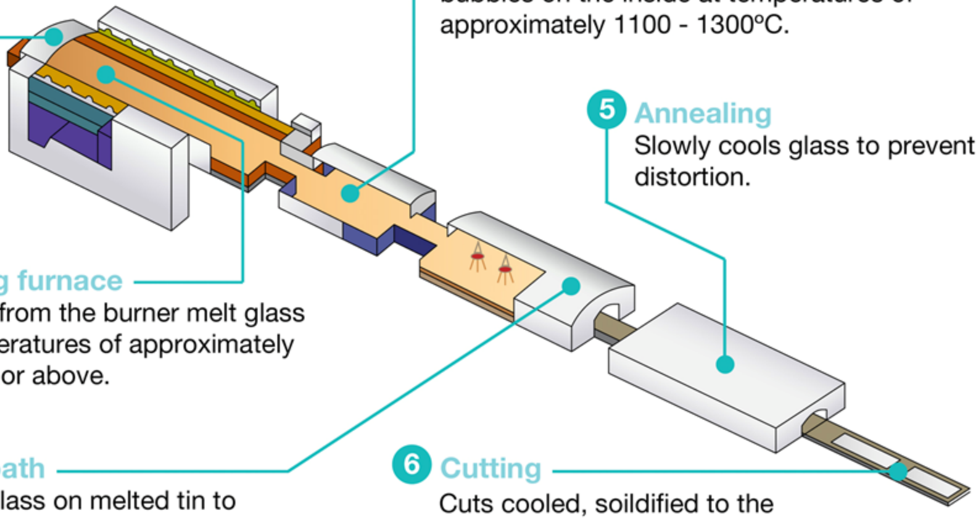


Victoria and Albert Museum, London, Public Domain

Johnson Wax Admin Building : 1939, Frank Lloyd Wright


Highsmith, Carol M. Library of Congress, Prints and Photographs Division.

New Technology: Commercial Float Glass



1 Raw materials charge
Where raw blended glass materials enter.

2 Melting furnace
Flames from the burner melt glass at temperatures of approximately 1600ºC.or above.

3 Refining furnace
A process that cools glass and removes air bubbles on the inside at temperatures of approximately 1100 - 1300ºC.

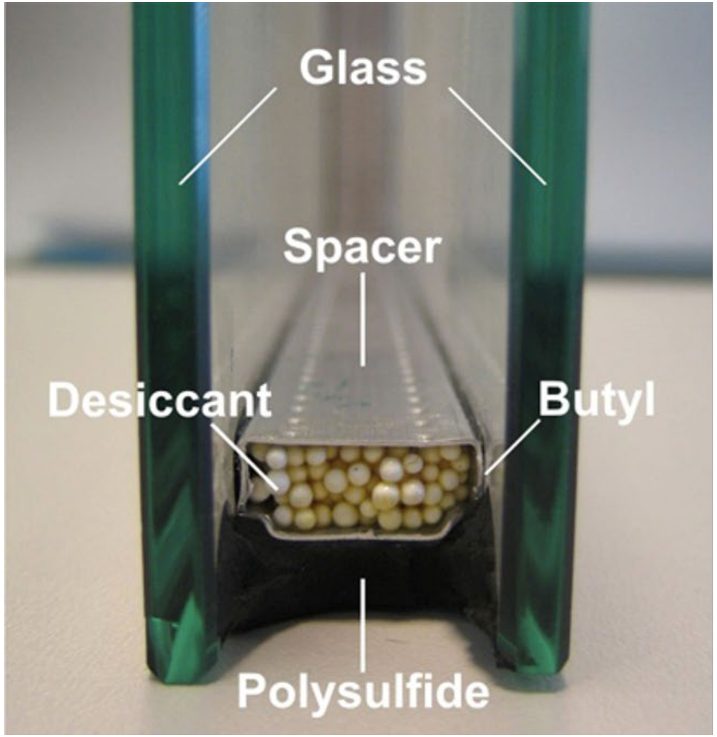
4 Float bath
Floats glass on melted tin to evenly form the width and thickness and ensure planarity on both sides.

5 Annealing
Slowly cools glass to prevent distortion.

6 Cutting
Cuts cooled, soildified to the necessary size.

The total length is an amazing 600 meters!

Insulated Glass Units (IGUs)



COMFORT DRIVERS

Comfort & Health

- Thermal Comfort (6 factors)
- Visual Comfort (glare)
- Acoustic comfort (loud noises)
- Hygienic comfort (air pollutants or mold)

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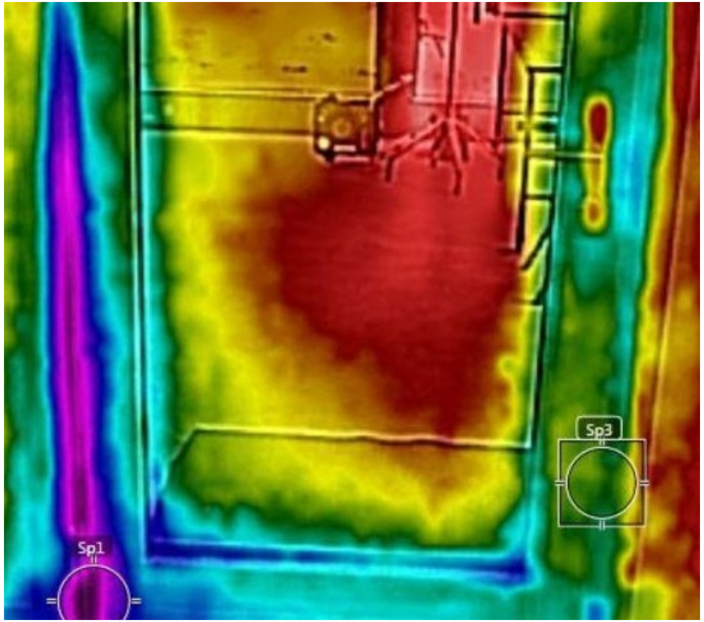
Plymouth School of Creative Arts

Poor Window Performance

- Condensation
- Summertime Overheating
- Glare

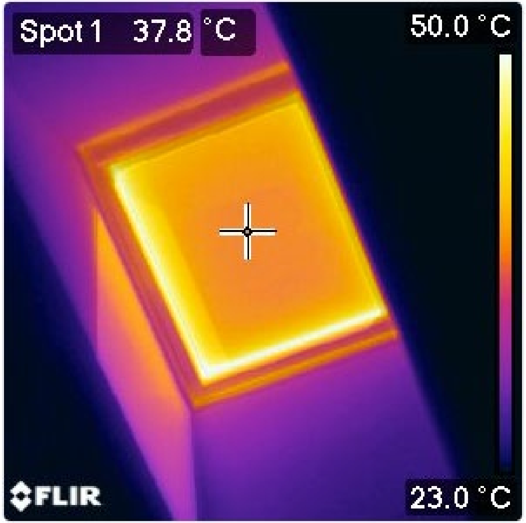


- Drafts
- Winter Heat Loss
- Mold Growth

Window Comfort and Health Concerns

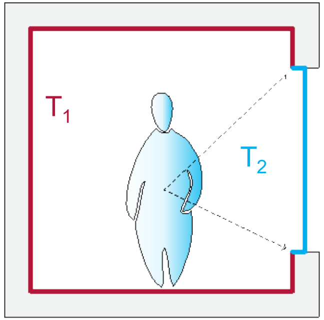
Nick Grant @ecominimalnick · 1h

Feeling warm in my office despite 23°C air temperature. Feels like a radiator is on, I wonder why??



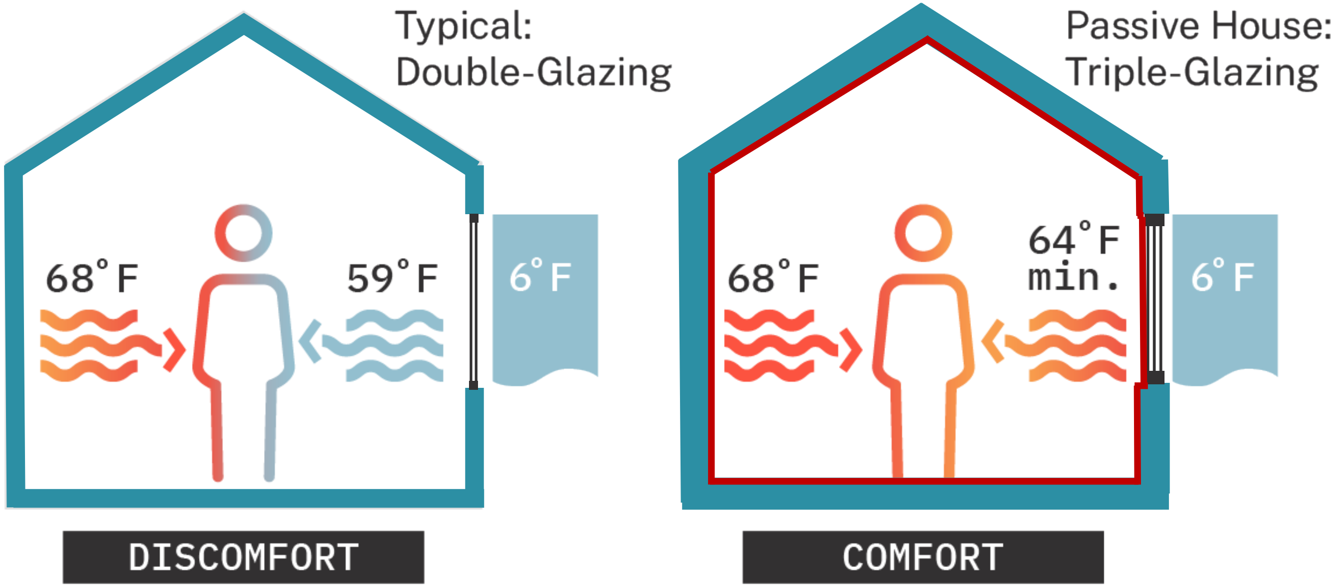
2 3

Radiation Temperature Asymmetry



BLDGtyp

Uglass Matters



Even temperatures allows removal of perimeter mechanical systems

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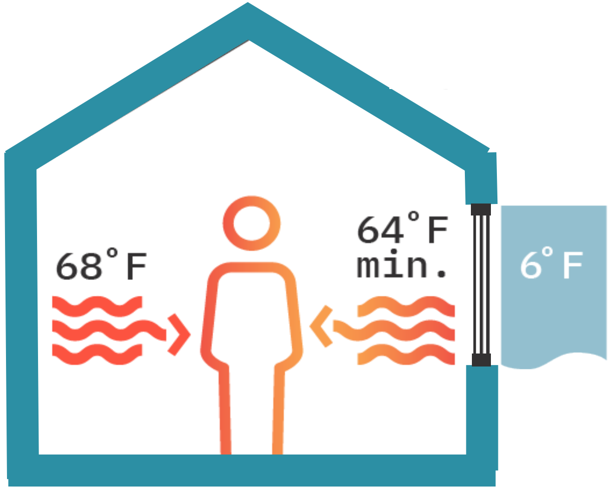
PH Comfort and Hygiene Criteria

1. Comfort Criterion - The minimum average window surface temperature can be no lower than 7.56 °F (3.5°C) than the average interior surface temperature. Based on the installed U value of a window.

2. Hygiene Criterion - sets limits that restrict the minimum interior surface temperature at the coldest point of the interior surface per climate zone, eliminating the potential for condensation and mold growth. Measured by climate specific temperature factors (f_{Rsi}).



PASSIVE HOUSE
WINDOW CERTIFICATION

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Passive House Component Certification

Transparent building envelope

- Windows
- Roof windows
- Skylights
- Curtain wall systems
- Glass roofs
- Openable elements in glass roof
- Shutters
- Entry doors
- Sliding doors
- Glazing
- Glazing edge bonds

Passive House Institute

Component Database

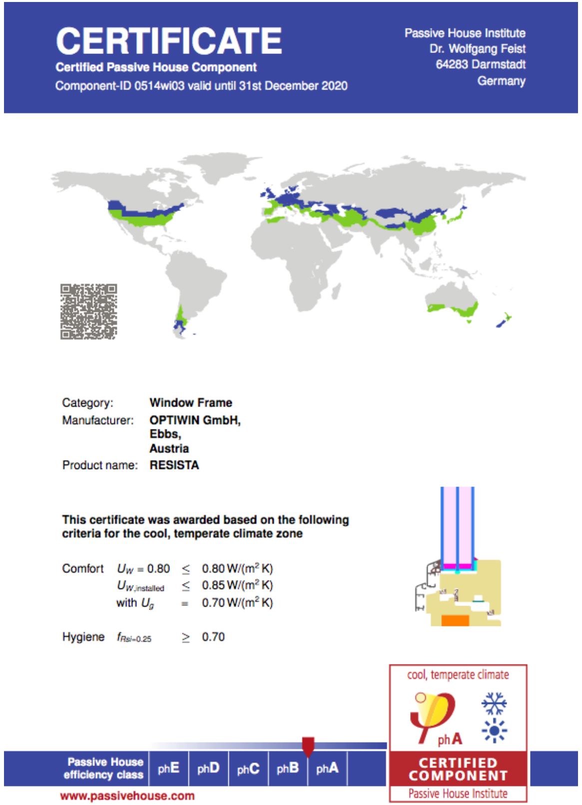
https://database.passivehouse.com/en/components/

What Makes a PH Window

cool, temperate climate
phA
CERTIFIED COMPONENT
Passive House Institute

Source: Zola ThermoPlus Clad Window Profile

Certified PH Windows



CERTIFICATE
Certified Passive House Component
Component-ID 0514wi03 valid until 31st December 2020

Passive House Institute
Dr. Wolfgang Feist
64283 Darmstadt
Germany

Category: **Window Frame**
Manufacturer: **OPTIWIN GmbH, Ebbs, Austria**
Product name: **RESISTA**

This certificate was awarded based on the following criteria for the cool, temperate climate zone

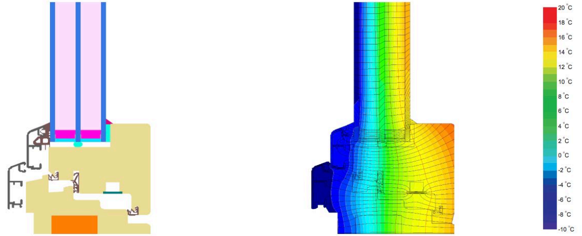
Comfort $U_W = 0.80 \leq 0.80\ W/(m^2 K)$
$U_{W,installed} \leq 0.85\ W/(m^2 K)$
with $U_g = 0.70\ W/(m^2 K)$

Hygiene $f_{Rsi=0.25} \geq 0.70$

cool, temperate climate
phA
CERTIFIED COMPONENT
Passive House Institute

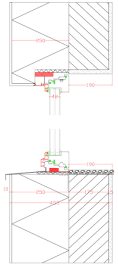
Passive House efficiency class: phE phD phC phB phA

www.passivehouse.com



Calculation model | Isothermal

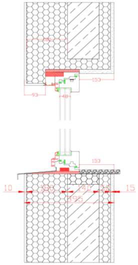
EIFS



$\Psi_{install}$	W/(m K)
Top	0.007
Side	0.007
Bottom	0.017

$U_{W,installed} = 0.82\ W/(m^2 K)$

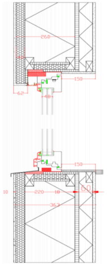
Insulated formwork blocks



$\Psi_{install}$	W/(m K)
Top	0.006
Side	0.006
Bottom	0.018

$U_{W,installed} = 0.82\ W/(m^2 K)$

Timber frame



$\Psi_{install}$	W/(m K)
Top	0.010
Side	0.010
Bottom	0.029

$U_{W,installed} = 0.84\ W/(m^2 K)$

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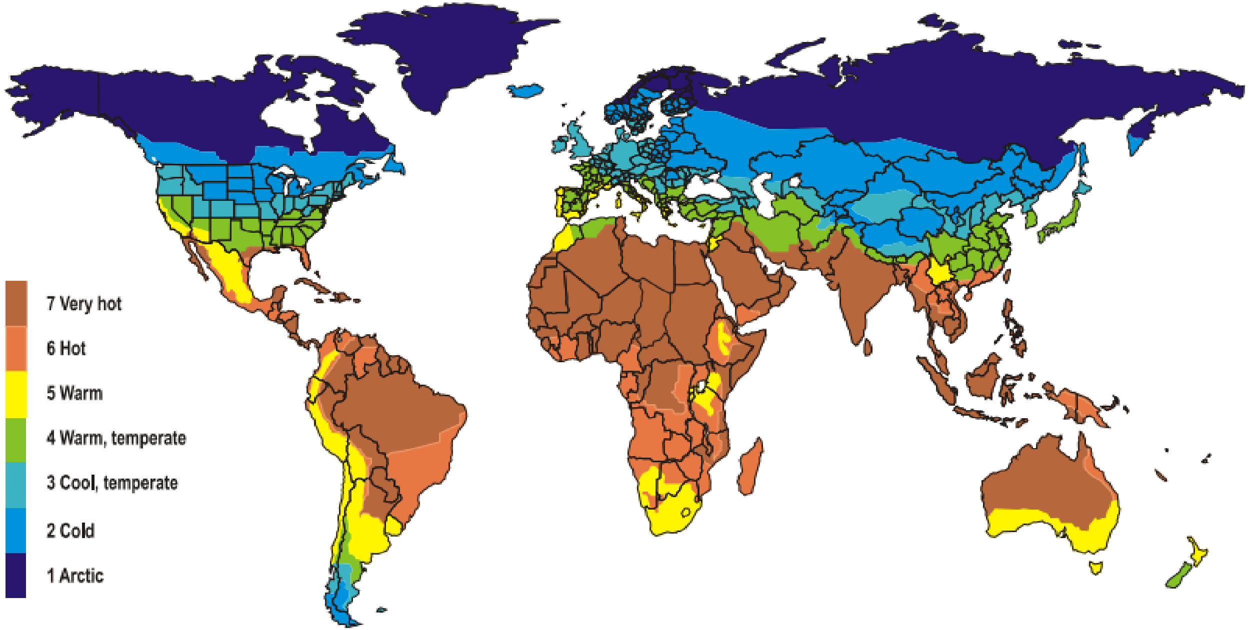
Choose the Right Window for Your Climate



Certification Criteria & Reference Glazing

Climate Zone	Hygiene criterion: $f_{Rsi} \geq 0.70$ hr.ft ^{2}.ºF/Btu	U-value (Component) Btu/ hr.ft ^{2}.ºF	U-value (installed) Btu/ hr.ft ^{2}.ºF	Reference glazing* Btu/ hr.ft ^{2}.ºF
1. Arctic	0.80	0.07	0.08	0.06
2. Cold	0.75	0.10	0.11	0.09
3. Cool Temperate	0.70	0.14	0.15	0.12
4. Warm Temperate	0.65	0.18	0.18	0.16
5. Warm	0.55	0.21	0.22	0.19
6. Hot	None	0.21	0.22	0.19
7. Very Hot	None	0.18	0.18	0.16

* Reference Glazing:

- The U-values used by PHI for glazing are the same for all window frames being certified – irrespective of the type of glass *actually* being used.
- With some manufacturers, you get better than what is on the PHI Certificate
- PHI use 0.12 for glass U-value, but some firms supply 0.10 or even less, (15% better)

Mold Prevention at Interior Surfaces

The fRsi factor allows us to evaluate a given construction to assure mold resistance, for mold resistance, the fRsi factor must be greater than the climate specific limit

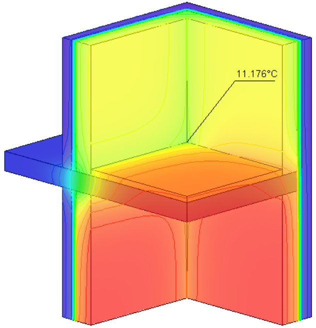
$$f_{Rsi} = (t_{si} - t_e) \div (t_i - t_e)$$

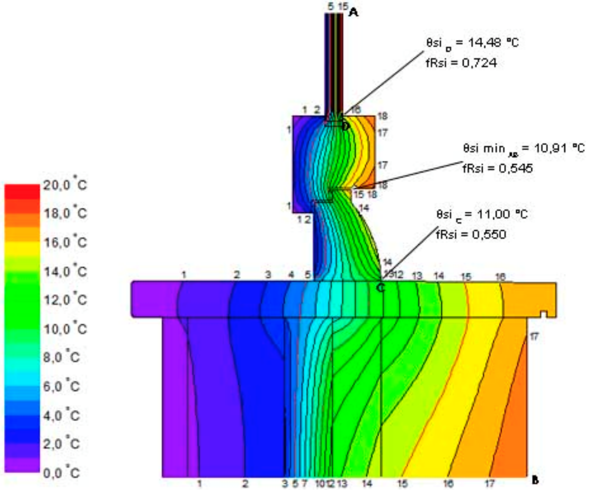
f_{Rsi} Temperature factor at the internal surface

t_{si} Interior Surface Temp

t_e Exterior Design Temp

t_i Interior Design Temp

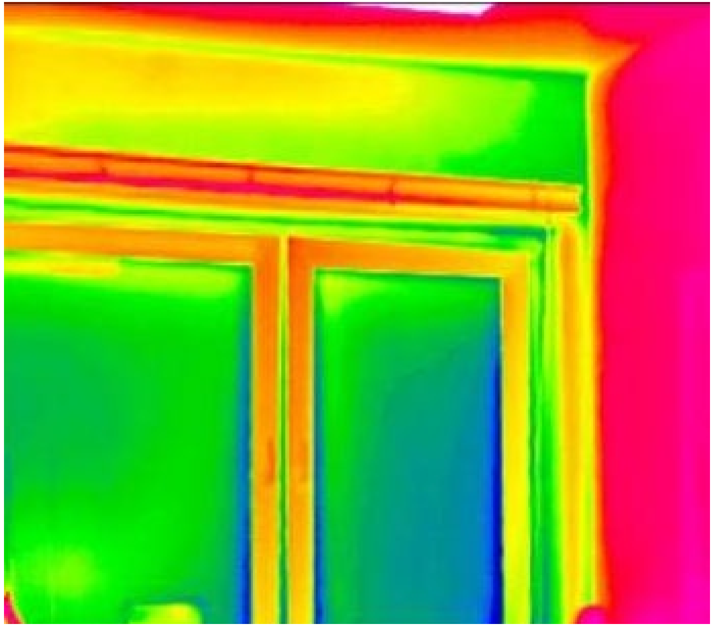




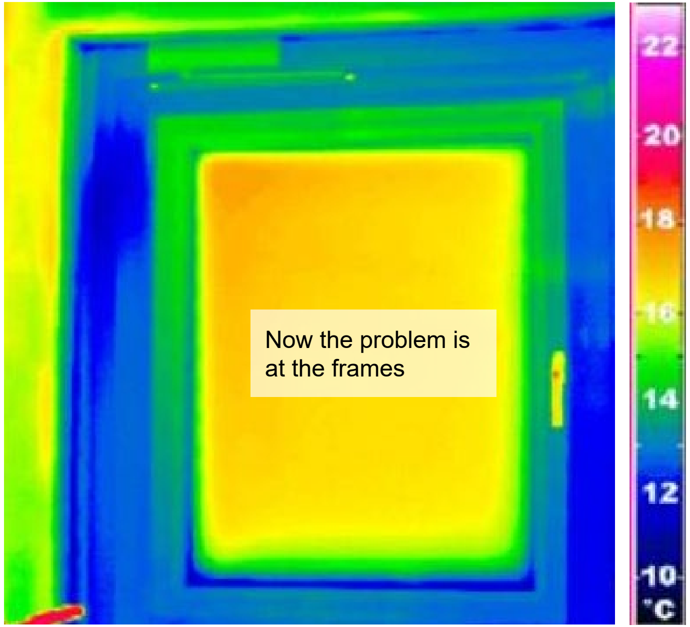
Note: For f_{Rsi} calculation, surface temps and exterior conditions must be modeled as per ISO 10211 & 13788

Glazing and Frame Performance

Typical Windows: Poor glazing and Frame



Improved Glazing and Low -e Coatings



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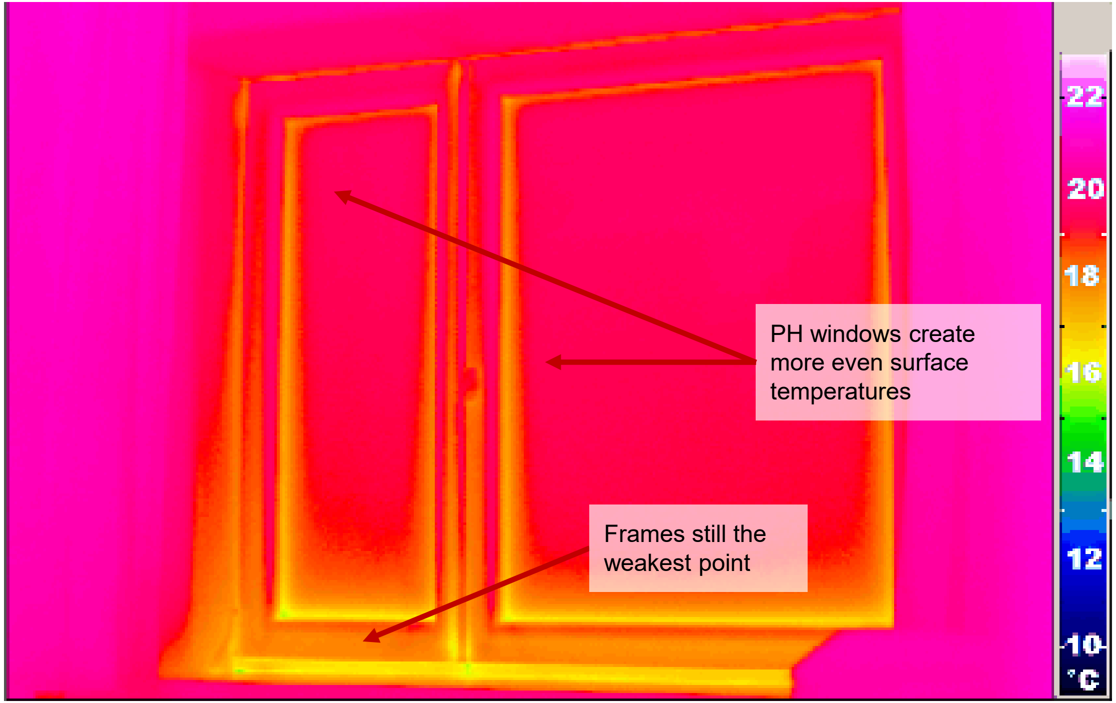
As window performance increases frames become the weakest link!

Outdoor -5°C (14°F)
Indoor 20 °C (68 °F)

Frames Determine Certification Class

PH Glass and Frame



The better the frame performs the higher certification class!

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The Passive House Network

Four PHI Window Classes

Passive House Efficiency Class	Description	Ψ_{opaque}
phA^{+}	Very advanced component	≤ 0.037 Btu/hr.ft.°F
phA	Advanced component	≤ 0.063 Btu/hr.ft.°F
phB	Basic component	≤ 0.089 Btu/hr.ft.°F
phC	Certifiable component	≤ 0.115 Btu/hr.ft.°F

$$\Psi_{opaque} = \Psi_g + \frac{U_f \cdot A_f}{L_{spacer}}$$

Ψ_g = Psi-value of the glazing spacer

U_f = U-value of the frame

A_f = area of the frame

L_{spacer} = length of the glazing spacer

PH WINDOW TYPES AND APPLICATIONS

Passive House Window Types

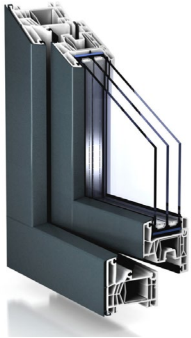
- Windows
- Operable and fixed
- Entry Doors
- Sliding doors
- Skylights
- Pitched and flat
- Curtain walls
- Glass roofs

Window Materials

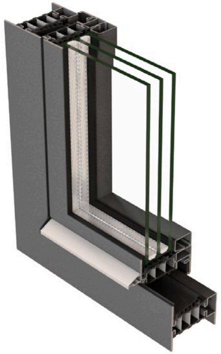

Aluminium -Clad Wood


All Aluminium

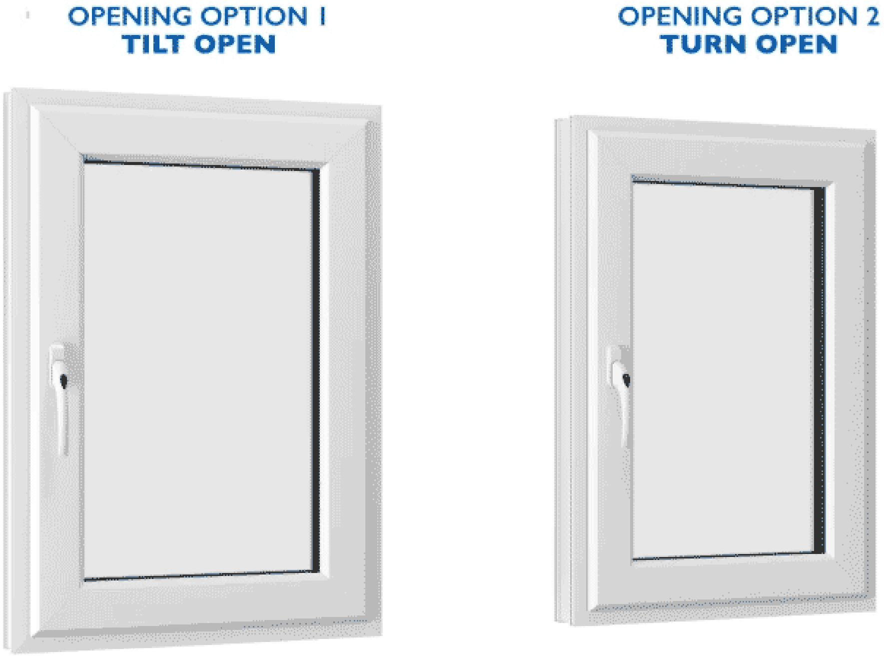

Fiberglass


uPVC


All Wood


Steel

Tilt and Turn Operation



Source: Bespoke Windows CA

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Tilt and Turn Windows

- Most common operation type
- Continuous seal
- Limited in size and shape
- In-swing only

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Fixed Windows

- Typically, best performing
- Greater size and shape options
- Less expensive
- Installation can be trickier

Passive House Entry Doors

475 High Performance Building Supply

- Continuous air seal
- Thicker profile
- Multiple point locking system
- Uses triple pane glass or super insulated panels

Lift and Slide Doors


MoreMas

- Airtight
- Large openings
- Triple pane glass
- Heavy units shipping and installation can be tricky
- Operation is different than normal swing doors

Skylights

- Pitched or flat roof
- Insulated curbs and frame
- Triple pane glass

- Operable or fixed
- Shading is important
- Only a few certified options

Curtain Walls and Glass Roofs

Loadingdock5

- Commercial applications
- Thermally broken profiles
- Operability for ventilation and egress

Single Family Home

Historic Retrofits


BaxtIngui


475 HPBS

PH Multifamily: Candela Lofts

PH High -Rise

Section 2:
How to Design & Detail Passive House Windows

Utilizing your High-Performance Windows

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Fenestration 101

Photometry, Shading, Orientation & Daylight modeling

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What is Happening Here?

Daylight Potential

Photometry Terms and Units

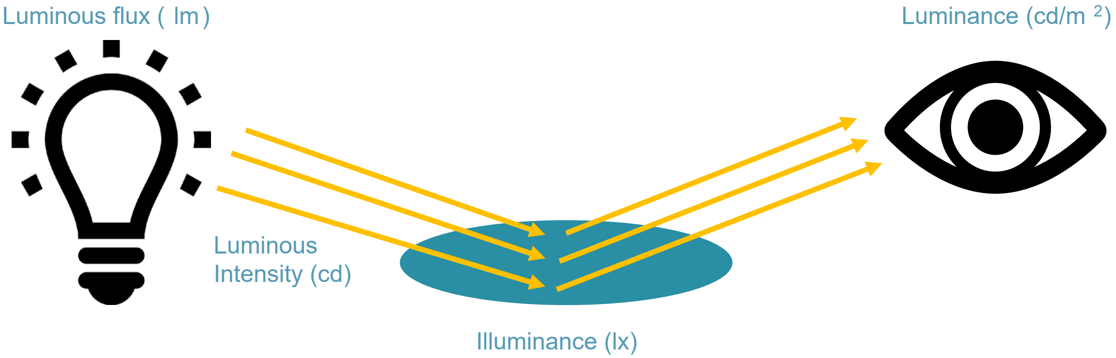
Luminous Flux: Is the total quantity of visible light emitted by a source per unit of time, measured in Lumens (lm)

Illuminance: Is the total Luminous Flux that hits a surface, measured as Lux (lx)

$$\text{Lux} = \text{Lumen} / m^2$$

Luminous Intensity: The amount of visible light emitted by a source in a given direction, measured in Candelas (cd)

Luminance: Is the Luminous Intensity (Candela) over a specific area measured as Candela/m^2



Daylighting Goals

- Uniform levels
- No Glare
- Quality of Light
- Commercial vs Residential
- No Overheating

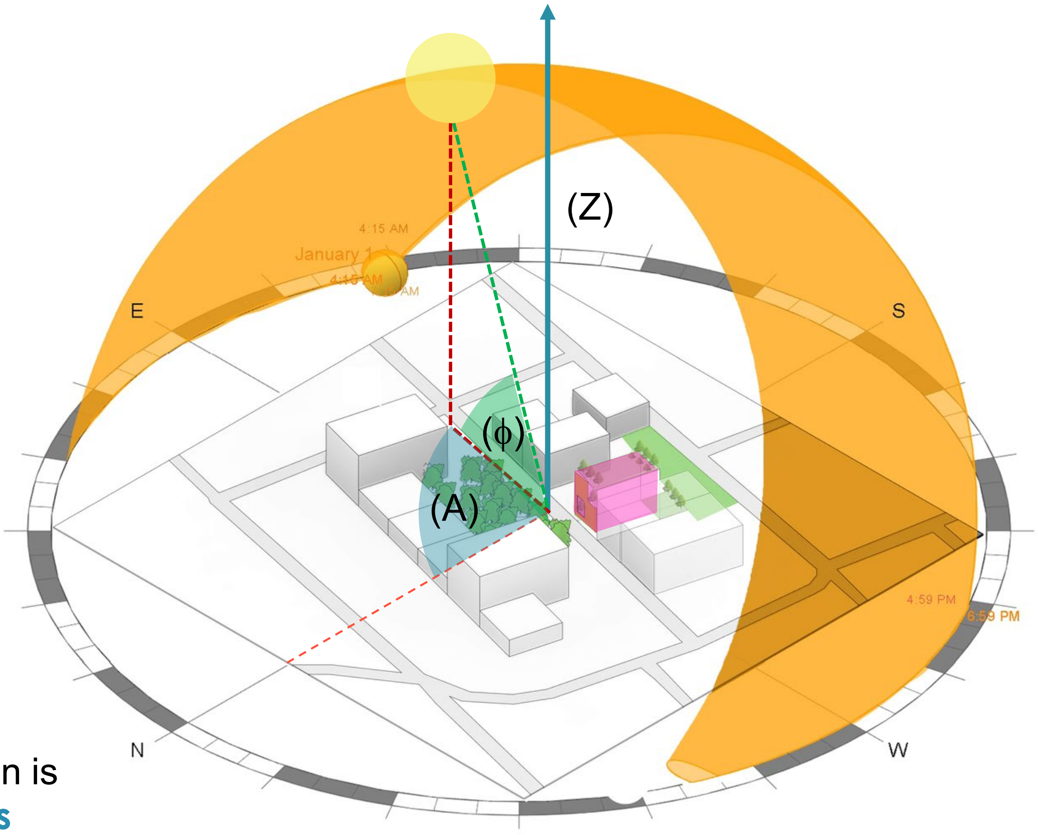
LAMILUX UK
Plymouth School of Creative Arts

Orientation and Siting

Zenith (Z)

Elevation Angle (ϕ)

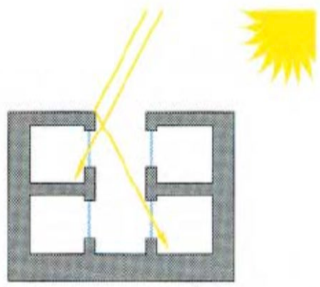
Azimuth Angle (A)



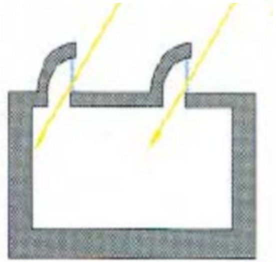
Analyzing the building site and its orientation is critical to providing enough **solar access**

Source: Keivani Architects

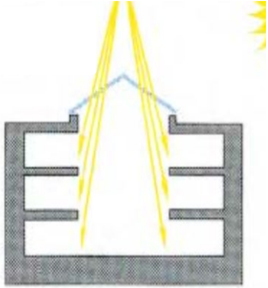
Daylighting Strategies for Buildings



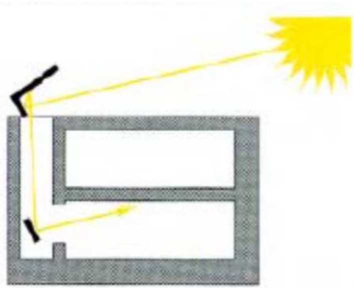
Light Well



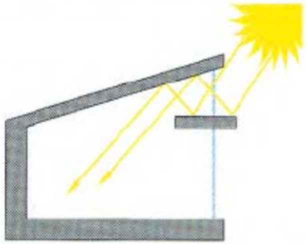
Roof Monitors



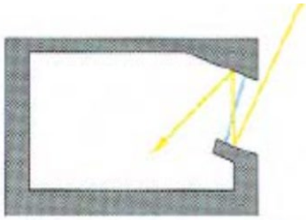
Atrium



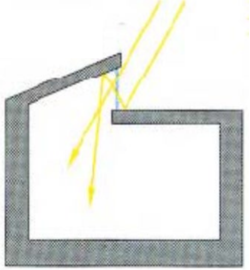
Light Duct



Light Shelf



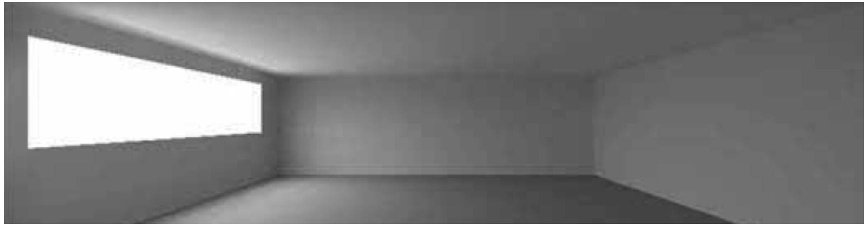
External Reflectors



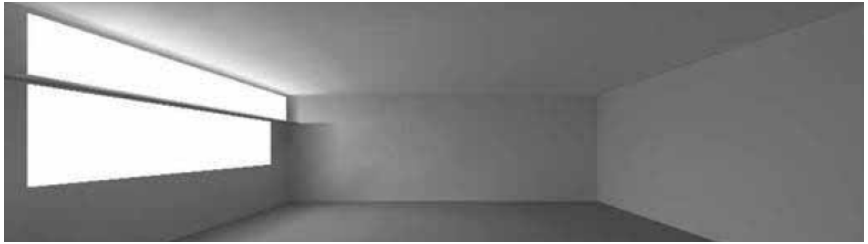
Clerestory

Reflective blinds

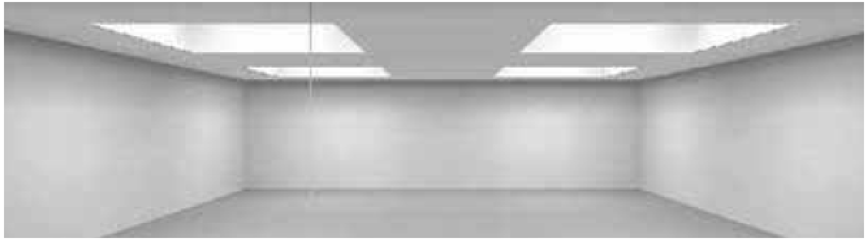
Daylighting with Skylights



Window with blinds



Clerestory with Light Shelf and blinds

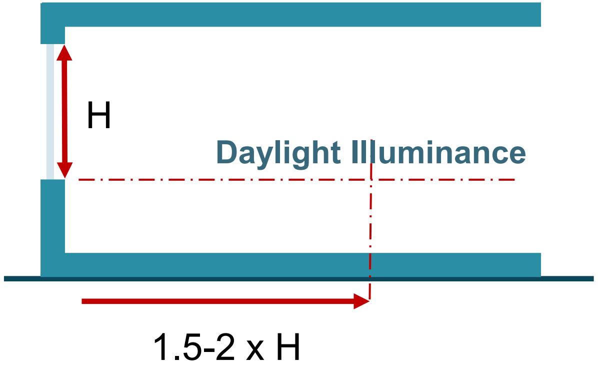


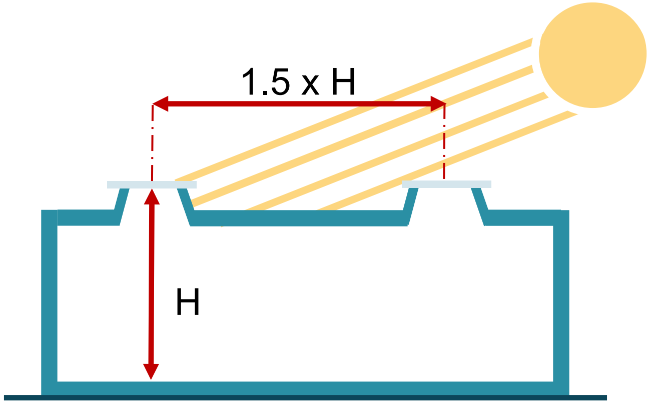
Skylights with splayed light wells

AAMA Skylight Council

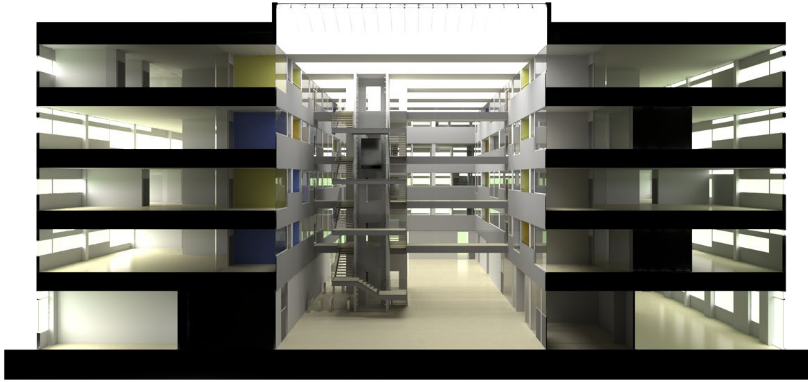
Daylighting Rules of Thumb

- Windows provide daylight 1.0 - 2x the head height of light deep into the space.
- Space skylights at 1.0 - 1.5 times the ceiling height (center -to-center in both directions).
- Skylights can **be 3 - 10 times smaller** than a window and collect the **same amount of light.**

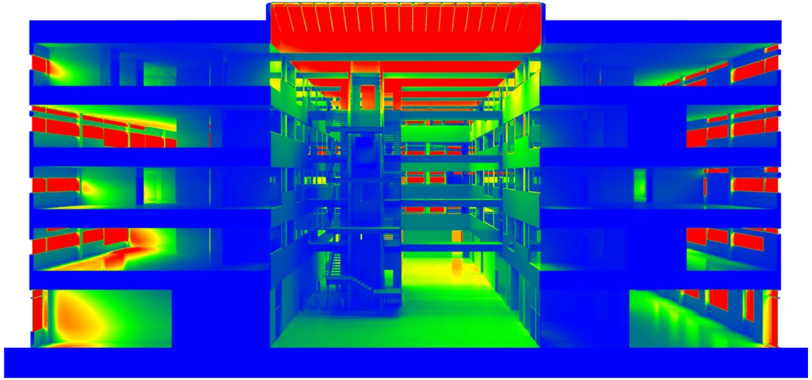


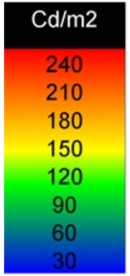


Daylight Modeling



- 3D Modeling Tools that evaluate lighting in buildings.
- Can be used to model lighting levels from natural & artificial sources.
- Photo realistic renderings and/or False - Color Images.
- Different goals for residential vs commercial construction.



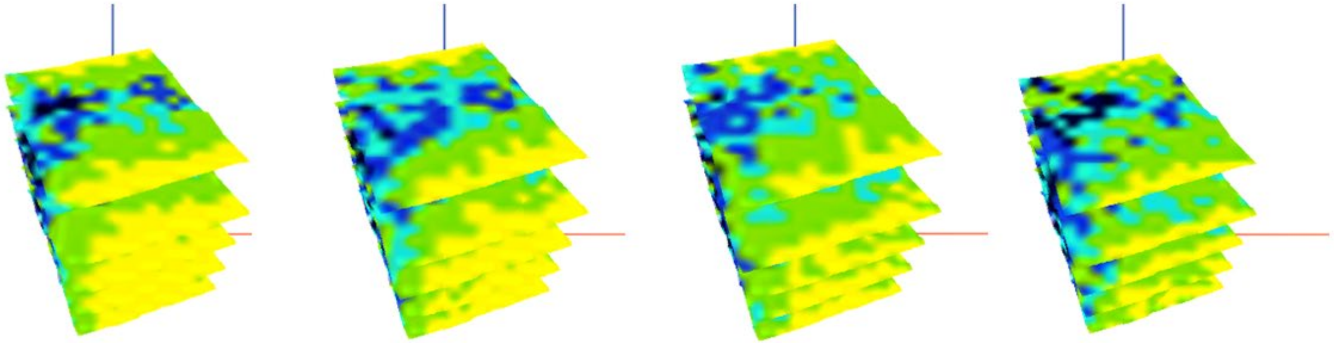


Luminance measured here

Velux Group: Data Visualizer

Spatial Daylight Autonomy (sDA)

No Shading | Horizontal Projection | Horizontal Brise Soleil | Slatted Horizontal Protection



Hours of the year where illuminance is at least 300lux

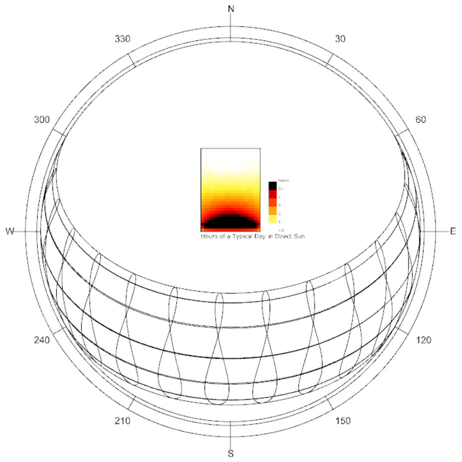
1-730 hrs | 731-1460 hrs | 1461-2190 hrs | 2191-2920 hrs | 2921-3650 hrs

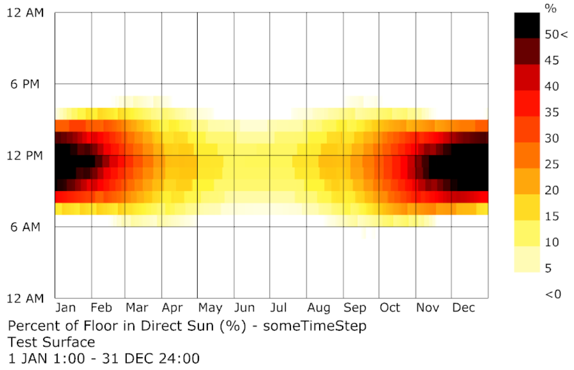
Satisfactory is sDA300/50%
(more than 300 lux for more than 50% of the 10hr workday)

Source: Sketchup Blog

Annual Sunlight Exposure (ASE)

- How much space receives too much direct sunlight
- Indicator of possible visual or thermal discomfort
- ASE1000.250 – percent of floor that has >1000 lux for >250hrs per occupied year
- Used in Commercial Projects



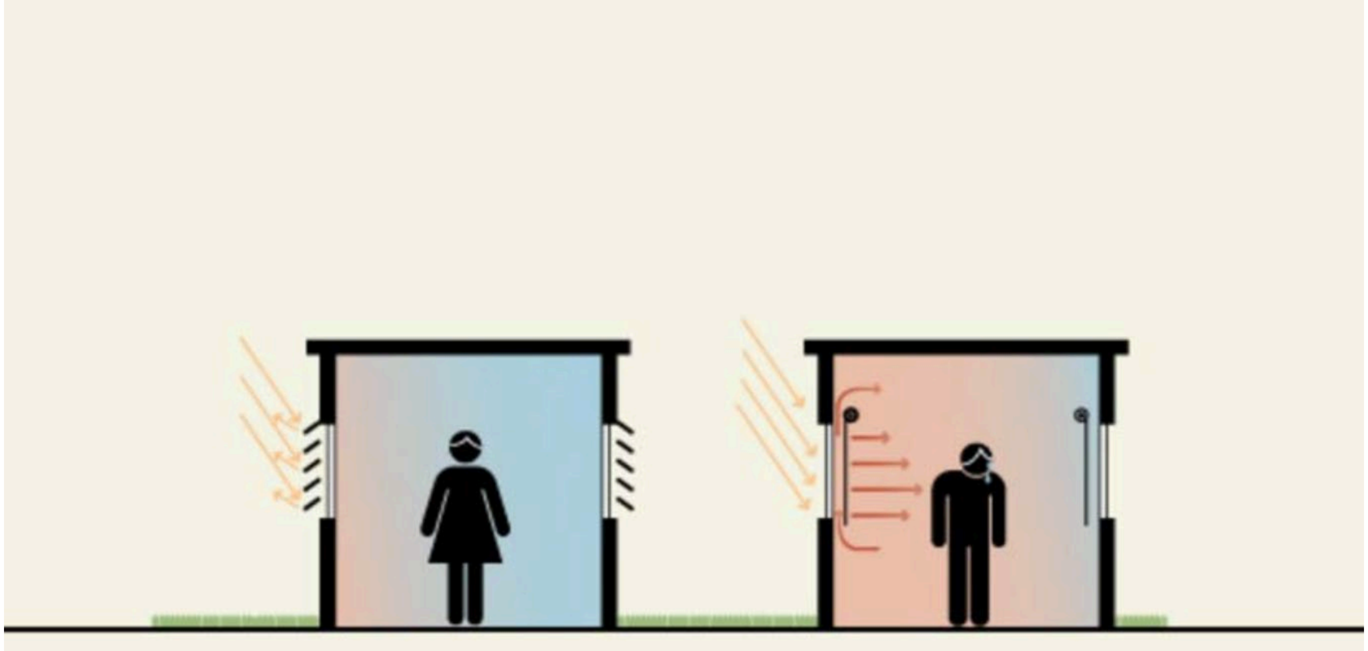


Chris Mackey Lady Bug Example

What's Happening Here?

Balanced Fenestration

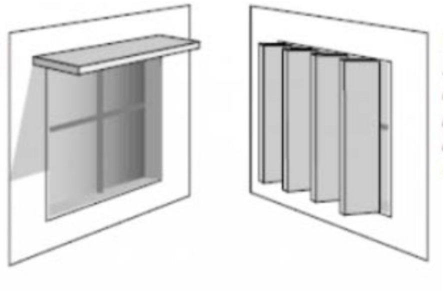
Shading Strategies



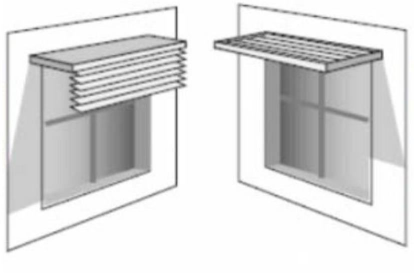
External Shades vs. Internal

Source : Mansour Glass

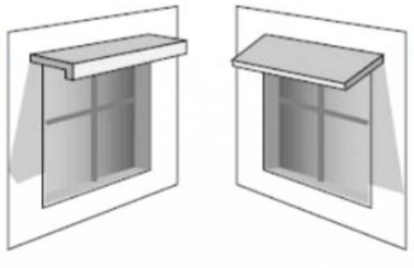
Exterior Shading Strategies



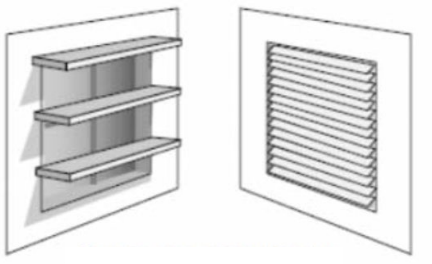
Standard overhangs for Southern windows and vertical fins for east west orientations



Using Louvers or slatted features lets in more daylight while still providing shading



Dropping the edge or angling the overhang reduces the overhang length while maintaining the same shading



Breaking up the overhang allows for smaller projection lengths

https:// www.researchgate.net /figure/External -Shading -Devices

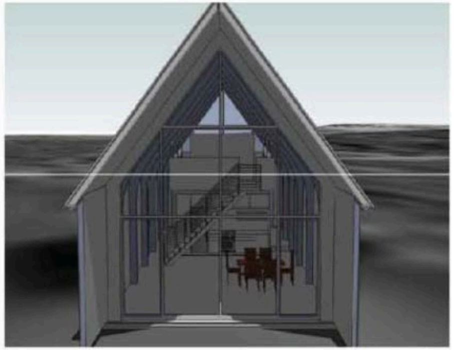
Shading Strategies

Solar Study: Hudson Passive House

Sun Path at Noon

January/December

March/September

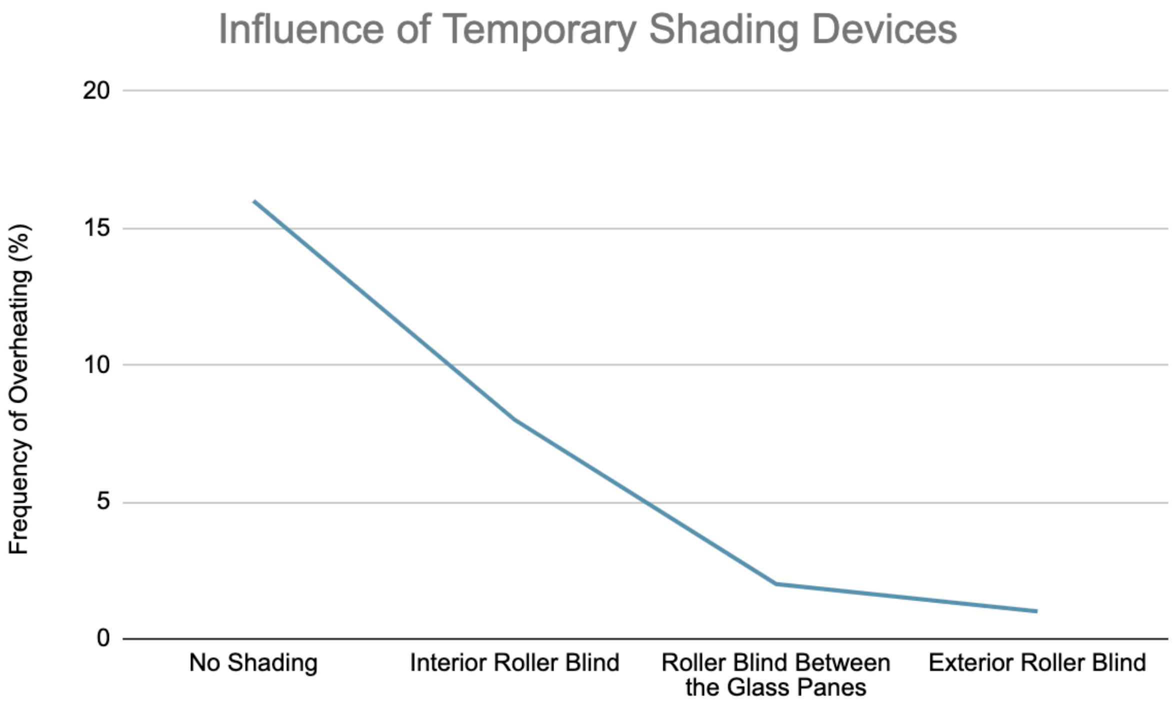


June

Daylight modeling can be useful to calibrate the shading strategy during the design phase

BarlisWedlick

Shading Effectiveness



PHPP Four Types of Shading

1. Shading object, e.g. nearby building, trees, garden walls
2. Window reveals (sides of the window)
3. Overhang (top reveal of the window, or balcony / roof overhang, whichever is greater)
4. Additional shading (user -determined)

Shading sheet calculates both summer and winter shading (therefore additional shading reduction factor can be calculated for both seasons with different sun angles).

Horizon		Lateral reveal		Reveal / Overhang				
Height of the shading object	Horizontal distance	Window reveal depth	Distance from glazing edge to reveal	Overhang depth	Distance from upper glazing edge to overhang	Additional reduction factor winter shading	Additional reduction factor summer shading	Reduction factor z for temporary sun protection
h_{Hori} [ft]	d_{Hori} [ft]	o_{Reveal} [in]	d_{Reveal} [in]	o_{over} [in]	d_{over} [in]	$r_{other,w}$ [%]	$r_{other,s}$ [%]	z [%]

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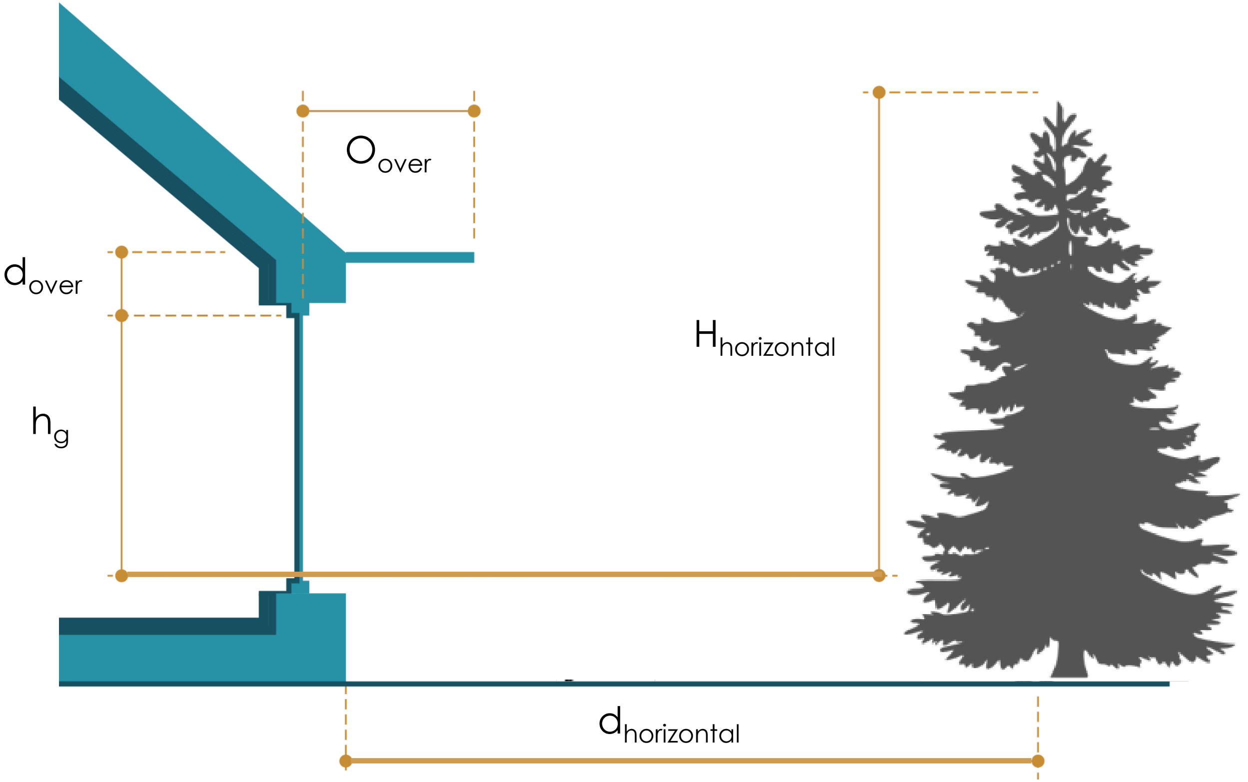
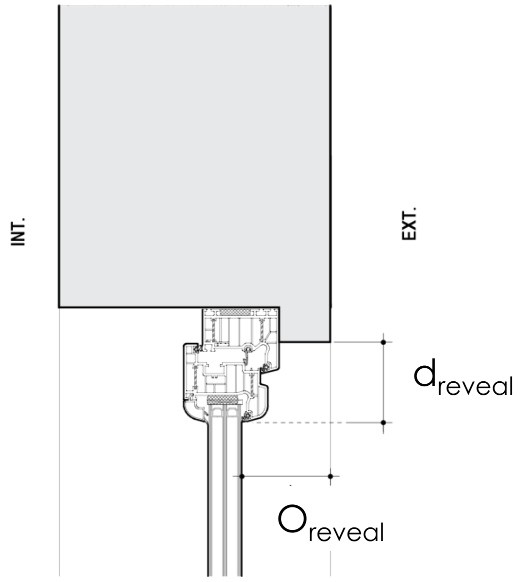
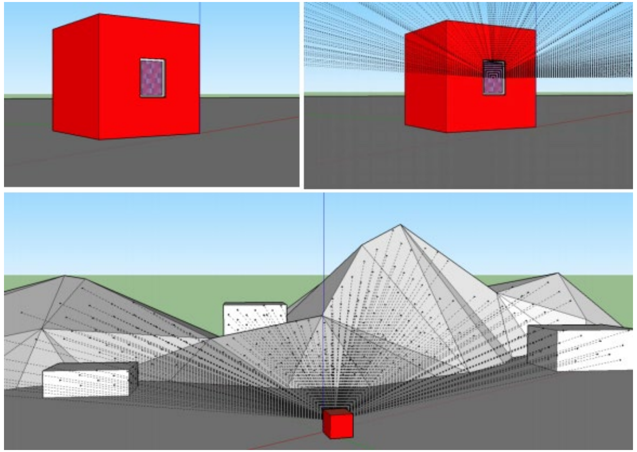
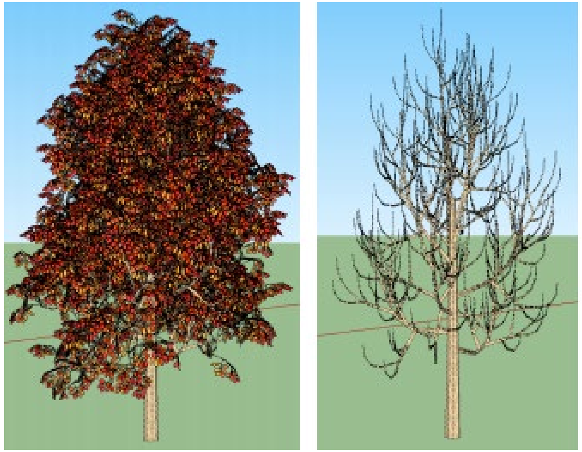
Shading (per Window)





Shading With DesignPH





1. More accurate shading analysis.
2. Sketchup Plug in.
3. Generates a shading mask for each window by ray tracing.
4. Essential for modelling complex shading elements.
5. Can hide and unhide objects to quickly model changes in landscape (deciduous trees).

PERFORMANCE AND COMPONENTS

Window Performance

- Orientation
- Shading
- SHGC & VT
- Airtightness

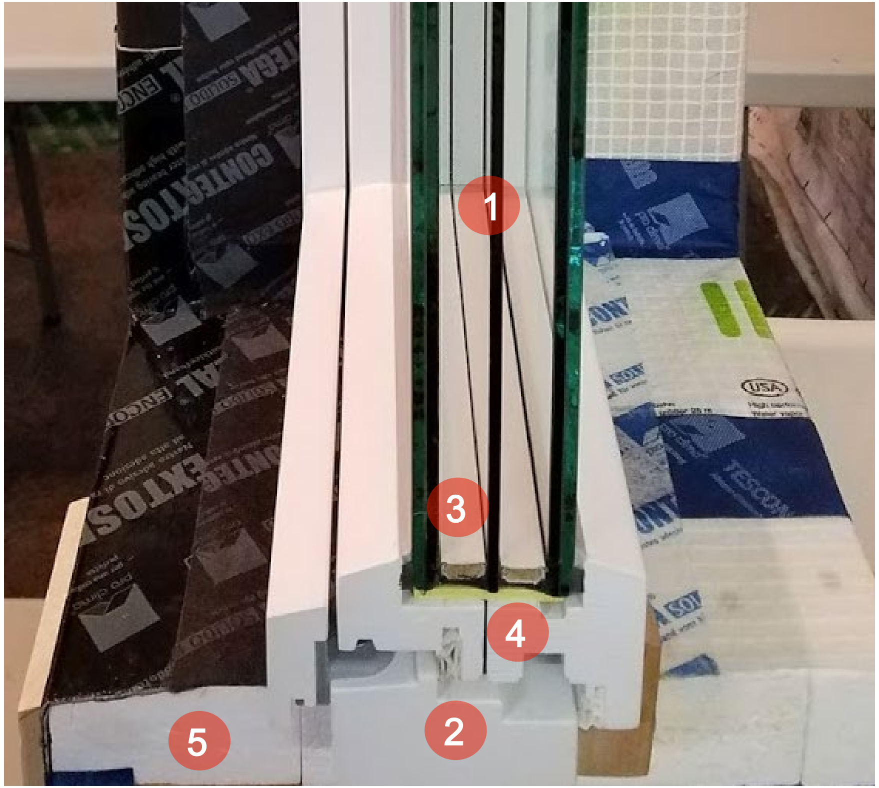
- Glazing U-value
- Frame U-value
- Psi Spacer
- Installation/integration

Traditional vs Passive Windows

Traditional American Double Hung

European Tilt and Turn

PH Window Components



1. Triple -pane IGU
2. Continuous Airtight gasket
3. Warm Edge Spacer
4. Thermally broken frame
5. Over insulation around frame

Measuring Window Component Performance

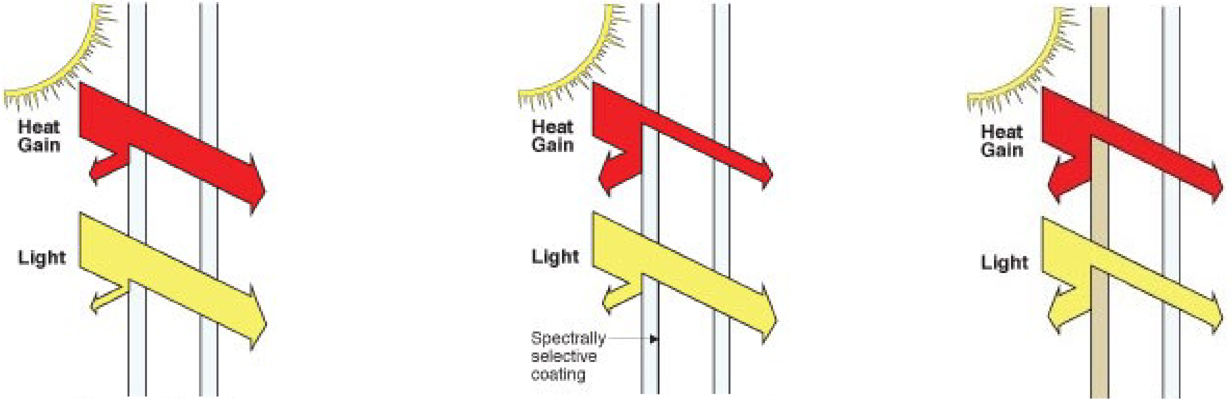
1. U-value - the rate of transfer of heat through matter, also known as Thermal Transmittance. The lower the U -value the slower heat moves through the unit and the better it insulates.

2. Solar Heat Gain Coefficient (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.

3. Visual Transmittance (VT) - is a fraction of the visible spectrum of sunlight that is transmitted through the glazing of a window. VT is expressed as a number between 0 and 1. A window with a higher VT transmits more visible light.

4. Air Leakage - is the amount of air that leaks through the window (not measured in PH certification but may be calculated in NFRC testing). Lower is better.

SHGC vs Visual Transmittance



Clear Double Glazing | Low E coating | Bronze Tint

Heat Gain | Visible Light

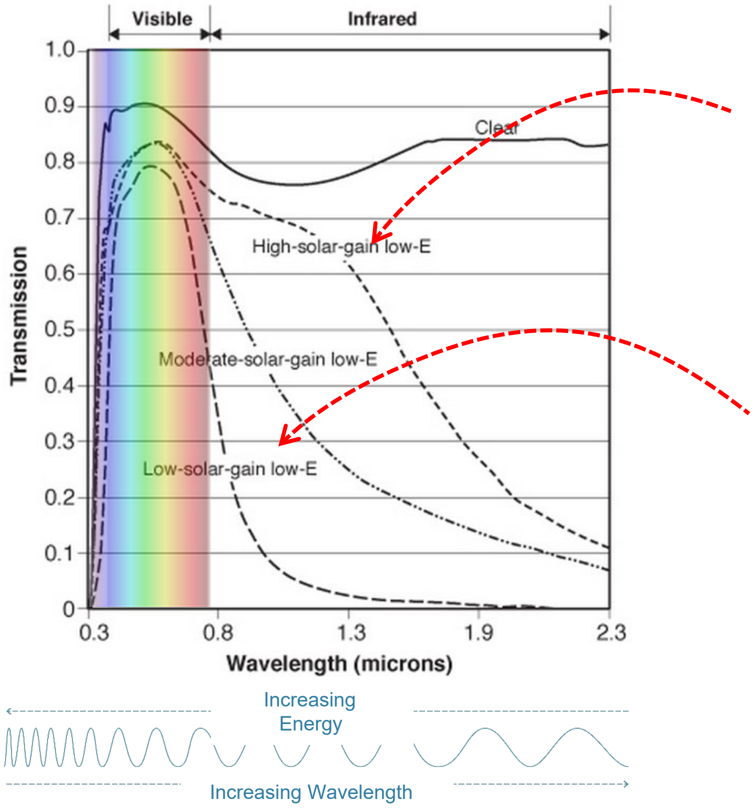
VT to SHGC Ratio

Sunglasses (bronze tint) between 1 and 1.2
Better/desired 2
Maximum theoretically possible 2.5

Optimize diffuse daylight

High VT combined with orientation / shading solutions

Low-E Coating and SHGC



In heating dominated climates, HIGH SHGC specification can be beneficial for south facing windows.

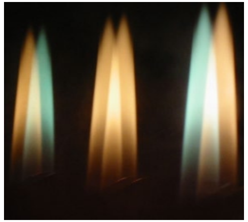
HOWEVER - US climates use with caution! Can lead to significant overheating if not shaded properly.

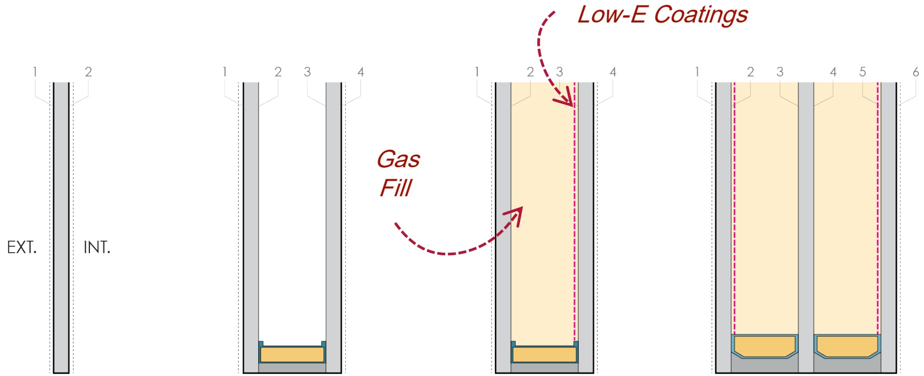
In cooling dominated climates, this specification might be required to prevent over -heating.

BUT - low solar gain glass might also be needed on east and west facing windows in heating dominated climates to prevent over-heating!

Types of Glass: IGUS and Heat Loss

Coating position, quick test



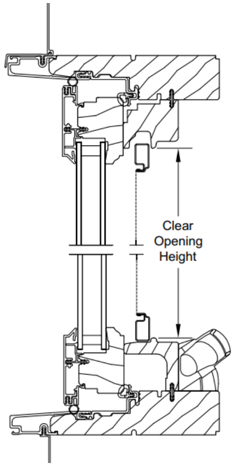


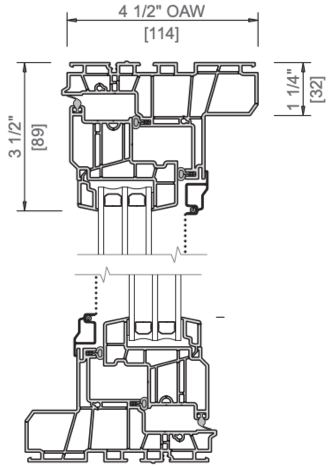
Glazing	Single	Double with air fill + Aluminum Spacers	Double Low-E with gas fill + Aluminum spacers	Triple Low -E with gas fill + Plastic Spacers
U_g 0.09	1.00	0.50	0.18 – 0.28	0.09 – 0.14
Int. Surface Temp*	28.8 °F	48.4°F	59.5°F	63.5°F
SHGC	0.85	0.76	0.5 – 0.68	0.4 – 0.62

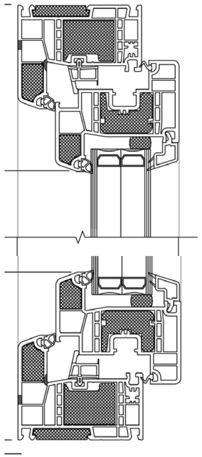
*With Exterior at 14° F, Interior at 68° F

Source: Passipedia.org

Evolution of Window Performance







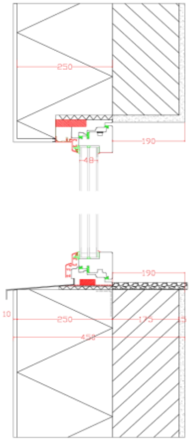
Frame Type	Marvin Double Glazed	Pella 350	Passive House Triple Glazed*
U-Value (Btu / hr.ft2. °F)	0.38	0.26	0.13
R-Value (hr.ft2. °F/ Btu)	2.6	3.9	7.6

Window Detailing

Installation Matters

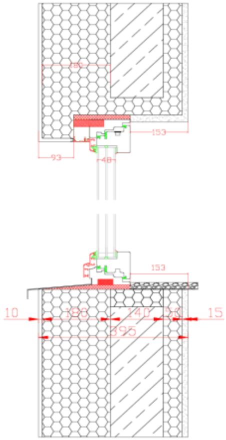
PH Window Detailing

EIFS



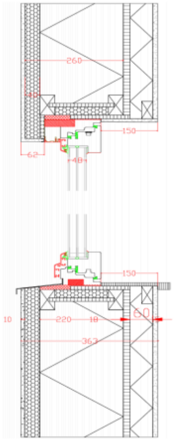
$\Psi_{install}$	W/(m K)
Top	0.007
Side	0.007
Bottom	0.017
$U_{W,installed}$	= 0.82 W/(m² K)

Insulated formwork blocks



$\Psi_{install}$	W/(m K)
Top	0.006
Side	0.006
Bottom	0.018
$U_{W,installed}$	= 0.82 W/(m² K)

Timber frame



$\Psi_{install}$	W/(m K)
Top	0.010
Side	0.010
Bottom	0.029
$U_{W,installed}$	= 0.84 W/(m² K)

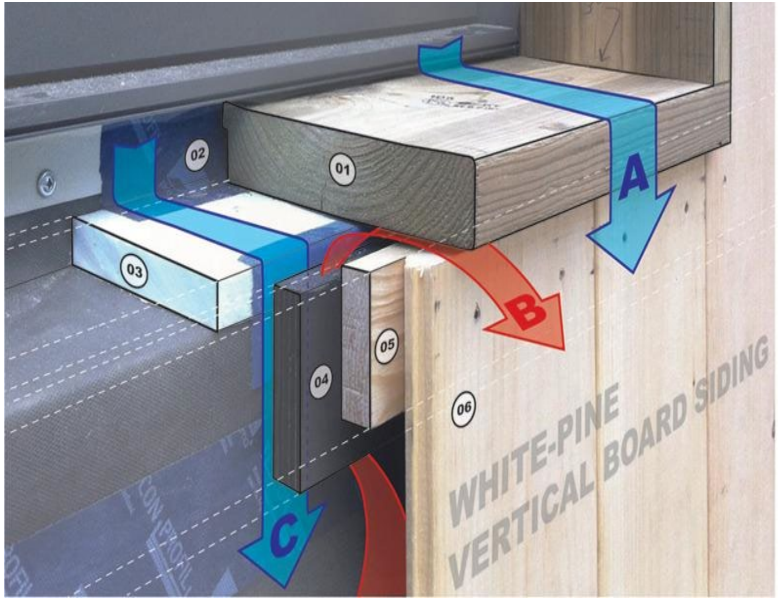
Thermal Bridge Free Installation

475 High Performance Building Supply

PH Window Integration

Interior

Exterior



Window continuity to control layers! …Water, Air, and Thermal

Source: BLDGtyp Wisconsin Cabin

PH Window Integration

Ecological Building Systems

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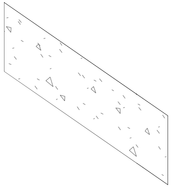
PH Window Integration



BLDGtyp

PH Window Integration

Case Study:
Single Family New Build

EASTONCOMBS, New Marlborough, MA

Window Installation

Window Transportation and Unloading Windows

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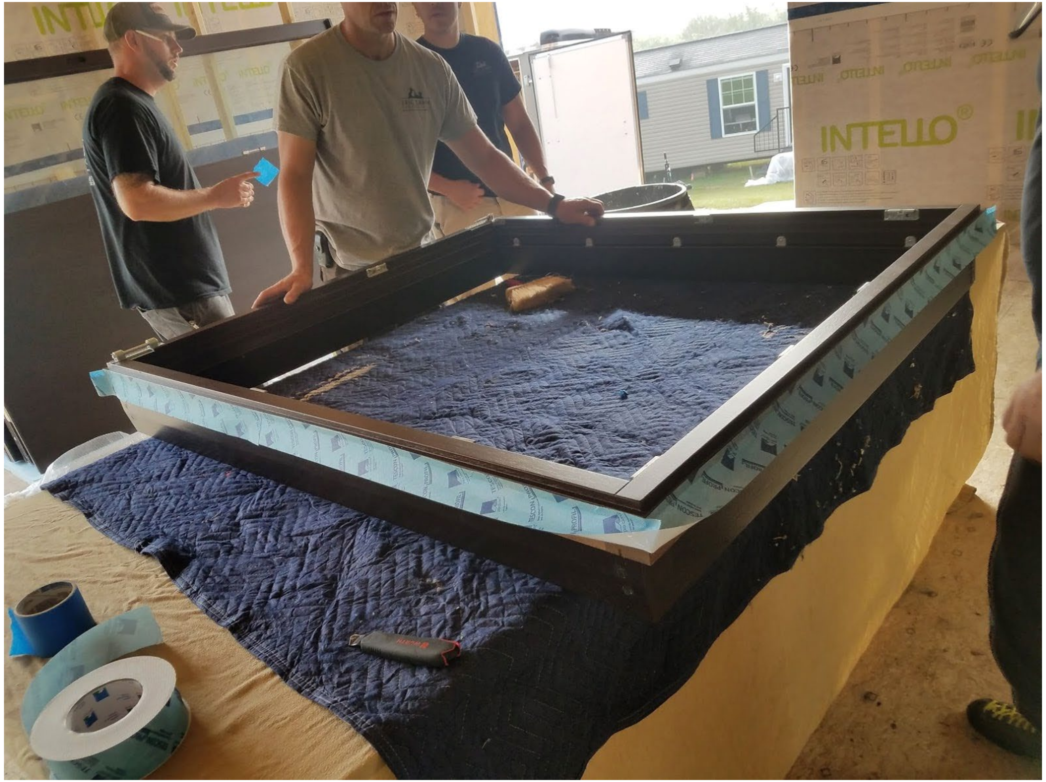
Preparing the Rough Opening

Zero Reveal Taping



Independent Sash and Frame Installation

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PH Window Integration

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PH Window Integration

Continuous Airtightness

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Large Openings

Delivery Limitations

Building the Frame Onsite

Site Glazing

Installed Lift and Slide Unit

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Window Install Complete

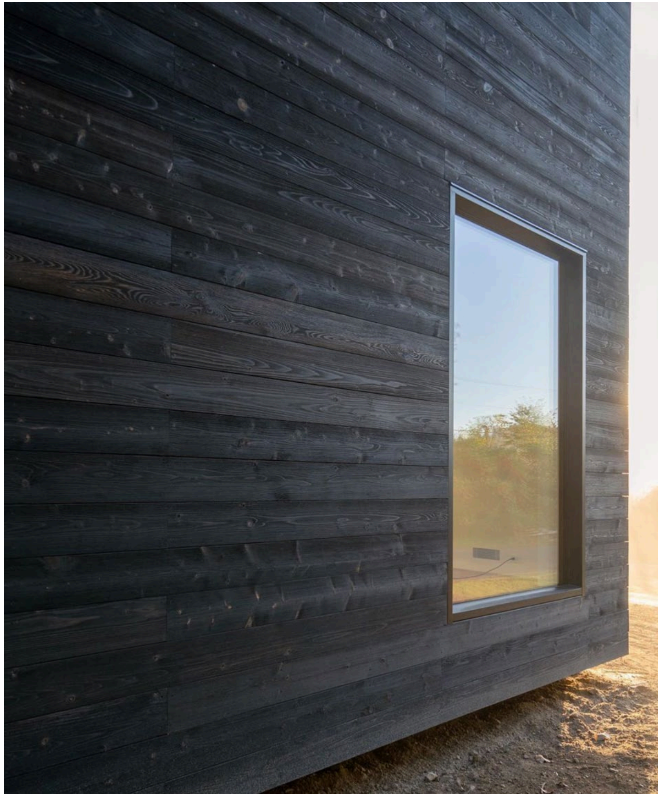
Window Integration Detail

Integration of the Thermal Layer

Control Layers Completed

Finish Siding

Successful Completion



Section 3: Calculating Passive House Windows

How to Transform Windows into Solar Panels

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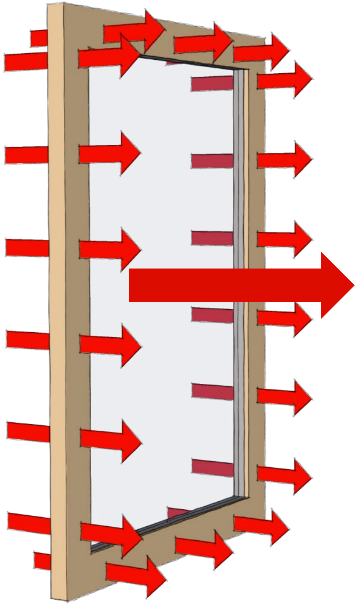
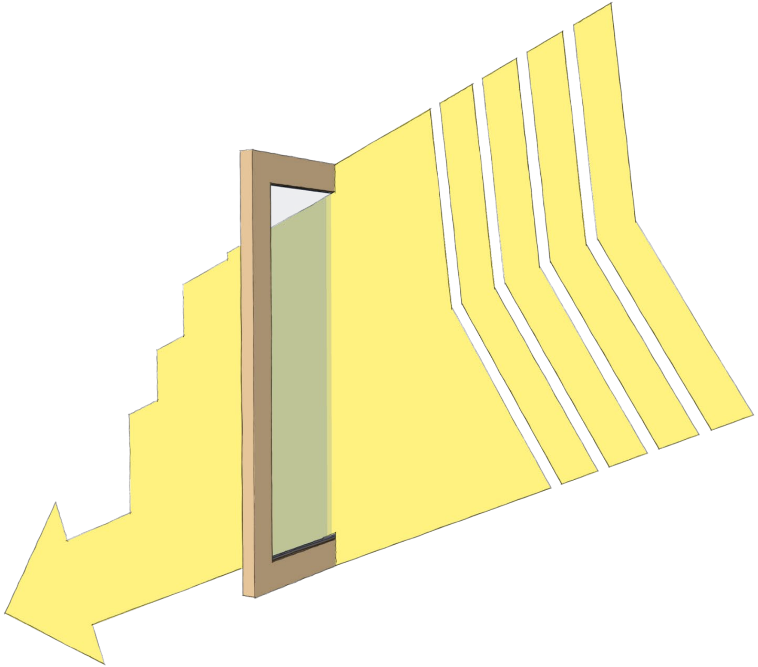
PH WINDOW ENERGY BALANCE CALCULATION

Energy Balance: Heat Loss vs Heat Gain



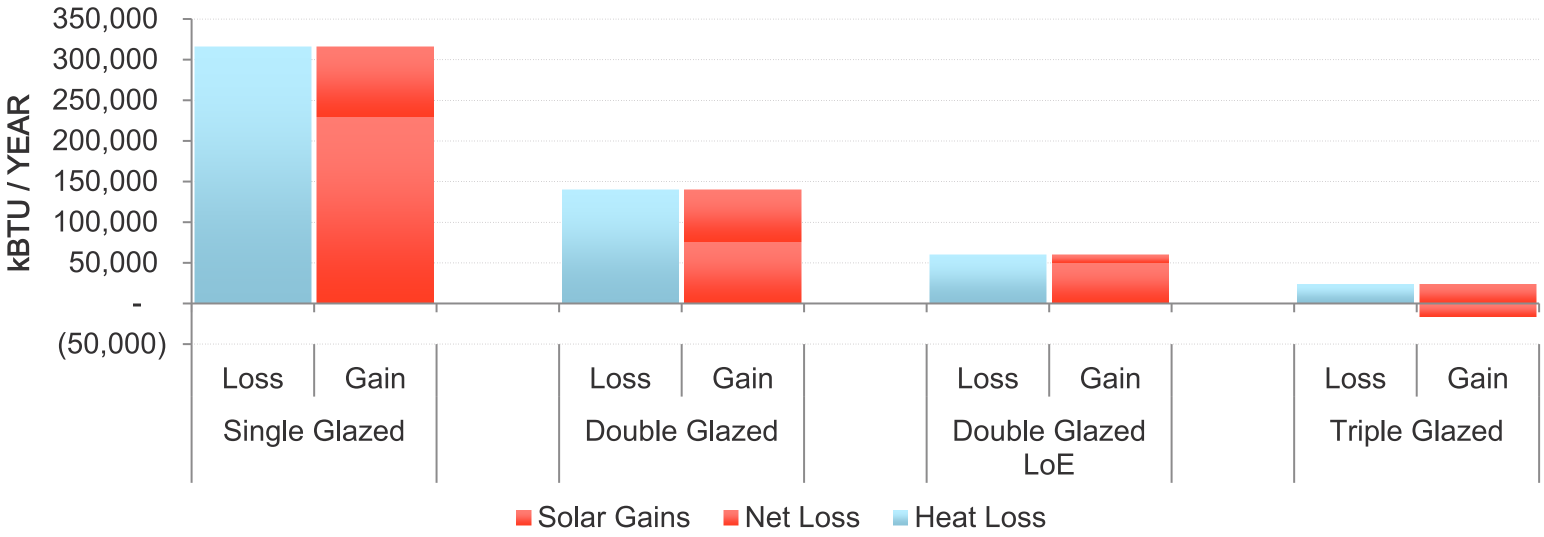
Heat loss through the glass, frame and spacer/installation thermal bridges



Solar heat gain through the glass

Energy Balance: South Facing Window

Glass	Single	Double	Double LoE	Triple LoE
R-Value	1	2	4.7	11
U-Value	1	0.5	0.21	0.09
Surface Temp	29 °F	48 °F	60 °F	65 °F



Passive House Institute

PH Window Energy Balance Calculation

1. Calculate Transmission Losses; U -value

2. Calculate Window Thermal Bridges:
   Ψ_{spacer} and $\Psi_{install}$

3. Solar Gains and Shading Calculation

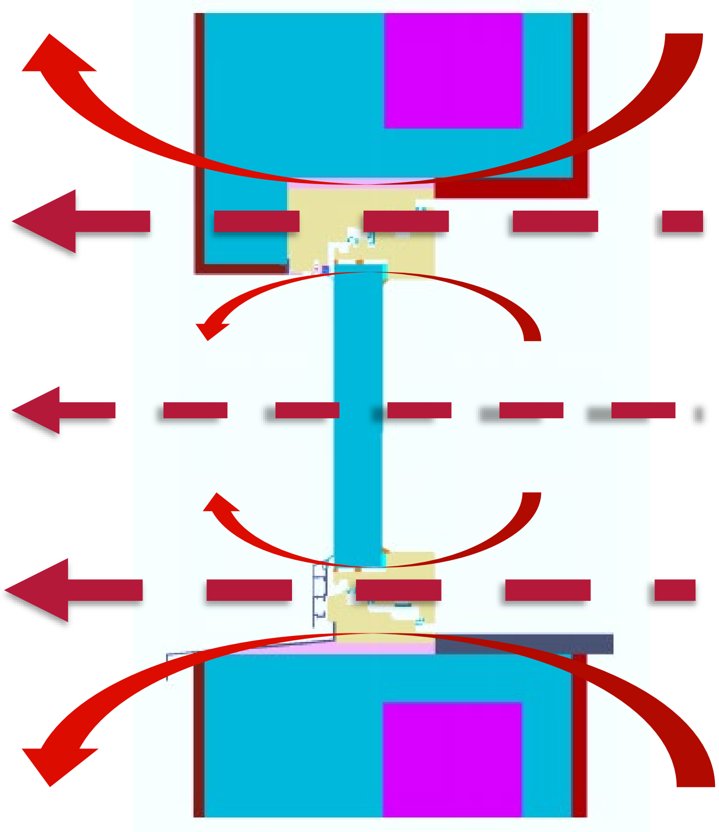
4. Window Energy Balance

WINDOW CALCULATIONS: Heat Losses and U -Value

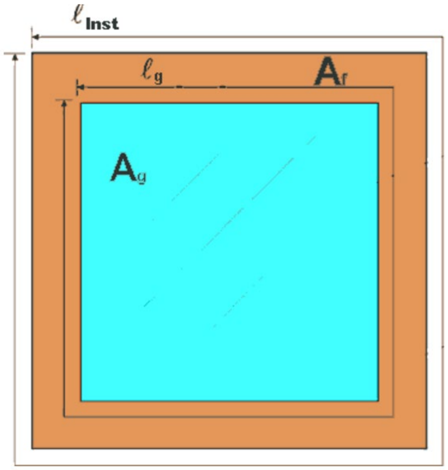
Window Losses By Component

Heat Loss

1. Glass (U_g)
2. Frame (u_f)
3. Glass edge(Ψ_{spacer})
4. Installation ($\Psi_{installation}$)



PH Window U-Value Calculation



$$U_W = \frac{A_g U_g + A_f U_f + l_g \Psi_g \; (+ \; l_{Inst} \Psi_{Inst})}{A_g + A_f}$$

Glazing surface area	A_g	(glazing)
Frame surface area	A_f	(frame)
Glass edge length	l_g	(glazing perimeter)
Frame edge length	l_{Inst}	(frame perimeter)

Four Different Window U-Values (Area-Based)

U_g
U-Value of the Glass

U_f
U-Value of the Frame

U_w
U-Value of the Window

$U_{w\text{-installed}}$
U-Value of the Window in the Wall

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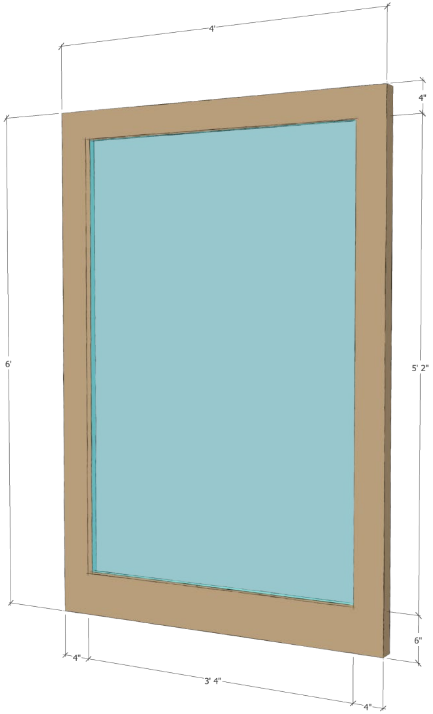
Calculate UW -Installed



Window Measurements:

Width (to outside of frame): 4' -0"

Height (to outside of frame): 6' -0"

Frame Width (top, 2 sides): 4"

Frame Width (bottom): 6"

U_g = 0.08 Btu/hr -ft ^{2}-F
U_f = 0.11 Btu/hr-ft ^{2}-F
Psi-spacer = 0.06 Btu/ hr-ft -F
Psi-Install = 0.01 Btu/ hr-ft -F

Tip on calculation of areas and lengths:

1. Draw a small sketch of window with all its dimensions
2. First calculate A_w, then A_g. Then subtract A_g from A_w to calculate A_F

Calculate Window Areas & Lengths

$$U_{w\text{-}installed} = \frac{(U_g \times A_{glass}) + (U_f \times A_{frame}) + (\Psi_{spacer} \times L_{spacer}) + (\Psi_{install} \times L_{install})}{A_{window}}$$

$$A_{win} = w_w \times h_w = 4'\text{-}0'' \times 6'\text{-}0'' = 24\ ft^2$$

$$A_{glass} = w_g \times h_g = 3'\text{-}4'' \times 5'\text{-}2'' = 17.2\ ft^2$$

$$A_{frame} = A_{win} - A_{glass} = 24\ ft^2 - 17.2\ ft^2 = 6.8\ ft^2$$

$$L_{spacer} = 2\,w_g + 2\,h_g = 2 \text{ x } 3'\text{-}4'' + (2 \times 5'\text{-}2'') = 17'\text{-}0''$$

$$L_{installation} = 2\,w_w + 2\,h_w = 2 \text{ x } 4'\text{-}0'' + (2 \times 6'\text{-}0'') = 20'\text{-}0''$$

Calculating UW -Installed

$$U_{w\text{-installed}} = \frac{(U_g \times A_{glass}) + (U_f \times A_{frame}) + (\Psi_{spacer} \times L_{spacer}) + (\Psi_{installed} \times L_{installed})}{A_{window}}$$

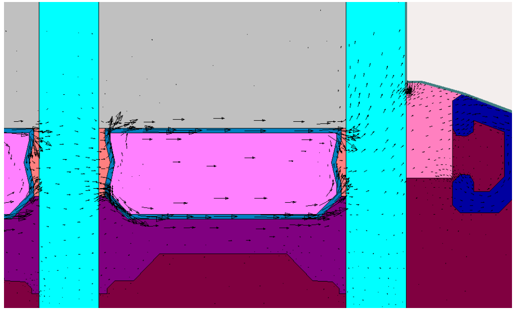
$$U_{w\text{-installed}} = \frac{0.08\ \text{Btu/(hr.ft}^2.^\circ\text{F)} \times 17.2\ \text{ft}^2 + 0.11\ \text{Btu/(hr.ft}^2.^\circ\text{F)} \times 6.8\ \text{ft}^2 + 0.06\ \text{Btu/(hr.ft.}^\circ\text{F)} \times 17'\text{-}0'' + 0.01\ \text{Btu/(hr.ft.}^\circ\text{F)} \times 20'\text{-}0''}{24\ \text{ft}^2}$$

$$U_{w\text{-installed}} = 0.139\ \text{Btu/(hr.ft}^2.^\circ\text{F)}$$

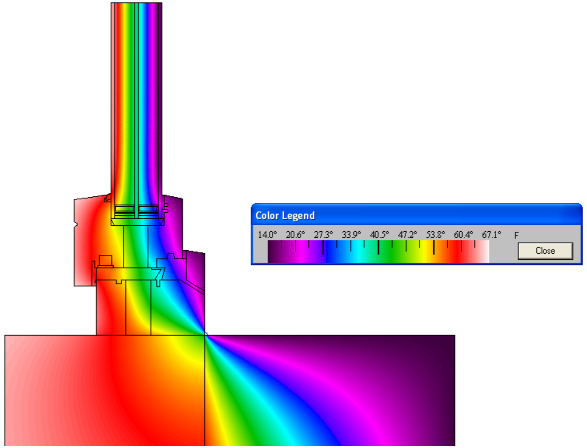
WINDOW CALCULATIONS:
Thermal Bridges

The Passive House Network

Two Thermal Bridges In Windows



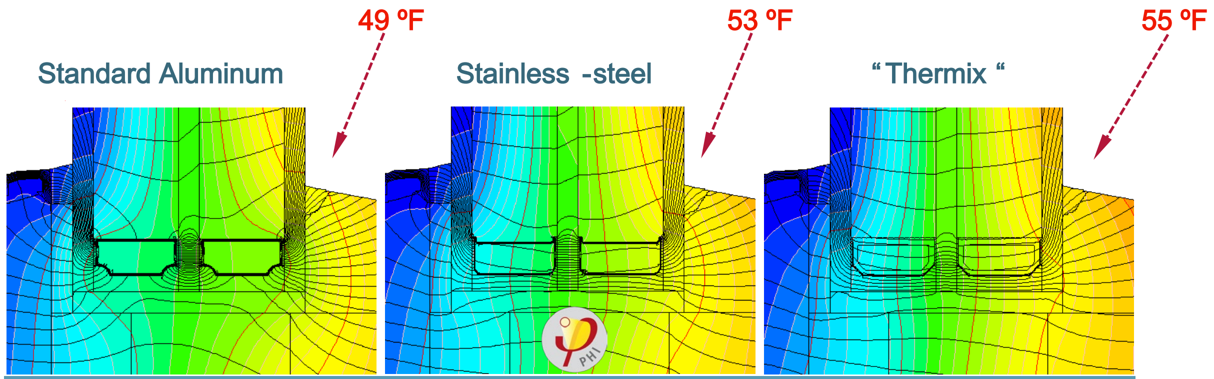
Ψ_{spacer}



$\Psi_{installation}$

Window Ψ : Spacer Value

Lower Ψ_{spacer} increases window performance and raises internal surface temperature



Standard Aluminum	Stainless-steel	"Thermix"
Ψ_{spacer} = 0.044 Btu/(hr. ft .ºF)	Ψ_{spacer} = 0.031 Btu/(hr. ft .ºF)	Ψ_{spacer} = 0.023 Btu/(hr. ft .ºF)
R_w 6.4 (hr.ft². ºF)/Btu	R_w 6.8 (hr.ft². ºF)/Btu	R_w 7.1 (hr.ft². ºF)/Btu

Calculation of the window R -value with:

R_g = 8.1 (hr.ft².ºF)/ Btu

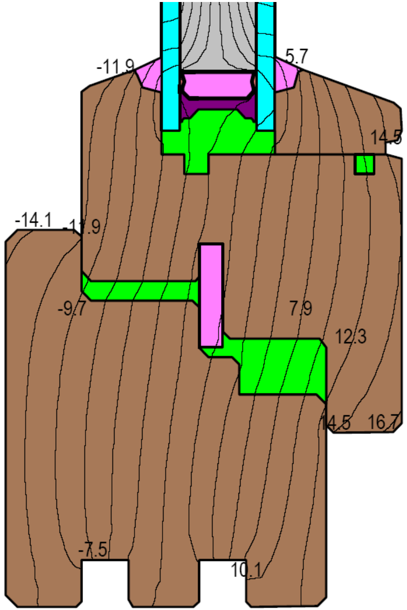
$R_{f,bottom}$ = 7.8 (hr.ft².ºF)/ Btu

$R_{f,top}$ = 8.1 (hr.ft².ºF)/ Btu

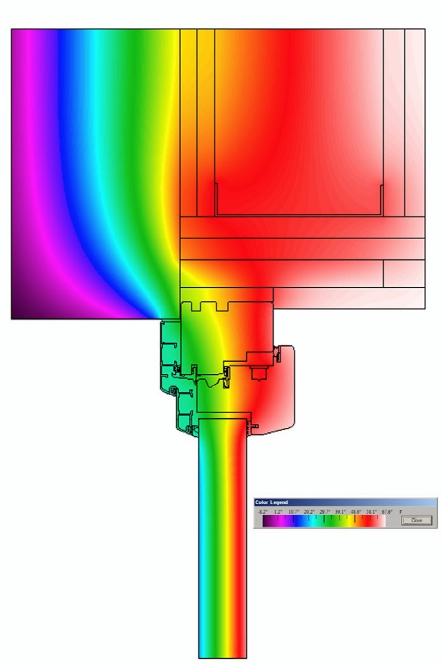
Source: PHI Berthold Kaufmann

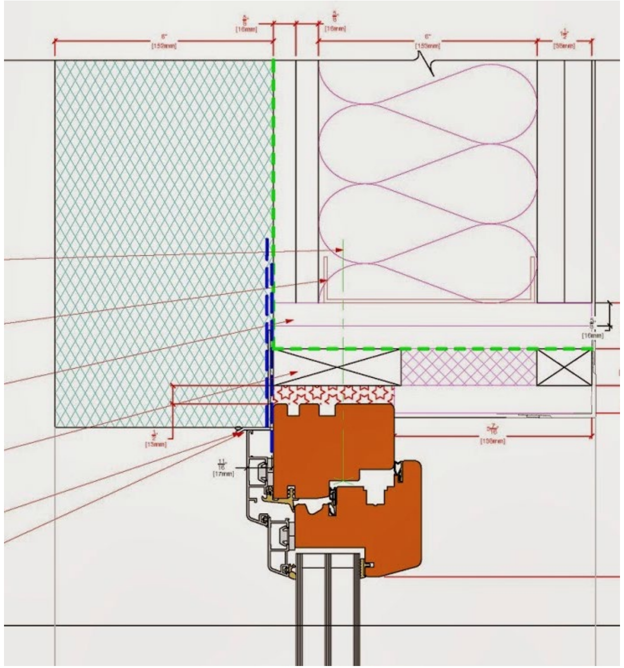
Glazing Bar Ψ Value: Condensation

38.7 °F *(at 5 °F outside temp.)*



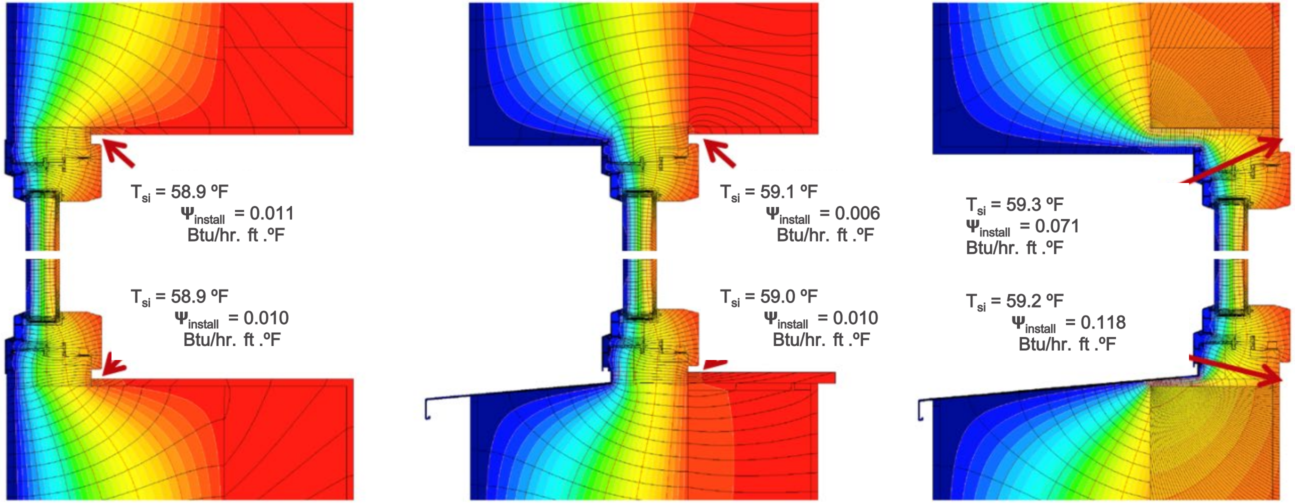
Window Ψ Value: Installation





Yaro Windows, 255 Columbia St. Brooklyn, NY

Window Install Position



$U_{w\text{-}installed}$ = 0.151 Btu/hr.ft ^{2}.ºF ($R_{w\text{-}installed}$ = 6.62 hr.ft ^{2}.ºF/Btu)	$U_{w\text{-}installed}$ = 0.148 Btu/hr.ft ^{2}.ºF ($R_{w\text{-}installed}$ = 6.76 hr.ft ^{2}.ºF/Btu)	$U_{w\text{-}installed}$ = 0.215 Btu/hr.ft ^{2}.ºF ($R_{w\text{-}installed}$ = 4.65 hr.ft ^{2}.ºF/Btu)

To determine the final energy balance impact of moving the installed position, the shading effect of the setback and the resultant solar gains must also be taken into account.

Passipedia.org

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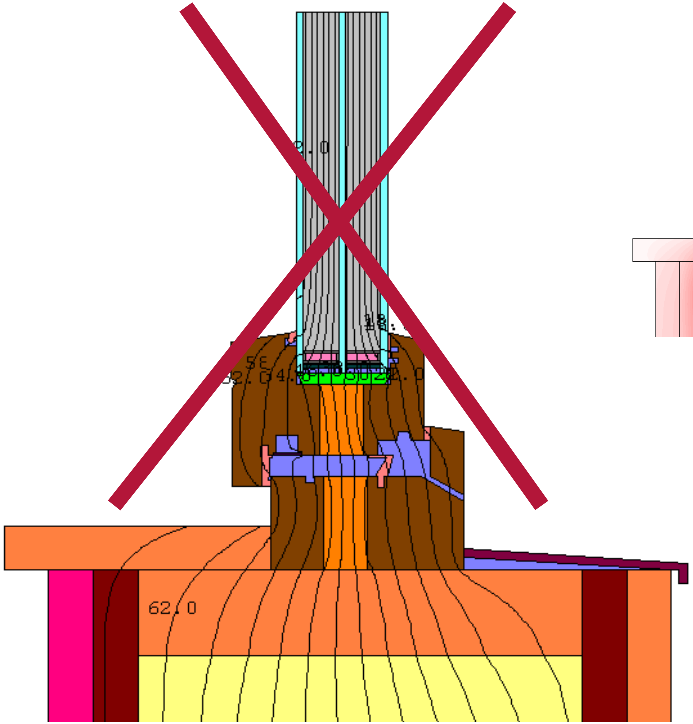
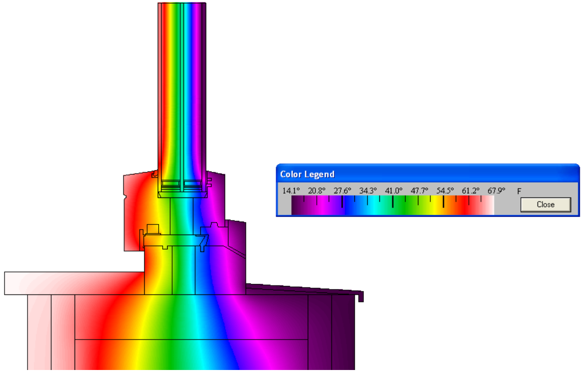
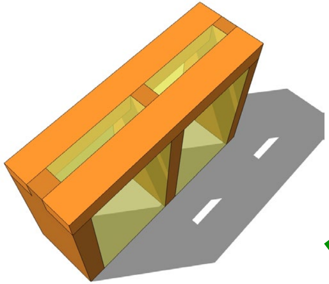
Solid Stud Wood Frame

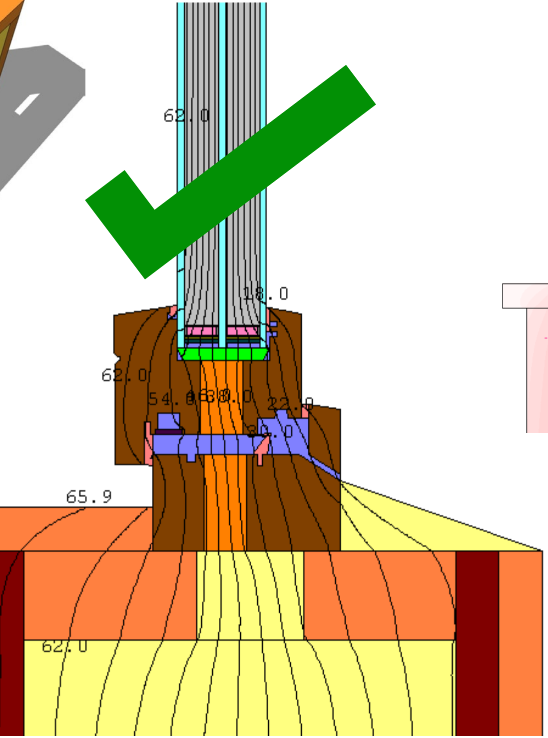


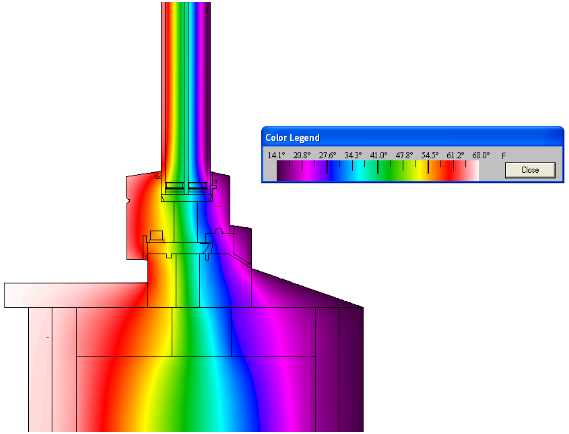


Ψ_e (for PHPP) **0.013** Btu/hr*f*F

Double Stud Window Detail



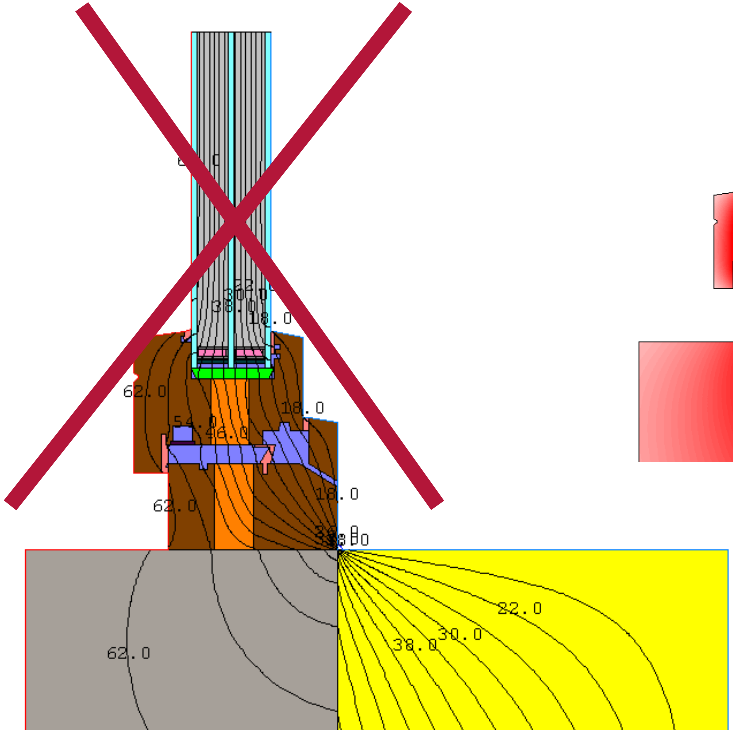


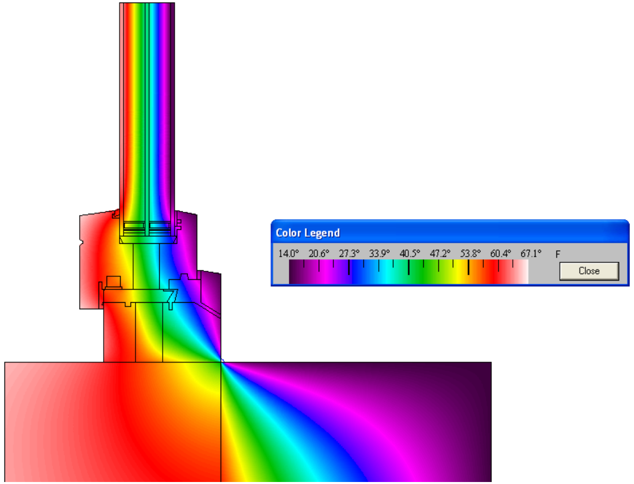


Ψ_e (for PHPP) **0.006** Btu/hr*f*F

The Passive House Network

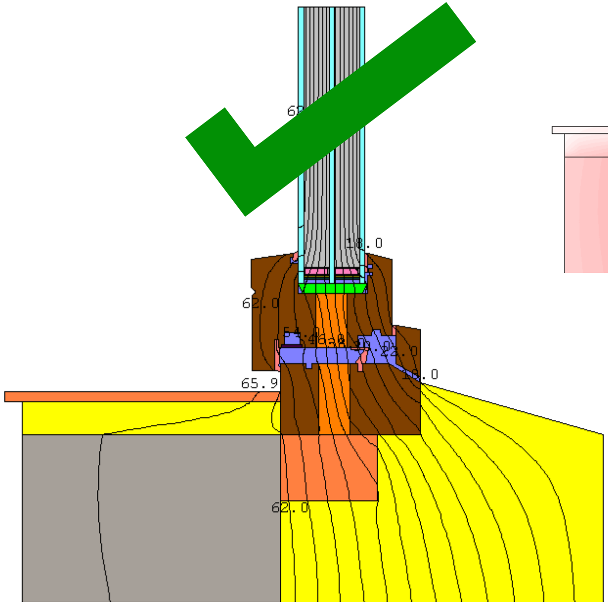
Window in Masonry Layer

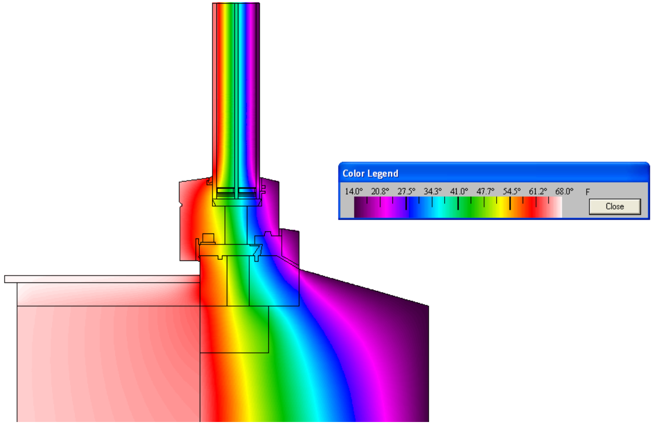




Ψ_e (for PHPP) **0.108** Btu/hr*f*F

Window External to Masonry Layer

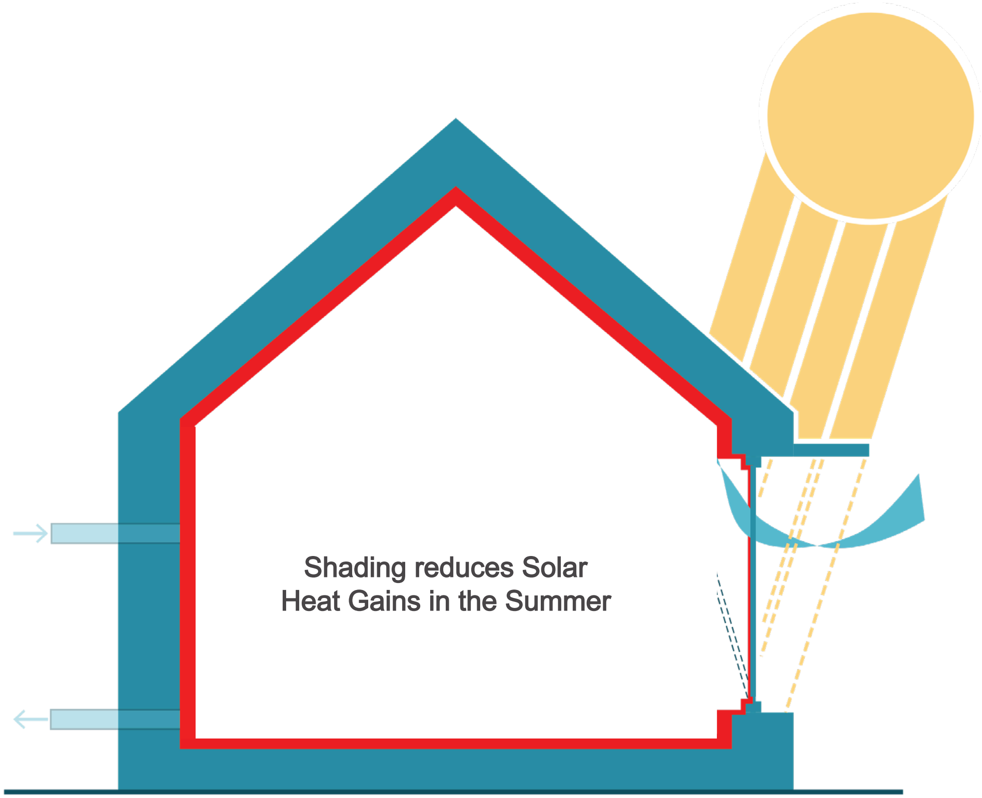




Ψ_e (for PHPP) **0.006** Btu/hr*f*F

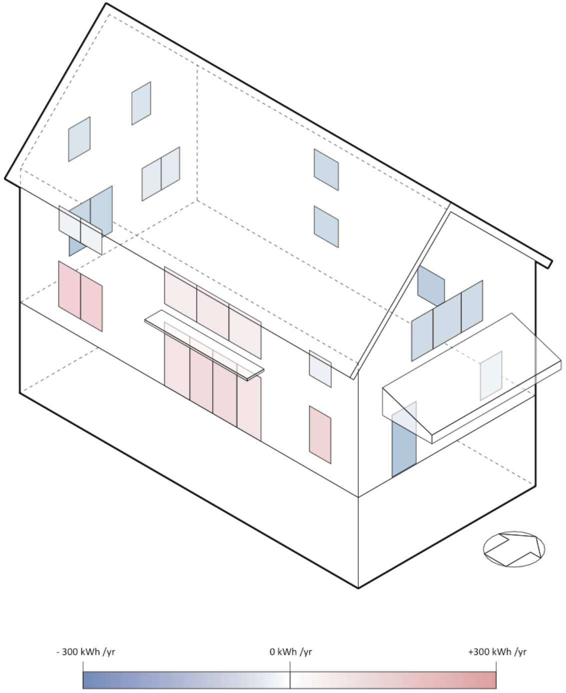
WINDOW CALCULATIONS:
Solar Gains

Controlling Solar Gains With Shading

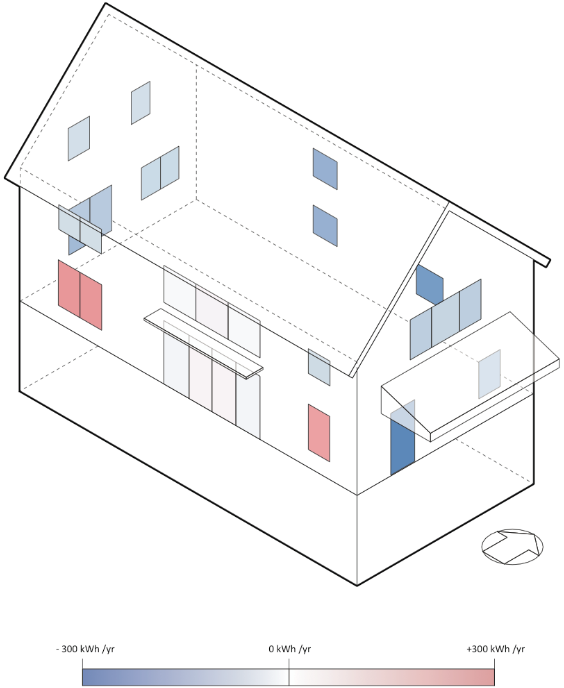


Seasonal Effect on Heat Gains

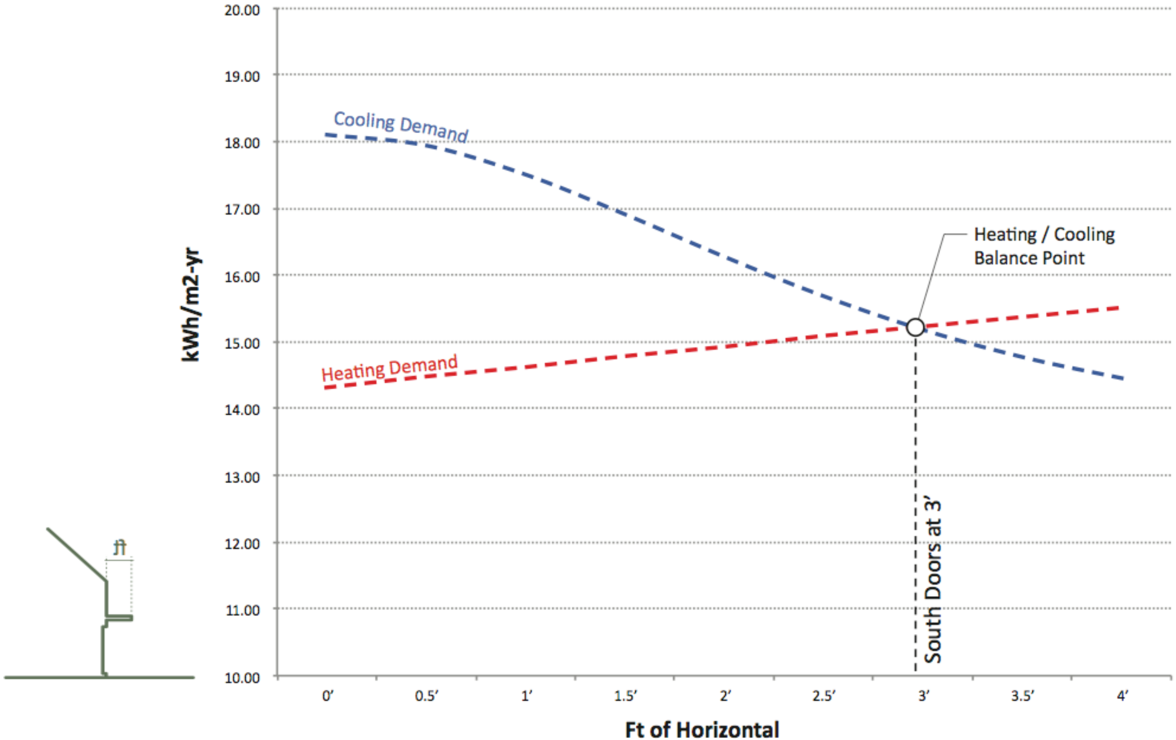
Winter Window Energy Balance



Summer Window Energy Balance



Seasonal Energy Balance: Shading Study



SOUTH-DOOR HORIZONTAL SHADING EFFECT ON HEAT / COOLING DEMAND

SOURCE:BLDGtyp, Butler Passive House, Lenox MA 2014

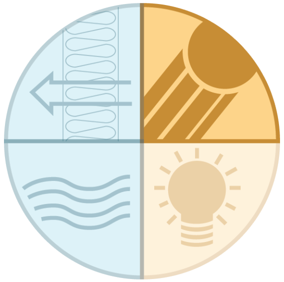
The Passive House Network

Calculating Solar Heat Gains

$$Q_S = r \times SHGC \times A_w \times G_{N,E,S,W}$$

r = Shading Factor × Dirt Factor × Non-Perp. Rad. Factor× Glazing Factor

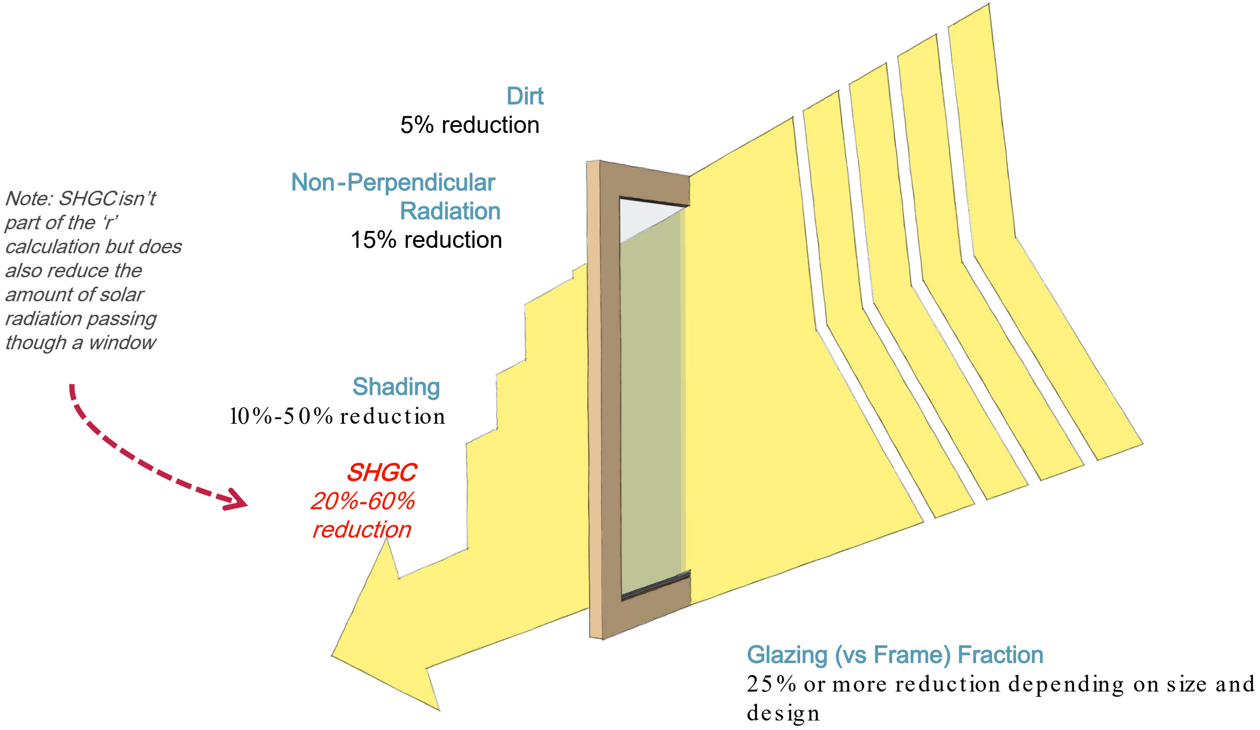
Q_s (Solar Heat Gains) =



Reduction Factor (unitless)
×
Solar Heat Gain Coefficient (unitless)
×
Gross area of the window (ft^2)
×
Global Radiation (kBtu /ft².yr)

=kBtu /yr

Four Reduction Factors (r)



r = shading × dirt × non-perp. radiation × glazing fraction

Example: Calculating Solar Gains

$$Q_S = r \times SHGC \times A_w \times G_{N,E,S,W}$$

EXAMPLE:

Calculate the Solar Gains for a south -facing window with the following characteristics:

NYC G_{south}	177 kBtu /ft ^{2}.yr
Width	3’-6”
Height	6’-0”
SHGC	0.6
Shading Factor	0.67
Glazing Factor	0.76
non-perpendicular radiation*	0.85
Dirt*	0.95

*reduction factor constants

Solution: Calculating Solar Gains

$$Q_S = r \times SHGC \times A_w \times G_{N,E,S,W}$$

Reminder: these two reduction factors are constants and pertain to dirt and non-perpendicular radiation respectively

$$Q_S = (0.67 \times 0.95 \times 0.85 \times 0.76) \times 0.6 \times 21\ ft^2 \times 177\ kBtu/ft^2.yr$$

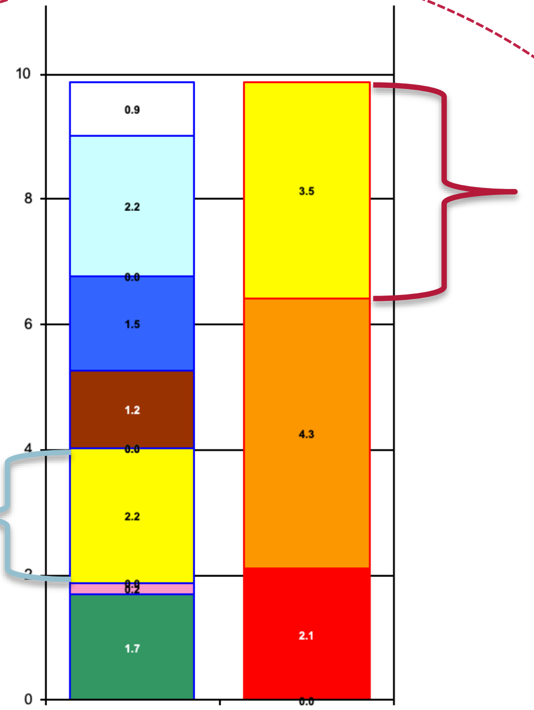
$$Q_S = 0.41 \times 0.6 \times 21\ ft^2 \times 177\ kBtu/ft^2.yr$$

$$Q_S = 917.0\ kBtu/yr$$

CALCULATING THE WINDOW ENERGY BALANCE

Energy Balance Heating (Annual Method)

Higher solar gains than losses in the wintertime

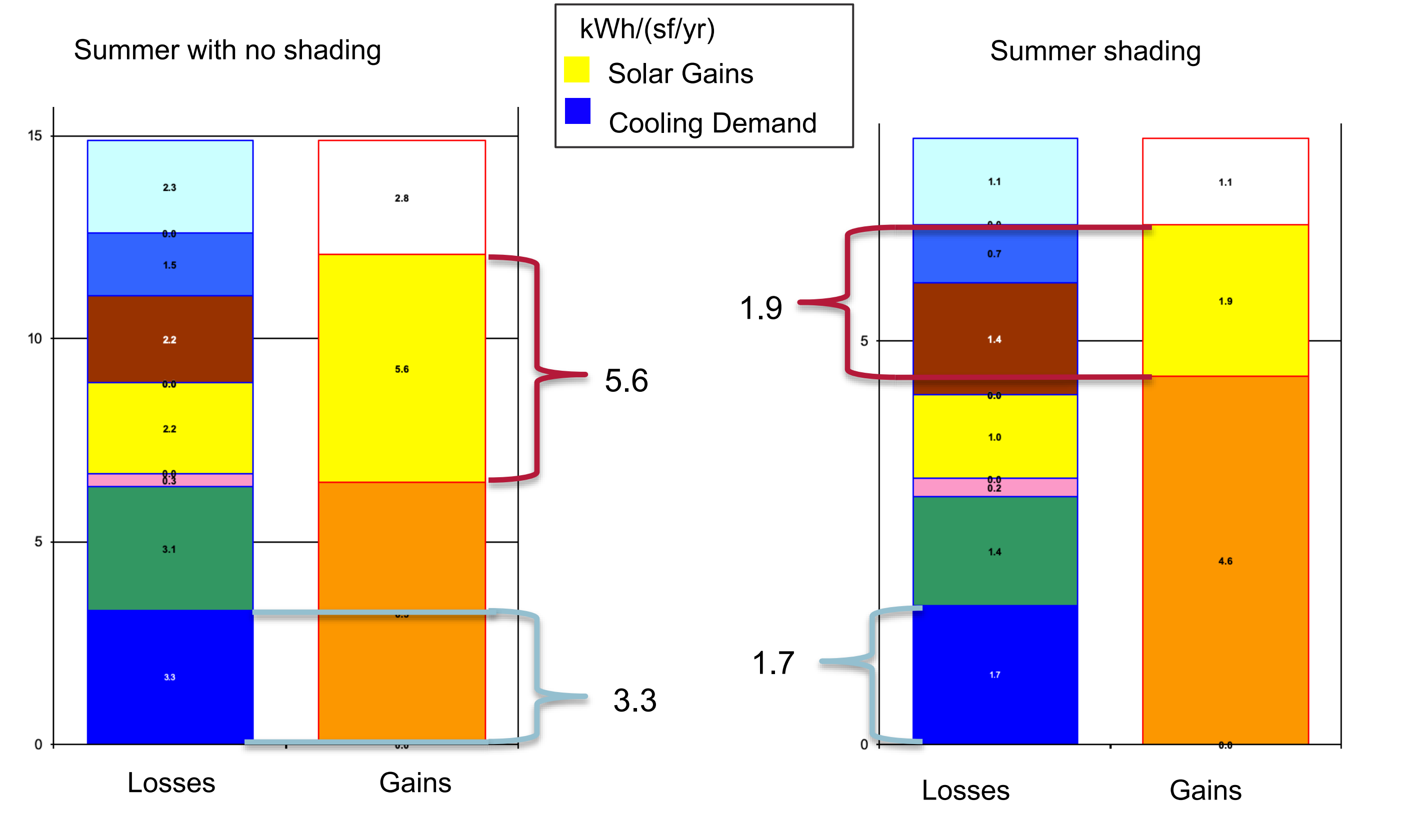


3.5 kWh/(sf/ yr)
Solar Gains

2.2 kWh/(sf/ yr)
Heat Loss

= Windows

Energy Balance Cooling (Annual Method)



Window Energy Balance Calculation

$$Q_H = [\text{Solar Gain } (Q_S) \times \eta] - \text{Transmission Loss } (Q_T)$$

$$Q_S = r \times SHGC \times A_w \times G_{N,E,S,W}$$

$$Q_T = A \times (1/R) \times f_t \times G_t$$

A = Area (ft^2)

R = Reduction Factor (unitless)

SHGC = Solar Heat Gain Coefficient (unitless)

$G_{N,E,S,W}$ = Global Radiation ($kBtu/ft^2.yr$)

1/R = U-Value ($Btu/hr.ft^2.°F$)

f_t = Temp. Correction Factor (if needed)

G_t = Yearly Heating Degree Hours (k. °F.hr/yr)

Calculating the Energy Balance

$$Q_S = r \times SHGC \times A_w \times G_{N,E,S,W}$$

$$Q_T = A \times (1/R) \times f_t \times G_t$$

EXAMPLE:

Calculate the overall yearly net energy balance for a south -facing window with the following characteristics:

NYC G_t	117kFh/yr	SHGC	0.6
Width	3'-6"	R_{Glass}	9.0
Height	6'-0"	R_{Frame}	6.5
Frame Width (Bottom)	5-1/2"	G_{south}	177 kBtu /ft ^{2}.yr
Frame Width (Side +Top)	3"	Spacer Length	16.583'
Shading Factor	0.67	Ψ_{spacer}	0.06 Btu/hr.ft.ºF
Glazing Factor	0.76	$\Psi_{install}$	-0.04 Btu/hr.ft.ºF

Calculating Solar Gains

$$Q_S = r \times SHGC \times A_w \times G_{N,E,S,W}$$

Reminder: these two reduction factors are constants and pertain to dirt and non-perpendicular radiation respectively

$$Q_S = (0.67 \times 0.95 \times 0.85 \times 0.76) \times 0.6 \times 21\ ft^2 \times 177\ kBtu/ft^2.yr$$

$$Q_S = 0.41 \times 0.6 \times 21\ ft^2 \times 177\ kBtu/ft^2.yr$$

$$Q_S = 917.0\ kBtu/yr$$

Calculating Transmission Losses

$$Q_T = A \times (1/R) \times f_t \times G_t$$

Q_T (Transmission Loss) = Area of the thermal envelope (ft^2)

×

1/R-Value (*U-Value:* $Btu/hr.ft^2.°F$)

×

Temp. Correction Factor (if needed)

×

Yearly Heating Degree Hours (k. °F.hr/yr)

=kBtu /yr

Window U -Value

$$U_{w\text{-installed}} = \frac{(U_g \times A_{glass}) + (U_f \times A_{frame}) + (\Psi_{spacer} \times L_{spacer}) + (\Psi_{installed} \times L_{installed})}{A_{window}}$$

$$U_{w\text{-installed}} = \frac{0.11\ \text{Btu/(hr.ft}^2.^\circ\text{F)} \times 15.875\ \text{ft}^2 + 0.154\ \text{Btu/(hr.ft}^2.^\circ\text{F)} \times 5.125\ \text{ft}^2 + 0.06\ \text{Btu/(hr.ft.}^\circ\text{F)} \times 16.583' + -0.04\ \text{Btu/(hr.ft.}^\circ\text{F)} \times 19'}{21\ \text{ft}^2}$$

$$U_{w\text{-installed}} = 0.132\ \text{Btu/(hr.ft}^2.\ ^\circ\text{F)}$$

Calculating Transmission Losses

$$Q_T = A \times (1/R) \times f_t \times G_t$$

Transmission Loss (Q_T) = 21 ft^2 × 0.132 Btu/(hr.ft². °F) × 1.0 × 117 k°F.hr/yr

Transmission Loss (Q_T) = 324.3 kBtu/yr

Calculating the Energy Balance

Remember, we need to apply the UTILIZATION FACTOR to see how much of these gains we get to 'keep'

Q_H = [Solar Gain (Q_S) × η] – Transmission Loss (Q_T)

Solar Gain (Q_S) = 917.0 kBtu/yr

Transmission Loss (Q_T) = 324.3 kBtu/yr

Q_H = 917.0 kBtu/yr - 324.3 kBtu/yr

Q_H = 592.7 kBtu/yr

Free heat provided by the windows

CALCULATING EFFECT OF SOLAR GAINS: Annual Cooling Demand

Sensible Cooling Demand: Solar Gains (QS)

NOTE:
Use Summer Non-Perp (0.90)
Use Summer Shading Factors

$$Q_S = r \times SHGC \times A_w \times G_{N,E,S,W}$$

Q_s (Solar Heat Gains) = Reduction Factor (unitless)
×
Solar Heat Gain Coefficient (unitless)
×
Gross area of the window (ft^2)
×
Global Radiation (kBtu /ft².yr)

=kBtu /yr

Solar Loads in Winter and Summer

Orientation of the area	Area ft²		SHGC (perp. radiation)		Reduction factor (see 'Windows' worksheet)		Radiation 1 BTU/hr.ft²		Radiation 2 BTU/hr.ft²		P_T 1 BTU/hr		P_T 2 BTU/hr
North	0	·	0.00	·	0.40	·	7.9	or	4.8	=	0	or	0
East	72	·	0.35	·	0.52	·	19.0	or	6.3	=	251	or	84
South	168	·	0.64	·	0.46	·	36.5	or	7.9	=	1821	or	396
West	0	·	0.00	·	0.40	·	15.8	or	6.3	=	0	or	0
Horizontal	0	·	0.00	·	0.40	·	22.2	or	9.5	=	0	or	0
Solar heating power P_S									Total	=	2072	or	480

Heating season

Seeking to maximize solar gains to reduce heating load

Orientation of the area	Area ft²		SHGC (perp. radiation)		Reduction factor (see 'Windows' worksheet)		Radiation 1 BTU/hr.ft²		Radiation 2 BTU/hr.ft²		P_T 1 BTU/hr		P_T 2 BTU/hr
North	0	·	0.00	·	0.40	·	27	or	17	=	0	or	0
East	72	·	0.35	·	0.60	·	68	or	55	=	1024	or	834
South	168	·	0.64	·	0.30	·	63	or	70	=	2069	or	2275
West	0	·	0.00	·	0.40	·	65	or	55	=	0	or	0
Horizontal	0	·	0.00	·	0.40	·	103	or	92	=	0	or	0
Sum opaque areas											1306	or	1151
Solar load P_S									Total	=	4399	or	4260

Cooling season

Seeking to minimize solar gains to reduce cooling load

Season Reduction Factors:

1. Reduction factor higher to the east in summer than in winter – risk of overheating (due to low sun angle).
2. Reduction factor lower to the south in summer than in winter – reducing risk of overheating from south due to higher sun angle.

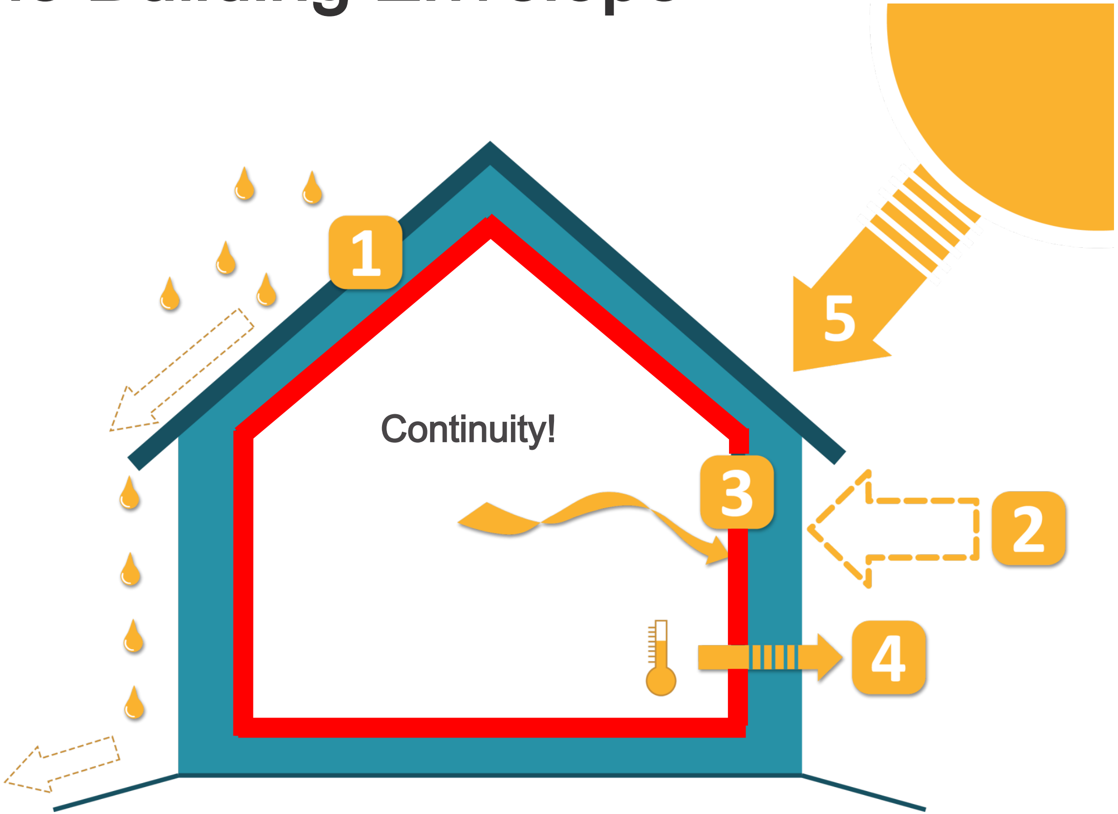
Section 4: How to Install Passive House Windows

Maximizing the Performance of your windows

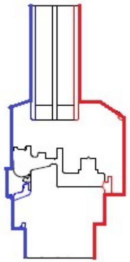
The Passive House Network

PASSIVE HOUSE
WINDOW INSTALL BASICS

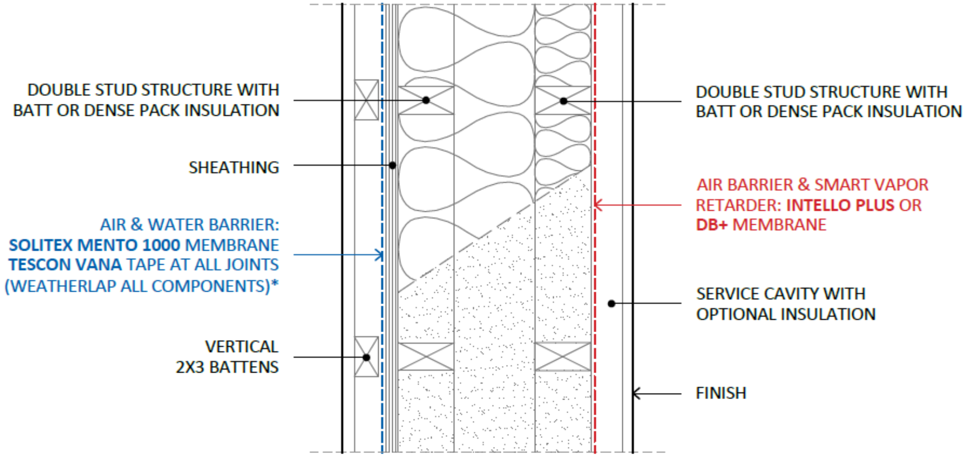
Goals of the Building Envelope



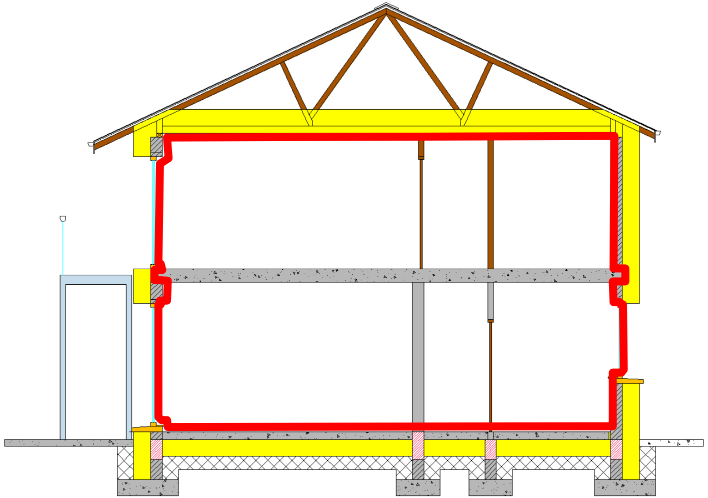
Control Layers



Connection of control layers?



Airtightness: The “Red Line” Test



Airtightness:

0.6 ACH @ 50 Pa

One continuous air -tight layer:

Continuous Insulation

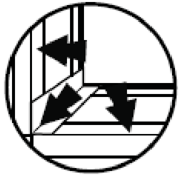
New Marlborough MA, EASTON + COMBS Architects

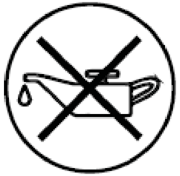
INSTALLATION METHODS

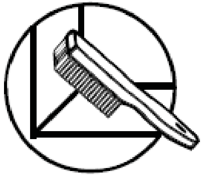
The Passive House Network

Step One: Prepare the Opening


Not frozen over


Airsealed buck joints


Grease/oil free


Swept clean

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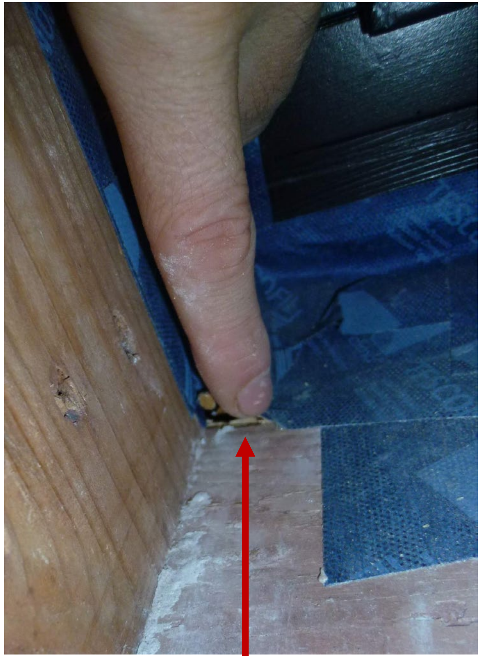
Improper Preparation



Tape is delaminating because it was applied to a dirty surface!

Unacceptable install conditions. No way to guarantee an airtight seal.

The Passive House Network

Step 2: Install the Sill

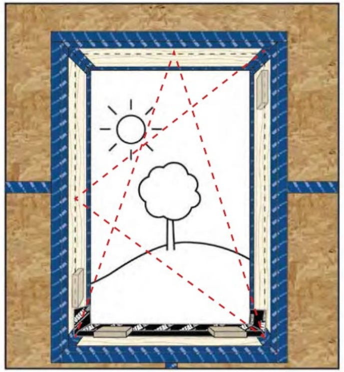
No metal sill pans!

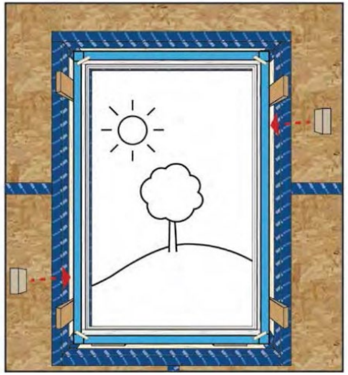
Non-conductive Sill
- Flexible membranes
- Flexible Tape
- Liquid Applied Flashing

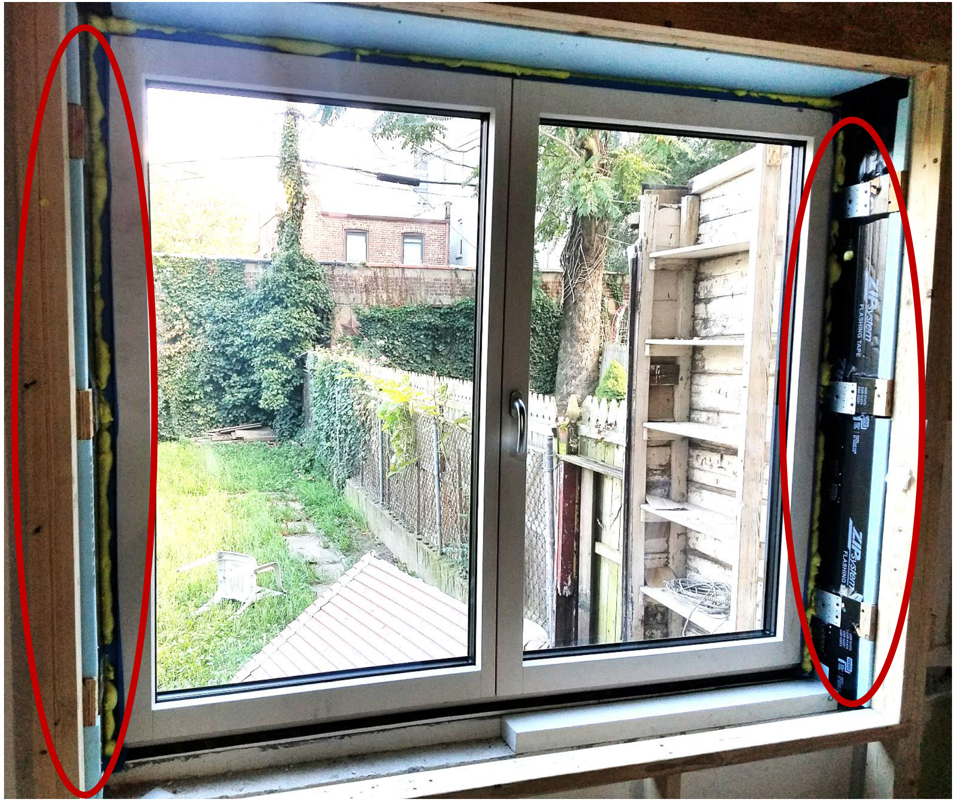
Connect to WRB

Back Damn

Step 3: Block, Shim, and Attach

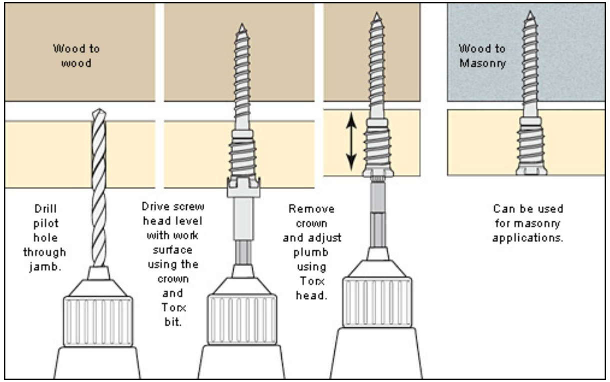






Shim-Screw Installation

Source: Conservation Technology



Clip Installation in a Double Stud Wall

- Window positioned in outer stud to maximize solar gains and enable easy exterior over -insulation.
- Shims used for precise positioning.
- Spray foam insulation fills gaps on all sides (not for airtightness!)
- Metal fixing straps brought to the interior to avoid thermal bridge.
- Airtight tape to be placed externally.

Triple studs not ideal in terms of R-value of the wall – but needed in this case to support weight of adjacent door.

Level, Plumb, and in Position

The Passive House Network

Step 4: Insulate Around the Frame

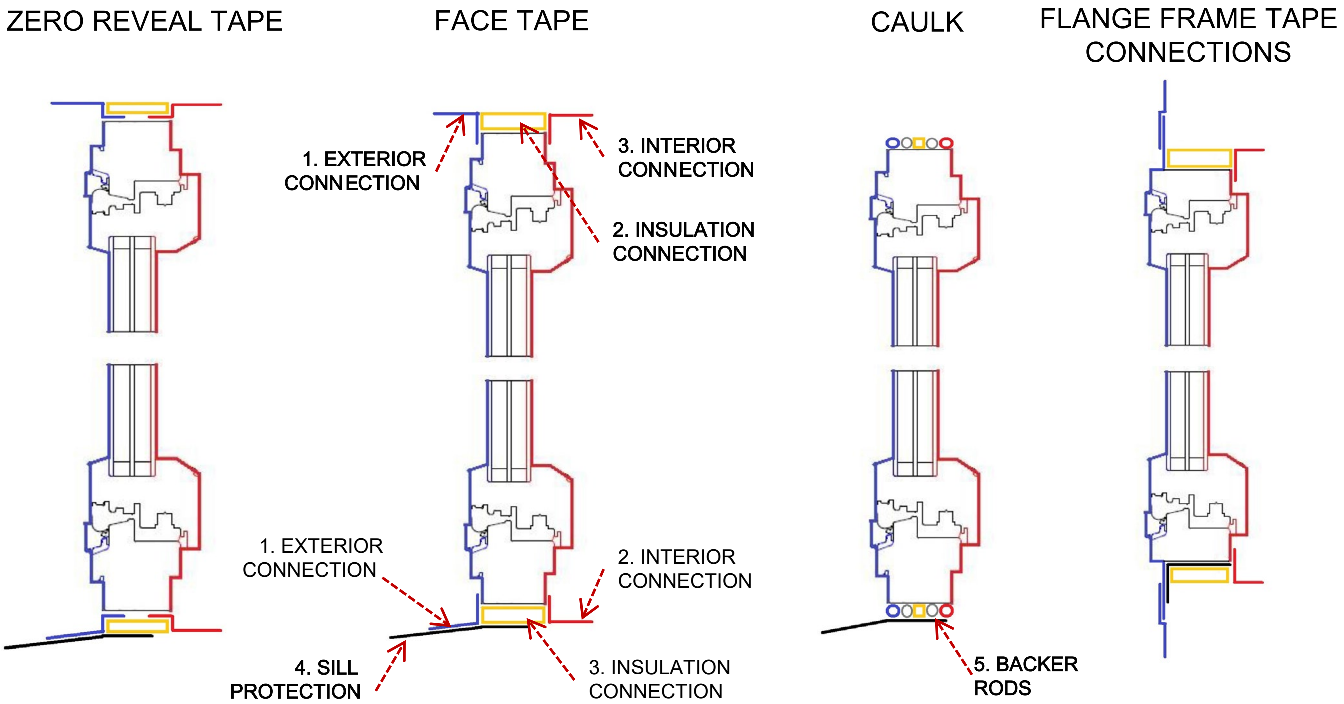
The Passive House Network

Insulate Around and/or Over the Frame

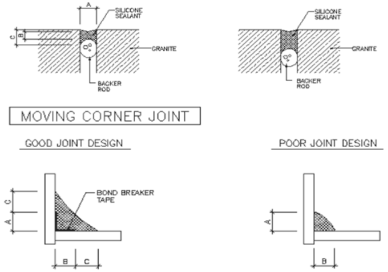
The Passive House Network

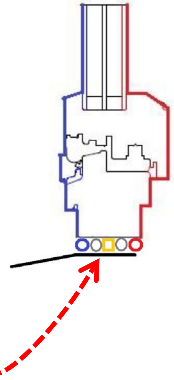
Step 5: Connect to Airtight Layer

Type of Connection



Caulk Connections





Caulking at interior and exterior, at all four sides with backer rods .

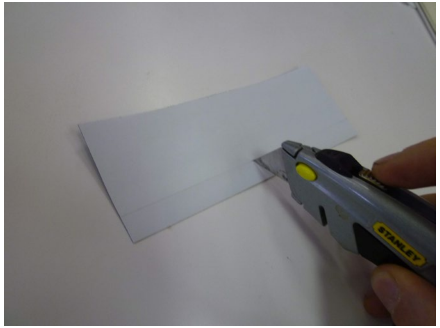
Faced Tape Installation and Airtight Clip

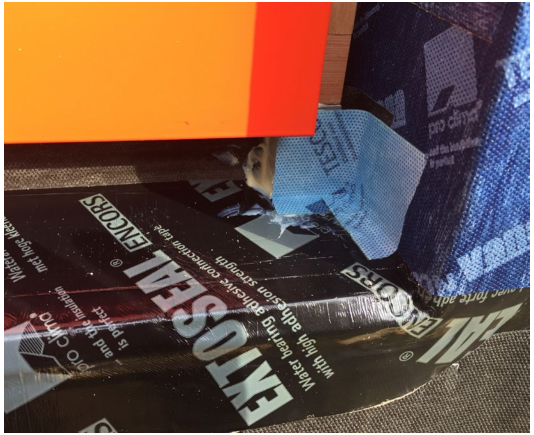
Clip is exposed

Face Tape

The Passive House Network

Corner Taping





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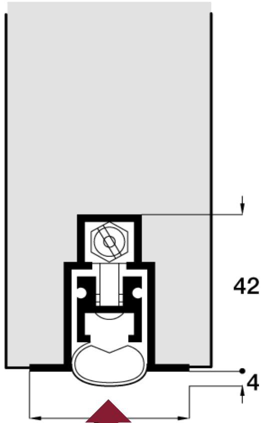
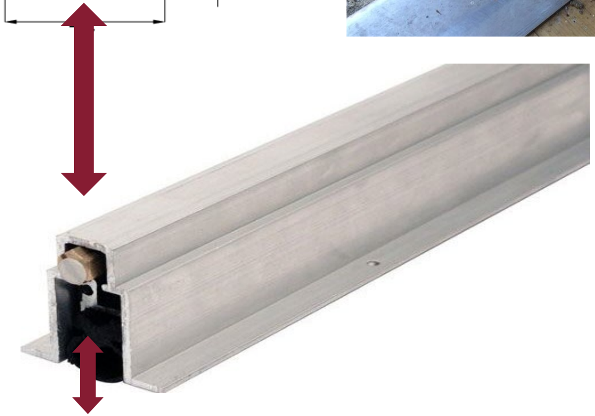
Zero Reveal Taping

Airtight Seal at Door Sill





SILVERNAILS - LIFT SLIDE INSTALL

The Passive House Network

Delivery to Site

Delivery to Site

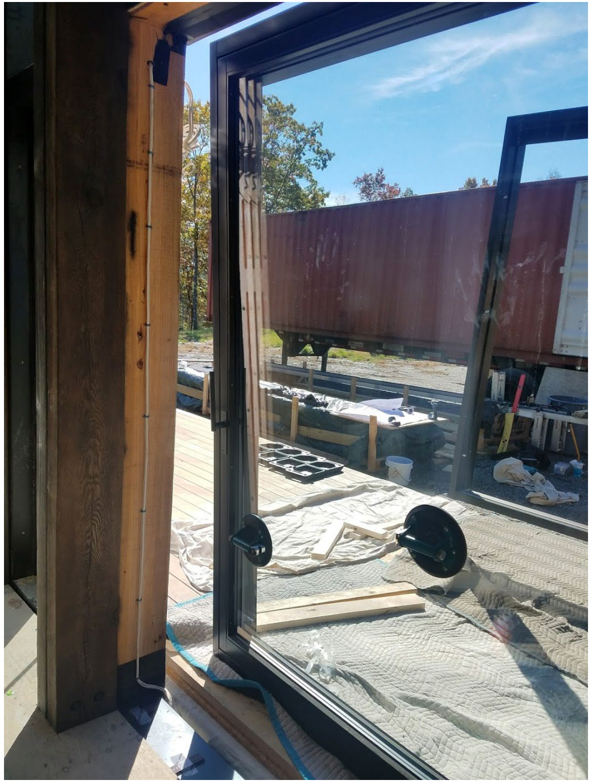
Rough Opening Preparation

Rough Opening Preparation

Preparing the Windows: Positioning and Cleaning

The Passive House Network

Preparing the Windows: Removing Operable Sash



Pre-taping and Planning

The Passive House Network

Installing the Window

The Passive House Network

Installing the Window: Level and Plumb

Securing the Threshold

Installing and Adjusting the Sash

Insect Screen

Shading

Shading

Finished Product

Finished Product

Finished Project

Coming Up…

Continuing Education and Upcoming Events

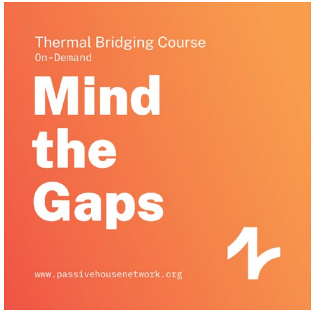
Events

Virtual (September 28th) + In-person (October 4 -6th)

Plus: PHN Presents, Symposiums, Event Recordings

Continuing Education

Hybrid Training
Sept 6 Pacific
Class



Learn to
model in
THERM

Dive Deeper into
the PHPP

Learn more
about EnerPHit

https://passivehousenetwork.org/education/

Training Survey

Your insights into this training will help us make this course better.

https://www.surveymonkey.com/r/V33BM5T

Thank You!

Education, Training & Exams	training@passivehousenetwork.org
Membership & Sponsorship	community@passivehousenetwork.org
Annual Conference	info@phnconference.org
Events and General Inquiries	info@passivehousenetwork.org

Seize the power of Passive House

The Passive House Network

Additional Resources

- Top 6 Rookie Air Sealing Mistakes | Passive House Accelerator
- Document Search | buildingscience.com - search for Air Barriers
- Berkeley Passive House | Berkely, California - Passive House California
- Straightforward Air-Sealing Strategies - Fine Homebuilding
- PG&E Air Sealing to Achieve Zero Net Energy
- Near Perfect Air Tightness Measured in Contemporary Home