Advanced Building Science

- Fenestration
  - Basic Components
  - U-Factor
  - Solar Heat Gain
  - Visible Transmission
  - Air Leakage
  - Condensation Resistance
  - Standards

- Readings
  - HF: Chapter 15
  - HPE: Chapter 3.3.5 to 3.3.8

Fenestration

Basic Components

- Glazing
  - types (clear, tinted, coated, laminated, patterned, etc.)
- Insulating Glazing Units
  - glazing (see above)
  - spacer (materials & profile)
  - sealants
  - desiccants
  - gas fill (air, argon, krypton, xenon)
- Frame
  - operator type
  - material and profile
- Window Treatments & Shading

Window Types

Source: ASHRAE Handbook Fundamentals 2013, Chapter 15.3

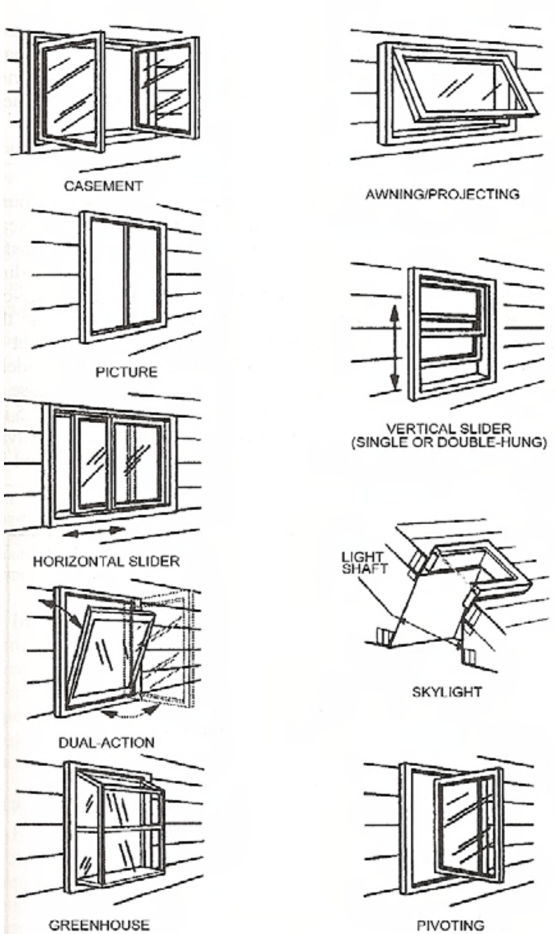


Fig. 2 Types of Residential Windows

Fenestration

U-Factor (Thermal Transmittance)

– Center-of-glass

– Edge-of-glass

– Frame

– Other (dividers, decorative grilles, and muntins)

Anatomy of an IGU

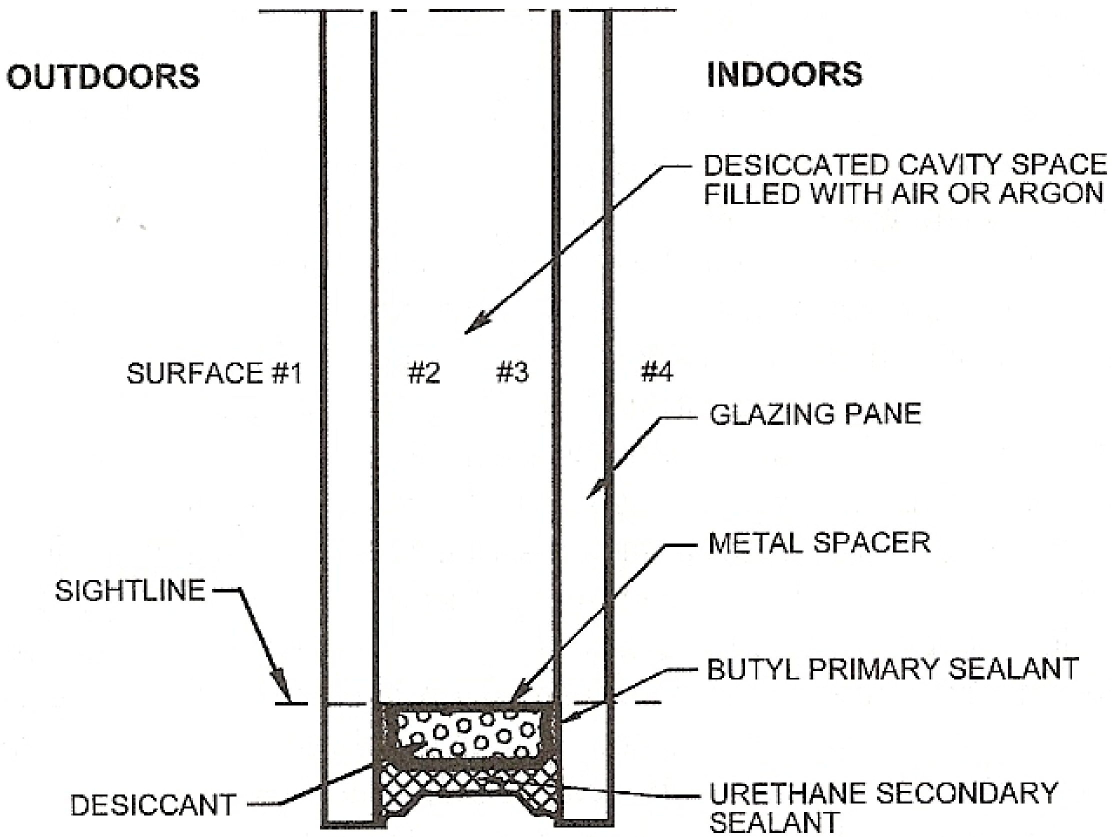
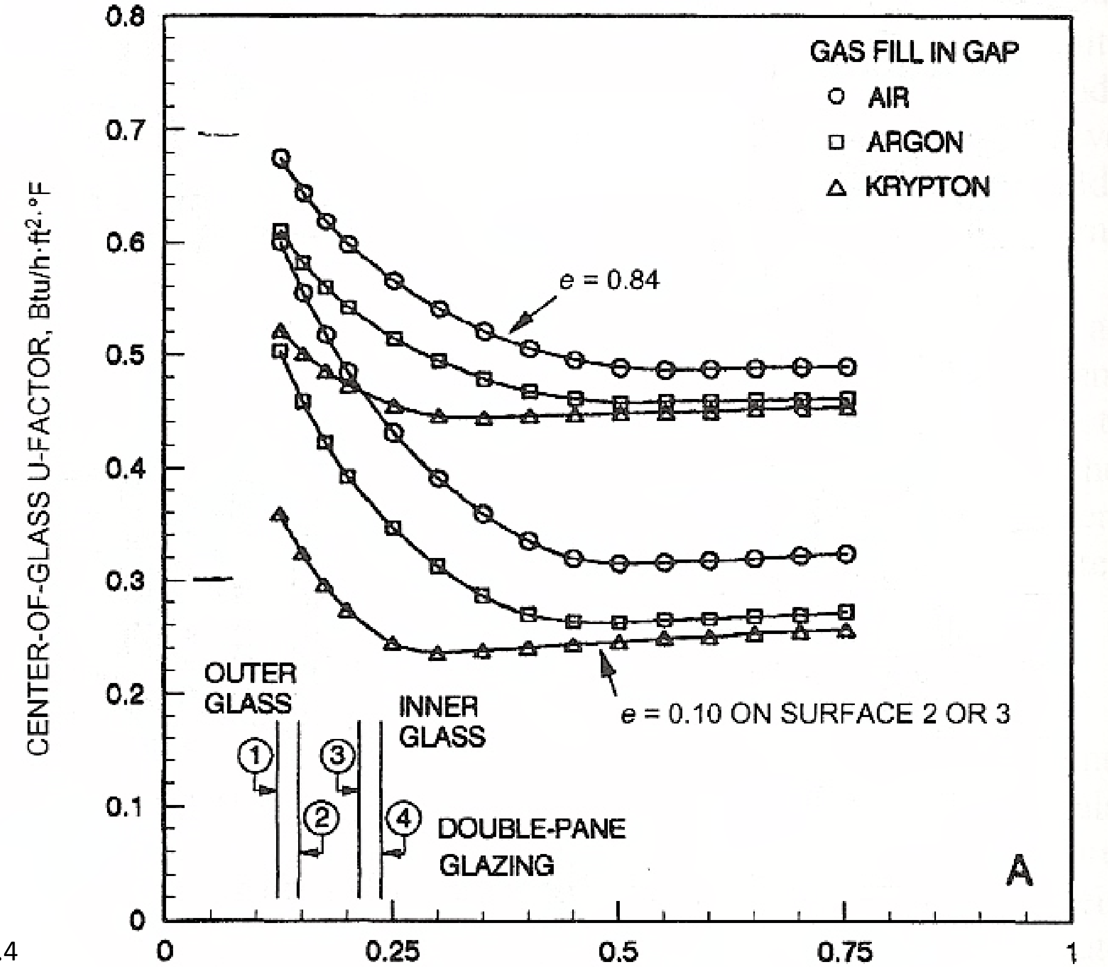


Fig. 1 Double-Glazing Unit Construction Detail

Source: ASHRAE Handbook Fundamentals 2013, Chapter 15.1

U-Factor for Double-Pane



Source: ASHRAE Handbook Fundamentals 2013, Chapter 15.4

U-Factor for Triple-Pane

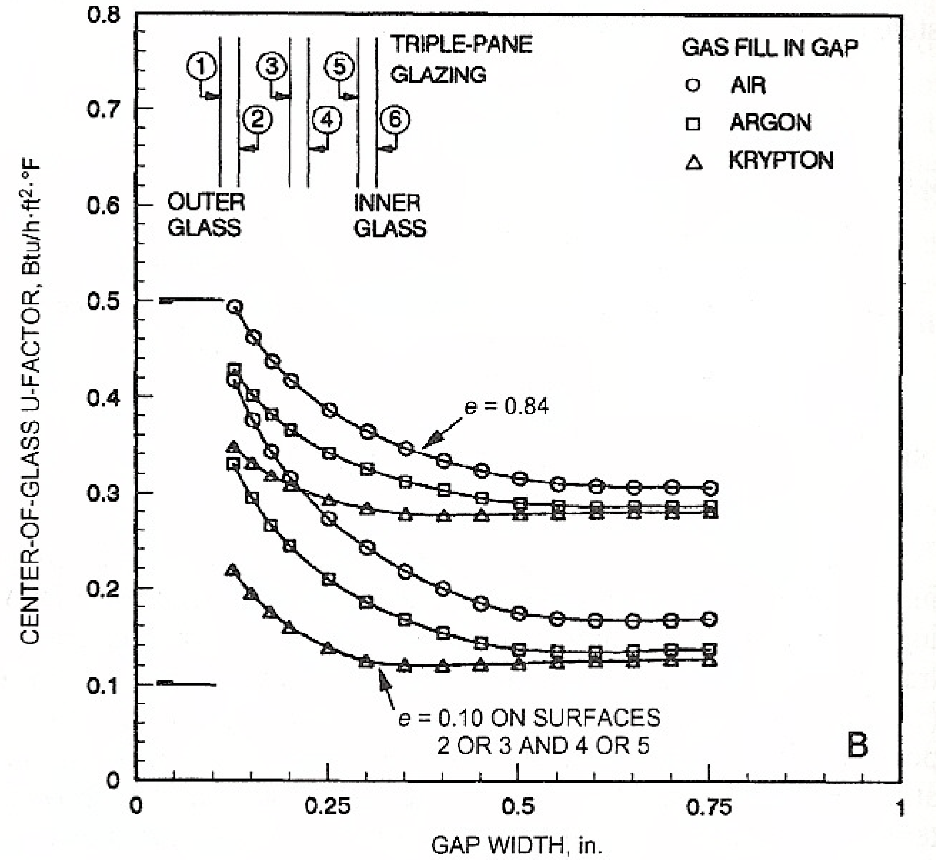


Fig. 3 Center-of-Glass U-Factor for Vertical Double- and Triple-Pane Glazing Units

Source: ASHRAE Handbook Fundamentals 2013, Chapter 15.4

Typical U-Factors

Table 1 Representative Fenestration Frame U-Factors in Btu/h·ft²·°F, Vertical Orientation

		Product Type/Number of Glazing Layers																
		Operable			Fixed			Garden Window		Plant-Assembled Skylight			Curtain Wall[e]			Sloped/Overhead Glazing[e]		
Frame Material	Type of Spacer	1[b]	2[c]	3[d]	1[b]	2[c]	3[d]	1[b]	2[c]	1[b]	2[c]	3[d]	1[f]	2[g]	3[h]	1[f]	2[g]	3[h]
Aluminum without thermal break	All	2.38	2.27	2.20	1.92	1.80	1.74	1.88	1.83	7.85	7.02	6.87	3.01	2.96	2.83	3.05	3.00	2.87
Aluminum with thermal break[a]	Metal	1.20	0.92	0.83	1.32	1.13	1.11			6.95	5.05	4.58	1.80	1.75	1.65	1.82	1.76	1.66
	Insulated	N/A	0.88	0.77	N/A	1.04	1.02			N/A	4.75	4.12	N/A	1.63	1.51	N/A	1.64	1.52
Aluminum-clad wood/ reinforced vinyl	Metal	0.60	0.58	0.51	0.55	0.51	0.48			4.86	3.93	3.66						
	Insulated	N/A	0.55	0.48	N/A	0.48	0.44			N/A	3.75	3.43						
Wood/vinyl	Metal	0.55	0.51	0.48	0.55	0.48	0.42	0.90	0.85	2.50	2.08	1.78						
	Insulated	N/A	0.49	0.40	N/A	0.42	0.35	N/A	0.83	N/A	2.02	1.71						
Insulated fiber-glass/vinyl	Metal	0.37	0.33	0.32	0.37	0.33	0.32											
	Insulated	N/A	0.32	0.26	N/A	0.32	0.26											
Structural glazing	Metal												1.80	1.27	1.04	1.82	1.28	1.05
	Insulated												N/A	1.02	0.75	N/A	1.02	0.75

Note: This table should only be used as an estimating tool for early phases of design.
[a]Depends strongly on width of thermal break. Value given is for 3/8 in.
[b]Single glazing corresponds to individual glazing unit thickness of 1/8 in. (nominal).
[c]Double glazing corresponds to individual glazing unit thickness of 3/4 in. (nominal).
[d]Triple glazing corresponds to individual glazing unit thickness of 1 3/8 in. (nominal).
[e]Glass thickness in curtainwall and sloped/overhead glazing is 1/4 in.
[f]Single glazing corresponds to individual glazing unit thickness of 1/4 in. (nominal).
[g]Double glazing corresponds to individual glazing unit thickness of 1 in. (nominal).
[h]Triple glazing corresponds to individual glazing unit thickness of 1 3/4 in. (nominal).
N/A: Not applicable

Source: ASHRAE Handbook Fundamentals 2013, Chapter 15.5

Assumed Indoor Surface Film Coefficients

Table 2 Indoor Surface Heat Transfer Coefficient h_i in Btu/h · ft² · °F, Vertical Orientation (Still Air Conditions)

Glazing ID[a]	Glazing Type	Glazing Height, ft	Winter Conditions[b]			Summer Conditions[c]		
			Glass Temp., °F	Temp. Diff., °F	h_i, Btu/h · ft² · °F	Glass Temp., °F	Temp. Diff., °F	h_i, Btu/h · ft² · °F
1	Single glazing	2	17	53	1.41	89	14	1.41
		4	17	53	1.31	89	14	1.33
		6	17	53	1.25	89	14	1.29
5	Double glazing with	2	45	25	1.36	89	14	1.41
	1/2 in. air space	4	45	25	1.27	89	14	1.33
		6	45	25	1.22	89	14	1.29
23	Double glazing with	2	56	14	1.31	87	12	1.38
	$e = 0.1$ on surface 2	4	56	14	1.23	87	12	1.31
	and 1/2 in. argon space	6	56	14	1.19	87	12	1.27
43	Triple glazing with	2	63	7	1.25	93	18	1.45
	$e = 0.1$ on surfaces 2 and 5	4	63	7	1.18	93	18	1.36
	and 1/2 in. argon spaces	6	63	7	1.15	93	18	1.32

Notes:

[a]Glazing ID refers to fenestration assemblies in Table 4.

[b]Winter conditions: room air temperature $t_i = 70$°F, outdoor air temperature $t_o = 0$°F, no solar radiation

[c]Summer conditions: room air temperature $t_i = 75$°F, outdoor air temperature $t_o = 89$°F, direct solar irradiance $E_D = 248$ Btu/h · ft²

$h_i = h_{ic} + h_{iR} = 1.46(\Delta T/L)^{0.25} + \varepsilon\sigma(T_i^4 - T_g^4)/\Delta T$, where $\Delta T = T_i - T_g$, °R; L = glazing height, ft; T_g = glass temperature, °R; σ = Stefan-Boltzmann constant; and ε = surface emissivity.

Source: ASHRAE Handbook Fundamentals 2013, Chapter 15.6

Fenestration

Solar Heat Gain & Visible Transmittance

- Incident Solar Radiation
  - spectral irradiances
  - solar angles
  - optical properties
- Solar Heat Gain Coefficient
  - old method used shading coefficient
- Visible Transmittance
- Total Solar Gain
  - beam + diffuse
- Shading Devices
  - angle dependency (profile angle)

Solar Spectrum

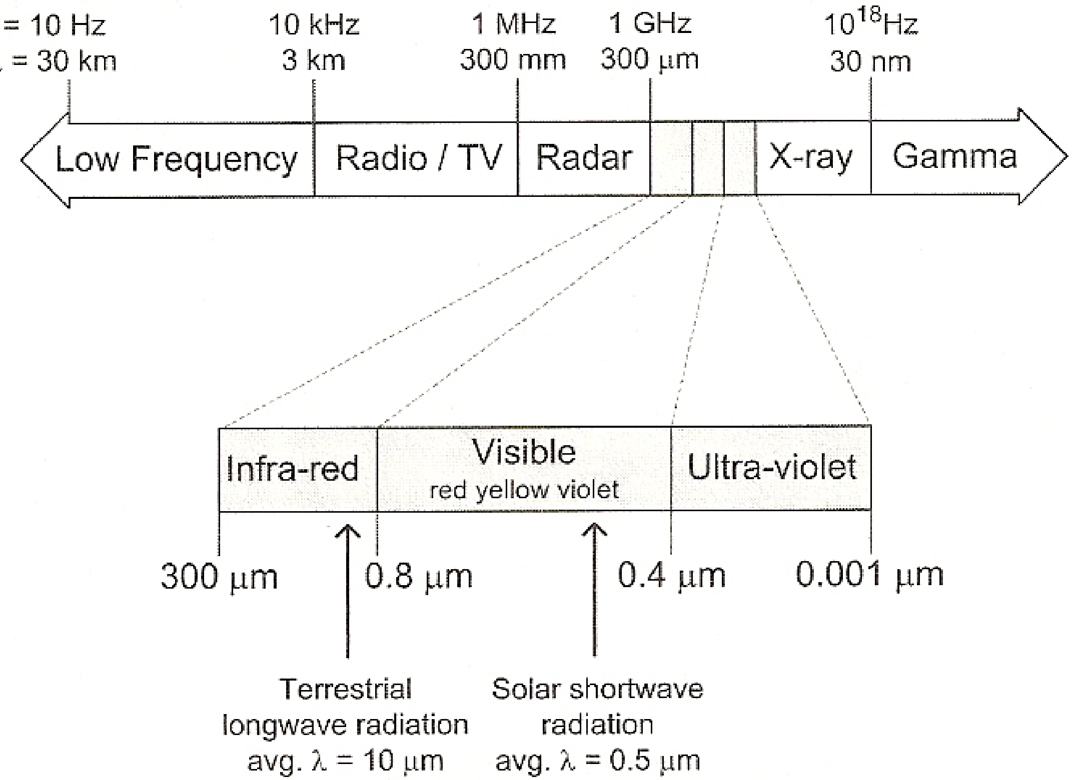
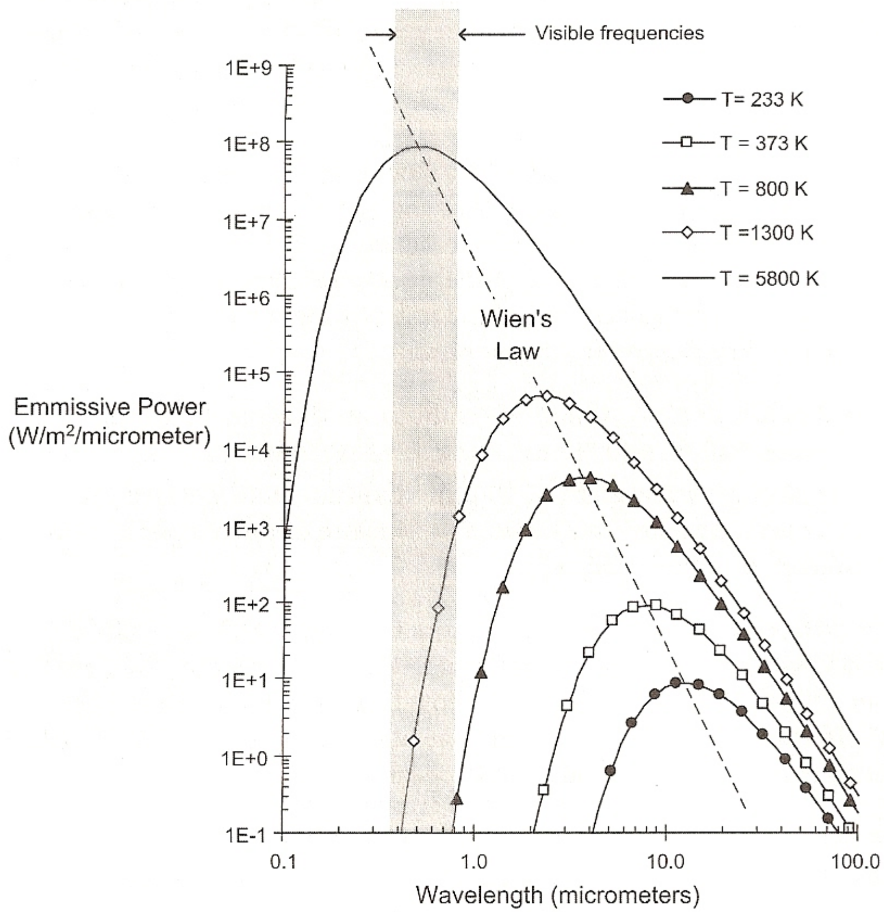


Figure 4.3: Wavelength and frequency ranges for common types of electromagnetic radiation

Source: Straube & Burnett, Building Science for Building Enclosures, Chapter 4

Spectral Distribution



Source: Straube & Burnett, Building Science for Building Enclosures, Chapter 4

Figure 4.4: Plank's spectral distribution of thermal radiation from a black body

Key Wavelengths

Table 4.1: Wavelength versus color

Color	Wavelength range (μm)
IR-C "Far Infra-Red"	3.00 - 1000
IR-B	1.40 - 3.00
IR-A "Near Infra- Red"	0.780 - 1.49
Red	0.610 - 0.830
Orange	0.591 - 0.610
Yellow	0.570 - 0.591
Green	0.500 - 0.570
Blue, Indigo	0.450 - 0.500
Violet	0.360 - 0.450
UV-A	0.315 - 0.400
UV-B	0.280 - 0.315
UV-C	0.100 - 0.280

Source: Straube & Burnett, Building Science for Building Enclosures, Chapter 4

Solar Gain on Windows

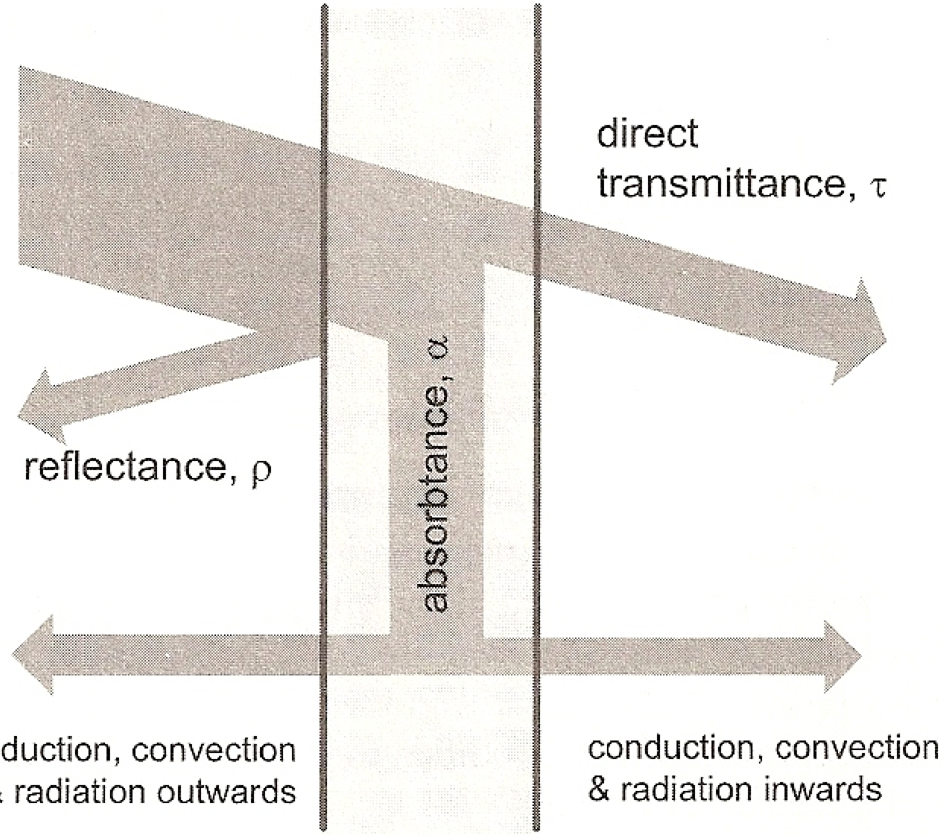


Figure 4.5: Reflectance, transmittance, and absorptance for glass

Source: Straube & Burnett, Building Science for Building Enclosures, Chapter 4

Transmittance vs. Reflectance

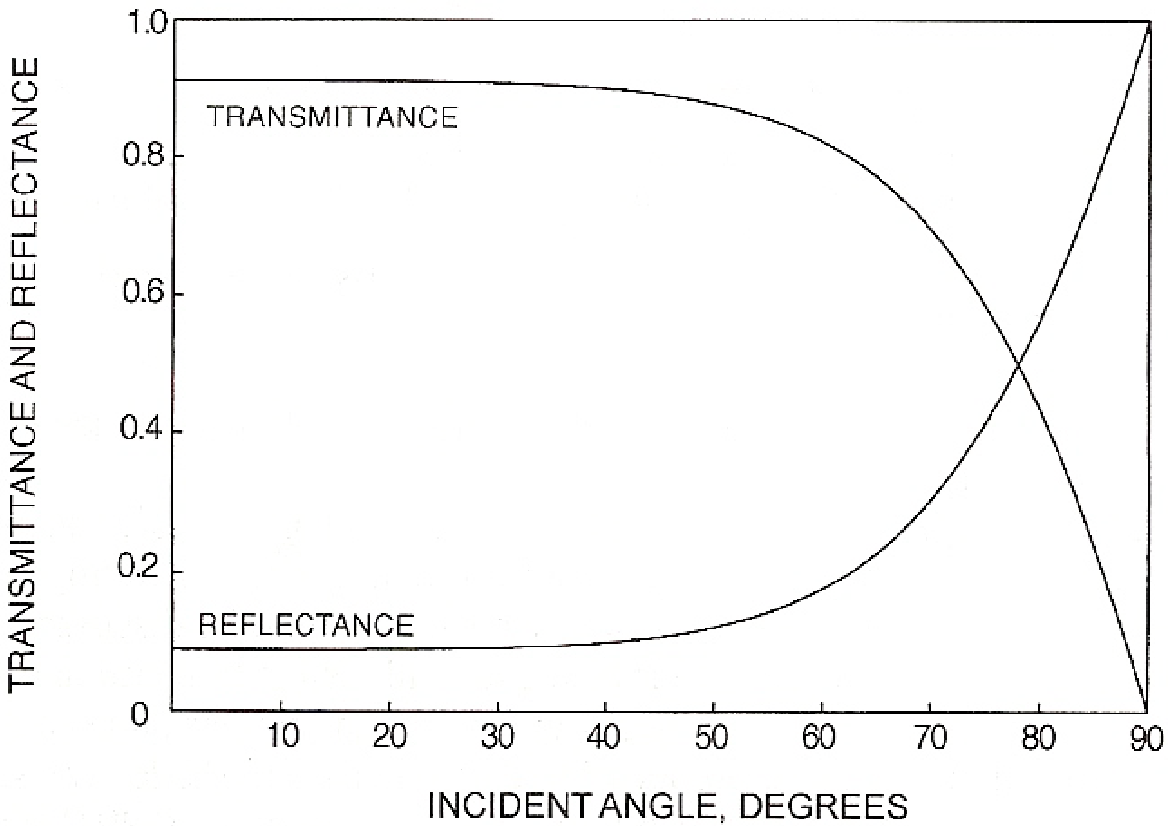


Fig. 7 Transmittance and Reflectance of Glass Plate
(Refractive index $n = 1.55$, thickness $t = 1/8$ in., absorptivity $\alpha = 0.0003$ in.)

Source: ASHRAE Handbook Fundamentals 2013, Chapter 15.14

Incident Angle

2009 ASHRAE Handbook—Fundamentals

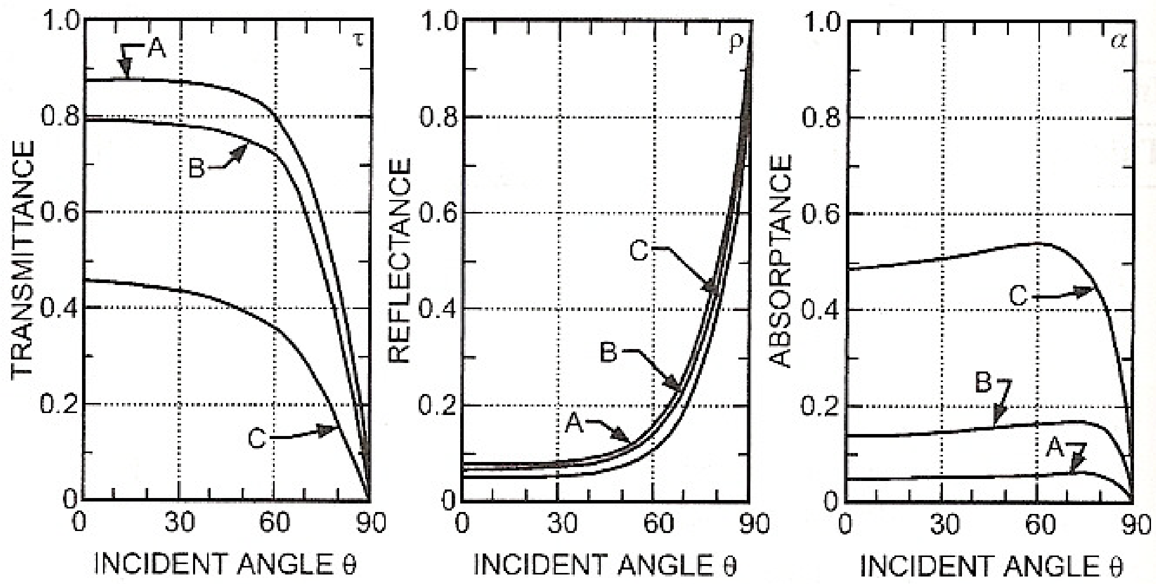


Fig. 8 Variations with Incident Angle of Solar-Optical Properties for (A) Double-Strength Sheet Glass, (B) Clear Plate Glass, and (C) Heat-Absorbing Plate Glass

Source: ASHRAE Handbook Fundamentals 2013, Chapter 15.14

Spectrally Selective Glass

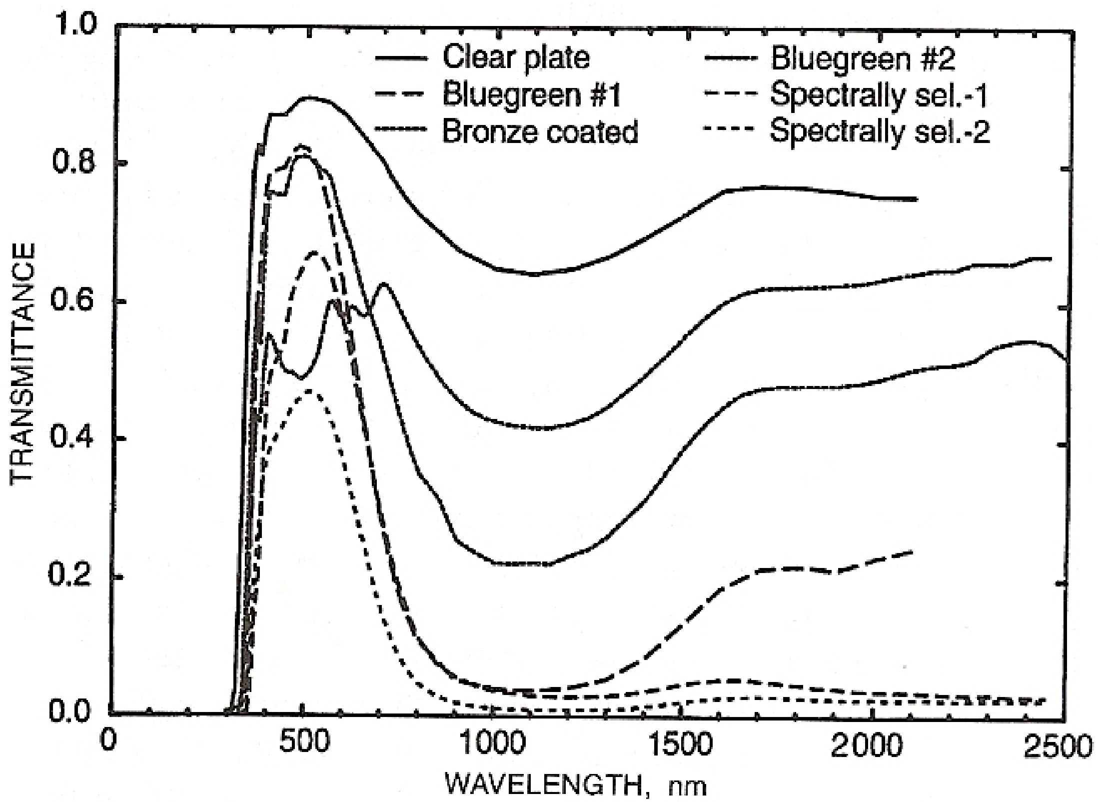


Fig. 9 Spectral Transmittances of Commercially Available Glazings
(McCluney 1993)

Source: ASHRAE Handbook Fundamentals 2013, Chapter 15.14

Wavelength Responses

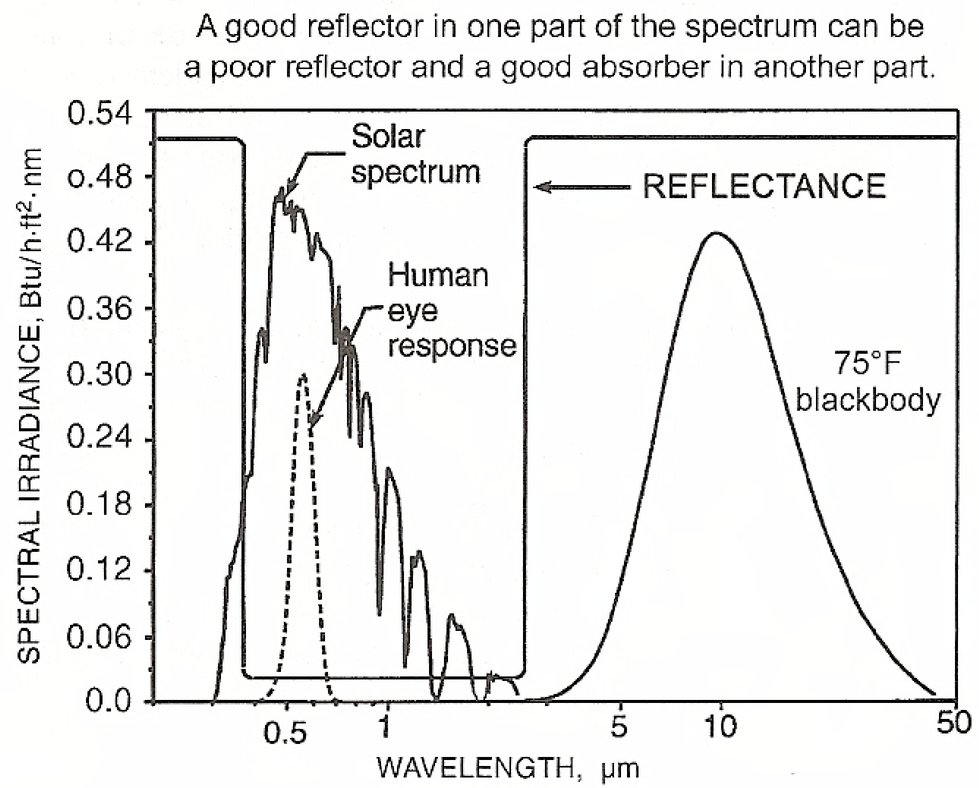


Fig. 11 Solar Spectrum, Human Eye Response Spectrum, Scaled Blackbody Radiation Spectrum, and Idealized Glazing Reflectance Spectrum

Source: ASHRAE Handbook Fundamentals 2013, Chapter 15.16

Idealized Glass Transmittance

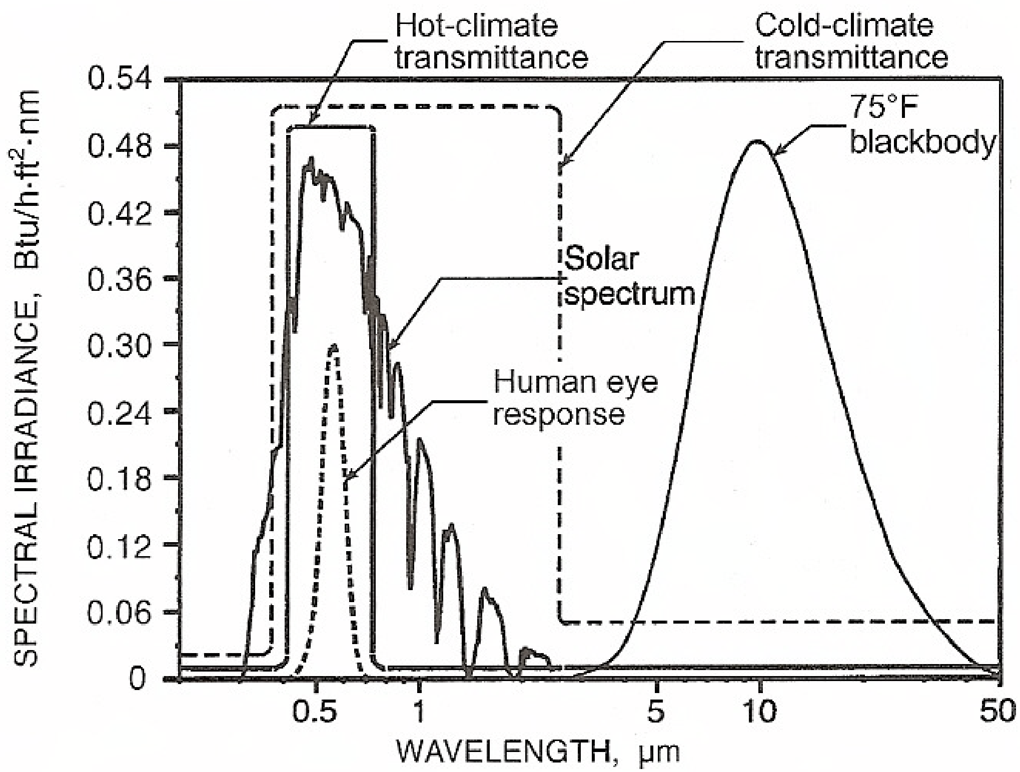


Fig. 12 Demonstration of Two Spectrally Selective Glazing Concepts, Showing Ideal Spectral Transmittances for Glazings Intended for Hot and Cold Climates

Source: ASHRAE Handbook Fundamentals 2013, Chapter 15.16

Solar Radiation Heat Gain

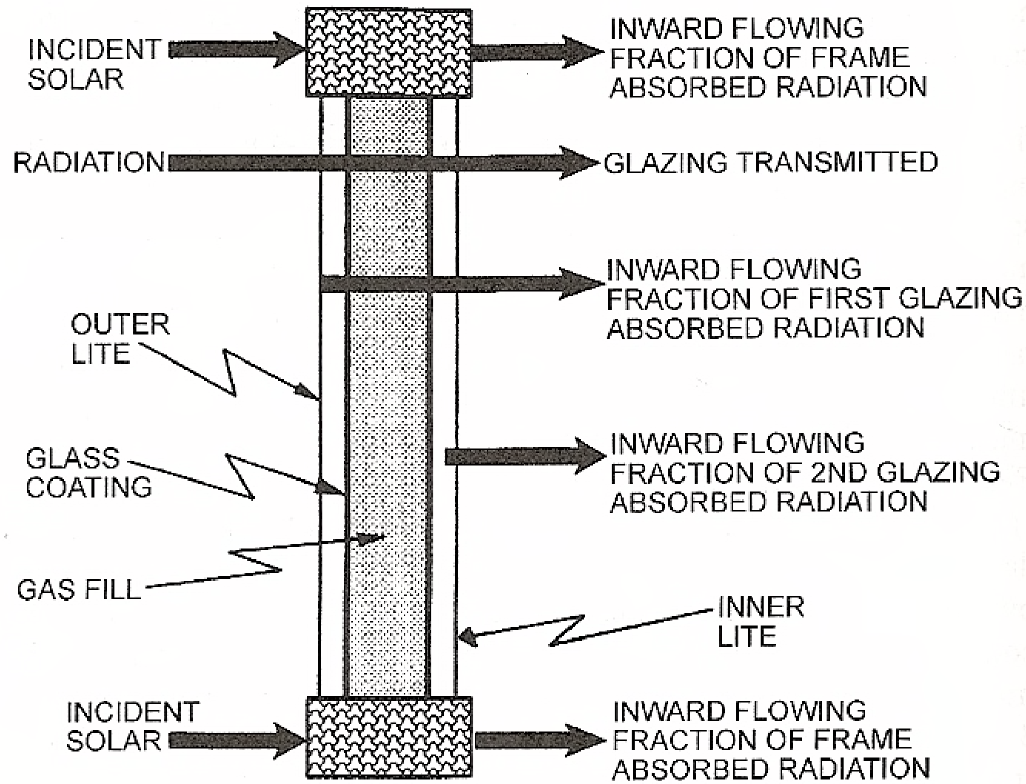


Fig. 13 Components of Solar Radiant Heat Gain with Double-Pane Window, Including Both Frame and Glazing Contributions

Source: ASHRAE Handbook Fundamentals 2013, Chapter 15.18

Solar Radiation Heat Gain

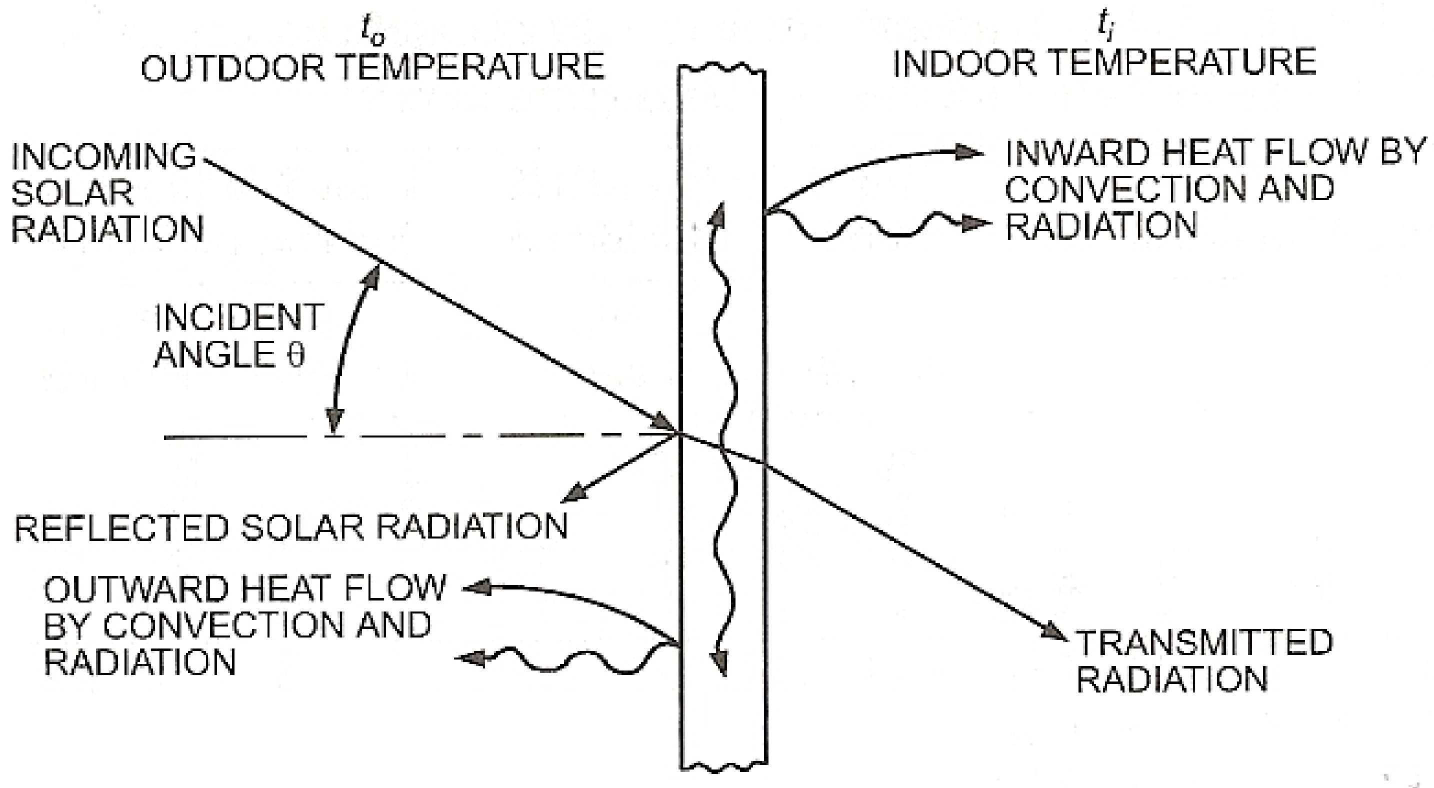
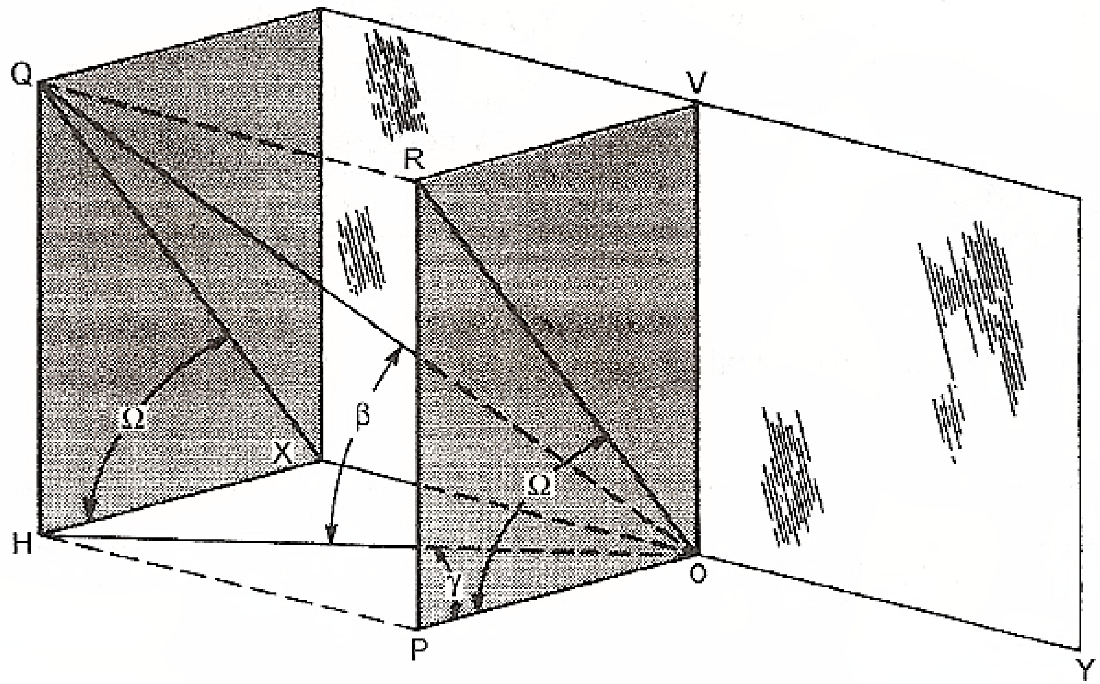


Fig. 14 Instantaneous Heat Balance for Sunlit Glazing Material

Source: ASHRAE Handbook Fundamentals 2013, Chapter 15.28

Sun Angles & Shading Devices



PROFILE ANGLE Ω = ∠ ROP or ∠ QXH
SOLAR ALTITUDE β = ∠ QOH
SURFACE SOLAR AZIMUTH γ = ∠ HOP
TAN Ω = TAN β/COS γ

Fig. 15 Profile Angle for South-Facing Horizontal Projections

Source: ASHRAE Handbook Fundamentals 2013, Chapter 15.29

Sun Angles & Shading Devices

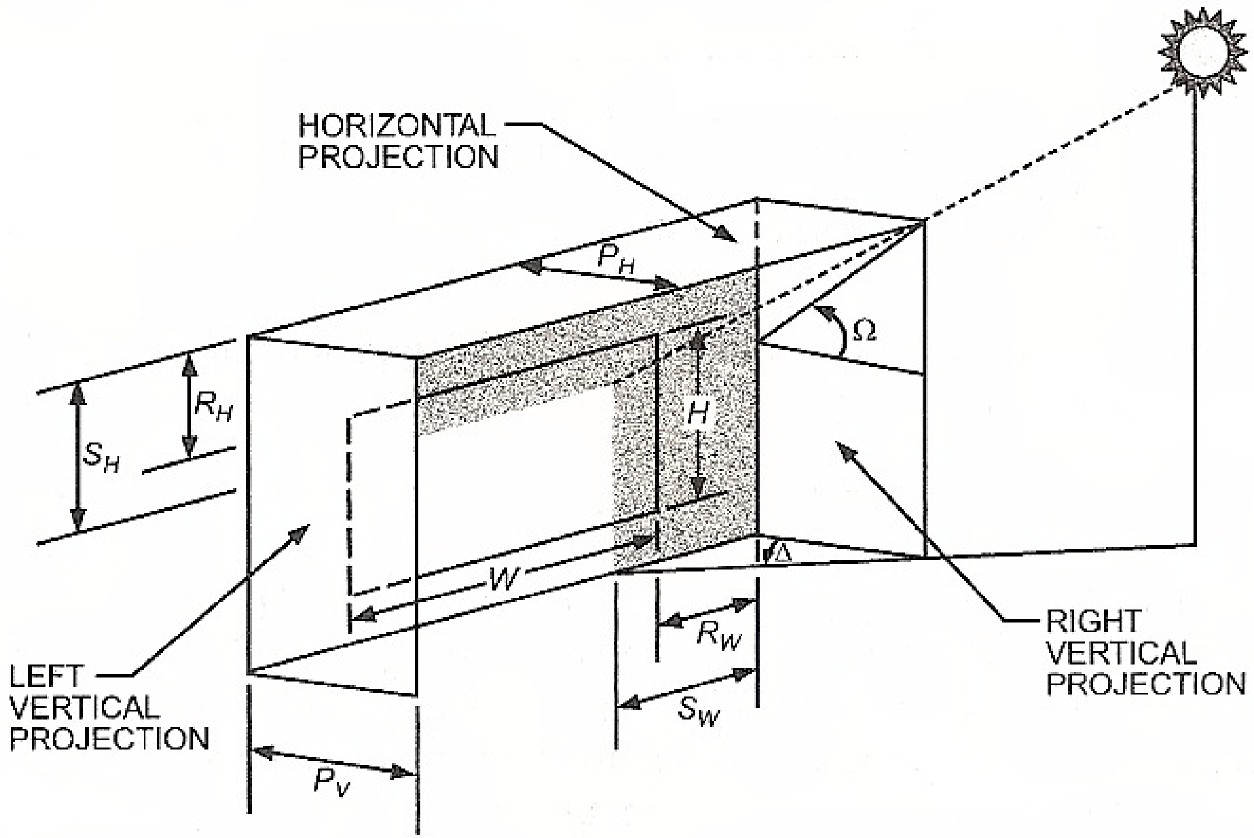


Fig. 16 Vertical and Horizontal Projections and Related Profile Angles for Vertical Surface Containing Fenestration

Source: ASHRAE Handbook Fundamentals 2013, Chapter 15.30

Fenestration

Air Leakage

- Not as significant as one might expect

- For window units, it is usually given in
  - cfm per linear foot of crack
  - cfm per unit area

- Installation leakage can be far greater than unit leakage

Fenestration

Daylighting

- Important, but beyond our scope

- From an energy perspective
  - Useful in residential, but very difficult to quantify
  - Very important in commercial, because daylight can produce a similar amount of light with less heat energy
    - but becoming less so with CFL & LED technologies

- But this issue is bigger than energy,
  - Some evidence of productivity, learning, and health benefits

Visible Transmittance

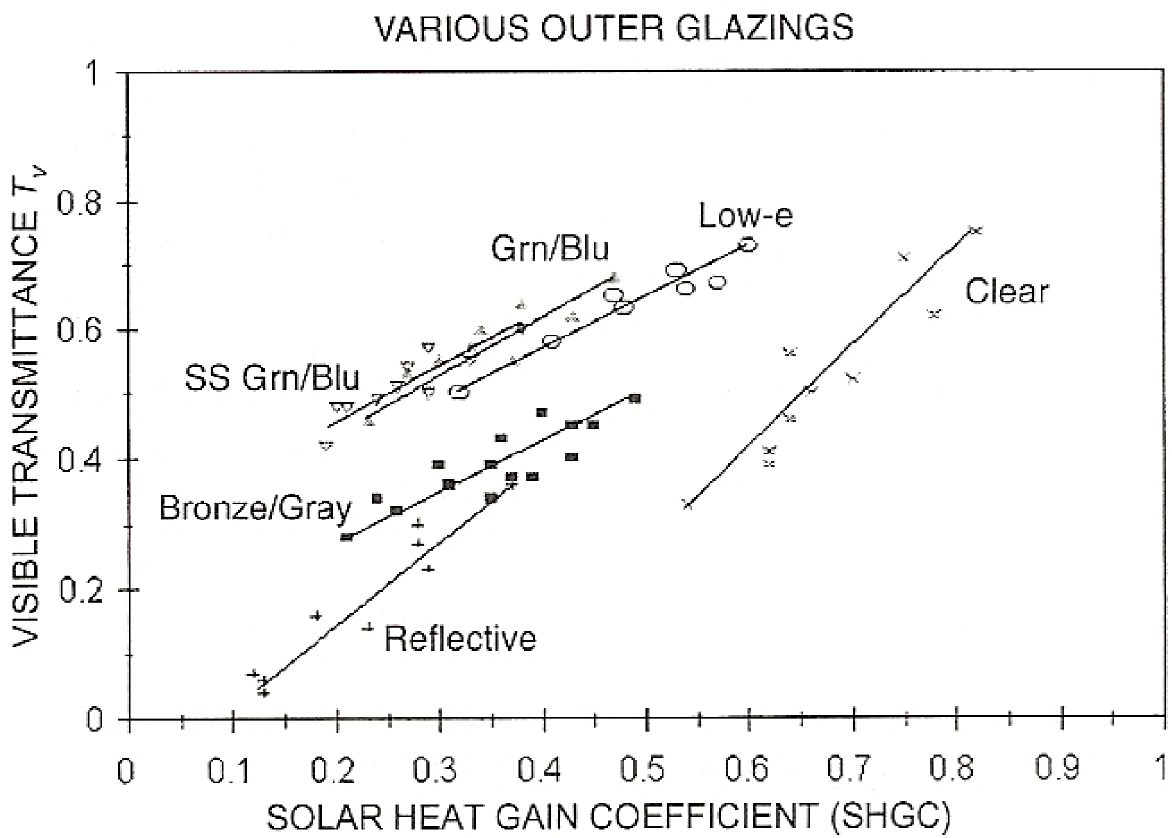


Fig. 24 Visible Transmittance Versus SHGC for Several Glazings with Different Spectral Selectivities

Source: ASHRAE Handbook Fundamentals 2013, Chapter 15.52

Fenestration

Condensation

- Temperature distribution for a typical window
- Glass surface temperatures
- Condensation index, condensation resistance factor, and temperature index

Vertical Temperature Distribution

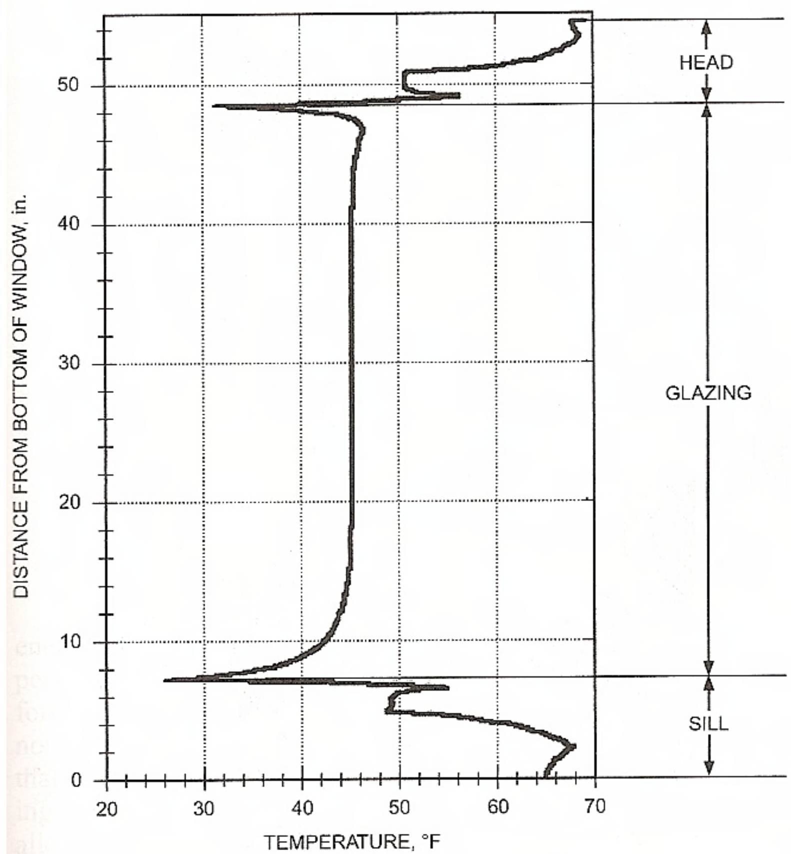


Fig. 26 Temperature Distribution on Indoor Surfaces of Glazing Unit

Source: ASHRAE Handbook Fundamentals 2013, Chapter 15.54

Indoor Surface Temperatures

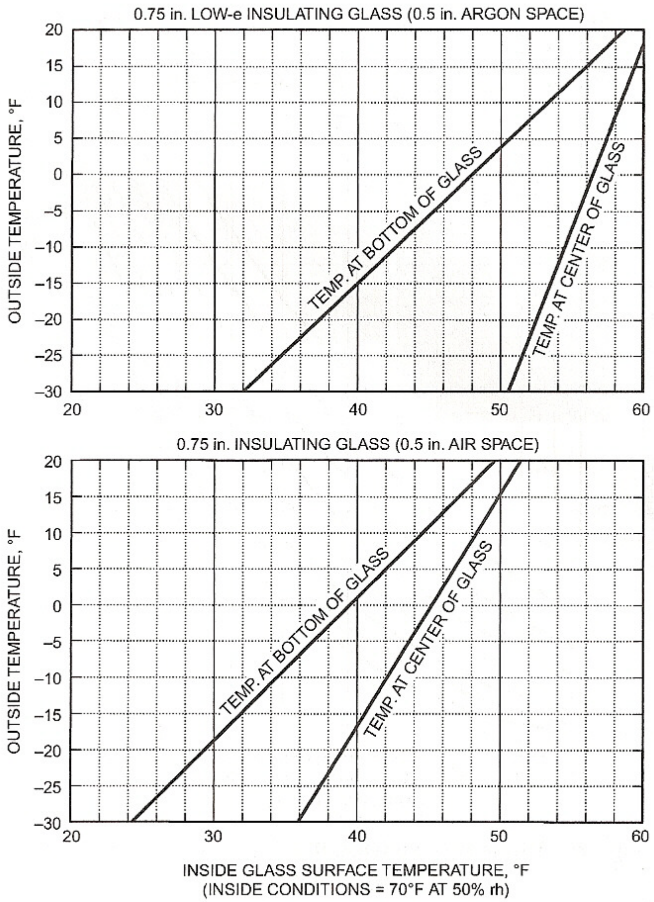


Fig. 27 **Minimum Indoor Surface Temperatures Before Condensation Occurs**

Source: ASHRAE Handbook Fundamentals 2013, Chapter 15.55

Condensation Resistance

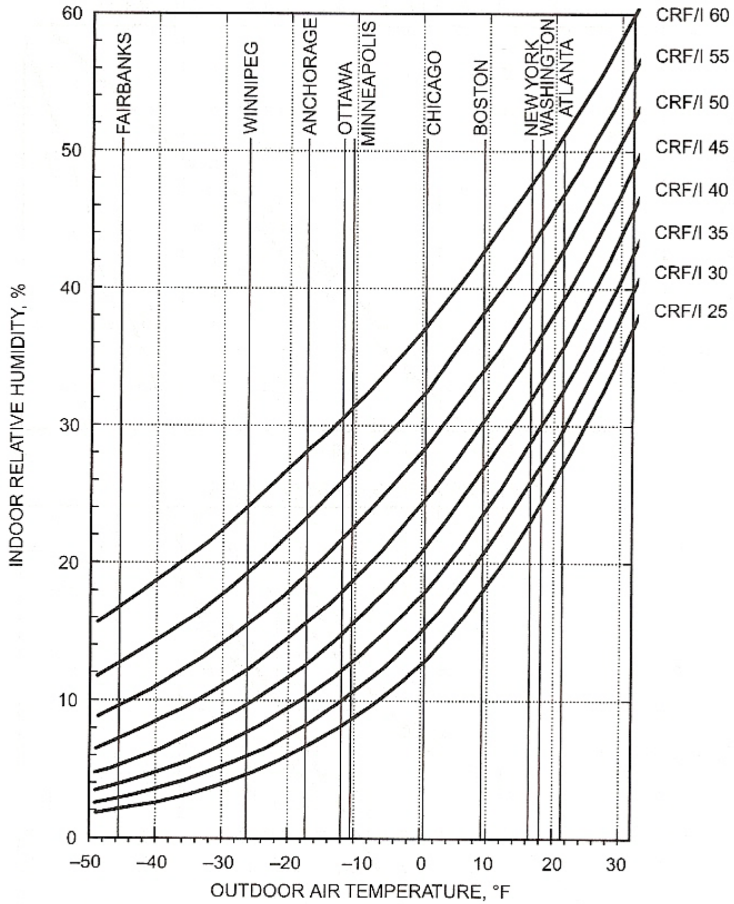


Fig. 28 Minimum Condensation Resistance Requirements (t_h = 68°F)

Source: ASHRAE Handbook Fundamentals 2013, Chapter 15.55

Window Condensation

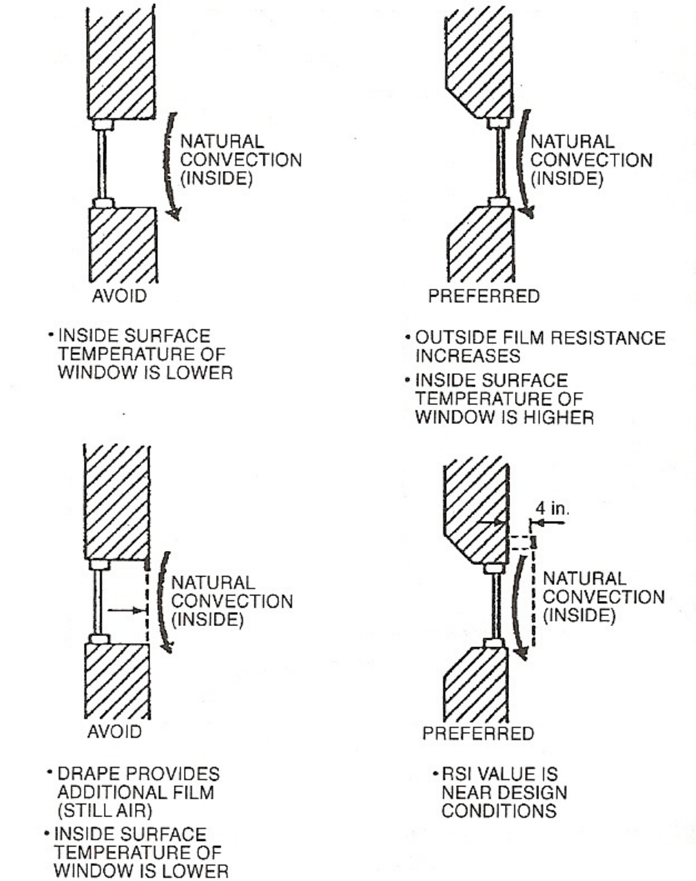


Fig. 29 Location of Fenestration Product Reveals and Blinds/Drapes and Their Effect on Condensation Resistance

Source: ASHRAE Handbook Fundamentals 2013, Chapter 15.56

Fenestration

Occupant Comfort and Acceptance

- Thermal comfort
  - glass temperature
  - air movement
  - solar gain
- Visual comfort
- Sound reduction
- Safety and security
- Life-cycle costs

Windows & Thermal Comfort

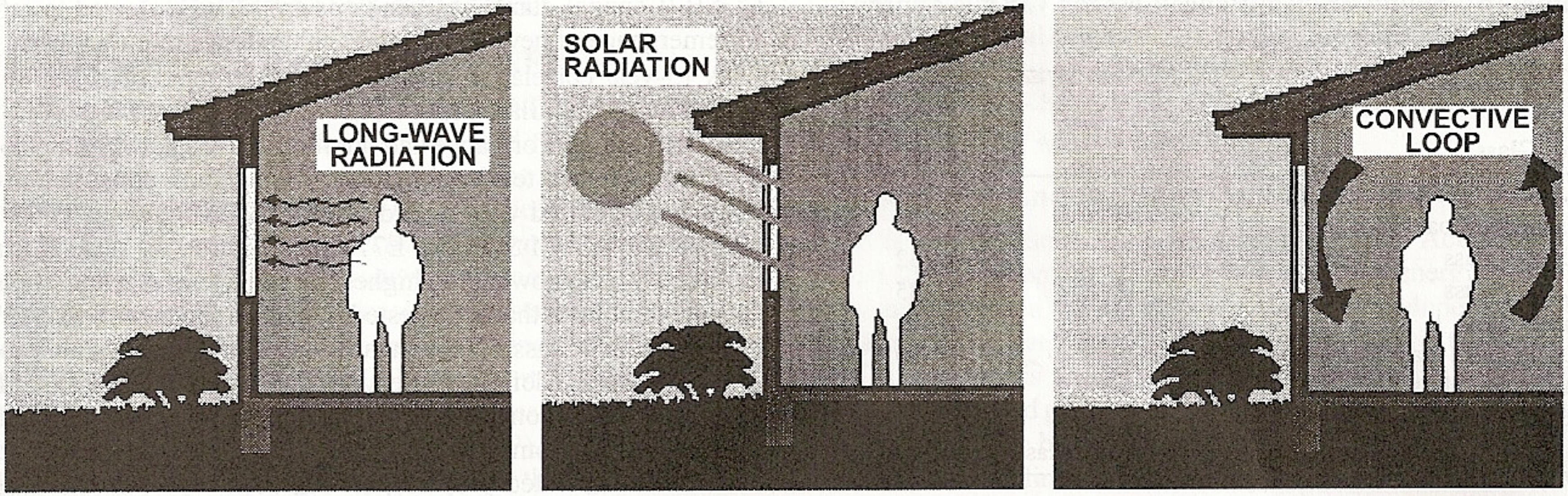


Fig. 30 Fenestration Effects on Thermal Comfort: Long-Wave Radiation, Solar Radiation, Convective Draft

Source: ASHRAE Handbook Fundamentals 2013, Chapter 15.56

Fenestration

- Standards
  - National Fenestration Ratings Council (NFRC)

Absortpance & Emittance

Table 4.5: Absorptance and emittance of common building materials

Material	Solar absorptance (α)	Thermal emittance (ε)
Most common materials	Varies with color and texture	0.90
Red brick	0.60 – 0.80	0.90
Yellow or buff brick	0.50 – 0.70	0.90
White or cream stucco or brick	0.30 – 0.45	0.90
Black, non-metallic surfaces	0.85 – 0.95	0.90 – 0.98
Bright aluminum paint	0.20 – 0.30	0.30 – 0.40
Polished aluminum (foil)	0.10 – 0.30	0.03 – 0.04
Spectrally selective surfaces	>0.85	< 0.12
Window glass	0.04 – 0.40	0.90 – 0.94
Ice	0.03 – 0.15	0.95
Snow – fresh	0.20 – 0.30	0.90
Zinc galvanized sheet	New 0.2, oxidized 0.65	0.20 – 0.30
Green anodized aluminum	0.66	0.88
Machine-rolled stainless steel	0.40	0.11
Uncolored concrete	0.65 – 0.68	0.90
Water	0.84 – 0.93	0.90
Green grass	0.74	0.90

Source: Straube and Burnett, Building Science for Building Enclosures, Chapter 4

In Summary

Questions and Discussion

Next Class

- Building Loads
  - Intro to Loads
  - Heating Load Calculations

- HF: Chapter 17; Chapter 18 (review only)
- HPE: Appendix A (supplemental)