Table 10 Visible Transmittance (T_v), Solar Heat Gain Coefficient (SHGC), Solar Transmittance (T), Front Reflectance (R^f), Back Reflectance (R^b), and Layer Absorptance ($\mathcal{A}_n^f$) for Glazing and Window Systems

ASHRAE Handbook Fundamentals Ch.15, 2017

					Center-of-Glazing Properties							Total Window SHGC at Normal Incidence				Total Window T_v at Normal Incidence			
	Glazing System				Incidence Angles							Aluminum		Other Frames		Aluminum		Other Frames	
ID	Glass Thick., mm		Center Glazing T_v		Normal 0.00	40.00	50.00	60.00	70.00	80.00	Hemis., Diffuse	Operable	Fixed	Operable	Fixed	Operable	Fixed	Operable	Fixed
Uncoated Single Glazing																			
1a	3	CLR	0.90	SHGC	0.86	0.84	0.82	0.78	0.67	0.42	0.78	0.78	0.79	0.70	0.76	0.80	0.81	0.72	0.79
				T	0.83	0.82	0.80	0.75	0.64	0.39	0.75								
				R^f	0.08	0.08	0.10	0.14	0.25	0.51	0.14								
				R^b	0.08	0.08	0.10	0.14	0.25	0.51	0.14								
				$\mathcal{A}_1^f$	0.09	0.10	0.10	0.11	0.11	0.11	0.10								
1b	6	CLR	0.88	SHGC	0.81	0.80	0.78	0.73	0.62	0.39	0.73	0.74	0.74	0.66	0.72	0.78	0.79	0.70	0.77
				T	0.77	0.75	0.73	0.68	0.58	0.35	0.69								
				R^f	0.07	0.08	0.09	0.13	0.24	0.48	0.13								
				R^b	0.07	0.08	0.09	0.13	0.24	0.48	0.13								
				$\mathcal{A}_1^f$	0.16	0.17	0.18	0.19	0.19	0.17	0.17								
1c	3	BRZ	0.68	SHGC	0.73	0.71	0.68	0.64	0.55	0.34	0.65	0.67	0.67	0.59	0.65	0.61	0.61	0.54	0.60
				T	0.65	0.62	0.59	0.55	0.46	0.27	0.56								
				R^f	0.06	0.07	0.08	0.12	0.22	0.45	0.12								
				R^b	0.06	0.07	0.08	0.12	0.22	0.45	0.12								
				$\mathcal{A}_1^f$	0.29	0.31	0.32	0.33	0.33	0.29	0.31								
1d	6	BRZ	0.54	SHGC	0.62	0.59	0.57	0.53	0.45	0.29	0.54	0.57	0.57	0.50	0.55	0.48	0.49	0.43	0.48
				T	0.49	0.45	0.43	0.39	0.32	0.18	0.41								
				R^f	0.05	0.06	0.07	0.11	0.19	0.42	0.10								
				R^b	0.05	0.68	0.66	0.62	0.53	0.33	0.10								
				$\mathcal{A}_1^f$	0.46	0.49	0.50	0.51	0.49	0.41	0.48								
1e	3	GRN	0.82	SHGC	0.70	0.68	0.66	0.62	0.53	0.33	0.63	0.64	0.64	0.57	0.62	0.73	0.74	0.66	0.72
				T	0.61	0.58	0.56	0.52	0.43	0.25	0.53								
				R^f	0.06	0.07	0.08	0.12	0.21	0.45	0.11								
				R^b	0.06	0.07	0.08	0.12	0.21	0.45	0.11								
				$\mathcal{A}_1^f$	0.33	0.35	0.36	0.37	0.36	0.31	0.35								
1f	6	GRN	0.76	SHGC	0.60	0.58	0.56	0.52	0.45	0.29	0.54	0.55	0.55	0.49	0.53	0.68	0.68	0.61	0.67
				T	0.47	0.44	0.42	0.38	0.32	0.18	0.40								
				R^f	0.05	0.06	0.07	0.11	0.20	0.42	0.10								

Table 10 Visible Transmittance T_v, Solar Heat Gain Coefficient (SHGC), Solar Transmittance T, Front Reflectance R^f, Back Reflectance R^b, and Layer Absorptance $\mathcal{A}^f_n$ for Glazing and Window Systems (*Continued*)

	Glazing System				Center-of-Glazing Properties: Incidence Angles							Total Window SHGC at Normal Incidence: Aluminum		Total Window SHGC at Normal Incidence: Other Frames		Total Window T_v at Normal Incidence: Aluminum		Total Window T_v at Normal Incidence: Other Frames	
ID	Glass Thick., mm		Center Glazing T_v		Normal 0.00	40.00	50.00	60.00	70.00	80.00	Hemis., Diffuse	Operable	Fixed	Operable	Fixed	Operable	Fixed	Operable	Fixed
21g	3	GRN LE	0.68	SHGC	0.46	0.44	0.42	0.38	0.30	0.16	0.40	0.42	0.43	0.38	0.41	0.61	0.61	0.54	0.60
				T	0.36	0.32	0.30	0.26	0.18	0.08	0.28								
				R^f	0.17	0.16	0.17	0.20	0.29	0.48	0.20								
				R^b	0.23	0.23	0.25	0.29	0.37	0.57	0.27								
				$\mathcal{A}^f_1$	0.38	0.41	0.42	0.43	0.43	0.38	0.40								
				$\mathcal{A}^f_2$	0.10	0.11	0.11	0.11	0.10	0.06	0.10								
21h	6	GRN LE	0.61	SHGC	0.36	0.33	0.31	0.28	0.22	0.12	0.30	0.34	0.34	0.30	0.32	0.54	0.55	0.49	0.54
				T	0.24	0.21	0.19	0.16	0.11	0.05	0.18								
				R^f	0.11	0.10	0.11	0.14	0.22	0.43	0.14								
				R^b	0.19	0.20	0.22	0.25	0.34	0.55	0.24								
				$\mathcal{A}^f_1$	0.56	0.59	0.61	0.61	0.59	0.48	0.58								
				$\mathcal{A}^f_2$	0.09	0.09	0.09	0.08	0.08	0.04	0.08								
21i	3	GRY LE	0.52	SHGC	0.46	0.44	0.42	0.38	0.30	0.16	0.39	0.42	0.43	0.38	0.41	0.46	0.47	0.42	0.46
				T	0.35	0.32	0.30	0.25	0.18	0.08	0.28								
				R^f	0.16	0.16	0.17	0.20	0.28	0.48	0.20								
				R^b	0.23	0.23	0.25	0.29	0.37	0.57	0.27								
				$\mathcal{A}^f_1$	0.39	0.42	0.43	0.44	0.44	0.38	0.41								
				$\mathcal{A}^f_2$	0.10	0.11	0.11	0.11	0.10	0.06	0.10								
21j	6	GRY LE	0.37	SHGC	0.34	0.32	0.30	0.27	0.21	0.12	0.28	0.32	0.32	0.28	0.30	0.33	0.33	0.30	0.33
				T	0.23	0.20	0.18	0.15	0.11	0.04	0.17								
				R^f	0.11	0.11	0.12	0.15	0.23	0.44	0.15								
				R^b	0.20	0.20	0.22	0.25	0.34	0.55	0.24								
				$\mathcal{A}^f_1$	0.58	0.60	0.61	0.61	0.59	0.48	0.59								
				$\mathcal{A}^f_2$	0.08	0.08	0.08	0.08	0.07	0.04	0.08								
21k	6	BLUGRN LE	0.62	SHGC	0.39	0.37	0.34	0.31	0.24	0.13	0.33	0.36	0.36	0.32	0.35	0.55	0.56	0.50	0.55
				T	0.28	0.25	0.23	0.20	0.14	0.06	0.22								
				R^f	0.12	0.12	0.13	0.16	0.24	0.44	0.16								
				R^b	0.23	0.23	0.25	0.28	0.37	0.57	0.27								
				$\mathcal{A}^f_1$	0.51	0.54	0.56	0.56	0.55	0.46	0.53								
				$\mathcal{A}^f_2$	0.08	0.09	0.08	0.08	0.08	0.05	0.08								
21l	6	HI-P GRN W/LE CLR	0.57	SHGC	0.31	0.30	0.29	0.26	0.21	0.12	0.27	0.29	0.29	0.26	0.28	0.51	0.51	0.46	0.50
				T	0.22	0.21	0.19	0.17	0.12	0.06	0.18								
				R^f	0.07	0.07	0.09	0.13	0.22	0.46	0.12								
				R^b	0.23	0.23	0.24	0.28	0.37	0.57	0.27								
				$\mathcal{A}^f_1$	0.67	0.68	0.67	0.66	0.62	0.46	0.65								
				$\mathcal{A}^f_2$	0.04	0.05	0.05	0.05	0.04	0.03	0.04								
Low-e Double Glazing, e = 0.05 on surface 2																			
25a	3	LE CLR	0.72	SHGC	0.41	0.40	0.38	0.34	0.27	0.14	0.36	0.38	0.38	0.34	0.36	0.64	0.65	0.58	0.63
				T	0.37	0.35	0.33	0.29	0.22	0.11	0.31								
				R^f	0.35	0.36	0.37	0.40	0.47	0.64	0.39								
				R^b	0.39	0.39	0.40	0.43	0.50	0.66	0.42								
				$\mathcal{A}^f_1$	0.24	0.26	0.26	0.27	0.28	0.23	0.26								
				$\mathcal{A}^f_2$	0.04	0.04	0.04	0.04	0.03	0.03	0.04								
25b	6	LE CLR	0.70	SHGC	0.37	0.36	0.34	0.31	0.24	0.13	0.32	0.34	0.34	0.30	0.33	0.62	0.63	0.56	0.62
				T	0.30	0.28	0.27	0.23	0.17	0.08	0.25								
				R^f	0.30	0.30	0.32	0.35	0.42	0.60	0.34								
				R^b	0.35	0.35	0.35	0.38	0.44	0.60	0.37								
				$\mathcal{A}^f_1$	0.34	0.35	0.35	0.36	0.35	0.28	0.34								
				$\mathcal{A}^f_2$	0.06	0.07	0.07	0.06	0.06	0.04	0.06								

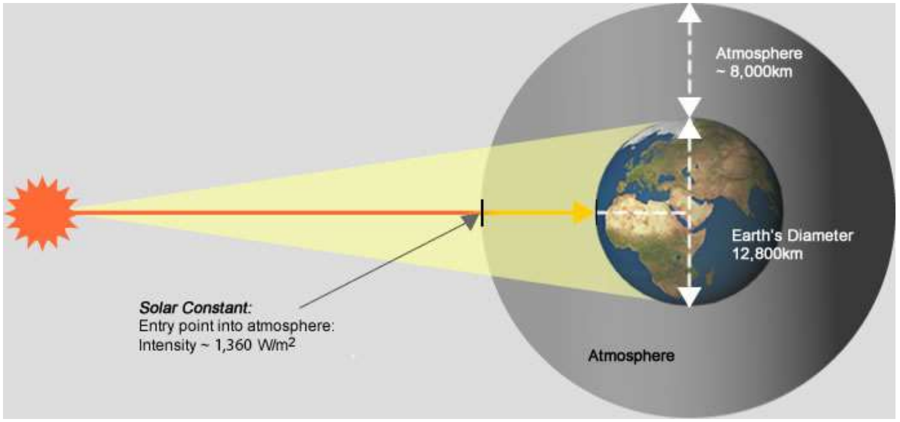
Visible Transmittance (VT)

- VT=the percentage of incident light (only the visible spectrum) as a normal angle of incidence that passes through a particular glazing
  - SHGC deals with the full solar radiation spectrum
  - VT deals only with the visible (light) spectrum.
- The higher VT, the greater daylighting transmission
- VT is influenced by the color of the glass as well as coatings.
- Spectrally selective glazings and selective coatings: to reduce SHGC with little reduction in VT
- Light-to-Solar Gain ratio (LSG) = VT/SHGC
  - The greater the LSG, the more suitable for daylighting in hot climates or in cooling-dominated buildings
- Table E.15

Solar constant of 1,367 W/m^2

	Ultraviolet	Radiation in the visible portion of the spectrum	infrared
Wavelength range (nm)	0-380	380-780	780-∞
Fraction in range (%)	6.4%	48.0%	45.6%
Energy in range (W/m^2)	87	656	623

Solar constant: the amount of the sun's radiation (heat energy) reaching the Earth's outer atmosphere is relatively stable and is called the solar constant.



http://www.greenrhinoenergy.com/solar/radiation/extraterrestrial.php

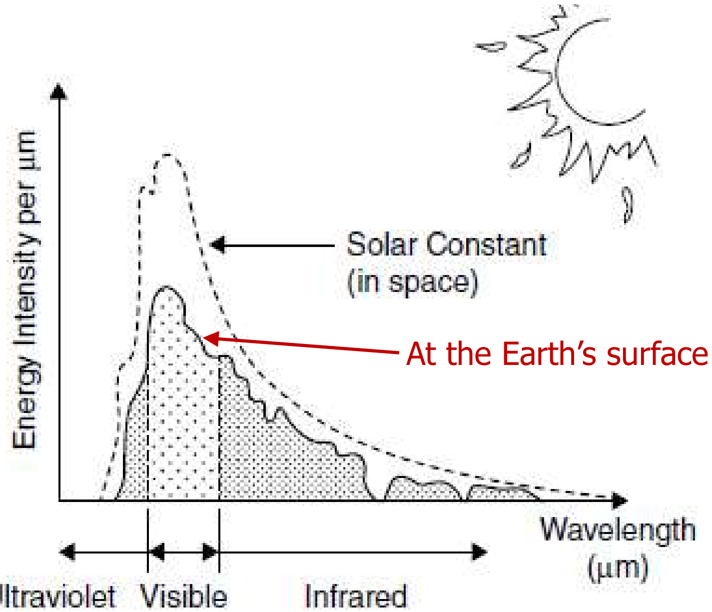
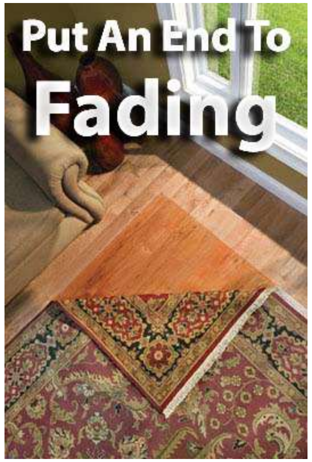


Fig. 6.1 *At the Earth's surface the solar radiation spectrum consists of ultraviolet radiation, visible radiation (light), and infrared radiation. (Drawing by Erik Winter; © 2004 Alison Kwok; all rights reserved.)*

Duffie, J.A. and Beckman, W.A. (1991), Solar engineering of thermal process, John Wiley & Sons, Inc.

Low-emittance (low-ε) coatings

- low- ε coating
  - blocks a great deal of the radiant heat transfer between the glazing panes, reducing the overall heat flow through the window, thus improving the U-factor.
  - An important added benefit of these low-e films is their reduction of UV transmission, thus reducing fading of objects and surface finishes in rooms.



- Two types of low-e coats:
  - Hard-coat:
    - Sprayed on the glass surface
    - Higher SHGC, higher U-value.
    - durable, less expensive, but less thermally effective.
  - Soft-coat:
    - So fragile and thus needs extreme care when handling it.
    - Higher VT, lower U-value, 70% less UV transmission
    - more expensive, better thermal performance, but subject to degradation by oxidation.

https://www.abbywindows.com/uncategorized/low-e-coatings-soft-vs-hard/
https://philadelphia.cbslocal.com/2013/07/17/the-best-vinyl-windows-use-heat-mirror-technology/

Low-emittance (low-ε) coatings

- Three types:
  - low-ε glazing for heating dominated climates (buildings): low-e coating on the outside surface of the inside pane.
    - It traps outgoing infrared radiation
    - For passive solar heating applications: low U factor, high SHGC
  - low-ε glazing for cooling dominated climates (buildings): low-e coating on the inside surface of the outside pane.
    - When the sun is an enemy. It rejects more of the solar gain.
    - Low U factor, low SHGC, low VT
  - Selective low-ε glazing: selective low-e coating on the inside surface of the outside pane.
    - It blocks incoming infrared radiation with a relatively high VT for daylighting.

Selective transmission films = heat mirror

- Heat flow due to radiation can be greatly reduced by the introduction of a selective transmission (or low-emittance) film.
- As shown in Fig. 9.13, these films admit most of the incoming solar radiation in both the visible and near-infrared (short) wavelengths.
- Warm objects within a room emit far-infrared (long-wave) radiation. This long-wave radiation is reflected back (**like a mirror**) into the room by the selective film.
- These selective films are typically available as separate sheets that can be inserted between sheets of glazing as a window is fabricated. As a separate sheet, a selective film can be also applied to existing windows.
- Products from Southwall Technologies (now Eastman): Heat Mirror 77 to Heat Mirror 22

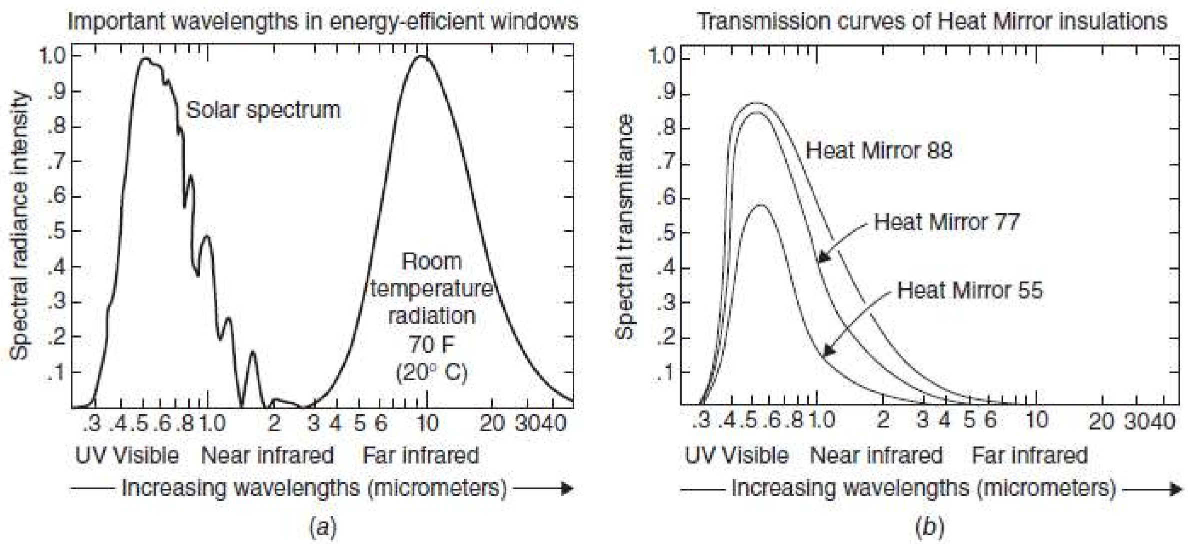
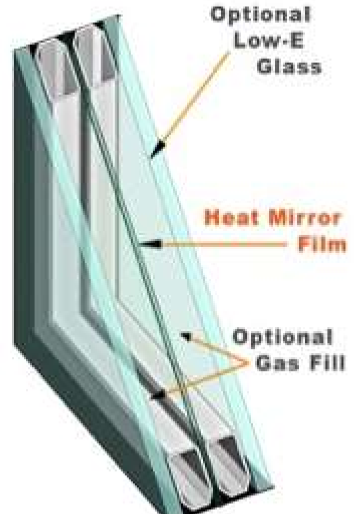


Fig. 9.13 Performance of selective transmitters. (a) Spectral characteristics of solar (short-wavelength) radiation and room-temperature (long-wavelength) radiation. (b) Transmission and reflection performance for several Heat Mirror selective transmitter films. Incoming solar radiation (both visible and near-infrared) is mostly transmitted, whereas heat radiated from room-temperature objects is reflected and thereby kept within heated spaces. (Courtesy of Southwall Corporation.)

Heat Mirror

- Heat Mirror® technology invented by scientists at MIT.
- The films utilize nanoscale coatings of metal to reflect heat back to its source.
- A wide range of glass types and gas fills available that allow consumers and architects to choose the right level of insulation, visible light and solar control for their specific needs.



Insulating glass comparison table
To make sure you get the exact window performance for your project, Heat Mirror® advanced insulating glass provides a wide range of visible light, solar control, and thermal insulation to meet almost any performance requirement.

	Airtight chambers	Insulating performance*		Solar heat gain coefficient	Visible light transmittance, %	UV blocking, %
		R-Value	U-Value			
Standard dual-pane clear IG	1	R2	0.50	0.78	82	42
Standard dual-pane coated IG	1	R4	0.25	0.27	65	95
Standard triple-pane coated IG	2	R5	0.19	0.25	57	97
Heat Mirror® IG	2	R6	0.16	0.24–0.51	57–70	99.5
Heat Mirror® IG	3	R10	0.10	0.23–0.44	51–62	100
Heat Mirror® IG	4	R20**	0.05	0.22–0.38	45–55	100

*Center of glass values calculated using WINDOW 6.3 software and standard NFRC environmental conditions.
**Requires Krypton gas fill

https://www.eastman.com/Brands/HeatMirror/Residential/Pages/How_It_Works.aspx
https://philadelphia.cbslocal.com/2013/07/17/the-best-vinyl-windows-use-heat-mirror-technology/

Inert gas in the air gap

- Two gases: Argon(1/2"), Krypton(1/4")
- These less conductive gases reduces heat transfer by convective currents, producing lower U-factors.
- A very reliable seal is required to preserve this gas fill over the life of the window

Superwindows

- The currently available high-performance glazing options are combined in one product.
  - Ex.: Window 11 in Table E.15 → U=0.85 (W/m^{2}K)

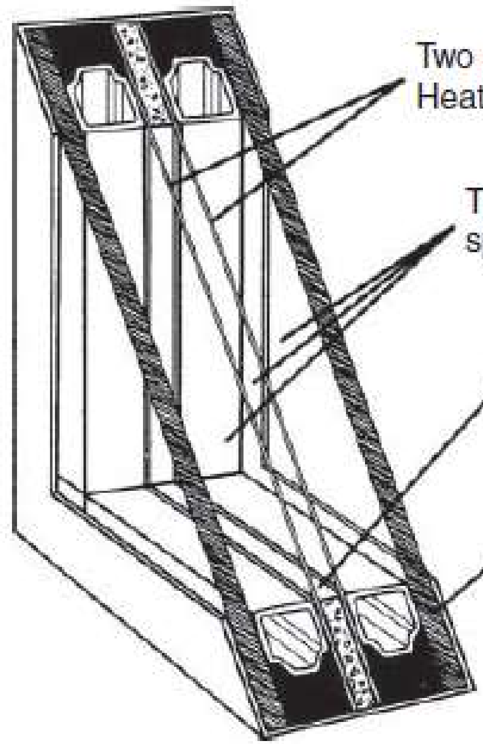
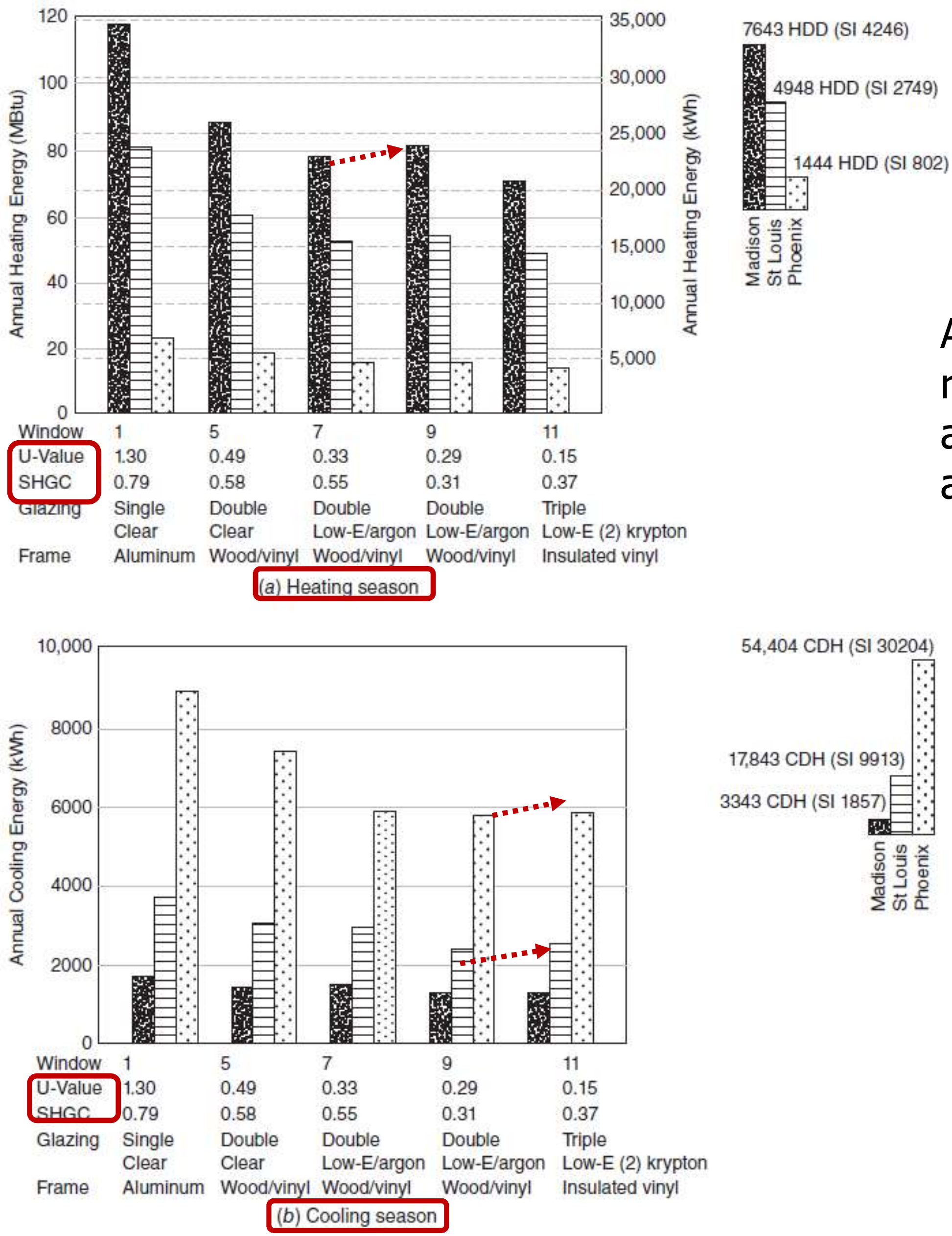


Fig. 9.14 *The Superglass window system (an early superwindow) utilized two Heat Mirror films between two outer panes of glass. Three air spaces are thus created and filled with a nonreactive gas mixture to retard convection. Nonmetallic spacers reduce heat flow at window edges. The resulting window provided a center-of-glass insulating value of R-8.1 (SI: R-1.43). Very low transmission of UV radiation is another characteristic. (Courtesy of Hurd Millwork Company, Medford, WI.)*



A typical 143 m^2 residence with a glazing area of 15% of the floor area

Fig. 9.15 *(a, b) Seasonal energy performance comparison of various windows—assuming a typical 1540-ft² (143-m²) residence with a glazing area of 15% of the floor area, equal glazing area on all four orientations, and no external or internal shading. Window numbers correspond to those in Table E.15. MBtu = million Btu; HDD = heating degree days, base 65°F (18.3°C); CDH = cooling degree hours, base 74°F (23.3°C). U-factors in figure are I-P values; multiply these by 5.678 for SI U-factors. (John Carmody, Stephen Selkowitz, and Lisa Heschong,* Residential Windows: A Guide to New Technologies and Energy Performance. *New York: W. W. Norton & Company. Copyright © 1996 by John Carmody, Stephen Selkowitz, and Lisa Heschong; adapted by permission.)*

Shading

- Internal vs. external: which is advantageous in terms of blocking solar radiation? And, how much?
  - Internal shading is more popular because they are not subject to weathering, dirt accumulation, are easier for users to adjust.
- Fixed vs. adjustable
- Fixed shading devices are very common.
  - March – heating vs. September – cooling
- Adjustable shading
  - Manual, motorized, automatic
- (old) shading coefficient: Tables E.21-E.24 (e-book available at SNU library)
- (new) IAC, BAC (ASHRAE F. 2017, Ch.15) (Interior and between-glass solar attenuation coefficient)

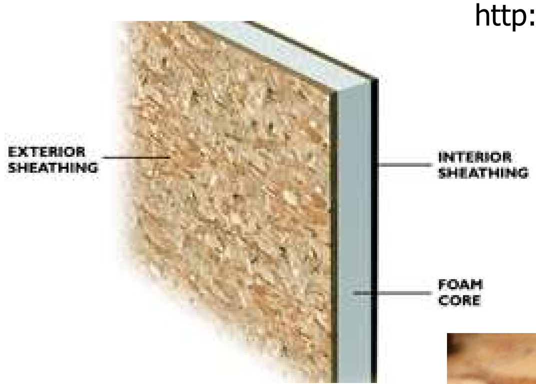
Designed by Ludwig Mies van der Rohe
(built in 1929-1930) in Brno

http://www.tugendhat.eu/

Trends in Envelope Thermal Performance

- Structural systems: SIP (Structural Insulation Panel)
  - SIPs are pre-manufactured panels that consist of two sheets of rigid structural facing bonded to an insulating core that is 4” or more inches thick.
  - Facings are generally OSB (oriented strand board) or plywood, and the core is most commonly polystyrene foam.
  - SIPs offer excellent insulation, accelerated construction, airtight assembly, noise attenuation, and superior structural strength.

http://www.southface.org/



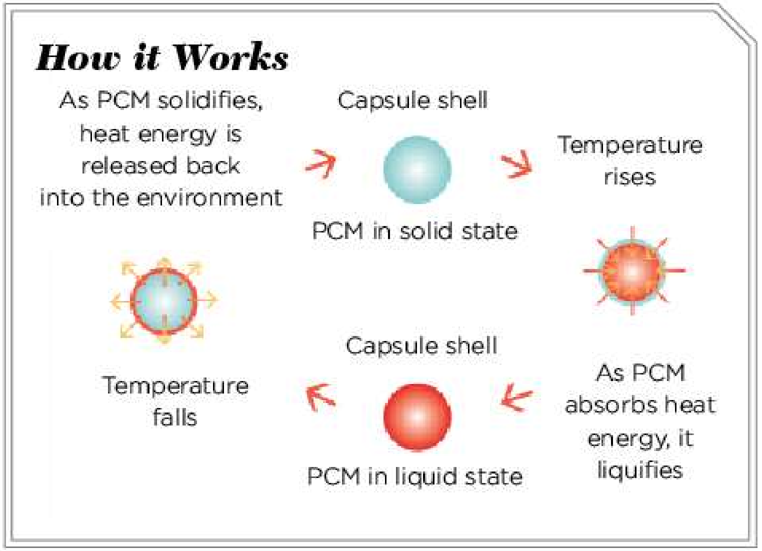
OSB →

http://www.sips.org/

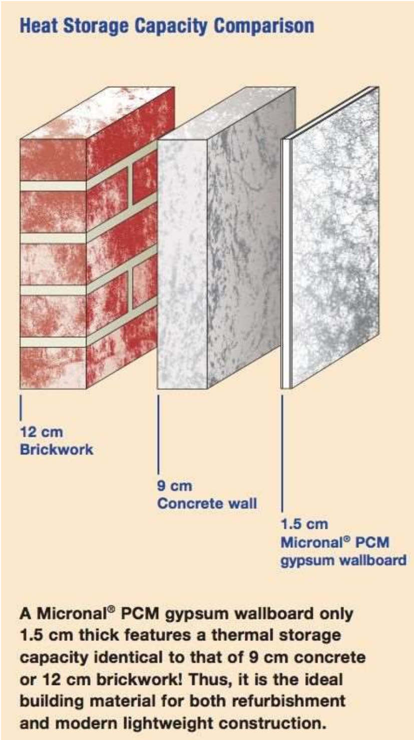
http://www.pbssips.com/

Trends in Envelope Thermal Performance

- Phase-Change Wallboard
  - It can melt and solidify at room temperature.
  - It absorbs heat during the day, and releases it at night. It can store and release heat from solar radiation and/or internal load.
  - concept: increase the heat capacity considerably with very little increase in weight.



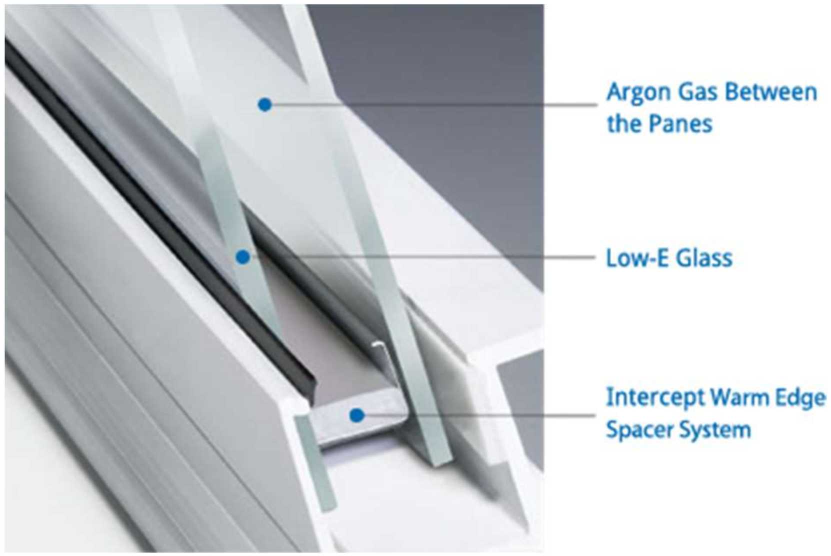
https://www.homebuilding.co.uk/phase-change-materials/



https://www.treehugger.com/green-architecture/why-is-phase-changing-drywall-in-the-news-instead-of-in-the-home-depot.html

Trends in Envelope Thermal Performance

- Windows
  - Developments in: coatings (tinted, reflective, selective, photochromic [darkened under specific types of light, most ultraviolet (UV) radiation], low-e), low-conductivity gas, spacers, frames, operable blinds, shading devices
  - Smart windows: on-demand variable light transmission
- Commissioning of the building envelope
  - To ensure that envelope design, construction, and maintenance meet the owner's requirements



Heat flow via air movement

- Infiltration vs. ventilation
  - Infiltration = unintended, difficult to predict
  - Ventilation = deliberate, easily quantified
- Sensible + latent loads
- Units: CFM or L/s or CMH
- Heat flow by infiltration/ventilation
  - $Q=1.2V\Delta T$ (sensible heat loss/gain, V[L/s])
  - $Q=3010V\Delta W$ (latent heat loss/gain, W:kg/kg[DA])

How to estimate infiltration

- It is difficult to accurately quantify infiltration. Therefore, "rough" estimation methods exist.
- Level I: Air change method
  - Based on construction type and climate
  - Table F.3
- Level II: Crack method: more effort
  - assumes that all infiltration is due to cracks around doors and windows
  - Data on window and door construction and wind velocities required
    - If air leakage rates are known → Alt #1: Table E.15 → leakage data
    - If air leakage rates are unknown → Alt #2: use Table F.4
      - Velocity head factor (from Part A) → *k* factor (depending on types of windows and doors, from Parts C&D) → infiltration (L/s.m, CFM/ft of crack, from Part B)
- Level III: nodal airflow network method

TABLE F.3 Estimated Overall Infiltration Rates for Small Buildings

Part A. Construction Types

Construction Type	Description
Tight	Good multifamily residential construction with close-fitting doors, windows, and framing is considered tight. New houses with full vapor retarder, no fireplace, well-fitted windows, weather-stripped doors, one-story, and less than 1500 ft^2 (140 m^2) floor area fall into this category.
Medium	Medium structures include new two-story frame houses or one-story houses more than 10 years old with average maintenance, a floor area greater than 1500 ft^2 (140 m^2), average-fit windows and doors, and a fireplace with damper and glass closure. Below-average multifamily construction falls in this category.
Loose	Loose structures are poorly constructed single and multifamily residences with poorly fitted windows and doors. Examples include houses more than 20 years old, of average maintenance, having a fireplace without damper or glass closure, or having more than an average number of vented appliances. Average manufactured homes are in this category.

Part B. Design Infiltration Rate (ACH) for Winter: Indoors 68°F (20°C); Wind Speed = 15 mph (6.7 m/s)

Construction Type	*Winter Outdoor Design Temperature*									
	°F: 50	40	30	20	10	0	−10	−20	−30	−40
	°C: 10	4	−1	−7	−12	−18	−23	−29	−34	−40
Tight	0.41	0.43	0.45	0.47	0.49	0.51	0.53	0.55	0.57	0.59
Medium	0.69	0.73	0.77	0.81	0.85	0.89	0.93	0.97	1.00	1.05
Loose	1.11	1.15	1.20	1.23	1.27	1.30	1.35	1.40	1.43	1.47

Part C. Design Infiltration Rate (ACH) for Summer: Indoors 75°F (24°C); Wind Speed = 7.5 mph (3.4 m/s)

Construction Type	*Summer Outdoor Design Temperature*					
	°F: 85	90	95	100	105	110
	°C: 29	32	35	38	41	43
Tight	0.33	0.34	0.35	0.36	0.37	0.38
Medium	0.46	0.48	0.50	0.52	0.54	0.56
Loose	0.68	0.70	0.72	0.74	0.76	0.78

Part D. Infiltration Rates per Unit Floor Area

Ceiling Height	Air Flow	*Air Changes per Hour*																	
		0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0
7.5 ft	cfm/ft^2	0.04	0.05	0.06	0.08	0.09	0.10	0.11	0.13	0.14	0.15	0.16	0.18	0.19	0.20	0.21	0.23	0.24	0.25
2.3 m	L/s m^2	0.20	0.25	0.31	0.41	0.46	0.51	0.56	0.66	0.71	0.76	0.81	0.91	0.97	1.02	1.07	1.17	1.22	1.27
8.0 ft	cfm/ft^2	0.04	0.05	0.07	0.08	0.09	0.11	0.12	0.13	0.15	0.16	0.17	0.19	0.20	0.21	0.23	0.24	0.26	0.27
2.4 m	L/s m^2	0.20	0.25	0.36	0.41	0.46	0.56	0.61	0.66	0.76	0.81	0.86	0.97	1.02	1.07	1.17	1.22	1.32	1.37
8.5 ft	cfm/ft^2	0.04	0.06	0.07	0.09	0.10	0.11	0.13	0.14	0.16	0.17	0.18	0.20	0.21	0.23	0.24	0.26	0.27	0.28
2.6 m	L/s m^2	0.20	0.31	0.36	0.46	0.51	0.56	0.66	0.71	0.81	0.86	0.91	1.02	1.07	1.17	1.22	1.32	1.37	1.42
9.0 ft	cfm/ft^2	0.05	0.06	0.08	0.09	0.11	0.12	0.14	0.15	0.17	0.18	0.20	0.21	0.23	0.24	0.26	0.27	0.29	0.30
2.7 m	L/s m^2	0.25	0.31	0.41	0.46	0.56	0.61	0.71	0.76	0.86	0.91	1.02	1.07	1.17	1.22	1.32	1.37	1.47	1.52

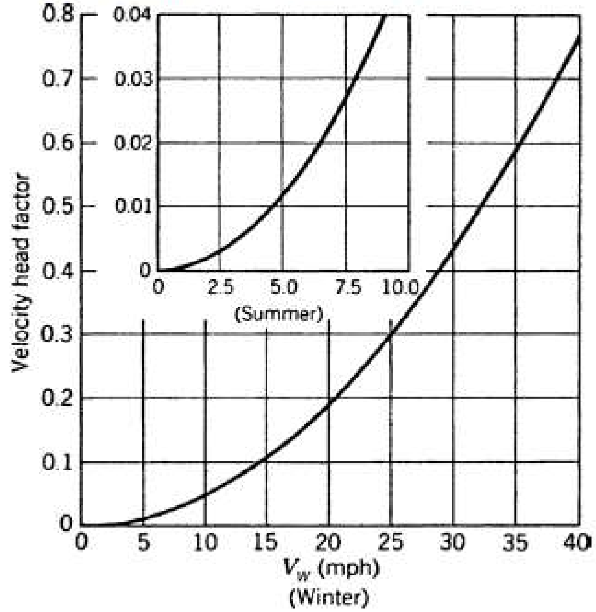
Part E. Infiltration Heat Flow Rates per Unit Floor Area

Ceiling Height	Heat Flow	*Air Changes per Hour*																	
		0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0
7.5 ft	Btu/h ft^2 °F	0.04	0.05	0.07	0.08	0.09	0.11	0.12	0.14	0.15	0.16	0.18	0.20	0.20	0.22	0.23	0.24	0.26	0.27
2.3 m	W/m^2 K	0.23	0.28	0.40	0.45	0.51	0.63	0.68	0.80	0.85	0.91	1.02	1.14	1.14	1.25	1.31	1.36	1.48	1.53
8.0 ft	Btu/h ft^2 °F	0.04	0.06	0.07	0.09	0.10	0.12	0.13	0.14	0.16	0.17	0.19	0.22	0.22	0.23	0.24	0.26	0.27	0.29
2.4 m	W/m^2 K	0.23	0.34	0.40	0.51	0.57	0.68	0.74	0.80	0.91	0.97	1.08	1.25	1.25	1.31	1.36	1.48	1.53	1.65
8.5 ft	Btu/h ft^2 °F	0.05	0.06	0.08	0.09	0.11	0.12	0.14	0.15	0.17	0.18	0.20	0.23	0.23	0.24	0.26	0.28	0.29	0.30
2.4 m	W/m^2 K	0.28	0.34	0.45	0.51	0.63	0.68	0.80	0.85	0.97	1.02	1.14	1.31	1.31	1.36	1.48	1.59	1.65	1.70
9.0 ft	Btu/h ft^2 °F	0.05	0.06	0.08	0.10	0.11	0.13	0.15	0.16	0.18	0.19	0.21	0.24	0.24	0.26	0.28	0.29	0.31	0.32
2.4 m	W/m^2 K	0.28	0.34	0.45	0.57	0.63	0.74	0.85	0.91	1.02	1.08	1.19	1.36	1.36	1.48	1.59	1.65	1.76	1.82

Sources: Parts A through C reprinted with permission of the ASHRAE, from the 2001 *ASHRAE Handbook—Fundamentals*; Parts D and E from *ASHRAE Cooling and Heating Load Calculation Manual*, 1979. This citation to an older version of the *Handbook* is intentional and provides access to historic reference information of ongoing interest. SI units appended by the authors.

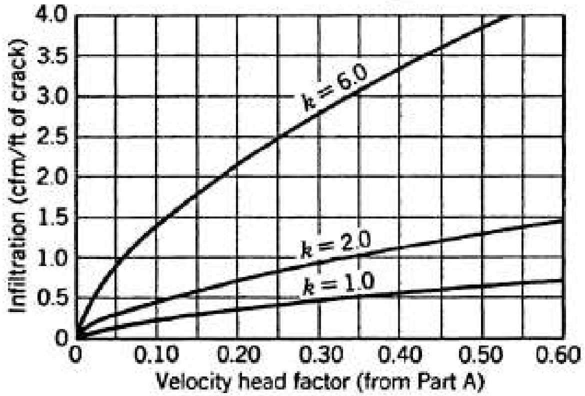
TABLE F.4 Approximate Infiltration through Doors and Windows of Small Buildings

Part A. Converting Wind Speed to Velocity Head Factor



Note: Design conditions are often assumed as:
Winter wind V_w = 15 mph (6.7 m/s) corresponding to a velocity head factor of 0.105
Summer wind V_w = 7.5 mph (3.4 m/s) corresponding to a velocity head factor of 0.028

Part B. Infiltration Rates for Velocity Head Factors



Note: Enter this graph with velocity head factor (from Part A) to find infiltration rate in cfm/ft of crack (using values of *k* found in Part C or D). L/s per m = (cfm/ft) (0.646).

TABLE F.4 | Approximate Infiltration through Doors and Windows of Small Buildings (*Continued*)

Part C. Classifications of Windows for Infiltration		
Window Fit	**Wood Double-Hung (Locked)**	**Other Types**
Tight, $k = 1.0$	Weather stripped; average gap (1⁄64 in. [0.4 mm] crack).	Wood casement and awning windows; weather stripped. Metal casement windows; weather stripped.
Average, $k = 2.0$	Non–weather stripped; average gap (1⁄64 in. [0.4 mm] crack) or weather stripped; large gap (3⁄32 in. [2.4 mm] crack).	All types of vertical and horizontal sliding windows; weather stripped. If average gap (1⁄64 in. [0.4 mm] crack), this could be a tight-fitting window. Metal casement windows; non–weather stripped. If large gap (3⁄32 in. [2.4 mm] crack), this could be a loose-fitting window.
Loose, $k = 6.0$	Non–weather stripped; large gap (3⁄32 in. [2.4 mm] crack).	Vertical and horizontal sliding windows; non–weather stripped.

Part D. Classification of Residential-type Doors for Infiltration	
Door Fit	**Comments**
Tight, $k = 1.0$	Very small perimeter gap and perfect fit weather stripping—often characteristic of new doors.
Average, $k = 2.0$	Small perimeter gap having stop trim fitting properly around door; weather stripped.
Loose, $k = 6.0$	Large perimeter gap having poor fitting stop trim; weather stripped. or Small perimeter gap; no weather stripping.

Source: Reprinted with permission of ASHRAE, from *Cooling and Heating Load Calculation Manual*, 2nd edition, 1992. SI units appended by the authors.

Ventilation

- Tables F.1, F.2 discussed in Chapter 3
- ASHRAE standard 62.1: The Standards for Ventilation and Indoor Air Quality

Calculating envelope heat flows

- Heating load: based on “worst-hour” conditions, used to size heating systems
  - Hand calculations, spreadsheet, computer simulation
- Cooling load: based on “worst-hour” conditions, used to size cooling systems
  - Hand calculations, spreadsheet, computer simulation
- Annualized heat flow: based on year-long climate conditions, used to predict annual energy use, costs or demonstrate compliance with energy standards.
  - Computer simulation: steep learning curve, detailed information required.

Heating load calculation

- Above-ground components
  - $Q=UA\Delta T$
    - U, A: outcome of the design process
    - ΔT: climate-dependent (Appendix B)
- Slab-on-grade floors
  - $Q=F_2P\Delta T$ (Example 9.3)
- Below grade basement walls and floors
  - $Q=U_{avg}A(T_i - T_g)$ (Example 9.4)
- Infiltration and ventilation
  - $Q=1.2V\Delta T$ (sensible heat, V[L/s])
  - $Q=3010V\Delta W$ (sensible heat, W:kg/kg[DA])

- Design for energy efficiency
  - Reduce U, reduce A (more compact), reduce ΔT, reduce V

Heating load calculation example

Design heat loss (textbook p.311)

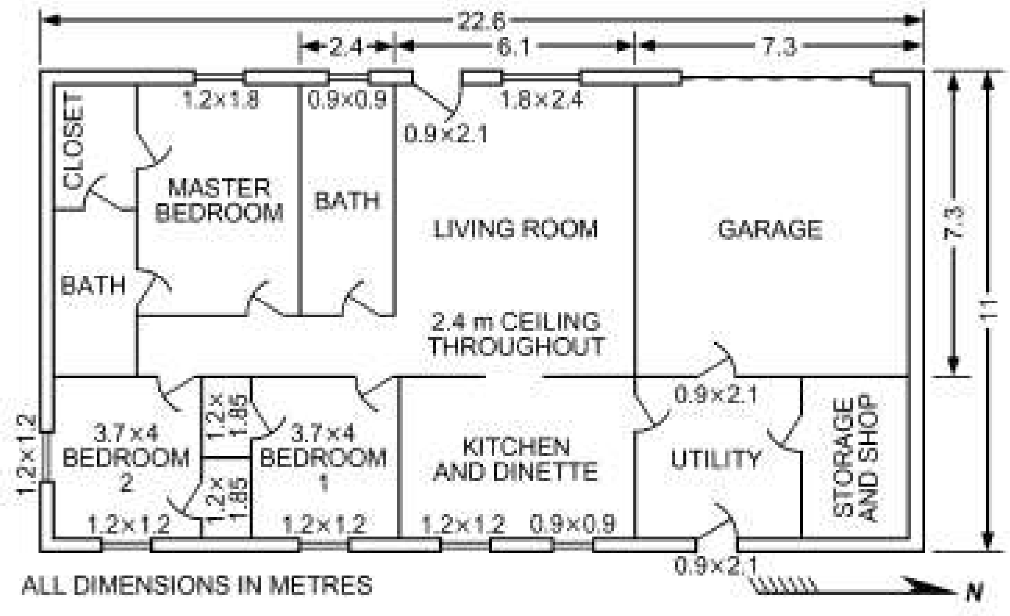


Fig. 1 Example House

ASHRAE F. 2017. 17.13

Solution

Cooling load calculation

- More complex than heating load since it requires the dynamics of the system, e.g., sun, internal heat generation, etc. (in heating load, those are neglected)
- To-consider variables
  - The orientation of an assembly (north, south, etc.)
  - The tilt of an assembly (vertical, horizontal, tilted)
  - The surface reflectance of an assembly
  - The thermal capacity of an assembly
  - SHGC of a transparent/translucent assembly
  - Shading
  - Internal heat generation: lights, occupants, equipment

Heat gain ≠ cooling load

- Heat gain = total instantaneous heat flow
  - This instantaneous heat gain does not immediately affect indoor air temperature.
- Cooling load = instantaneous heat gain – any part of heat gain stored + any previously stored heat gain now being transferred to a room air

Sol-air temperature

- =equivalent temperature (상당외기온도): 벽면, 지붕면에 일사가 있을 때 그 효과를 반영하기 위해, 그 효과를 실제의 기온과 합하여 구한 온도
- A temperature that would produce the same heat flow combined between ΔT and solar radiation.

For a white roof:

- t_e = 32.2 + 0.45*826/17-3.9
  = 50.1′C

For a dark roof:

t_e = 32.2 + 0.90*826/17-3.9
= 72′C

$$t_e = t_o + \frac{\alpha \times I}{h_o} - 7°F$$

where

t_e = sol-air temperature

t_o = outdoor (ambient) dry-bulb temperature

α = absorptance of surface for solar radiation (for light-colored surfaces, usually assumed as 0.45; for dark-colored surfaces, usually assumed as 0.90; detailed values are listed in Table 14.11)

I = total solar radiation incident on the surface, Btu/h ft^2 (see Appendix C for solar heat gain factors, which are approximately equivalent to I for horizontal surfaces)

h_o = coefficient of heat transfer by long-wave radiation and convection at the surface (usually assumed as 3.0 Btu/h ft^2 °F)

The simplified sol-air temperature formula in SI units is:

$$t_e = t_o + \frac{\alpha I}{h_o} - 3.9°C$$

where the differences from I-P units are as follows:

It is common practice to assume 0 for vertical surface.

I = total solar radiation incident on the surface, W/m^2

h_o = usually assumed as 17.0 W/m^2 K

EXAMPLE 9.6 What is the sol-air temperature for a horizontal white roof, compared to a dark roof, on a clear July 21 at noon, at 40°N latitude? Assume outdoor air temperature of 90°F (32°C).

SOLUTION

From Table C.3 of Appendix C, on July 21 at noon at 40°N latitude, the solar heat gain factor on a horizontal surface = 262 Btu/h ft^2 (827 W/m^2).

Textbook p.1632

Sol-air temperature: $t_e = t_o + \frac{\alpha I}{h_o} - 7°F$

For a white roof:

$$t_e = 90°F + \frac{0.45 \times 262 \text{ Btu/h ft}^2}{3.0 \text{ Btu/h ft}^2 °F} - 7°F$$

$$= 90 + 39.3 - 7 = 122.3°F$$

For a dark roof:

$$t_e = 90°F + \frac{0.90 \times 262 \text{ Btu/h ft}^2}{3.0 \text{ Btu/h ft}^2 °F} - 7°F$$

$$= 90 + 78.6 - 7 = 161.6°F$$

In SI units: $t_e = t_o + \alpha I / h_o - 3.9°C$

$$t_e = 32°C + \frac{0.45 \times 827 \text{ W/m}^2 / 17 \text{ W/m}^2 \text{ K}}{= 50.0°C} - 3.9°C$$

$$t_e = 32°C + \frac{0.90 \times 827 \text{ W/m}^2 / 17 \text{ W/m}^2 \text{ K}}{= 71.9°C} - 3.9°C$$

Solar radiation has a marked impact upon surface temperature (and resulting heat flow). Elevated temperatures in full sun will drive considerably more heat through both roofs compared to shaded conditions. The white roof has a Δt about 1.4 times greater in full sun than in shade. The dark roof has a Δt about 1.3 times greater than the white roof under the stated conditions. ■

Envelope Thermal Design Standards

- Energy codes provide two paths
  - Prescriptive path: straightforward, simple, little analysis, little creativity
  - Performance-based path: detailed analysis, a wide range of solutions, creating innovation and creativity, market transformation
- LEED, ASHRAE