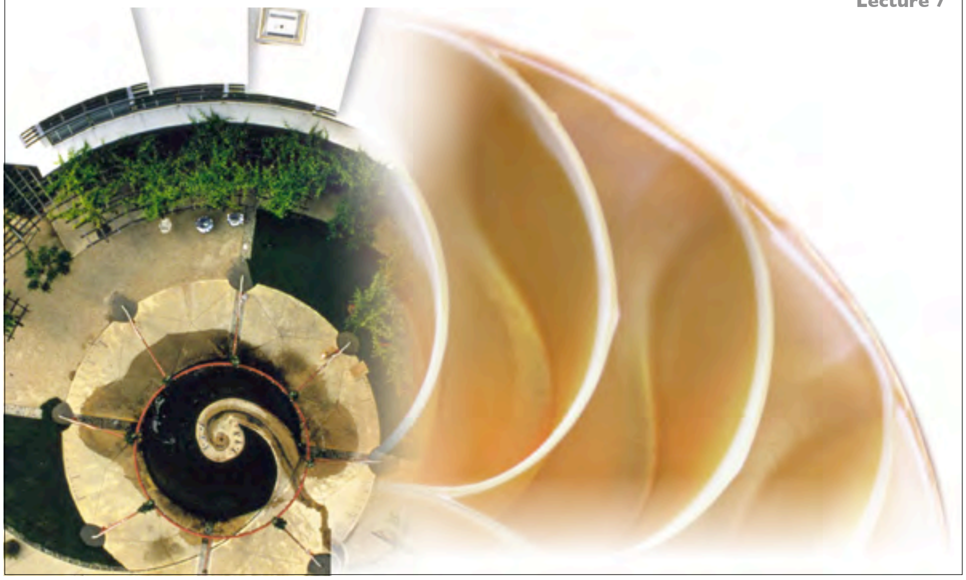
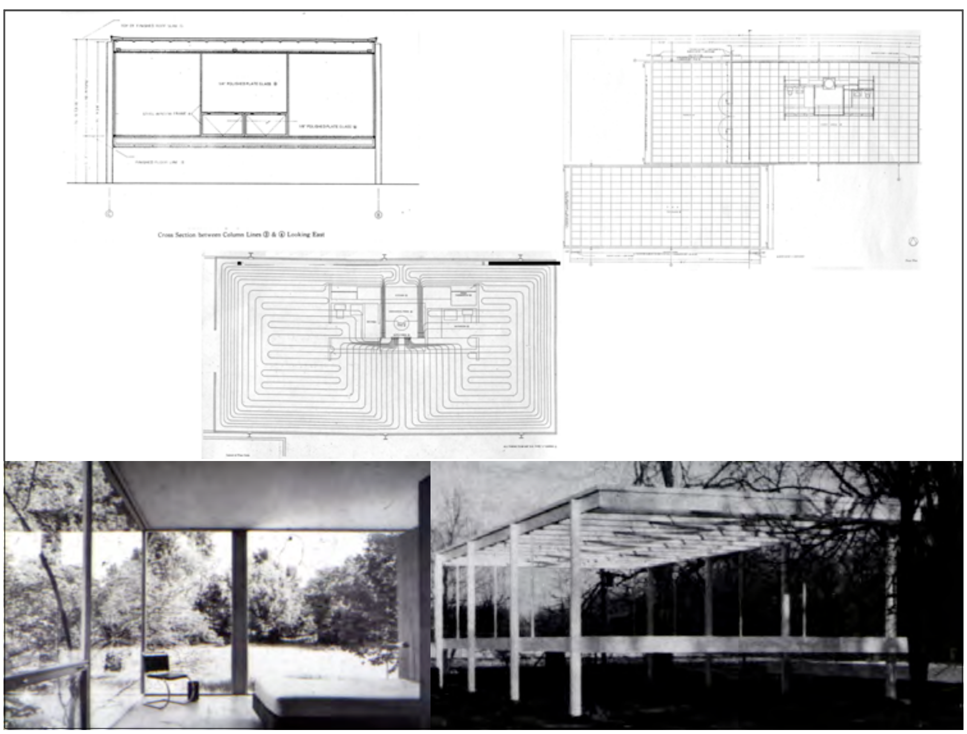
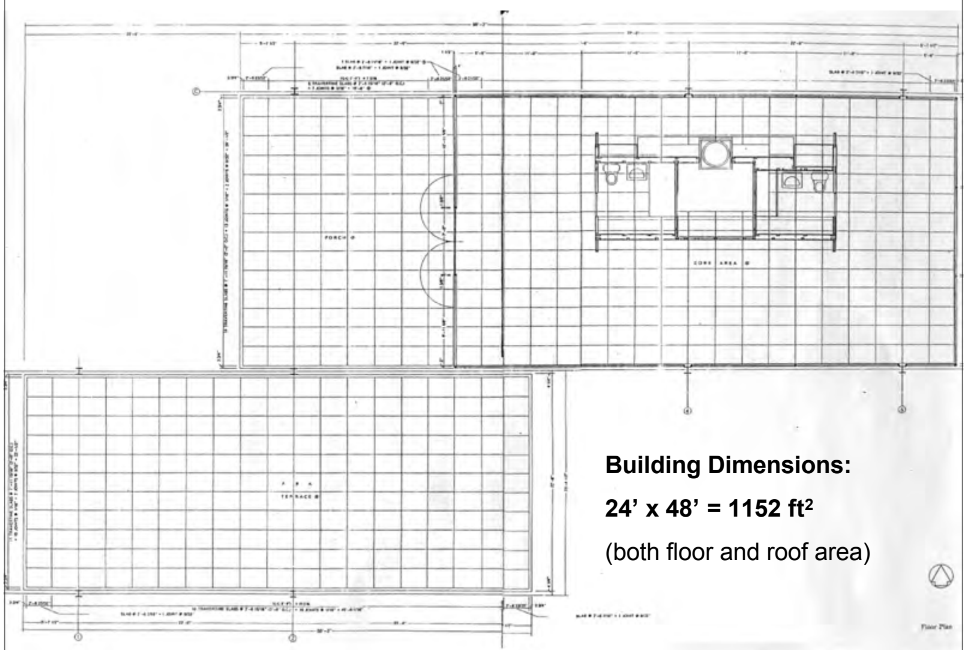
Whole Building Heat Transfer
Part 1

ARCH 331/431 Spring 2008
Lecture 7



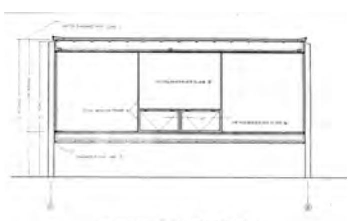




Building Dimensions:

24' x 48' = 1152 ft²

(both floor and roof area)

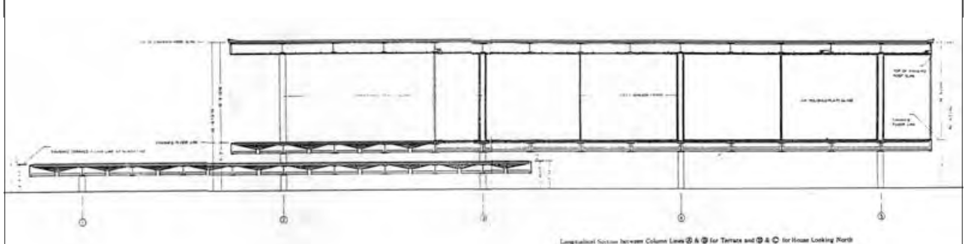


Floor & Roof Area = 1152 ft²

Wall Area (24' x 2 + 48' x 2) 8'

= 1152 ft²

Interior Volume = 9216 ft³



Determining UA

Step 1: The Building Envelope (conductive heat transfer)

$$Q = UA_{envelope} \times \Delta T$$

Q = Heat loss or gain (Btu/h)

U = conductance (Btu/h sf °F)

A = area (sf)

$\Delta T = T_{outside} - T_{inside}$ (°F)

U ~ C (conductance)

C = 1/R (resistance)

Finding UA is a process of finding the R-values of each layer of the building envelope

Table E.1, MEEB 10th

TABLE E.1 Thermal Properties of Conventional Building and Insulating Materials[a] *(Continued)*

Description		Density lb/ft³ (kg/m³)	Conductivity[b] (k) Btu-in / h ft² °F (W/m K)	Conductance (C) Btu / h ft² °F (W/m² K)	I-P Resistance[c] (R): Per Inch Thickness (1/k) °F ft² h / Btu-in	I-P Resistance[c] (R): For Thickness Listed (1/C) °F ft² h / Btu	Specific Heat Btu / lb °F (kJ/kg K)	SI Resistance[c] (R): Per Meter Thickness (1/k) K m / W	SI Resistance[c] (R): For Thickness Listed (1/C) K m² / W
Plywood or wood panels	0.75 in. 19.0 mm	34 540	—	1.07 6.1	—	0.93	0.29 1.21	—	0.16
Vegetable fiber board									
Sheathing, regular density[e]	0.5 in. 12.7 mm	18 290	—	0.76 4.3	—	1.32	0.31 1.3	—	0.23
	0.78125 in. 19.8 mm	18 290	—	0.49 2.8	—	2.06		—	0.36
Sheathing intermediate density[e]	0.5 in. 12.7 mm	22 350	—	0.92 5.2	—	1.09	0.31 1.30	—	0.19
Nail-base sheathing[e]	0.5 in. 12.7 mm	25 400	—	0.94 5.3	—	1.06	0.31 1.30	—	0.19
Shingle backer	0.375 in. 9.5 mm	18 290	—	1.06 6.0	—	0.94	0.31 1.30	—	0.17
Shingle backer	0.3125 in. 7.9 mm	18 290	—	1.28 7.3	—	0.78		—	0.14
Sound deadening board	0.5 in. 12.7 mm	15 240	—	0.74 4.2	—	1.35	0.30 1.26	—	0.24
Tile and lay-in panels, plain or acoustic		18 290	0.40 0.058	—	2.50	—	0.14 0.59	17.0	—
	0.5 in. 12.7 mm	18 290	—	0.80 4.5	—	1.25		—	0.22

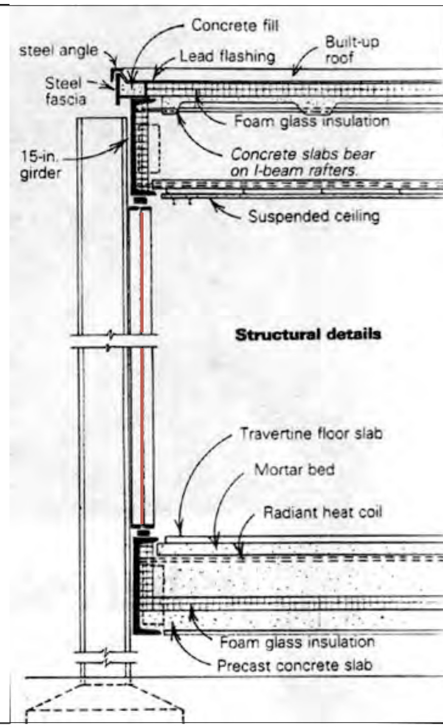


Table E.1, MEEB 10th

TABLE E.1 Thermal Properties of Conventional Building and Insulating Materials[a] *(Continued)*

Description	Density lb/ft^3 (kg/m^3)	Conductivity[b] (k) Btu-in / h ft^2 °F (W/m K)	Conductance (C) Btu / h ft^2 °F (W/m^2 K)	*I-P Resistance[c] (R)* Per Inch Thickness (1/k) °F ft^2 h / Btu-in	*I-P Resistance[c] (R)* For Thickness Listed (1/C) °F ft^2 h / Btu	Specific Heat Btu / lb °F (kJ/kg K)	*SI Resistance[c] (R)* Per Meter Thickness (1/k) K m / W	*SI Resistance[c] (R)* For Thickness Listed (1/C) K m^2 / W
Wood, bevel, 0.5 × 8 in., lapped (13 × 200 mm)	—	—	1.23 6.98	—	0.81	0.28 1.17	—	0.14
Wood, bevel, 0.75 × 10 in., lapped (19 × 250 mm)	—	—	0.95 5.40	—	1.05	0.28 1.17	—	0.18
Wood, plywood, 0.375 in. (9.5 mm) lapped	—	—	1.69 9.60	—	0.59	0.29 1.22	—	0.10
Aluminum, steel, or vinyl[p,q] over sheathing								
Hollow-backed	—	—	1.64 9.31	—	0.61	0.29[q,l] 1.22	—	0.11
Insulating-board backed nominal 0.375 in. (9.5 mm)	—	—	0.55 3.12	—	1.82	0.32 1.34	—	0.32
Insulating-board backed nominal 0.375 in. (9.5 mm), foil backed	—	—	0.34 1.93	—	2.96	—	—	0.52
Architectural (soda-lime float) glass	158 2528	6.9	— 56.8	—	—	0.21 0.84	—	0.018
Woods (12% moisture content)[e,r]								
Hardwoods						0.39[s] 1.63		
Oak	41.2–46.8 659–749	1.12–1.25 0.16–0.18	—	0.89–0.80	—		— 6.2–5.5	

E.3, MEEB 10th

TABLE E.3 Thermal Properties of Surface Air Films and Air Spaces

Part A. Surface Conductances[a] and Resistances[b] for Surface Air Films

		Surface Emittance, ε											
		I-P Units[c]						SI Units[d]					
		Nonreflective		Reflective				Nonreflective		Reflective			
		ε = 0.90		ε = 0.20		ε = 0.05		ε = 0.90		ε = 0.20		ε = 0.05	
Position of Surface	Direction of Heat Flow	h_i	R	h_i	R	h_i	R	h_i	R	h_i	R	h_i	R
Still Air													
Horizontal	Upward	1.63	0.61	0.91	1.10	0.76	1.32	9.26	0.11	5.17	0.19	4.32	0.23
Sloping–45°	Upward	1.60	0.62	0.88	1.14	0.73	1.37	9.09	0.11	5.00	0.20	4.15	0.24
Vertical	Horizontal	1.46	0.68	0.74	1.35	0.59	1.70	8.29	0.12	4.20	0.24	3.35	0.30
Sloping–45°	Downward	1.32	0.76	0.60	1.67	0.45	2.22	7.50	0.13	3.41	0.29	2.56	0.39
Horizontal	Downward	1.08	0.92	0.37	2.70	0.22	4.55	6.13	0.16	2.10	0.48	1.25	0.80
Moving Air (any position)		h_o	*R*					h_o	*R*				
Winter Wind													
15 mph (6.7 m/s)	Any	6.00	0.17					34.0	0.030				
Summer Wind													
7.5 mph (3.4 m/s)	Any	4.00	0.25					22.7	0.044				

Table E.14

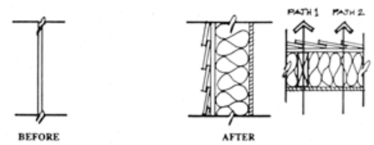
MEEB 10th

TABLE E.14 U-Factors of Representative Window Assemblies

Glazing System Description	Aluminum without Thermal Break Btu/h ft² °F (W/m² K)	Aluminum with Thermal Break Btu/h ft² °F (W/m² K)	Wood/ Vinyl Btu/h ft² °F (W/m² K)	Insulated Fiberglass/ Vinyl Btu/h ft² °F (W/m² K)
Single glazing with uncoated ⅛ in. [3.2 mm] clear pane	1.27 (7.21)	1.08 (6.13)	0.89 (5.03)	0.81 (4.60)
Single glazing with uncoated ¼ in. [6.4 mm] acrylic/polycarbonate pane	1.14 (6.47)	0.96 (5.45)	0.78 (4.43)	0.71 (4.03)
Double glazing with ⅛ in. [3.2 mm] panes: uncoated clear I clear with ¼ in. [6.4 mm] air space	0.87 (4.94)	0.65 (3.69)	0.55 (3.12)	0.49 (2.78)
Double glazing with ⅛ in. [3.2 mm] panes: uncoated clear I clear with ½ in. [13 mm] air space	0.81 (4.60)	0.60 (3.41)	0.51 (2.90)	0.44 (2.50)
Double glazing with ⅛ in. [3.2 mm] panes: uncoated clear I low-e (0.2) on surface[b] 3 with ½ in. [13 mm] air space	0.71 (4.03)	0.51 (2.90)	0.42 (2.39)	0.36 (2.04)
Triple glazing with ⅛ in. [3.2 mm] panes: uncoated clear I clear with ½ in. [13 mm] air spaces	0.67 (3.80)	0.46 (2.61)	0.39 (2.21)	0.34 (1.93)
Triple glazing with ⅛ in. [3.2 mm] panes: uncoated clear I low-e (0.2) on surfaces[b] 3 and 5 with ½ in. [13 mm] air spaces	0.58 (3.29)	0.38 (2.16)	0.31 (1.76)	0.27 (1.53)
Quadruple glazing with ⅛ in. [3.2 mm] panes: uncoated clear I low-e (0.1) on surfaces[b] 3 and 5 with ½ in. [13 mm] air spaces	0.54 (3.07)	0.34 (1.93)	0.28 (1.59)	0.24 (1.36)

Source: Excerpted with permission of the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. from the 2001 *ASHRAE Handbook—Fundamentals* (Chapter 30, Table 4).
[a]Based upon an operable 3-ft × 5-ft (0.9-m × 1.5-m) aluminum-framed window.
[b]Glazing surfaces are numbered starting with the surface closest to the sun; thus, surface 2 would be the inner surface of an exterior pane of glass.

Refer to
MEEB 10th
Table E.1
pp. 1549-1568



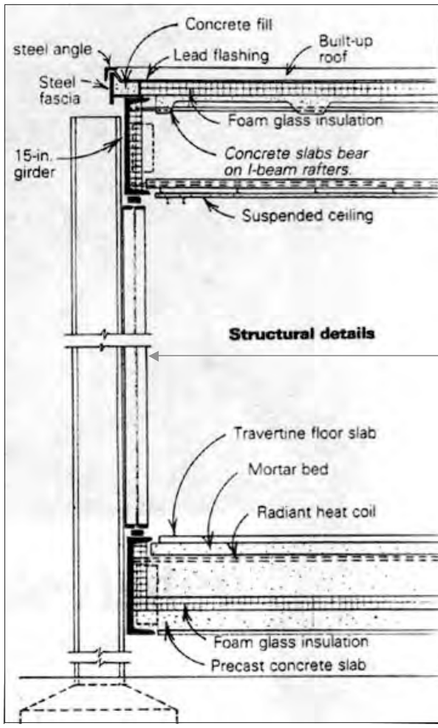
	R Resistance hr ft^2 °F / BTU	Path 1 (insulation) hr ft^2 °F / BTU	Path 2 (framing) hr ft^2 °F / BTU	
outside air film	0.17	0.17	0.17	outside air film
glass	0.04	0.79	0.79	1/2" wood siding
inside air film	0.68	0.62	0.62	1/2" plywood
		15.73		5-1/2" batt insulation
			5.50	5-1/2" wood framing
		0.45	0.45	1/2" gypsum board
		0.68	0.68	inside Air Film
	0.89	18.44	8.21	
		x 85%	x15%	
R glass total	**0.89**	15.67	1.23	
		16.91		**R wall total**

U value glass = 1/R total 1.124

0.059 **U value wall = 1/R total**

Additional Tables in MEEB 10th edition to find Envelope U-values

Table E.3	Properties of Surface Air Films and Air Spaces
Table E.6	U-values for Common Wall, Roof and Floor Assemblies
Table E.11	Heat Loss Coefficient of Floor Slabs (F), per Unit of Perimeter
Table E.10	U-values for Wood and Steel Doors
Table E.14	Window Characteristics (U-values)
Table E.16	Skylight U-Factors
Table E.27	Estimated Overall Infiltration Rates for Small Buildings



U = 0.158 BTU/hr ft² °F
A = 1152 ft²
UA_{roof} = 182 BTU/hr °F

U = 1.124 BTU/hr ft² °F
A = 1152 ft²
$UA_{walls/windows\ \&\ doors}$ = 1295 BTU/hr °F

U = 0.112 BTU/hr ft² °F
A = 1152 ft²
UA_{floor} = 129 BTU/hr °F

Building Envelope Summary

Before Design Changes | After Design Changes*

Building Element	Description	U value BTU/h ft² °F	Area ft2	U x A BTU/h °F	U x A BTU/h °F	Area ft2	U value BTU/h ft² °F	Description
Roof	metal deck with foam-glass insulation	0.158	1152	**182**	**182**	1152	0.158	no changes
Walls	Walls	1.124	1152	**1295**	**605**	576	1.050	existing glass
					34	576	0.059	insulated wood frame
Windows	(same as walls)							(same as walls)
Doors	(same as walls)							(same as walls)
Floor	travertine + concrete over metal deck w/foam-glass insulation	0.112	1152	**129**	**129**	1152	0.112	no changes
			UA envelope	**1606**	**950**	**UA envelope**		

**The "After Design Changes" portion of this chart shows what would happen to the conductive heat loss (UAenvelope) if 1/2 of the glass walls were replaced with the wood frame walls developed earlier in this lecture.*

Determining UA

Step 2: Infiltration (convective heat transfer)

$$Q = .018 \times V_{air} \times ACH \times \Delta T$$

Q = heat loss or gain

.018 = volumetric heat capacity of air (BTU/ft³ °F)

ACH = air changes per hour

V_{air} = volume of air (ft^3)

ΔT = $T_{inside} - T_{outside}$

MEEB Table E.27

Estimated Infiltration Rates for Small Buildings

TABLE E.27 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)

	Winter Outdoor Design Temperature									
Construction	°F: 50	40	30	20	10	0	−10	−20	−30	−40
Type	°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)

	Summer Outdoor Design Temperature					
Construction	°F: 85	90	95	100	105	110
Type	°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	Air	Air Changes per Hour																	
Height	Flow	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/ft²	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 m²	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/ft²	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 m²	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/ft²	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 m²	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/ft²	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 m²	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

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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

Determining UA

Step 2: Infiltration (convective heat transfer)

$$Q = .018 \times V_{air} \times ACH \times \Delta T$$

$$Q = .018 \times 9216\ ft^3 \times 1.30 \times \Delta T$$

$$Q = 216\ BTU/hr \cdot {}^\circ F \times \Delta T$$

$$\text{"UA"}_{infiltration} = 216\ BTU/hr \cdot {}^\circ F$$

Farnsworth House Results

$$Q = UA_{ref} \times \Delta T$$

Step 1: $UA_{envelope}$ = 1521 BTU/hr - °F

Step 2: "UA"$_{infiltration}$ = 216 BTU/hr - °F

Total: $UA_{reference}$ = 1737 BTU/hr - °F

Note:

Step 3: "UA"$_{perimeter}$ is not applicable since the Farnsworth House is not built with the floor in **contact with the earth.**