

# Measure Guideline: Energy-Efficient Window Performance and Selection

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*NorthernSTAR*

November 2012

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**Measure Guideline:  
Energy-Efficient Window Performance and Selection**

## **Acknowledgments**

## Contents

List of Figures .....	vii
List of Tables .....	viii
Definitions.....	ix
Executive Summary .....	x
Progression Summary.....	xi
1 Introduction .....	1
2 Measuring Window Performance .....	2
3 Window Technologies.....	6
4 Window Selection Process .....	16
5 Cost and Performance .....	23

**6 Impact of Design on Performance ..... 52**

**7 Installation ..... 61**

**References ..... 65**

## List of Figures

Figure 1. Heat flow through a window .....	2
Figure 2. Window properties on the NFRC label.....	2
Figure 3. Heat loss through a window by conduction, convection, and radiation.....	3
Figure 4. Solar gain through a window .....	3
Figure 5. Visible light through a window .....	4
Figure 6. Air leakage through window assembly .....	4
Figure 7. Condensation on window surface.....	5
Figure 8. Advancements to improve energy efficiency .....	6
Figure 9. Spectral transmittance curves for glazings with low-e coatings.....	8
Figure 10. Surface placement of low-e coatings .....	8
Figure 11. Various metal and nonmetal spacer systems.....	11
Figure 12. Thermogram of double-glazed clear window with an aluminum spacer (left) and double-glazed low-e window with an insulating spacer (right). Cold regions in purple and blue represent the large amounts of heat flowing through the spacer.....	12
Figure 13. Aluminum frame.....	13
Figure 14. Aluminum frame with thermal break.....	13
Figure 15. Wood frame .....	13
Figure 16. Wood with clad frame.....	13
Figure 17. Vinyl frame.....	14
Figure 18. Insulated vinyl frame .....	14
Figure 19. Hybrid frame .....	14
Figure 20. Climate zone map referenced in IECC 2006 and later versions .....	17
Figure 21. ENERGY STAR zone map .....	18
Figure 22. Results from the Window Selection Tool .....	20
Figure 23. Manufacturers listed for a specific window in the Window Selection Tool.....	21
Figure 24. Products by a manufacturer listed in the Windows Selection Tool .....	21
Figure 25. RESFEN computer simulation data entry screen .....	22
Figure 26. IECC climate zone map with cities used in simulations .....	23
Figure 27. Comparison of inside glass surface temperature for different glazing types .....	47
Figure 28. Probability of discomfort near a window in the winter .....	47
Figure 29. Probability of discomfort near a window in the summer.....	48
Figure 30. Peak summer cooling loads in Phoenix, Arizona.....	50
Figure 31. Peak summer cooling loads in Minneapolis, Minnesota .....	50
Figure 32. Annual energy cost by orientation in Boston, Massachusetts .....	52
Figure 33. Annual energy cost by orientation in Sacramento, California .....	53
Figure 34. Annual energy cost by orientation in Phoenix, Arizona .....	54
Figure 35. Annual energy cost by window area in Boston, Massachusetts .....	55
Figure 36. Annual energy cost by window area in Sacramento, California .....	56
Figure 37. Annual energy cost by window area in Phoenix, Arizona .....	57
Figure 38. Annual energy cost by shading type in Boston, Massachusetts .....	58
Figure 39. Annual energy cost by shading type in Sacramento, California .....	59
Figure 40. Annual energy cost by shading type in Phoenix, Arizona .....	60

*Unless otherwise noted, all figures were created by the NorthernSTAR team.*

## List of Tables

Table 1. Properties of Generic Set of Windows .....	15
Table 2. Prescriptive Window Requirements in the 2009 IECC .....	17
Table 3. Prescriptive Window Requirements in the 2012 IECC .....	18
Table 4. Current ENERGY STAR Performance Requirements .....	19
Table 5. Proposed 2013 ENERGY STAR Performance Requirements.....	19
Table 6. Properties of Windows Used in Climate Zones 1 and 2 .....	24
Table 7. Savings of New Windows in Miami, Florida.....	25
Table 8. Savings of New Windows in Houston, Texas .....	25
Table 9. Savings of New Windows in Phoenix, Arizona.....	25
Table 10. Properties of Windows Used in Climate Zones 3 and 4 .....	26
Table 11. Savings of New Windows in Atlanta, Georgia .....	27
Table 12. Savings of New Windows in Las Vegas, Nevada .....	27
Table 13. Savings of New Windows in San Francisco, California.....	27
Table 14. Savings of New Windows in Washington, D.C. ....	28
Table 15. Savings of New Windows in Albuquerque, New Mexico .....	28
Table 16. Savings of New Windows in Seattle, Washington .....	28
Table 17. Properties of Windows Used in Climate Zones 5–8.....	29
Table 18. Savings of New Windows in Chicago, Illinois .....	30
Table 19. Savings of New Windows in Boston, Massachusetts.....	30
Table 20. Savings of New Windows in Denver, Colorado.....	30
Table 21. Savings of New Windows in Minneapolis, Minnesota .....	31
Table 22. Savings of New Windows in Billings, Montana .....	31
Table 23. Savings of New Windows in Bismarck, North Dakota .....	31
Table 24. Savings of New Windows in Fairbanks, Alaska .....	32
Table 25. Properties of Windows Used in Climate Zones 1 and 2 .....	33
Table 26. Savings of Replacement Windows in Miami, Florida.....	34
Table 27. Savings of Replacement Windows in Houston, Texas .....	34
Table 28. Savings of Replacement Windows in Phoenix, Arizona.....	34
Table 29. Properties of Windows Used in Climate Zones 3 and 4 .....	35
Table 30. Savings of Replacement Windows in Atlanta, Georgia .....	36
Table 31. Savings of Replacement Windows in Las Vegas, Nevada .....	36
Table 32. Savings of Replacement Windows in San Francisco, California .....	36
Table 33. Savings of Replacement Windows in Washington, D.C. ....	37
Table 34. Savings of Replacement Windows in Albuquerque, New Mexico .....	37
Table 35. Savings of Replacement Windows in Seattle, Washington .....	37
Table 36. Properties of Windows Used in Climate Zones 5–8.....	38
Table 37. Savings of Replacement Windows in Chicago, Illinois .....	39
Table 38. Savings of Replacement Windows in Boston, Massachusetts .....	39
Table 39. Savings of Replacement Windows in Denver, Colorado.....	39
Table 40. Savings of Replacement Windows in Minneapolis, Minnesota .....	40
Table 41. Savings of Replacement Windows in Billings, Montana .....	40
Table 42. Savings of Replacement Windows in Bismarck, North Dakota.....	40
Table 43. Savings of Replacement Windows in Fairbanks, Alaska .....	41
Table 44. Example of Window Costs.....	42
Table 45. Simple Payback for New Windows .....	42
Table 46. Simple Payback for Replacement Windows .....	43
Table 47. Winter and Summer Comfort Index for Typical Windows .....	48

*Unless otherwise noted, all figures were created by the NorthernSTAR team.*

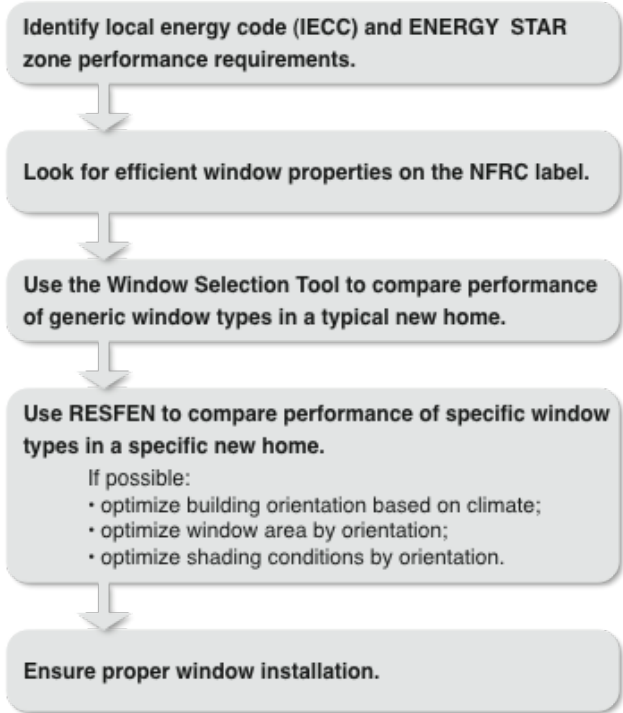


## Definitions

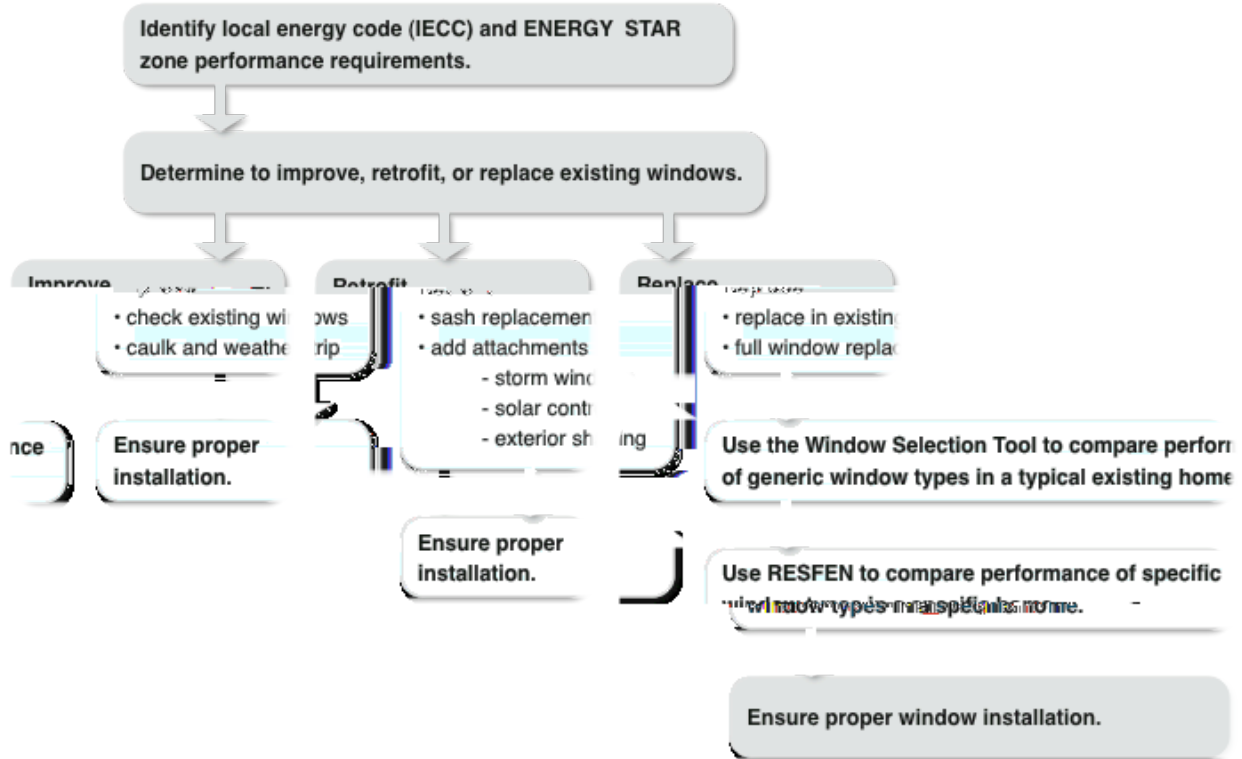
## Executive Summary

## Progression Summary

### NEW CONSTRUCTION



### EXISTING CONSTRUCTION



# 1 Introduction

## 2 Measuring Window Performance

- Insulating value
- Heat gain from solar radiation
- Infiltration

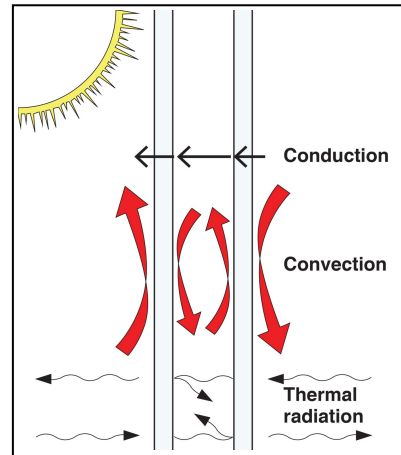


Figure 1. Heat flow through a window


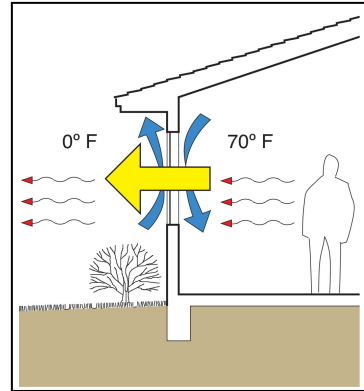
 <small>National Fenestration Rating Council®</small> <b>CERTIFIED</b>	<b>World's Best Window Co.</b> Millennium 2000+ Vinyl-Clad Wood Frame Double Glazing • Argon Fill • Low E Product Type: <b>Vertical Slider</b>	
	ENERGY PERFORMANCE RATINGS	
U-Factor (U.S./I-P)	Solar Heat Gain Coefficient	
<b>0.30</b>	<b>0.30</b>	
ADDITIONAL PERFORMANCE RATINGS		
Visible Transmittance	Air Leakage (U.S./I-P)	
<b>0.51</b>	<b>0.2</b>	
Condensation Resistance		
<b>51</b>	<b>—</b>	
<small>Manufacturer stipulates that these ratings conform to applicable NFRC procedures for determining whole product performance. NFRC ratings are determined for a fixed set of environmental conditions and a specific product size. NFRC does not recommend any product and does not warrant the suitability of any product for any specific use. Consult manufacturer's literature for other product performance information. <a href="http://www.nfrc.org">www.nfrc.org</a></small>		

Figure 2. Window properties on the NFRC label

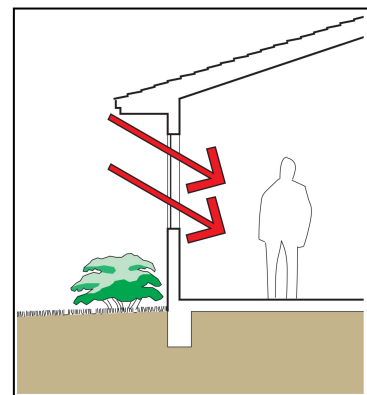
(Image courtesy of NFRC)

## 2.1 U-Factor



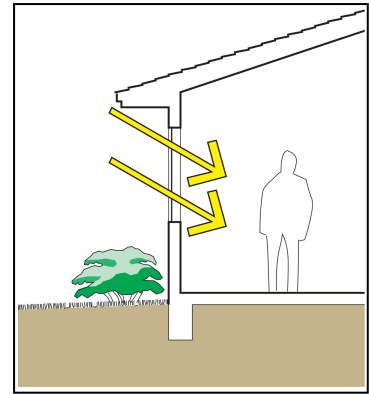
**Figure 3. Heat loss through a window by conduction, convection, and radiation**

## 2.2 Solar Heat Gain Coefficient



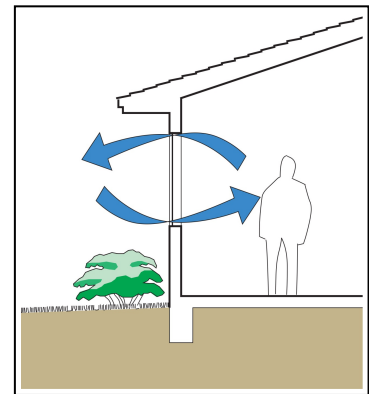
**Figure 4. Solar gain through a window**

### 2.3 Visible Transmittance



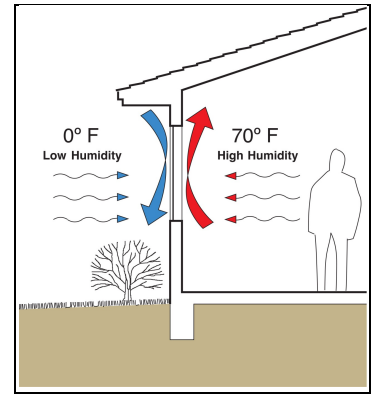
**Figure 5. Visible light through a window**

### 2.4 Air Leakage



**Figure 6. Air leakage through window assembly**

## 2.5 Condensation Resistance



**Figure 7. Condensation on window surface**



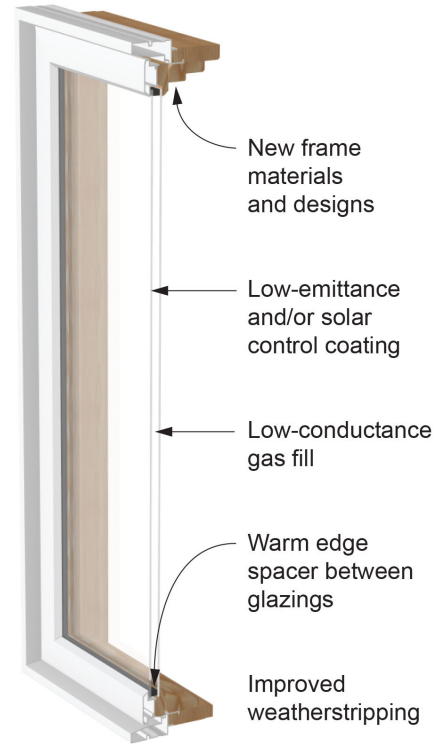
### 3 Window Technologies

- 
- 
- 
- 
- 

#### 3.1 Glazing Types

##### 3.1.1 Multiple Layers

##### 3.1.1.1 Suspended Films



**Figure 8. Advancements to improve energy efficiency**

### **3.1.2 Low-Emittance Coatings**

*emissivity*

*spectrally selective coatings*

#### **3.1.2.1 High-Solar-Gain Low-Emittance Coatings**

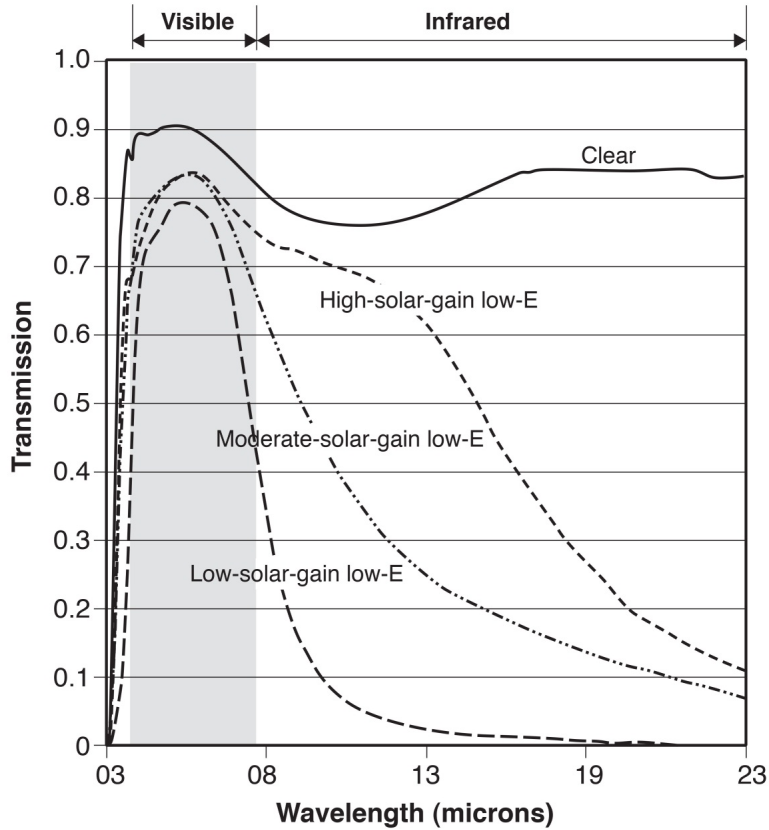


Figure 9. Spectral transmittance curves for glazings with low-e coatings

### 3.1.2.2 Moderate-Solar-Gain Low-Emittance Coatings

### 3.1.2.3 Low-Solar-Gain Low-Emittance Coatings

### 3.1.2.4 Coating Placement

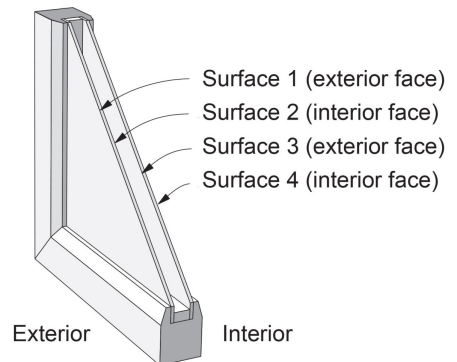


Figure 10. Surface placement of low-e coatings

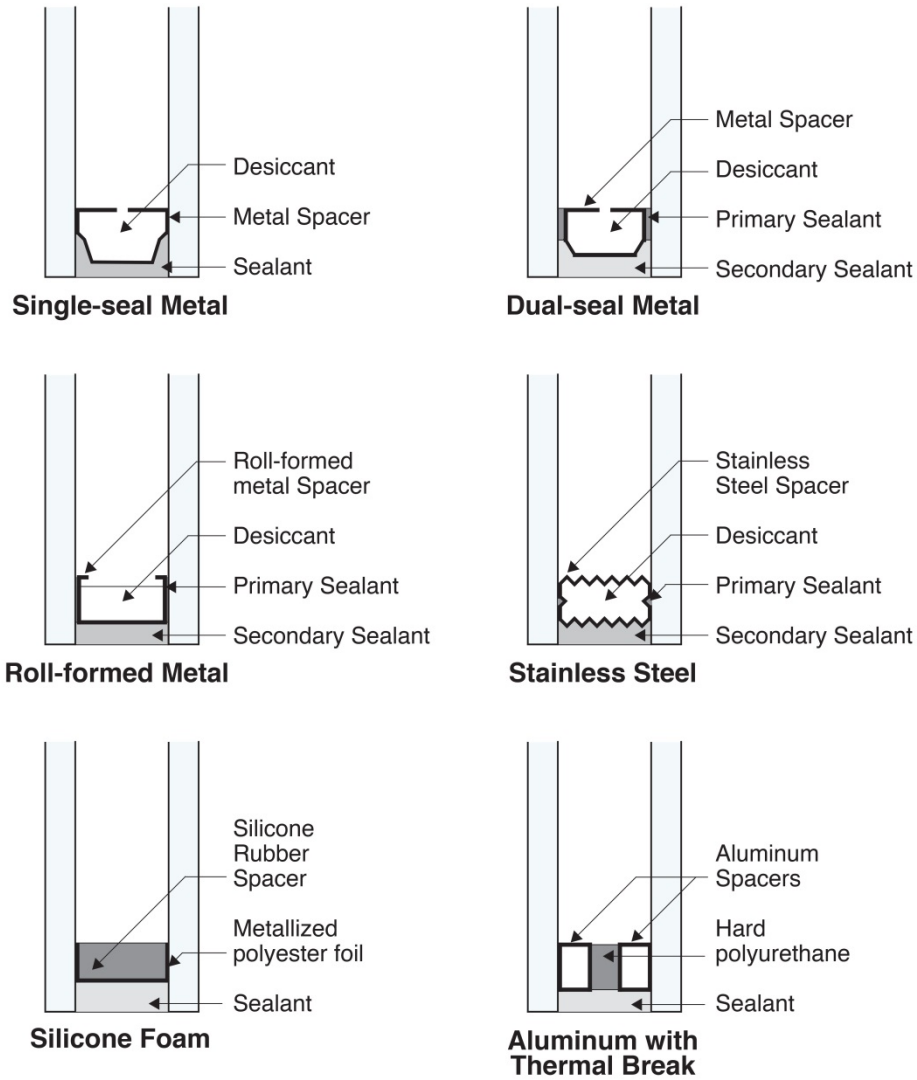
## **3.2 Low-Conductance Spacers and Gas Fills**

### **3.2.1 *Low-Conductance Gas Fills***

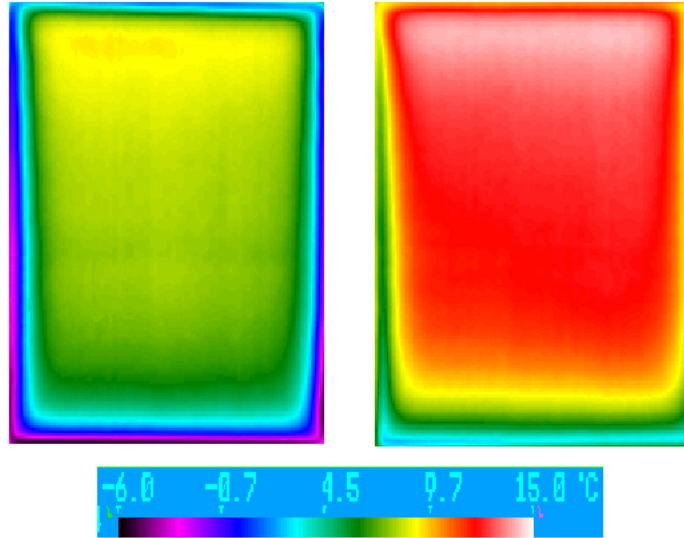
ch

### **3.2.2 *Warm Edge Spacers***

- 
- 
- 
-



**Figure 11. Various metal and nonmetal spacer systems**



**Figure 12. Thermogram of double-glazed clear window with an aluminum spacer (left) and double-glazed low-e window with an insulating spacer (right). Cold regions in purple and blue represent the large amounts of heat flowing through the spacer.**  
(Image courtesy of LBNL)

### **3.3 Frame Types**

#### **3.3.1 Metal Frames**

#### **3.3.2 Thermally Broken Metal Frames**

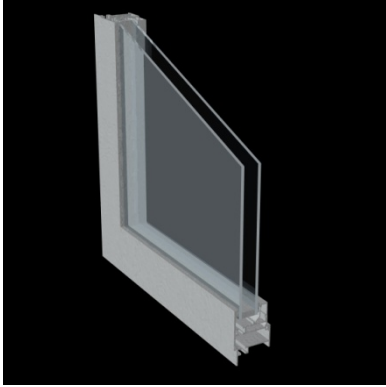


Figure 13. Aluminum frame

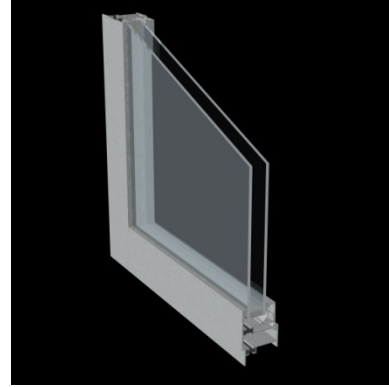


Figure 14. Aluminum frame with thermal break

### 3.3.3 Nonmetal Frames

#### 3.3.3.1 Wood

...

#### 3.3.3.2 Wood Clad



Figure 15. Wood frame



Figure 16. Wood with clad frame



### 3.3.3.3 Vinyl

### 3.3.3.4 Hybrid

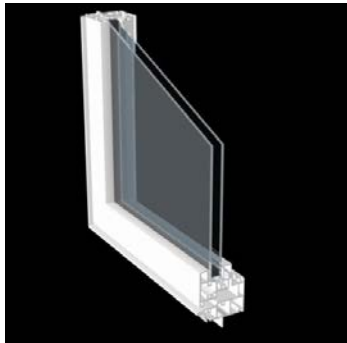


Figure 17. Vinyl frame

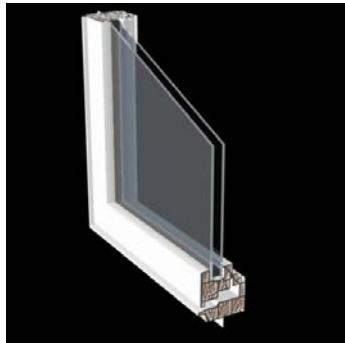


Figure 18. Insulated vinyl frame



Figure 19. Hybrid frame

### 3.3.3.5 Composite

### 3.3.3.6 Thermally Improved or Insulated Vinyl

3.3.3.7 *Fiberglass or Engineered Thermoplastics*

3.3.3.8 *Thermally Improved Wood and Composite Frames*

**Table 1. Properties of Generic Set of Windows**  
(EWC 2012a)

ID	Glazing	Frame	U	SHGC	VT
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					
16					
17					
18					
19					
20					

## **4 Window Selection Process**

**Meet code**

**Look for the ENERGY STAR label**

**Look for performance properties on the NFRC label**

**Use the Window Selection Tool (EWC 2012b)**

**Use RESFEN (LBNL 2012)**

**Use BEopt (NREL 2012a)**

### **4.1 Energy Codes**

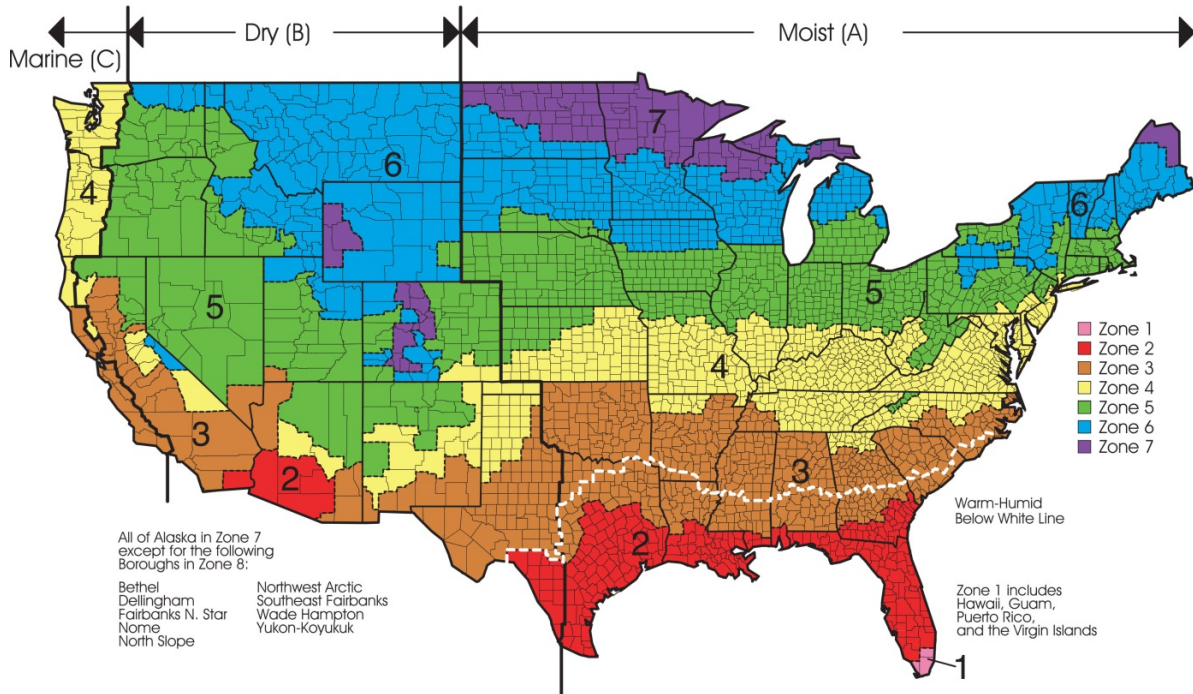


Figure 20. Climate zone map referenced in IECC 2006 and later versions

#### 4.1.1 Windows in the 2009 International Energy Conservation Code

Table 2. Prescriptive Window Requirements in the 2009 IECC

Climate Zone	Window U-Factor	Skylight U-Factor	Window and Skylight SHGC*
1			
2			
3			
4 except Marine			
5 and Marine 4			
6			
7 and 8			

### 4.1.2 Windows in the 2012 International Energy Conservation Code

Table 3. Prescriptive Window Requirements in the 2012 IECC

Climate Zone	Window U-Factor	Skylight U-Factor	Window and Skylight SHGC
1			
2			
3			
4 except Marine			
5 and Marine 4			
6			
7 and 8			

### 4.2 ENERGY STAR

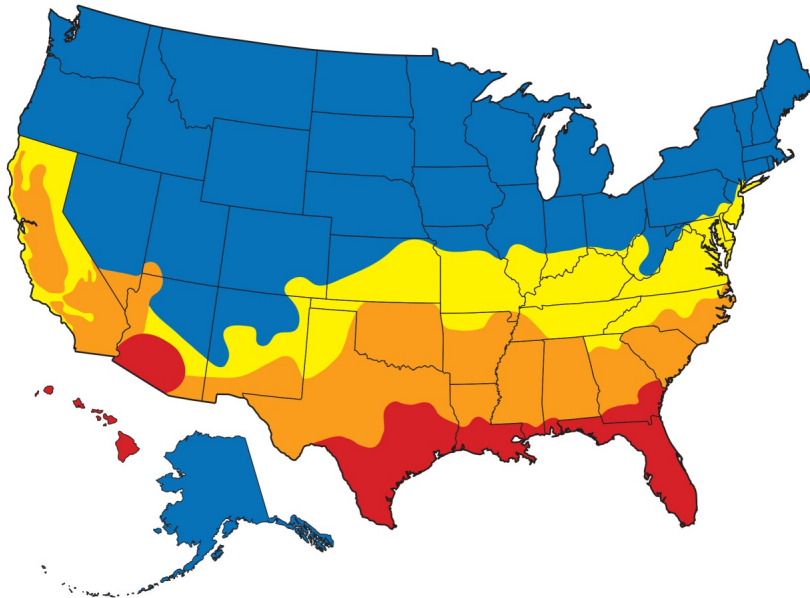


Figure 21. ENERGY STAR zone map  
(Image courtesy of EPA)

**Table 4. Current ENERGY STAR Performance Requirements**

Climate Zone	Window U-Factor	Window SHGC	Skylight U-Factor	Skylight SHGC
North	$\leq 0.30$	$\geq 0.35$ $\geq 0.40$	$\leq 0.55$	
North Central	$\leq 0.32$	$\leq 0.4$	$\leq 0.55$	$\leq$
South Central	$\leq 0.35$	$\leq 0.30$	$\leq 0.57$	$\leq 0.30$
South	$\leq 0.60$	$\leq 0.27$	$\leq 0.70$	$\leq 0.30$

- 
- 
- 
- 
- 

s, as well as air leakage ( $\leq 0.30$  cfm/ft

**Table 5. Proposed 2013 ENERGY STAR Performance Requirements**

Climate Zone	Window U-factor	Window SHGC	Skylight U-factor	Skylight SHGC
North Tradeoff	$\leq 0.27$	$\geq 0.32$	$\leq 0.45$	$\leq 0.35$
North Central	$\leq 0.29$	$\leq 0.40$	$\leq 0.47$	$\leq 0.30$
South Central	$\leq 0.31$	$\leq 0.25$	$\leq 0.50$	$\leq 0.25$
South	$\leq$	$\leq 0.25$	$\leq 0.$	$\leq 0.25$

### 4.3 Window Selection Tool

**Efficient Windows Collaborative** Home • Window Selection • Minneapolis, MN

Home | Guidance | Resources | Fact Sheets | Energy Codes | Publications | Membership | Contact Us | Search

**WINDOW SELECTION TOOL** | WINDOW TECHNOLOGIES | BENEFITS

**Minneapolis, Minnesota**

**Energy Costs**  
 Natural Gas: \$0.991/therm  
 Electricity: \$0.097/kWh

**Window Search**

Select Glass: [All glass types]  
 Select Frame: [All frame types]  
 ENERGY STAR®: Yes   
 Construction Type: New  Existing   
 Product Type: Windows  Skylights   
 Search for Windows

Window Types	Properties	Annual Energy Use	Manufacturer Information	ENERGY STAR® Qualified
Window 28 Triple-glazed, High-solar-gain Low-E Glass, Argon/Krypton Gas Non-metal Frame, Thermally Improved	U = 0.20 SHGC = 0.26-0.40 VT = 0.41-0.50	\$0 \$300 \$600 \$900 \$1100	Products	yes
Window 29 Triple-glazed, Low-Solar-Gain Low-E Glass, Argon/Krypton Gas Non-metal Frame, Thermally Improved	U = 0.20 SHGC = 0.25 VT = 0.40	\$0 \$300 \$600 \$900 \$1100	Products	yes
Window 23 Triple-glazed, High-solar-gain Low-E Glass, Argon/Krypton Gas Non-metal Frame	U = 0.21-0.25 SHGC = 0.26-0.40 VT = 0.41-0.50	\$0 \$300 \$600 \$900 \$1100	Products	yes
Window 24 Triple-glazed, Low-Solar-Gain Low-E Glass, Argon/Krypton Gas Non-metal Frame	U = 0.21-0.25 SHGC = 0.25 VT = 0.40	\$0 \$300 \$600 \$900 \$1100	Products	yes
Window 25 Double-glazed, High-solar-gain Low-E Glass, Argon/Krypton Gas Non-metal Frame, Thermally Improved	U = 0.26-0.30 SHGC = 0.41-0.60 VT = 0.51-0.60	\$0 \$300 \$600 \$900 \$1100	Products	yes
Window 26 Double-glazed, Moderate-solar-gain Low-E Glass, Argon/Krypton Gas Non-metal Frame, Thermally Improved	U = 0.26-0.30 SHGC = 0.26-0.40 VT = 0.51-0.60	\$0 \$300 \$600 \$900 \$1100	Products	yes
Window 27 Double-glazed, Low-solar-gain Low-E Glass, Argon/Krypton Gas Non-metal Frame, Thermally Improved	U = 0.26-0.30 SHGC = 0.41-0.60 VT = 0.41-0.50	\$0 \$300 \$600 \$900 \$1100	Products	yes
Window 20 Double-glazed, High-solar-gain Low-E Glass, Argon/Krypton Gas Non-metal Frame	U = 0.31-0.40 SHGC = 0.41-0.60 VT = 0.51-0.60	\$0 \$300 \$600 \$900 \$1100	Products	maybe
Window 21 Double-glazed, Moderate-solar-gain Low-E Glass, Argon/Krypton Gas Non-metal Frame	U = 0.31-0.40 SHGC = 0.26-0.40 VT = 0.51-0.60	\$0 \$300 \$600 \$900 \$1100	Products	maybe


■ Annual Heating ■ Annual Cooling

Note: The annual energy performance figures shown here were generated with regression expressions provided by Lawrence Berkeley National Laboratory (windows.lbl.gov/ES&R2008). Results assume a typical (new construction, 2250 sq ft / existing construction, 2150 sq ft) house with 15% window-to-floor area. The windows are equally distributed on all four sides and include typical shading (interior shades, overhangs, trees, and neighboring buildings). U-factor and SHGC are for the total window including frames. The costs shown here are annual costs for space heating and space cooling only and thus will be less than total utility bills. Costs for lights, appliances, hot water, cooking, and other uses are not included in these figures. The mechanical system uses a gas furnace for heating and air conditioning for cooling. Natural gas prices used are projections of the average natural gas price for the heating seasons of 2010-2020 in real 2009 dollars. Projections are based on state-specific natural gas retail price data by the Energy Information Administration (EIA) for the heating seasons of 2006-08 and are adjusted based on EIA projections of national natural gas price trends for 2010-2020. Electricity prices used are projections of the average electricity price for the cooling seasons of 2010-2020 in real 2009 dollars. Projections are based on state-specific electricity retail price data by the Energy Information Administration (EIA) for the cooling seasons of 2006-08 and are adjusted based on EIA projections of national electricity price trends for 2010-2020 (www.eia.doe.gov).

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 Disclaimer

Figure 22. Results from the Window Selection Tool

### Minneapolis, Minnesota



Window 28  
[Triple-glazed, High-solar-gain Low-E Glass, Argon/Krypton Gas](#)  
[Non-metal Frame, Thermally Improved](#)

U = ≤0.20  
 SHGC = 0.26-0.40  
 VT = 0.41-0.50


Manufacturer	View Products
Accurate Dorwin	<a href="#">Products Available»</a>
Fibertec Window & Door Mfg.	<a href="#">Products Available»</a>
Marvin Windows and Doors	<a href="#">Products Available»</a>
Paradigm Window Solutions	<a href="#">Products Available»</a>
Serious Materials	<a href="#">Products Available»</a>
Wasco Windows	<a href="#">Products Available»</a>

Disclaimer: Manufacturers have agreed that products listed here meet the energy performance requirements of the Efficient Windows Collaborative and have been tested and certified according to [NFRC](#) standards.

The Efficient Windows Collaborative does not provide any guarantees of service or useability for products or services purchased from these merchants.

**Figure 23. Manufacturers listed for a specific window in the Window Selection Tool**

### Minneapolis, Minnesota



Window 28  
[Triple-glazed, High-solar-gain Low-E Glass, Argon/Krypton Gas](#)  
[Non-metal Frame, Thermally Improved](#)

U = ≤0.20  
 SHGC = 0.26-0.40  
 VT = 0.41-0.50

[«Back to Manufacturers List](#)

Manufacturer	Product Line	U-factor	SHGC	VT	AL
Marvin Windows and Doors <a href="http://www.marvin.com">http://www.marvin.com</a>	Clad Ultimate Double Hung Picture - tri-pane, low-E 179, argon/krypton	0.20	0.43	0.52	
	Wood Magnum Tilt-Turn - tri-pane, low-E 179, krypton/argon	0.20	0.38	0.46	
	Wood Ultimate Awning - tri-pane, low-E 179, krypton/argon	0.20	0.37	0.45	

Disclaimer: Manufacturers have agreed that products listed here meet the energy performance requirements of the Efficient Windows Collaborative and have been tested and certified according to [NFRC](#) standards.

The Efficient Windows Collaborative does not provide any guarantees of service or useability for products or services purchased from these merchants.

**Figure 24. Products by a manufacturer listed in the Windows Selection Tool**

## 4.4 RESFEN



**House Data**

ID# 17 - e/w wood double h  
 Name e/w wood double hsg lowE  
 Location GA Atlanta  
 House Type 2-Story Existing Frame  
 HVAC System Type Gas Furnace / AC  
 Floor Area 2000 ft2  
 Envelope Package Exist01 (AL1)  
 Foundation Type Slab-On-Grade  
 Set to Defaults  
 Electric Cost User defined  
 0.101 \$/kWh  
 Gas Cost User defined  
 0.937 \$/Therm  
 Description

**Window Data**

Window Type	Area ft2	U-factor Btu/h-ft2-F	SHGC	Air Leakage cfm/ft2	Solar Gain Reduction
North 321: W/W 2 PY Low-E	50	0.37	0.53	0.3	None
East 321: W/W 2 PY Low-E	100	0.37	0.53	0.3	None
South 321: W/W 2 PY Low-E	50	0.37	0.53	0.3	None
West 321: W/W 2 PY Low-E	100	0.37	0.53	0.3	None
Skylight User defined	0	0	0	0	None

East, South and West windows are the same type as North  
 Total Window Area 300 ft2 15.0% of floor area

**Whole House**

	Heating	Cooling	Total (source)
Annual Energy Totals	31.1 MBtu	3827 kWh	70.2 MBtu
Annual Energy per ft2	15.5 kBtu/ft2	1.91 kWh/ft2	35.1 kBtu/ft2
Peak	60.1 kBtu/hr	4.46 kW	
Cost \$	290.99	386.49	677.48

For Help, press F1

Figure 25. RESFEN computer simulation data entry screen (Image courtesy of LBNL)

## 5 Cost and Performance

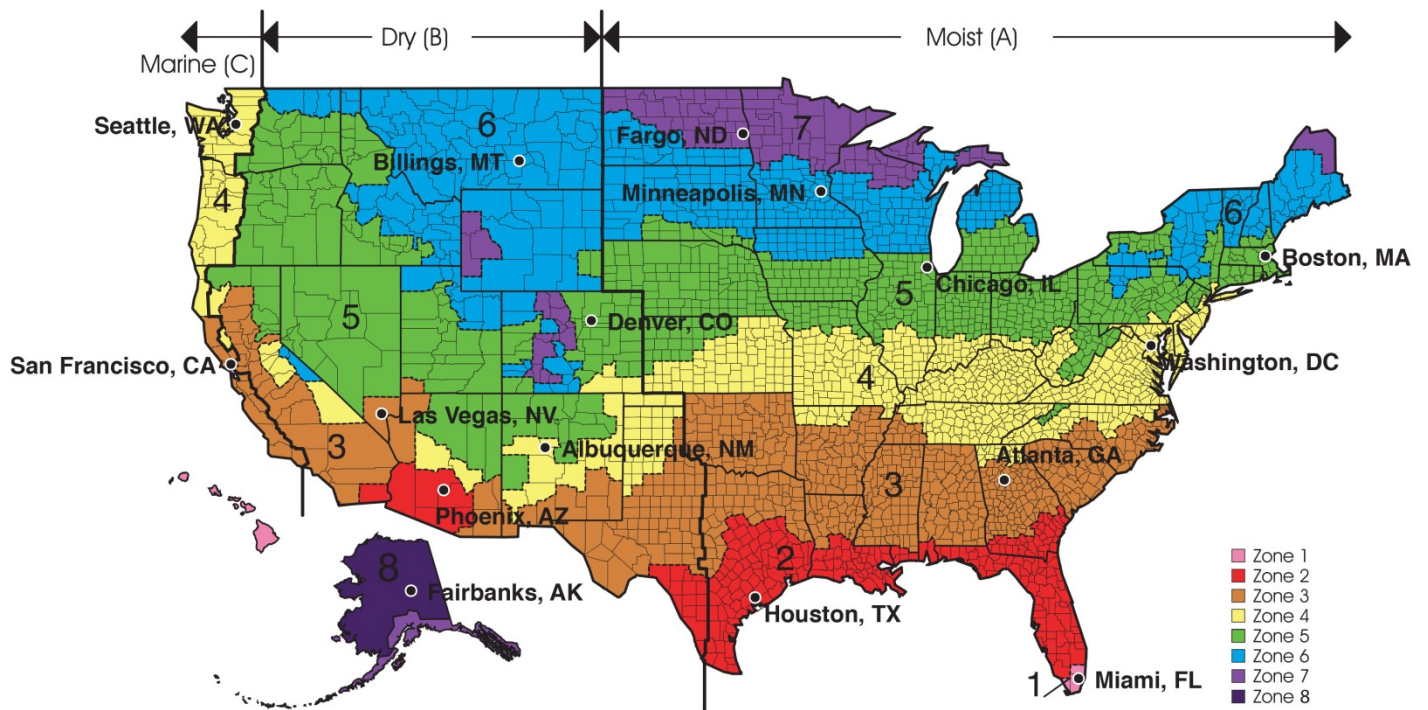


Figure 26. IECC climate zone map with cities used in simulations

## 5.1 Energy and Cost Savings for New Windows

### 5.1.1 Savings for New Windows in Climate Zones 1 and 2

**Table 6. Properties of Windows Used in Climate Zones 1 and 2**

ID	Glazing	Frame	U	SHGC	VT
6					
11					
16					
17					
20					



**5.1.2 Savings for New Windows in Climate Zones 3 and 4**

**Table 10. Properties of Windows Used in Climate Zones 3 and 4**

<b>ID</b>	<b>Glazing</b>	<b>Frame</b>	<b>U</b>	<b>SHGC</b>	<b>VT</b>
<b>11</b>					
<b>15</b>					
<b>16</b>					
<b>17</b>					
<b>19</b>					





**5.1.3 Savings for New Windows in Climate Zones 5–8**

**Table 17. Properties of Windows Used in Climate Zones 5–8**

ID	Glazing	Frame	U	SHGC	VT
15					
16					
17					
18					
19					









## 5.2 Energy and Cost Savings for Replacement Windows

### 5.2.1 Savings for Replacement Windows in Climate Zones 1 and 2

≤0.20) performs best

**Table 25. Properties of Windows Used in Climate Zones 1 and 2**

ID	Glazing	Frame	U	SHGC	VT
1					
7					
11					
17					
20					



**5.2.2 Savings for Replacement Windows in Climate Zones 3 and 4**

**Table 29. Properties of Windows Used in Climate Zones 3 and 4**

<b>ID</b>	<b>Glazing</b>	<b>Frame</b>	<b>U</b>	<b>SHGC</b>	<b>VT</b>
1					
11					
16					
17					
19					







**5.2.3 Savings for Replacement Windows in Climate Zones 5–8**

**Table 36. Properties of Windows Used in Climate Zones 5–8**

<b>ID</b>	<b>Glazing</b>	<b>Frame</b>	<b>U</b>	<b>SHGC</b>	<b>VT</b>
13					
15					
16					
18					
19					







### 5.3 Window Costs (New and Replacement)

**Table 44. Example of Window Costs**

Glazing Type	Frame Type	Average Costs New (ft <sup>2</sup> )	Average Costs Replacement (ft <sup>2</sup> )
Double, clear			
Double, low-e			
Triple, low-e			

**Table 45. Simple Payback for New Windows**

Annual Energy Savings	Simple Payback (Years) for Incremental Window Cost (ft <sup>2</sup> )				
	\$5	\$10	\$15	\$20	\$25
\$50					
\$100					
\$150					
\$200					
\$250					
\$300					
\$350					
\$400					
\$450					
\$500					
\$550					
\$600					

**Table 46. Simple Payback for Replacement Windows**

Annual Energy Savings	Simple Payback (Years) for Incremental Window Cost (ft <sup>2</sup> )				
	\$20	\$25	\$30	\$35	\$40
\$50					
\$100					
\$150					
\$200					
\$250					
\$300					
\$350					
\$400					
\$450					
\$500					
\$550					
\$600					

**5.4 Life Cycle Cost Analysis**

### ***5.4.1 Life Cycle Cost Summary***

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## **5.5 Other Benefits**

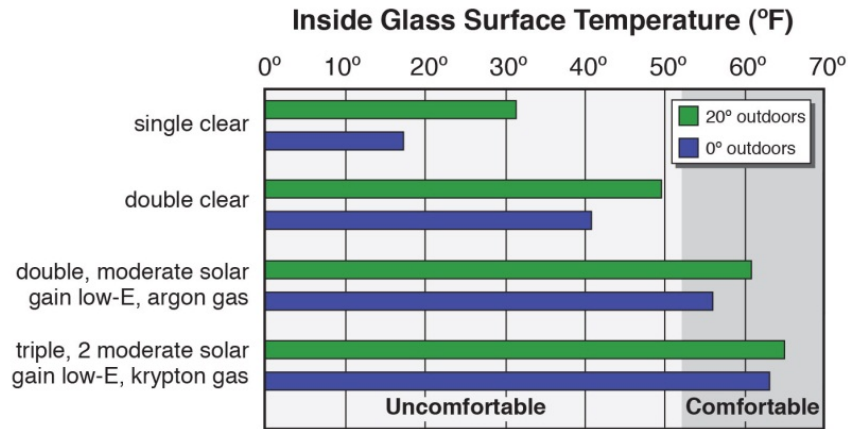
### **5.5.1 Comfort**

#### *5.5.1.1 Sources of Discomfort From Windows*

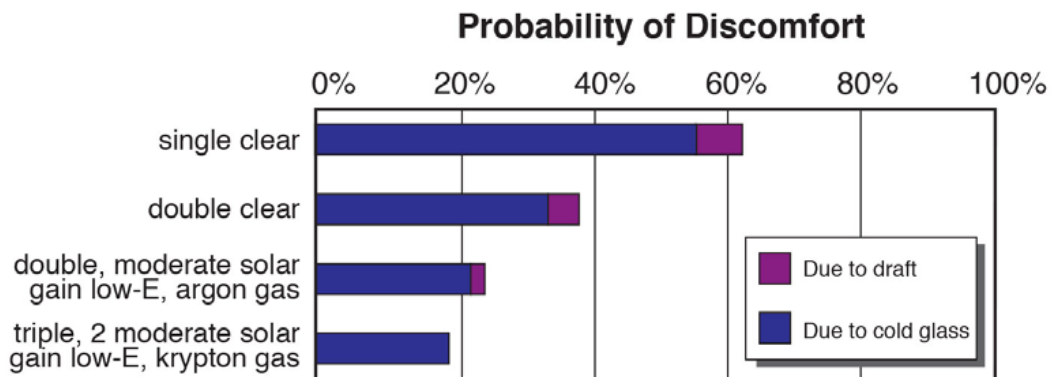
*radiant asymmetry*



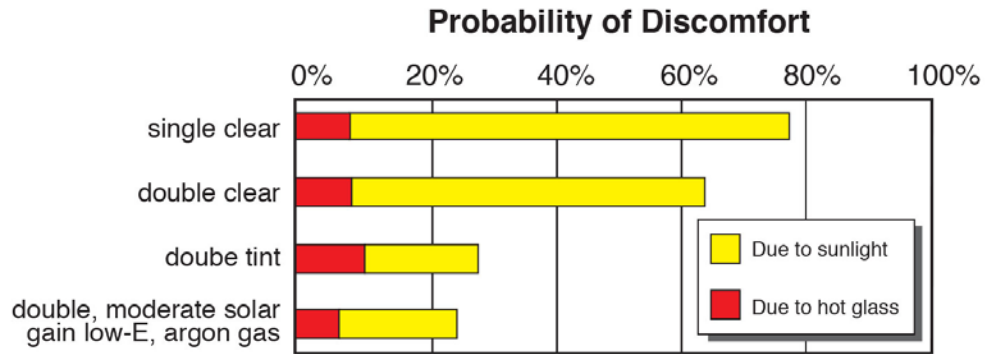
### *5.5.1.2 Quantifying Discomfort*



**Figure 27. Comparison of inside glass surface temperature for different glazing types**  
(Image courtesy of LBNL)



**Figure 28. Probability of discomfort near a window in the winter**  
(Image courtesy of LBNL)



**Figure 29. Probability of discomfort near a window in the summer**  
(Image courtesy of LBNL)

5.5.1.3 Comparing Windows Based on Thermal Comfort

**Table 47. Winter and Summer Comfort Index for Typical Windows**  
(Huizenga et al. 2006)

Glazing	U	SHGC	VT	Winter Comfort Index Minimum Exterior Temperature (°F)	Summer Comfort Index Diffuse	Summer Comfort Index Direct
Single Clear						
Single Bronze						
Double Clear						
Double Medium Gain Low-e						
Double High Gain Low-e						
Triple Clear						
Triple Medium Gain Low-e						
Triple High Gain Low-e						

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### ***5.5.2 Reduced Peak Demand and Heating, Ventilation, and Air Conditioning Costs***

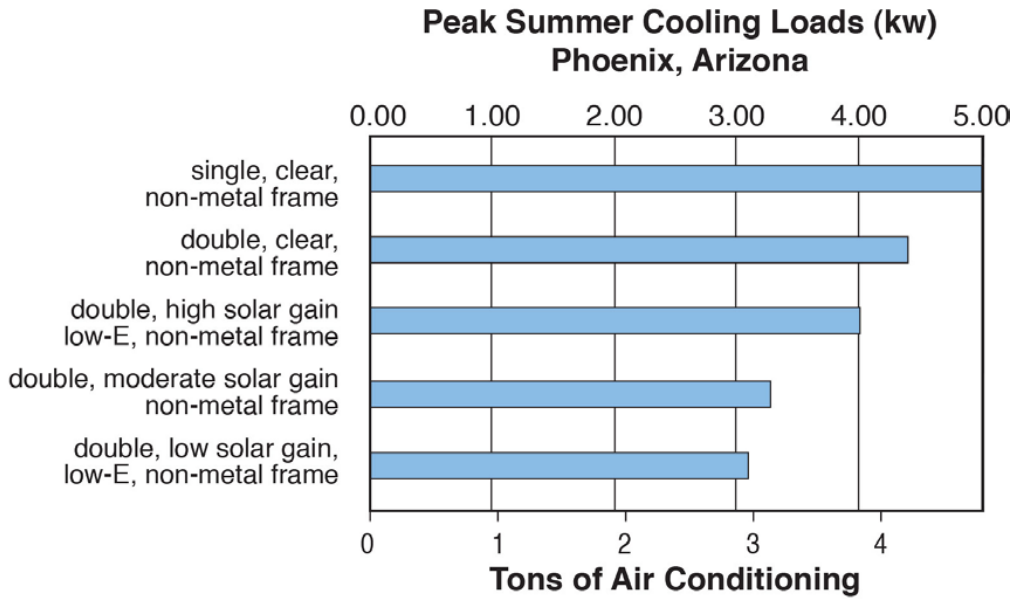


Figure 30. Peak summer cooling loads in Phoenix, Arizona

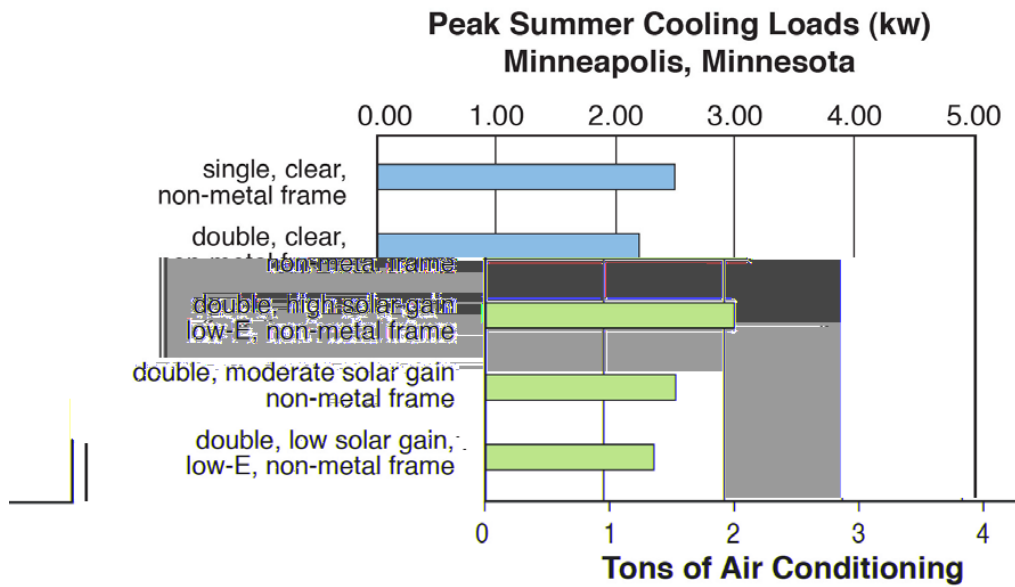


Figure 31. Peak summer cooling loads in Minneapolis, Minnesota

### 5.5.2.1 Rightsizing Heating, Ventilation, and Air Conditioning Systems

- **Health and comfort**
- **Mold prevention**
- **First cost savings**
- **Energy savings**

### 5.5.2.2 Heating, Ventilation, and Air Conditioning Sizing Tools

*Fundamentals*

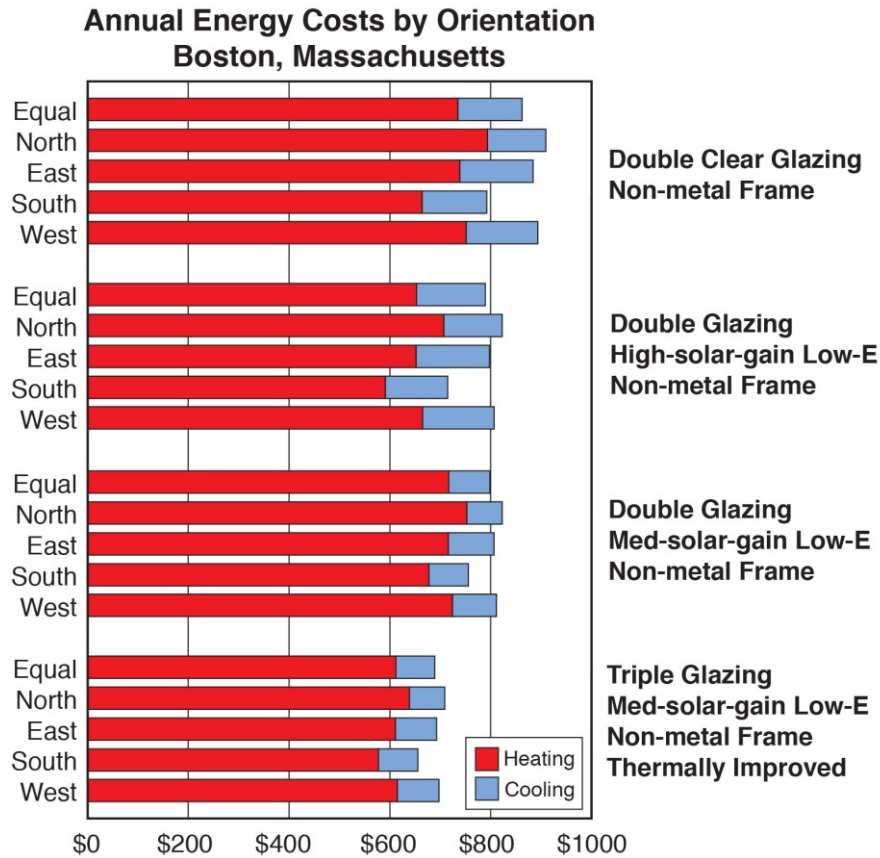
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## 6 Impact of Design on Performance

### 6.1 Orientation

#### 6.1.1 Orientation in the Northern Zone (Heating Dominated)



The annual energy performance figures assume a typical new construction 2250 sf house with 300 sf of window area. The windows include typical shading (interior shades, overhangs, trees, and neighboring buildings).

**Figure 32. Annual energy cost by orientation in Boston, Massachusetts**

6.1.2 Orientation in the Central Zones (Heating and Cooling)

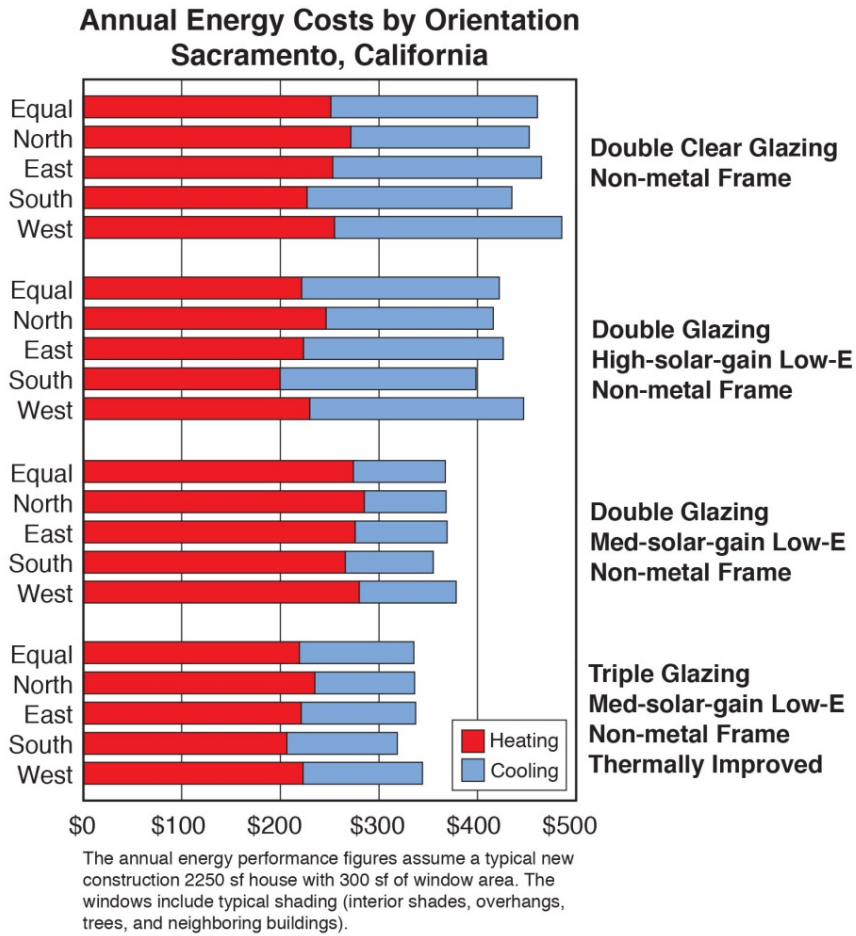
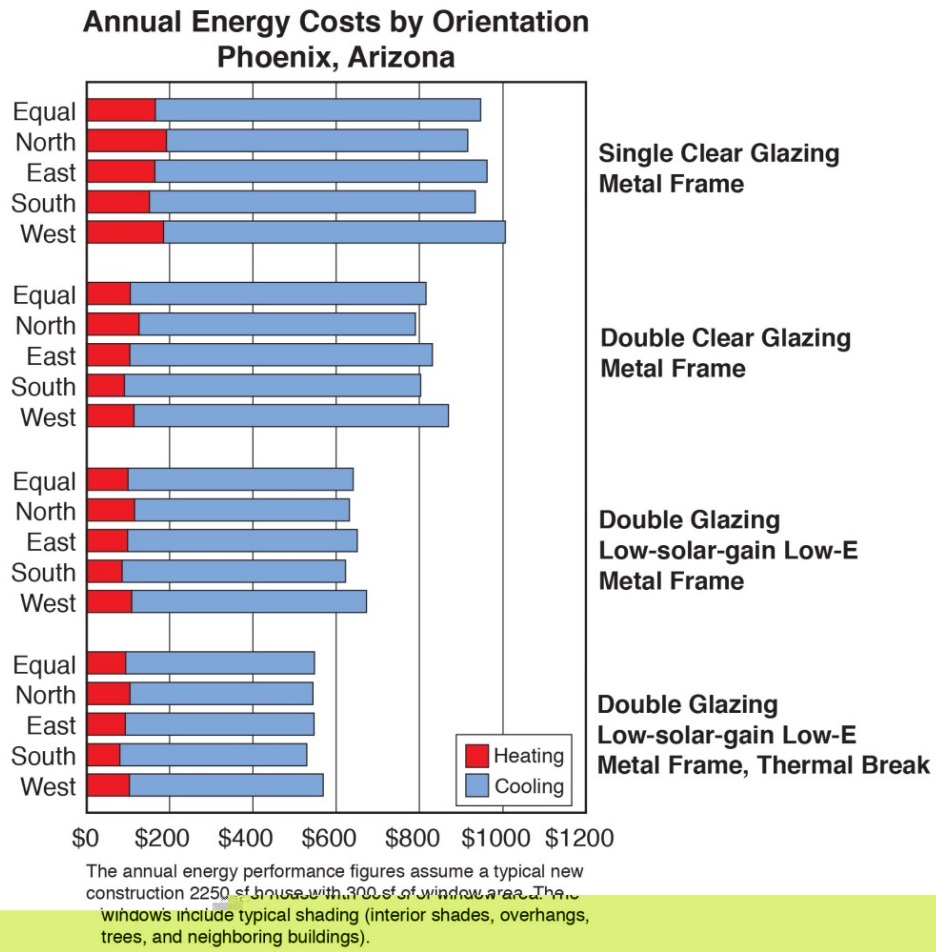


Figure 33. Annual energy cost by orientation in Sacramento, California



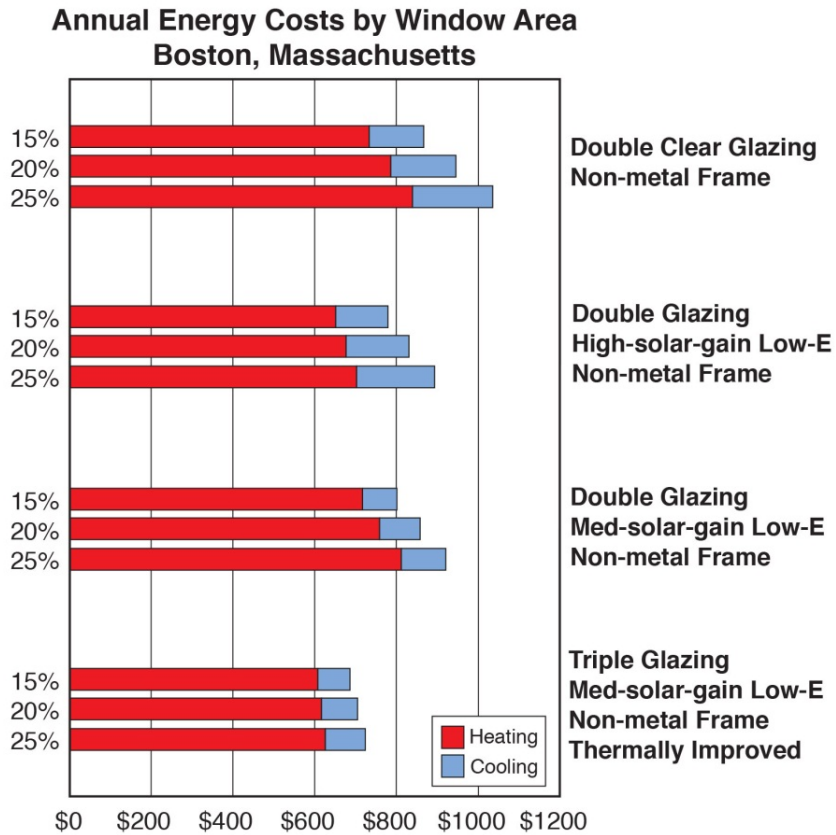
### 6.1.3 Orientation in the Southern Zone (Cooling Dominated)



**Figure 34. Annual energy cost by orientation in Phoenix, Arizona**

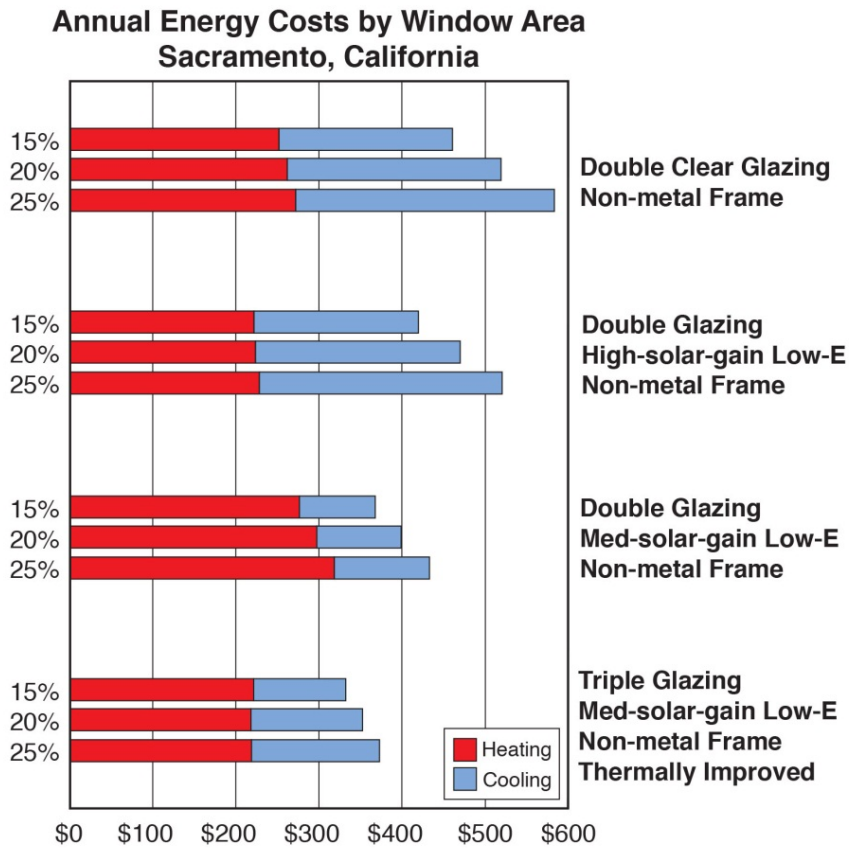
## 6.2 Window Area

### 6.2.1 Window Area in the Northern Zone (Heating Dominated)



**Figure 35. Annual energy cost by window area in Boston, Massachusetts**

**6.2.2 Window Area in the Central Zones (Heating and Cooling)**

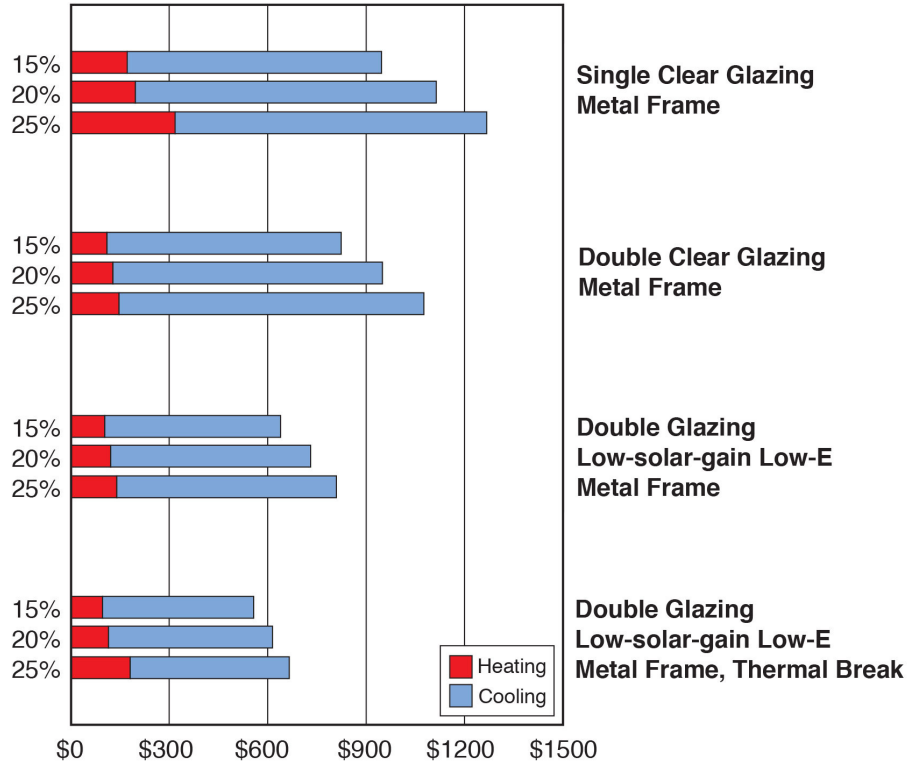


The annual energy performance figures assume a typical new construction 2250 sf house. The windows are equally distributed on all four sides and include typical shading (interior shades, overhangs, trees, and neighboring buildings).

**Figure 36. Annual energy cost by window area in Sacramento, California**

### 6.2.3 Window Area in the Southern Zone (Cooling Dominated)

**Annual Energy Costs by Window Area  
Phoenix, Arizona**

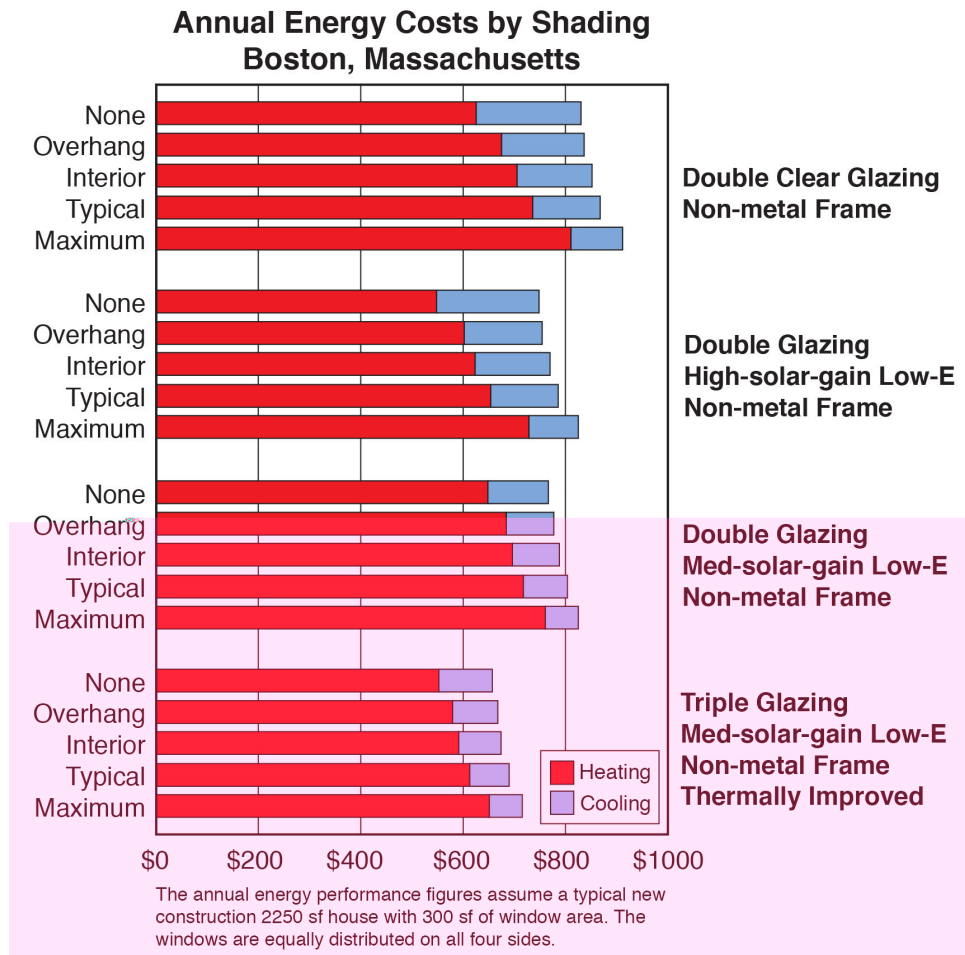


The annual energy performance figures assume a typical new construction 2250 sf house. The windows are equally distributed on all four sides and include typical shading (interior shades, overhangs, trees, and neighboring buildings).

**Figure 37. Annual energy cost by window area in Phoenix, Arizona**

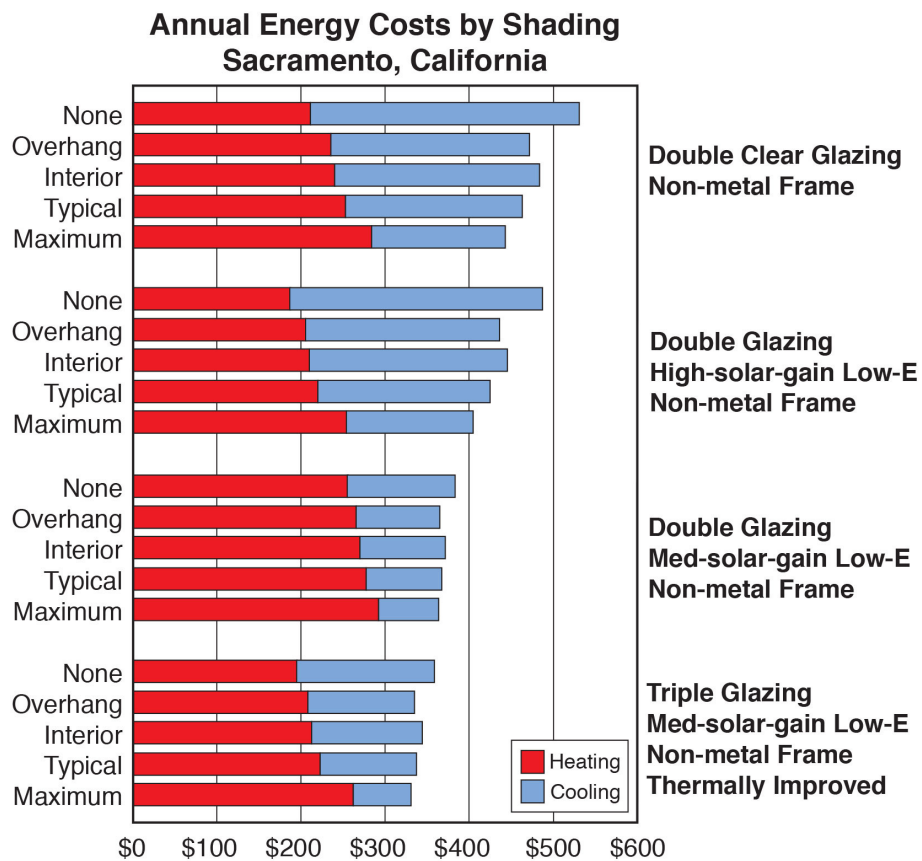
### 6.3 Shading

#### 6.3.1 Shading in the Northern Zone (Heating Dominated)



**Figure 38. Annual energy cost by shading type in Boston, Massachusetts**

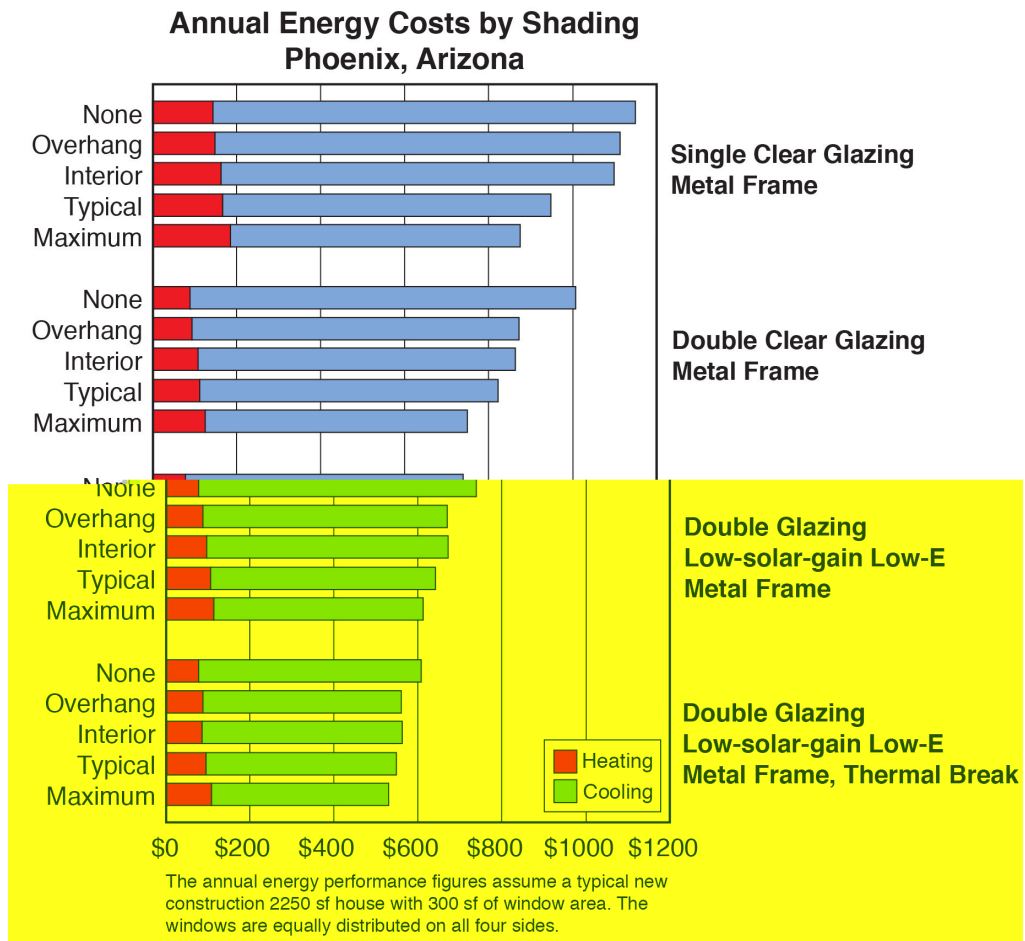
### 6.3.2 Shading in the Central Zones (Heating and Cooling)



The annual energy performance figures assume a typical new construction 2250 sf house with 300 sf of window area. The windows are equally distributed on all four sides.

**Figure 39. Annual energy cost by shading type in Sacramento, California**

### 6.3.3 Shading in the Southern Zone (Cooling Dominated)



**Figure 40. Annual energy cost by shading type in Phoenix, Arizona**





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## *Water Management Guide*

### **7.2 Watertight Installation**

#### ***7.2.1 Storage or Mass Wall System***

#### ***7.2.2 Perfect Barrier System***

### **7.2.3 *Drained Wall System***

## **7.3 Replacement Windows and Sashes**

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