HVAC I

Course Notes

$$Psia = Psig + 1\ atm \quad 14.7\ psi$$

$$1\ psi = 144\ lbf/ft^2$$

$$1\ W.G = 5.2\ lbf/ft^2$$

$$R = 1545.32\ \frac{ft.lbf}{lbm.R} = 8314\ J/kgK$$

$$R_a = \frac{R}{M_a} = 53.355\ \frac{ft.lbf}{lbm.R} = 287\ J/kgK$$

$$R_v = \frac{R}{M_w} = 85.78\ \frac{ft.lbf}{lbm.R} = 462\ J/kgK$$

$$g = 32.174\ ft/s^2 = 9.81\ m/s^2$$

$$1\ ton = 12000\ BTU/hr$$

$1 \ Btu/hr = 0.00029307 \ kW$

Moist air and the standard atmosphere[cont'd]

- Atmospheric pressure may be estimated as a function of elevation by the following equation:

$$P = a + bH \qquad (3\text{-}4)$$

Table 3-2 Constants for Eq. 3-4

	$H \le 4000$ ft or 1220 m		$H > 4000$ ft or 1220 m	
Constant	**IP**	**SI**	**IP**	**SI**
a	29.92	101.325	29.42	99.436
b	−0.001025	−0.01153	−0.0009	−0.010

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$$c_{p_a} = 0.24 \ \frac{Btu}{lbm\,F} = 1.0 \ \frac{kJ}{kg\,C}$$

$$c_{p_v} = 0.444 \ \frac{Btu}{lbm\,F} = 1.86 \ \frac{kJ}{kg\,C}$$

$$i_{fg_w} = 1061.2 \ \frac{Btu}{lbm} = 2501.3 \ kJ/kg$$

Essential Equations for humid air

$$W = 0.6219 \frac{P_v}{P_a} = 0.6219 \frac{P_v}{P - P_v}$$

$$\phi = \frac{P_v}{P_s} = \frac{\rho_v}{\rho_s}\Big|_{t,p}$$

$$i = i_a + W i_v$$

$$i_a = c_{pa} t \quad \Big| \quad i_v = i_{fg} + c_{pv} t$$

$\hookrightarrow$ sat. steam table is better

adiabatic Saturation

$$i_{a_1} + W_1 i_{v_1} + (W_2^* - W_1) i_w = i_{a_2} + W_2^* i_{v_2}$$

Adiabatic Saturation cont'd

$$W_1(i_{v1} - i^*_w) = C_{pa}(t^*_2 - t_1) + W^*_{s2}\ i^*_{fg2} \quad (3\text{-}21c)$$

solving for W_1:

$$W_1 = \frac{C_{pa}(t_2^* - t_1) + W_{s2}^* i_{fg2}}{i_{v_1} - i_w^*} \quad (3\text{-}21d)$$

W_{s2} can be calculated from the equation

$$W_{s2}^* = 0.6219 \frac{P_{s2}}{P_2 - P_{v2}} \quad (3\text{-}14b)$$

$p_{v2} = p_{s2}$ at t^*_2; the enthalpy of the vaporization i^*_{fg2} depends only on t^*_2; The enthalpy of the vapor i_{v1} is function of t_1; and t^*_w. Therefore, the humidity ratio of an air-water vapor mixture can be determined from the entering and leaving temperatures and pressures of the adiabatic saturator

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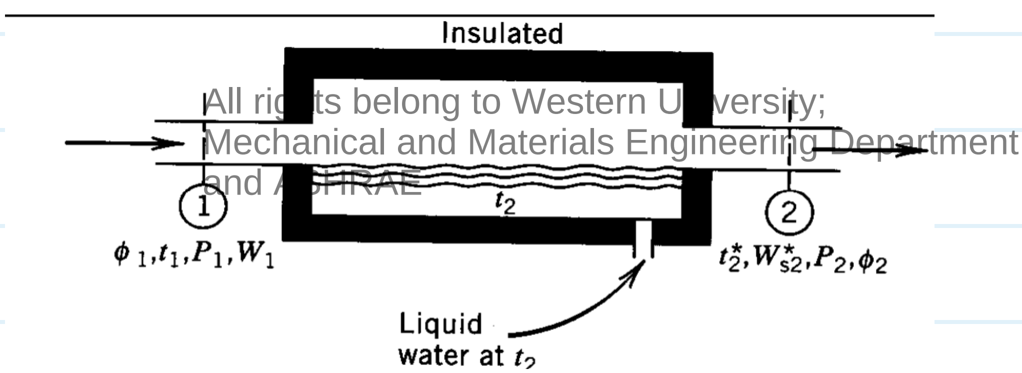
$t_2^* \rightarrow t_{wb}$

$i^*_w \rightarrow i_{liq} @ t_2$

$i_{v_1} \rightarrow i_{vap} @ t_1$

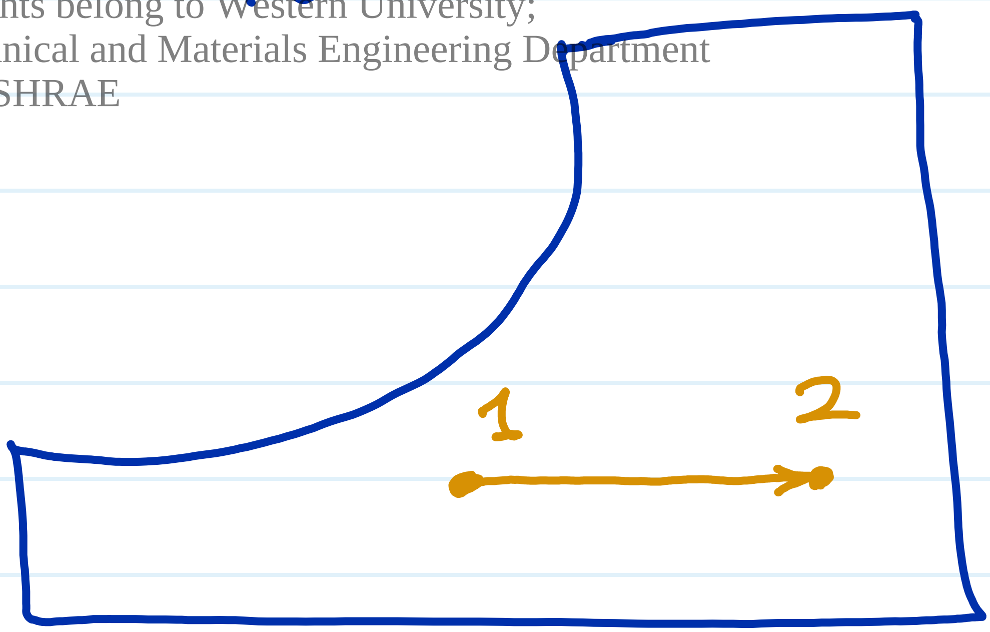


Heating or Simple Cooling

$$\dot{m}_a i_1 + \dot{q} = \dot{m}_a i_2$$

OR $$\dot{q} = \dot{m}_a (i_2 - i_1) = \dot{m}_a c_p (t_2 - t_1)$$

$$c_p = c_{pa} + W c_{pv}$$



Cooling with dehumidifying

$$\dot{m}_a i_1 = \dot{q} + \dot{m}_a i_2 + \dot{m}_w i_w$$

$$\dot{m}_a W_1 = \dot{m}_a W_2 + \dot{m}_w$$

usually negligible

$$\dot{q} = \dot{m}_a (i_1 - i_2) - \overbrace{\underbrace{\dot{m}_a (W_1 - W_2)}_{\dot{m}_w} i_w}$$

OR

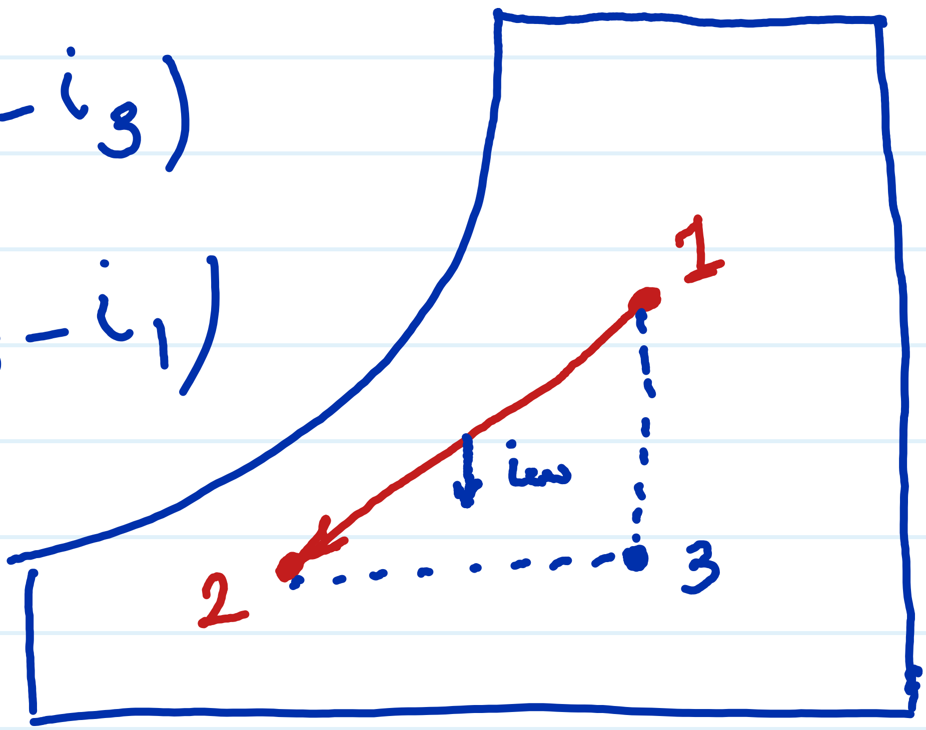
$$SHF = \frac{\dot{q}_s}{\dot{q}} \equiv \frac{\Delta i_{1-2}}{\Delta W_{1-2}} \quad \text{slope}$$

$$\dot{q} = \dot{q}_s + \dot{q}_l$$

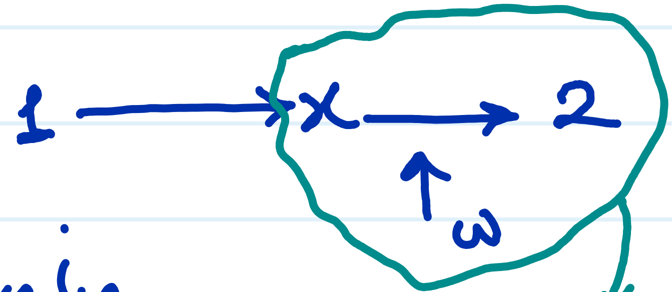
$$\dot{q}_s = \dot{m}_a (i_2 - i_3)$$

$$\dot{q}_l = \dot{m}_a (i_3 - i_1)$$

$$\dot{q}_l = \dot{m}_w i_{fg}$$



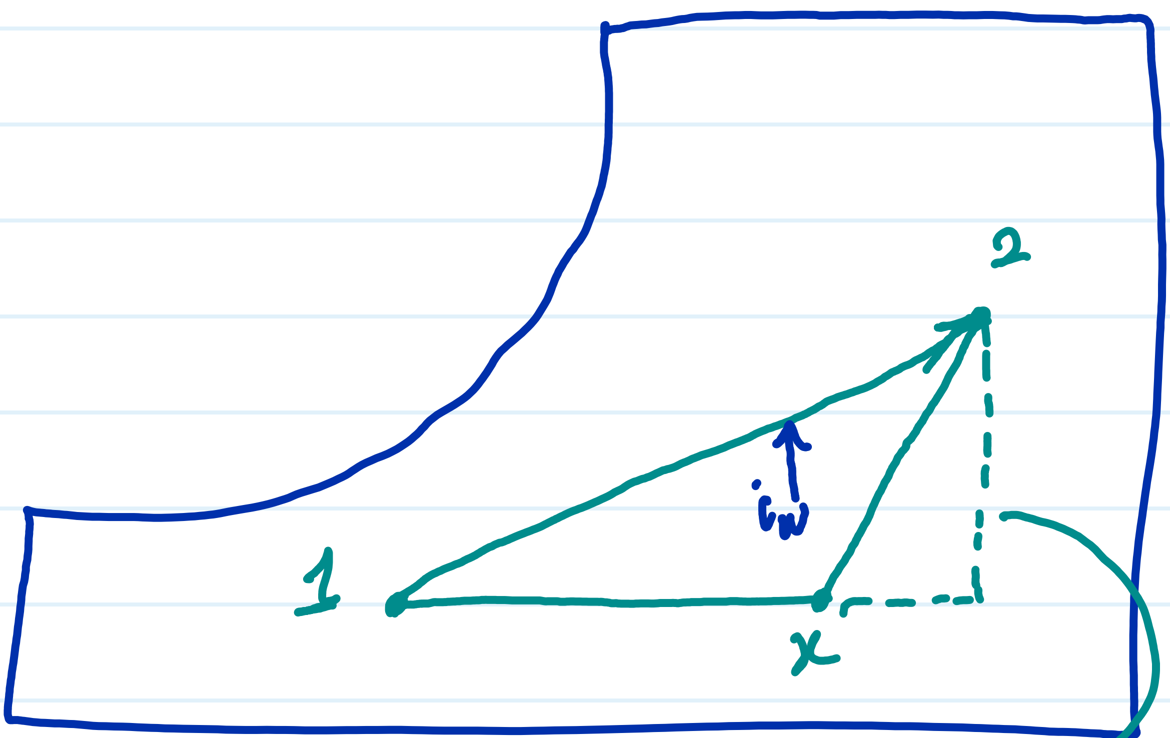
Heating with humidifying



$$\dot{m}_a i_1 + \dot{q} + \dot{m}_w i_w = \dot{m}_a i_2$$

$$\dot{m}_a W_1 + \dot{m}_w = \dot{m}_a W_2$$

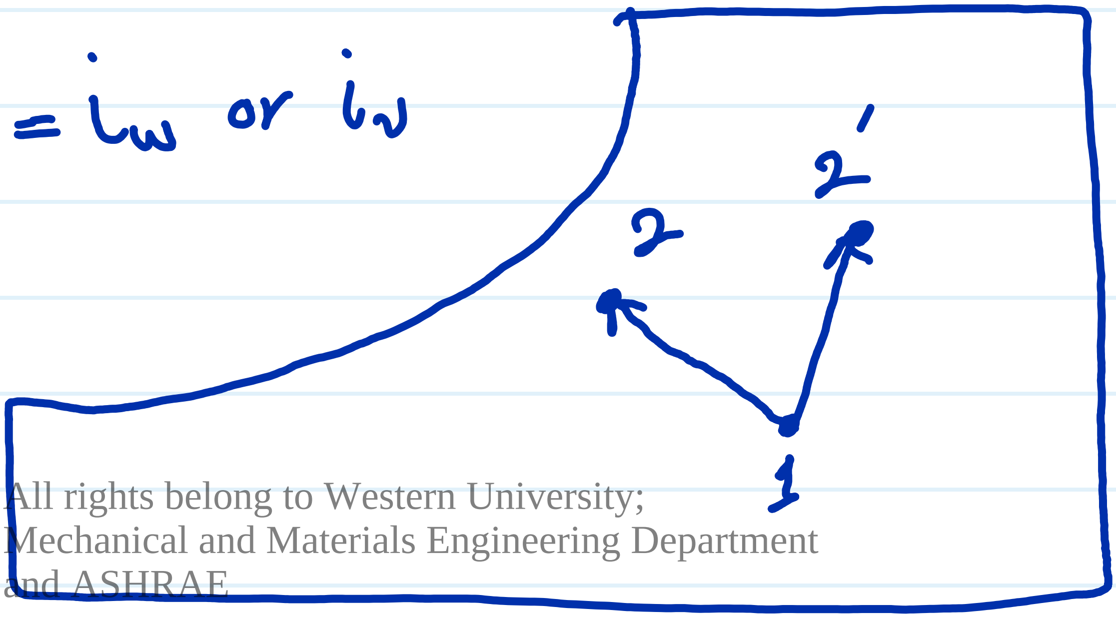
adiabatic humidification



steam has both sens. & latent thermal energy.

Adiabatic Humidification

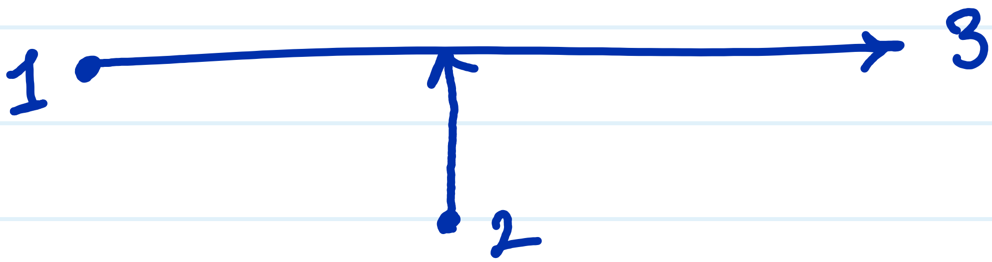
$$\frac{i_2 - i_1}{W_2 - W_1} = i_w \text{ or } i_v$$



(2) if added water is saturated liq.

(2') " " " " " vapor

Adiabatic Mixing



$$\dot{m}_{a1} i_1 + \dot{m}_{a2} i_2 = \dot{m}_{a3} i_3$$

$$\dot{m}_{a1} + \dot{m}_{a2} = \dot{m}_{a3}$$

$$\dot{m}_{a1} W_1 + \dot{m}_{a2} W_2 = \dot{m}_{a3} W_3$$

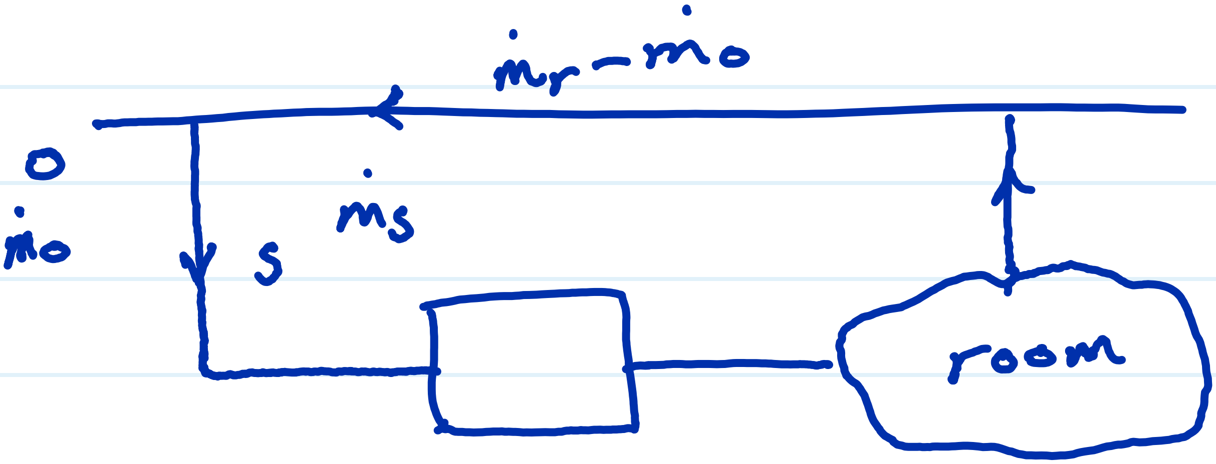
$$\frac{\dot{m}_{a1}}{\dot{m}_{a2}} = \frac{\overline{32}}{\overline{31}}$$

Adiabatic Mixing Of Two Streams Of Moist Air cont'd

If we solve Eq. 3-44 for i_3 and W_3:

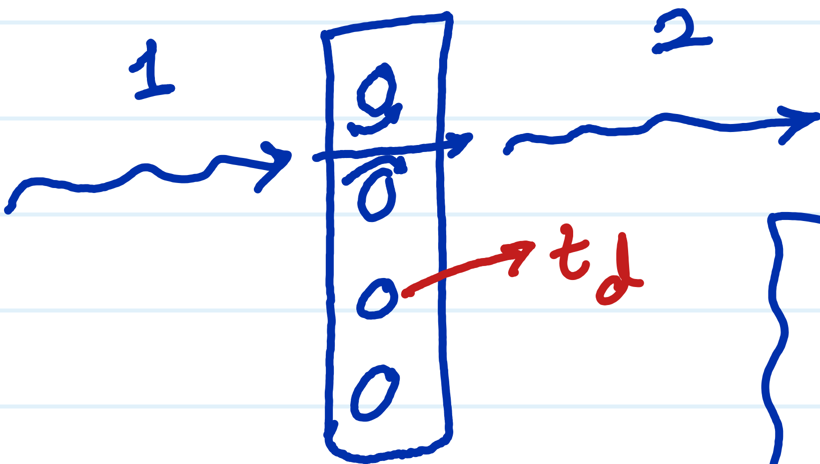
$$i_3 = \frac{\frac{\dot{m}_{a1}}{\dot{m}_{a2}} i_1 + i_2}{1 + \frac{\dot{m}_{a1}}{\dot{m}_{a2}}} \quad (3\text{-}44a) \qquad , \qquad W_3 = \frac{\frac{\dot{m}_{a1}}{\dot{m}_{a2}} W_1 + W_2}{1 + \frac{\dot{m}_{a1}}{\dot{m}_{a2}}} \quad (3\text{-}44b)$$

Outdoor & Indoor Mixing

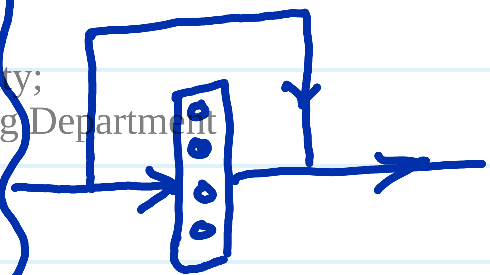


$$\dot{m}_s = \dot{m}_r - \dot{m}_o + \dot{m}_o = \dot{m}_r$$

Coil ByPass factor



another form of bypass:



$$\dot{q}_{coil} = \dot{m}_a c_p (t_1 - t_2)$$

OR

$$\dot{q}_{coil} = \dot{m}_a c_p (t_1 - t_d)(1-b)$$

$$b = \frac{t_2 - t_d}{t_1 - t_d}$$

$$1-b = \frac{t_1 - t_2}{t_1 - t_d}$$

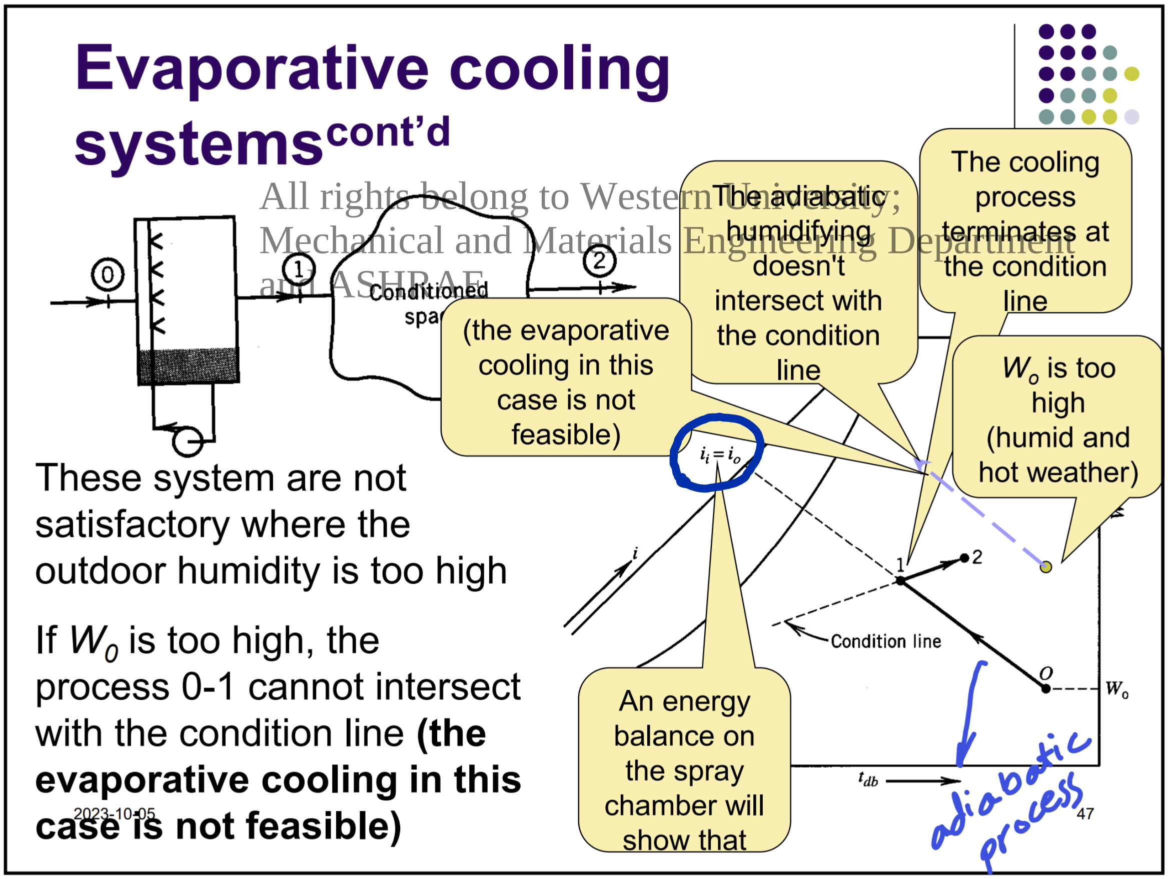
$t_d \ll t_{dew\,point\,(1-2)}$

the point the line 1-2 intersects with $\phi = 100\%$.

Evaporative Cooling

It converts the latent heat to sensible heat without adding extra energy.

$\Rightarrow \quad i_1 = i_0$



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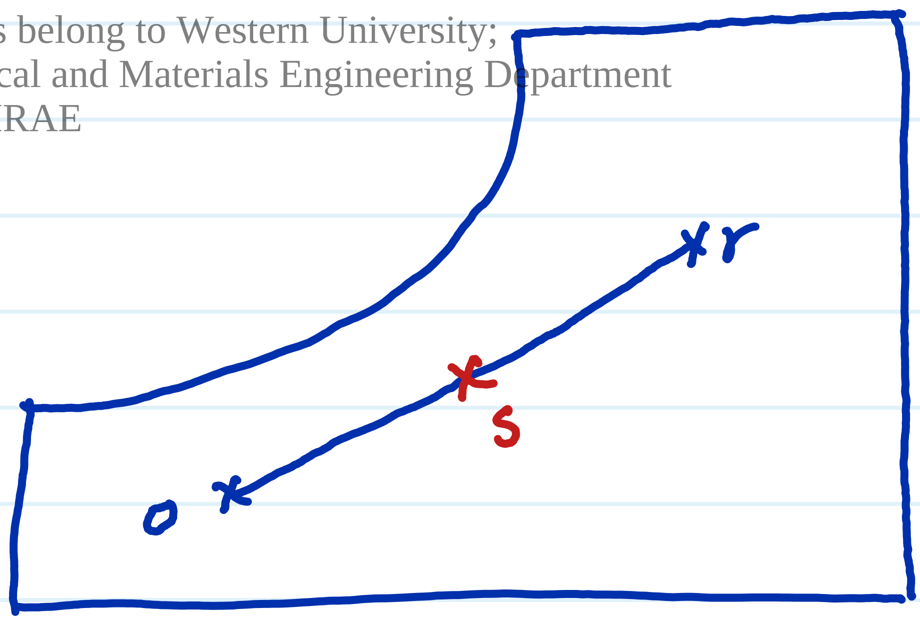
Economizer



deciding on the mixing ratio is done based on the minimum enthalpy difference

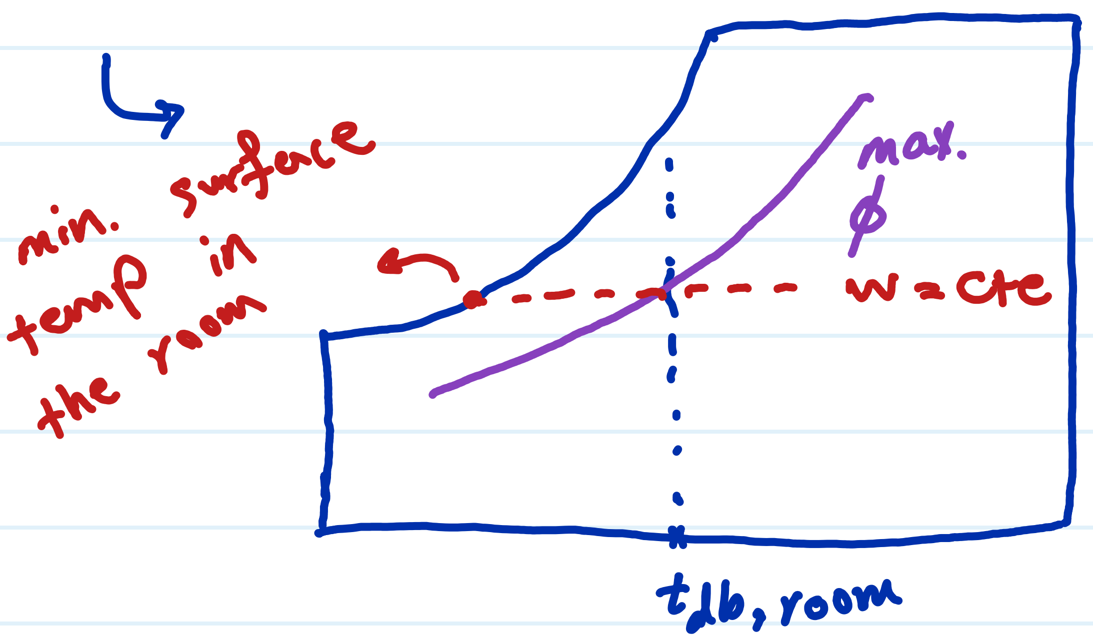
* one point about AHU:

the amount of energy to heat outdoor air and the room is equal to the the capacity of heaters.

supply to room + outside = mixed to supply

* one point about maximum ϕ of room

↳



Thermal Comfort

* metabolic rate per unit of a seated quiet person → "met"

1 met $= 18.4 \dfrac{Btu}{hr \cdot ft^2} = 58.2 \dfrac{W}{m^2}$

effective HT area of an adult $= 1.82\ m^2$
$= 19.6\ ft^2$

Table 4 Typical Metabolic Heat Generation for Various Activities

	$Btu/h \cdot ft^2$	met[a]
Resting		
Sleeping	13	0.7
Reclining	15	0.8
Seated, quiet	18	1.0
Standing, relaxed	22	1.2
Walking (on level surface)		
2.9 fps (2 mph)	37	2.0
4.4 fps (3 mph)	48	2.6
5.9 fps (4 mph)	70	3.8
Office Activities		
Reading, seated	18	1.0
Writing	18	1.0
Typing	20	1.1
Filing, seated	22	1.2
Filing, standing	26	1.4
Walking about	31	1.7
Lifting/packing	39	2.1
Driving/Flying		
Car	18 to 37	1.0 to 2.0
Aircraft, routine	22	1.2
Aircraft, instrument landing	33	1.8
Aircraft, combat	44	2.4
Heavy vehicle	59	3.2

Table 4 Typical Metabolic Heat Generation for Various Activities

	Btu/h·ft^2	met[a]
Miscellaneous Occupational Activities		
Cooking	29 to 37	1.6 to 2.0
Housecleaning	37 to 63	2.0 to 3.4
Seated, heavy limb movement	41	2.2
Machine work		
sawing (table saw)	33	1.8
light (electrical industry)	37 to 44	2.0 to 2.4
heavy	74	4.0
Handling 110 lb bags	74	4.0
Pick and shovel work	74 to 88	4.0 to 4.8
Miscellaneous Leisure Activities		
Dancing, social	44 to 81	2.4 to 4.4
Calisthenics/exercise	55 to 74	3.0 to 4.0
Tennis, singles	66 to 74	3.6 to 4.0
Basketball	90 to 140	5.0 to 7.6
Wrestling, competitive	130 to 160	7.0 to 8.7

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Table 5 Heart Rate and Oxygen Consumption at Different Activity Levels

Level of Exertion	Heart Rate, bpm	Oxygen Consumed, ft^3/h
Light work	< 90	< 1
Moderate work	90 to 110	1 to 2
Heavy work	110 to 130	2 to 3
Very heavy work	130 to 150	3 to 4
Extremely heavy work	150 to 170	> 4

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* a heavy two-pieces business suit with accessories → insulation value of 1 'clo'

$$1 \text{ clo} = 0.88 \frac{F\, ft^2 \cdot hr}{Btu} = 0.155 \frac{m^2 C}{W}$$

Thermal Resistance of Clothing

Clothing level	R-value (clo)	R-value (hr-ft^2-F/Btu)	R-value (m^2-C/W)
Summer dress	0.35 to 0.45	0.3 to 0.4	0.05 – 0.07
Light weight office dress	0.55 to 0.7	0.5 to 0.6	0.09 – 0.11
Medium weight office dress	0.7 to 0.9	0.6 to 0.8	0.11 – 0.14
Business suit	0.9 to 1.3	0.8 to 1.2	0.14 – 0.21

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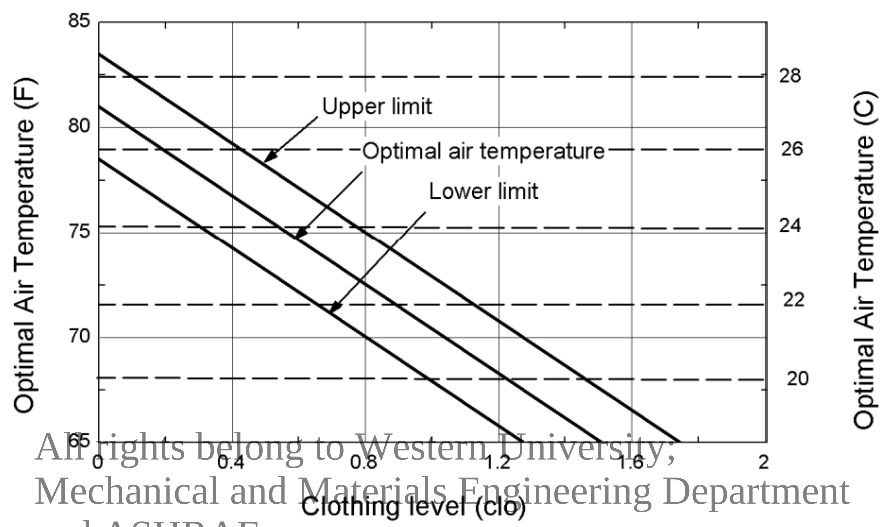
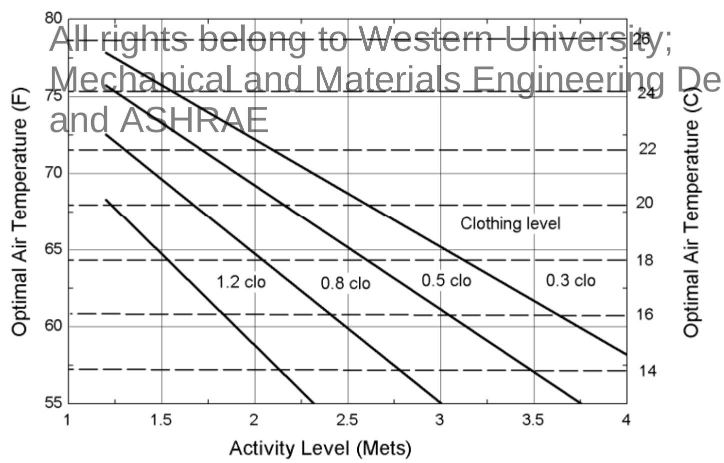
look at the standard 55 for more information.

Optimal air temperature for comfort under light activity



Optimal air temperatures for comfort



$$T_{a,opt} = 81.0 - 10.6\,R_c - 5.4\,(1 + R_c)(\dot{M} - 1.2) \quad \text{(F)}$$

$$T_{a,opt} = 27.2 - 5.9\,R_c - 3.0\,(1 + R_c)(\dot{M} - 1.2) \quad \text{(C)}$$

T_a : ambient air temperature

T_g : globe temperature (temp. without the effect of radiation)

T_{mrt} : mean radiant temperature

$$T_{mrt}^4 = T_g^4 + C\bar{v}^{0.5}(T_g - T_a)$$

C : 0.103×10^8 (IP) or 0.247×10^3 (SI)

$\bar{v}$: air velocity, fpm or m/s

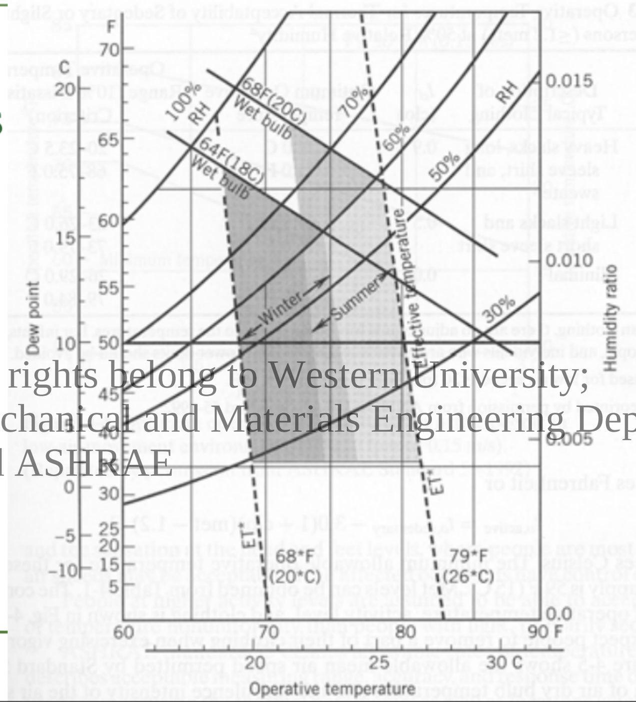
$$\boxed{t_o = \frac{T_{mrt} + T_a}{2}}$$ → operative temperature

t_{wbg} : wet bulb globe temperature

t_{nwb} : naturally ventilated wet bulb temp.

$$\boxed{t_{wbg} = 0.7\, t_{nwb} + 0.2\, t_g + 0.1\, t_{db}}$$

Comfort Conditions



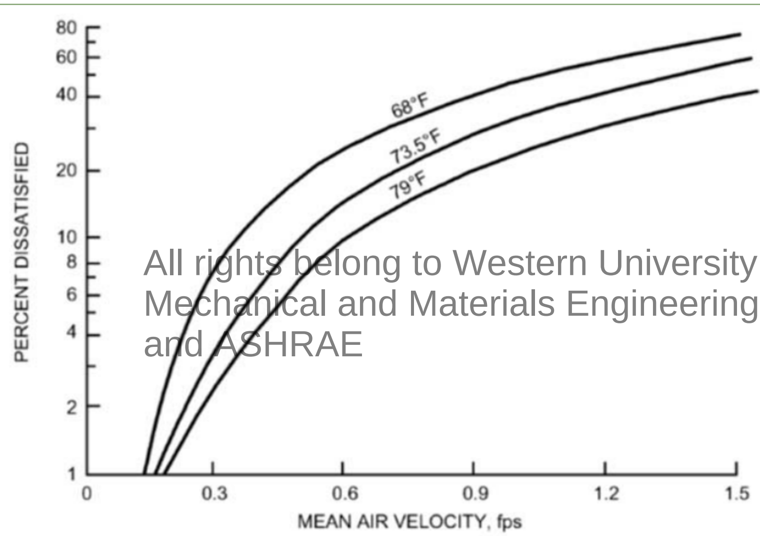


Fig. 8 Percentage of People Dissatisfied as Function of Mean Air Velocity

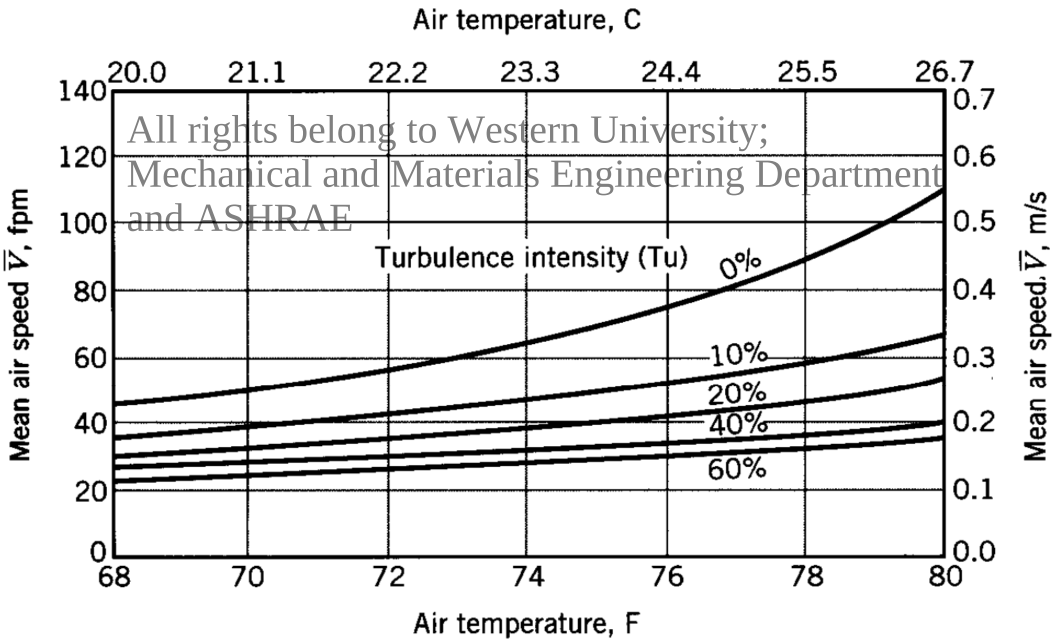


Figure 4-5 Allowable mean air speed as a function of air temperature and turbulence intensity. (Reprinted by permission from ASHRAE Standard 55-1992)

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$$\dot{Q}_t C_e + \dot{N} = \dot{Q}_t C_s$$

$\dot{Q}_t$: supply air rate + infiltration rate

= return air rate + exfiltration rate + room exhaust rate (L/s)

C_e : Concentration of contaminants in entering air (ppm) or %

C_s : Concentration of space contaminants (ppm) or %

$\dot{N}$: Contaminants generation rate in space (L/s)

Table 4-4 National Primary Ambient-Air Quality Standards for Outdoor Air as Set by the U.S. Environmental Protection Agency (7)

	Long Term Concentration			Short Term Concentration		
Contaminant	$\mu g/m^3$	ppm	Averaging	$\mu g/m^3$	ppm	Averaging
Sulfur dioxide	80	0.03	1 year	365[a]	0.14[a]	24 hours
Particles (PM 10)	50[b]	—	1 year	150[a]	—	24 hours
Carbon monoxide				40,000[a]	35[a]	1 hour
Carbon monoxide				10,000[a]	9[a]	8 hours
Oxidants (ozone)				235[c]	0.12[c]	1 hour
Nitrogen dioxide	100	0.055	1 year			
Lead	1.5	—	3 months[d]			

[a]Not to be exceeded more than once per year.

[b]Arithmetic mean.

[c]Standard is attained when expected number of days per calendar year with maximal average concentrations above 0.12 ppm (235 $\mu g/m^3$) is equal to or less than 1.

[d]Three-month period is a calendar quarter.

Source: Reprinted by permission from ANSI/ASHRAE Standard 62-1989 (1).

Ventilation Rate Procedure

Table 4-5 Outdoor-Air Requirements for Ventilation[a]—Commercial Facilities (Offices, Stores, Shops, Hotels, Sports Facilities)

Application	Estimated Maximum[b] Occupancy, persons per 1000 ft^2 or 100 m^2	Outdoor-Air Requirements: cfm/person	L/(s-person)	cfm/ft^2	L/(s-m^2)	Comments
Dry Cleaners, Laundries						Dry-cleaning processes may require more air.
Commercial laundry	10	25	13			
Commercial dry cleaner	30	30	15			
Storage, pickup	30	35	18			
Coin-operated laundries	20	15	8			
Coin-operated dry cleaner	20	15	8			
Food and Beverage Service						
Dining rooms	70	20	10			
Cafeteria, fast food	100	20	10			
Bars, cocktail lounges	100	30	15			Supplementary smoke-removal equipment may be required.
Kitchens (cooking)	20	15	8			Makeup air for hood exhaust may require more ventilating air. The sum of the outdoor air and transfer air of acceptable quality from adjacent spaces shall be sufficient to provide an exhaust rate of not less than 1.5 cfm/ft^2 [7.5 L/(s-m^2)].

for more information look at the standard 62.1

Heat Transfer Principles

Conduction

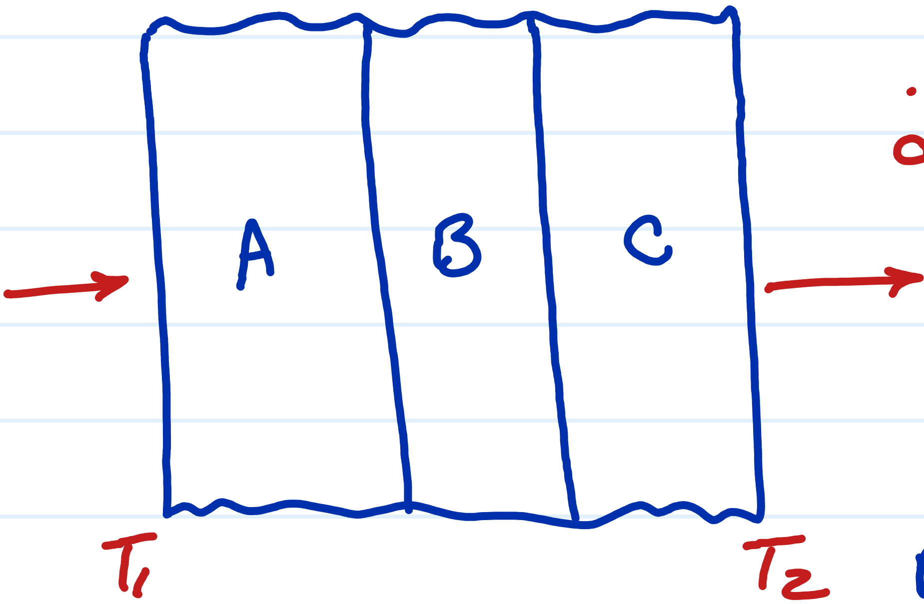
$$\dot{q} = -kA\frac{\Delta T}{\Delta x} = -\frac{\Delta T}{R'} = -\frac{A\Delta T}{R}$$

thermal resistance $\quad R' = \frac{\Delta x}{kA} \quad \frac{hr.F}{Btu}$ or $\frac{K}{W}$

unit thermal resistance $\quad R = \frac{\Delta x}{k} \quad \frac{hr.ft^2.F}{Btu}$ or $\frac{m^2K}{W}$

heat conductivity $\quad k \quad \frac{Btu\,.in}{hr\,ft^2.F}$ or $\frac{W}{m.k}$

unit conductance $\quad U = C = \frac{1}{R}$



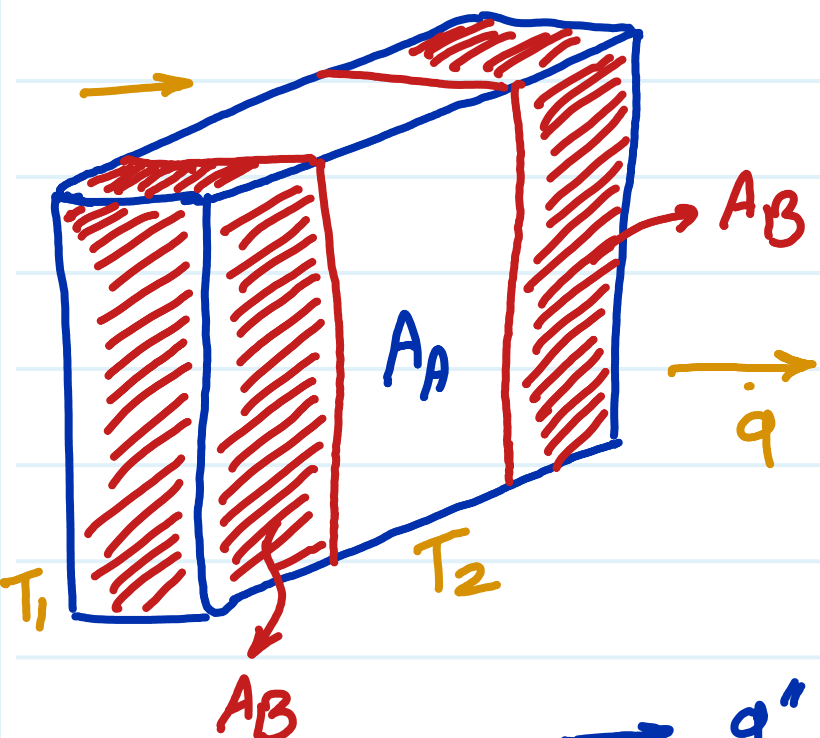
$$\dot{q} = \frac{\Delta T}{R'_{tot}}$$

$\dot{q}$

$$q'' = \frac{\Delta T}{R_{tot}}$$

$$R'_{tot} = R'_A + R'_B + R'_C$$

$$R_{tot} = R_A + R_B + R_C$$



$$\frac{1}{R'_{tot}} = \frac{1}{R'_A} + \frac{1}{R'_B}$$

$$\dot{q} = \frac{\Delta T}{R'_{tot}}$$

$$\rightarrow q'' = \frac{\dot{q}}{A_{tot}}$$

$$R_{tot,eq} = \frac{\Delta T}{q''} = R'_{tot} \cdot A_{tot}$$

Thermal Conduction cont'd

Curved wall

$$\dot{q} = -kA\frac{dT}{dx}$$

Integration of the heat transfer equation with k and q constants and A a function of r yields

$$\dot{q} = \frac{2\pi kL}{\ln(\frac{r_0}{r_i})}(t_i - t_0)$$

L is the length of the wall

The thermal resistance is: $R' = \frac{\ln(\frac{r_0}{r_i})}{2\pi kL}$

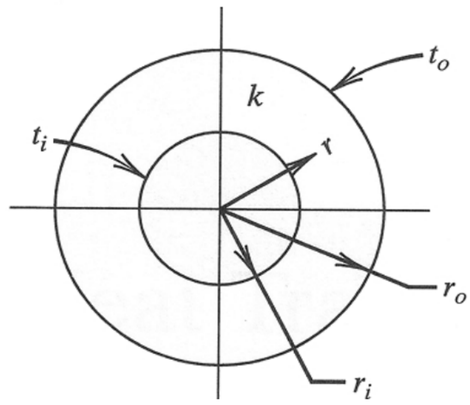


Figure 5-2 Radial heat flow in a hollow cylinder.

Table 5-1b Typical Thermal Properties of Common Building and Insulating Materials—Design Values[a]

Description	Thickness, mm	Density ρ, kg/m^3	Conductivity k, W/(m-C)	Conductance C, $W/(m^2\text{-}C)$	Specific Heat, kJ/(kg-C)
Building Board					
Asbestos–cement board	6.4	1900	—	93.7	—
Gypsum or plaster board	9.5	800	—	17.6	1.09
Gypsum or plaster board	12.7	800	—	12.6	—
Plywood (Douglas fir)	—	540	0.12	—	1.21
Plywood (Douglas fir)	6.4	540	—	18.2	—
Plywood (Douglas fir)	9.5	540	—	12.1	—
Plywood (Douglas fir)	12.7	540	—	9.1	—
Plywood or wood panels	19.0	540	—	6.1	—
Vegetable fiber board	—	—	—	—	1.21
Sheathing, regular density	12.7	290	—	4.3	—
Sheathing intermediate density	12.7	350	—	5.2	—
Sound deadening board	12.7	240	—	4.2	1.26
Tile and lay-in panels, plain or acoustic	—	290	0.058	—	0.59
Hardboard					
Medium density	—	800	0.105	9.50	—
High-density, standard-tempered grade	—	1010	0.144	6.93	—

continues

Table 5-1*b* Typical Thermal Properties of Common Building and Insulating Materials—Design Values[a] *(continued)*

Description	Thickness, mm	Density ρ, kg/m^3	Conductivity k, W/(m-C)	Conductance C, W/(m^2-C)	Specific Heat, kJ/(kg-C)
Particleboard					
Medium density	—	800	0.135	7.35	—
Underlayment	15.9	640	—	6.9	1.21
Wood subfloor	19.0	—	—	6.0	1.38
Building Membrane					
Vapor-permeable felt	—	—	—	94.9	—
Vapor-seal, 2 layers of mopped 0.73 kg/M2 felt	—	—	—	47.4	—
Finish Flooring Materials					
Carpet and fibrous pad	—	—	—	2.73	—
Carpet and rubber pad	—	—	—	4.60	1.38
Tile—asphalt, linoleum, vinyl, rubber	—	—	—	113.6	1.26
Wood, hardwood finish	19.0	—	—	8.35	0.112
Insulating Materials					
Blanket and Batt					
Mineral fiber, fibrous form processed from rock, slag, or glass					
approx. 75–100 mm	—	6.4–32	—	0.52	—
approx. 90 mm	—	19–26	—	0.38	—
approx. 140–165 mm	—	6.4–32	—	0.30	—
approx. 140 mm	—	10–16	—	0.27	—
approx. 150–190 mm	—	6.4–32	—	0.26	—
approx. 210–250 mm	—	6.4–32	—	0.19	—
Board and Slabs					
Cellular glass	—	136	0.050	—	—
Glass fiber, organic bonded	—	64–140	0.036	—	—
Expanded polystrene, molded beads	—	16	0.037	—	—
Mineral fiber with resin binder	—	240	0.042	—	—
Core or roof insulation	—	260–270	0.049	—	—
Acoustical tile	12.7	—	—	4.5	—
Acoustical tile	19.0	—	—	3.0	—
Loose Fill					
Cellulosic insulation (milled paper or wood pulp)	—	37–51	0.039–0.046	—	1.398
Perlite, expanded	—	32–66	0.039–0.045	—	1.09
	—	66–120	0.045–0.052	—	—
	—	120–180	0.052–0.060	—	—
Mineral fiber (rock, slag, or glass)					
approx. 95–130 mm	—	9.6–3.2	—	0.52	0.71
approx. 170–220 mm	—	9.6–3.2	—	0.31	—
approx. 190–250 mm	—	9.6–3.2	—	0.26	—
approx. 260–350 mm	—	9.6–3.2	—	0.19	5.28
Mineral fiber (rock, slag or glass)					
approx. 90 trim (closed sidewall application)	—	32–56	2.1–2.5	—	—

continues

Table 5-1*b* Typical Thermal Properties of Common Building and Insulating Materials—Design Values[a] *(continued)*

Description	Thickness, mm	Density ρ, kg/m^3	Conductivity k, W/(m-C)	Conductance C, W/(m^2-C)	Specific Heat, kJ/(kg-C)
Vermiculite, exfoliated	—	110–130	0.068	—	1.34
	—	64–96	0.063	15.7	—
Metals					
Aluminum (1100)	—	2660	221.5	—	0.90
Steel, mild	—	7600	45.3	—	0.50
Steel, stainless	—	7680	15.6	—	0.46
Roofing					
Asbestos–cement shingles	—	1900	—	27.0	1.00
Asphalt roll roofing	—	1100	—	36.9	1.51
Asphalt shingles	—	1100	—	12.9	1.26
Built-up roofing	10	1100	—	17.0	1.46
Slate	13	—	—	11.4	1.26
Wood shingles, plain and plastic film faced	—	—	—	6.0	1.30
Plastering Materials					
Cement plaster, sand aggregate	—	1860	0.72	—	0.84
Sand aggregate	10	—	—	75.5	0.84
Sand aggregate	20	—	—	37.8	0.84
Gypsum plaster					
Lightweight aggregate	13	720	—	17.7	—
Lightweight aggregate	16	720	—	15.2	—
Lightweight aggregate on metal lath	19	—	—	12.1	—
Masonry Materials					
Masonry Units					
Brick, fired clay	—	2080	0.92–1.12	—	—
	—	1920	0.81–0.98	—	0.79
Clay tile, hollow					
1 cell deep	100	—	—	5.11	—
2 cells deep	150	—	—	3.75	—
3 cells deep	200	—	—	3.07	—
Concrete blocks					
Normal mass aggregate (sand and gravel), 200 mm, 15–16 kg, 2020–2180 kg/m^3 concrete, 2 or 3 cores	—	—	—	5.1–5.8	0.92
Low-mass aggregate (expanded shale, clay, slate or slag, pumice), 150 mm, 7.3–7.7 kg, 360–1390 kg/m^3 concrete, 2 or 3 cores	—	—	—	3.0–3.5	—
Same with vermiculite-filled	—	—	—	1.87	—
cores, 200 mm, 8.6–10.0 mm, 1150–1380 kg/m^3 concrete	—	—	1.8–3.1	—	—
Same with vermiculite-filled cores	—	—	1.1–1.5	0.93–0.69	—

continues

Table 5-1*b* Typical Thermal Properties of Common Building and Insulating Materials—Design Values[a] *(continued)*

Description	Thickness, mm	Density ρ, kg/m^3	Conductivity k, W/(m-C)	Conductance C, W/(m^2-C)	Specific Heat, kJ/(kg-C)
Concretes					
Sand and gravel or stone aggregate concretes (concretes with more than 50% quartz or quartzite sand have	—	2400	1.4–2.9	—	—
conductivities in the	—	2240	1.3–2.6	—	—
higher end of the range)	—	2080	1.0–1.9	—	—
Limestone concretes	—	1920	1.14	—	—
	—	1600	0.79	—	—
Cement/lime, mortar, and	—	1600	0.97	1.04	—
stucco	—	1280	0.65	1.54	—
Lightweight aggregate concretes					
Expanded shale, clay, or slate; expanded slags;	—	1920	0.9–1.3	1.08–0.76	—
cinders; pumice (with	—	1600	0.68–0.89	1.48–1.12	—
density up to 1600 kg/m^3); and scoria (sanded concretes have conductivities in the higher end of the range)	—	1280	0.48–1.19	—	0.84
Siding Materials (on Flat Surface)					
Asbestos–cement shingles	—	1900	—	27.0	—
Wood, drop, 20 × 200 mm	—	—	7.21	—	1.17
Aluminum, steel, or vinyl, over sheathing, hollow-backed	—	—	9.13	—	1.22’1
Insulating-board backed					
9.5 mm nominal	—	—	3.12	—	1.34
9.5 mm nominal, foil-backed	—	—	1.93	—	—
Architectural (soda–lime float) glass	—	—	56.8	—	0.84
Woods (12% Moisture Content)					
Hardwoods					
Oak	—	659–749	0.16–0.18	—	1.63
Softwood					
Hem–fir, spruce–pine–fir	—	392–502	0.107–0.130	—	1.63

[a]Values are for a mean temperature of 24 C and are representative of dry materials for design but may differ depending on installation and workmanship.

Source: Reprinted with permission from *ASHRAE Handbook, Fundamentals Volume*, 1997.

Table 5-1*a* Typical Thermal Properties of Common Building and Insulating Materials—Design Values[a]

Description	Thickness, in.	Density ρ, lbm/ft^3	Conductivity k, (Btu-in.)/(hr-ft^2-F)	Conductance C, Btu/(hr-ft^2-F)	Specific Heat, Btu/(lbm-F)
Building Board					
Asbestos–cement board	0.25	120	—	16.50	0.24
Gypsum or plaster board	0.375	50	—	3.10	0.26
Gypsum or plaster board	0.50	50	—	2.22	0.26
Plywood (Douglas fir)	—	34	0.80	—	—
Plywood (Douglas fir)	0.25	34	—	3.20	—
Plywood (Douglas fir)	0.375	34	—	2.13	—
Plywood (Douglas fir)	0.50	34	—	1.60	—
Plywood or wood panels	0.75	34	—	1.07	0.29
Vegetable fiber board					
Sheathing, regular density	0.50	18	—	0.76	0.31
Sheathing intermediate density	0.50	22	—	0.92	0.31
Sound deadening board	0.50	15	—	0.74	0.30
Hardboard					
Medium density	—	50	0.73	—	0.32
Service grade	—	55	0.82	—	
High-density, standard-tempered grade	—	63	1.00	—	—
Particle board					
Medium density	—	50	0.94	—	0.31
Underlayment	0.625	40	—	1.22	0.29
Wood subfloor	0.75	—	—	1.06	0.33
Building Membrane					
Vapor-permeable felt		—	—	16.70	—
Vapor-seal, 2 layers of mopped 15 lb felt	—	—	—	8.35	—
Finish Flooring Materials					
Carpet and fibrous pad	—	—		0.48	0.34
Carpet and rubber pad	—	—	—	0.81	0.33
Tile—asphalt, linoleum, vinyl, rubber	—	—	—	20.00	0.30
Wood, hardwood finish	0.75	—	—	1.47	—
Insulating Materials					
Blanket and Batt					
Mineral fiber, fibrous form processed from rock, slag, or glass					
approx. 3–4 in.	—	0.4–2.0	—	0.091	—
approx. 3.5 in.	—	1.2–1.6	—	0.067	—
approx. 5.5–6.5 in.	—	0.4–2.0	—	0.053	—
approx. 5.5 in.	—	0.6–1.0	—	0.048	—
approx. 6–7.5 in.	—	0.4–2.0	—	0.045	—
approx 8.25–10 in.	—	0.4–2.0	—	0.033	—

continues

Table 5-1*a* Typical Thermal Properties of Common Building and Insulating Materials—Design Values[a] *(continued)*

Description	Thickness, in.	Density ρ, lbm/ft^3	Conductivity k, (Btu-in.)/(hr-ft^2-F)	Conductance C, Btu/(hr-ft^2-F)	Specific Heat, Btu/(lbm-F)
Board and Slabs					
Cellular glass	—	8.0	0.33	—	0.18
Glass fiber, organic bonded	—	4.0–9.0	0.25	—	0.23
Expanded polystyrene, molded beads.	—	1.0	0.36	—	—
Mineral fiber with resin binder	—	15.0	0.29	—	0.17
Core or roof insulation	—	16–17	0.34	—	—
Acoustical tile	0.50	—	—	0.80	0.31
Acoustical tile	0.75	—	—	0.53	—
Loose Fill					
Cellulosic insulation (milled paper or wood pulp)	—	2.3–32	0.27–0.32	—	0.33
Perlite, expanded	—	2.0–4.1	0.27–0.31	—	0.26
	—	4.1–7.4	0.31–0.36	—	—
	—	7.4–11.0	0.36–0.42	—	—
Mineral fiber (rock, slag, or glass)					
approx. 3.75–5 in.	—	0.6–2.0	—	0.091	0.17
approx. 6.5–8.75 in.	—	0.6–2.0	—	0.053	—
approx. 7.5–10 in.	—	0.6–2.0	—	0.045	—
approx. 10.25–13.75 in.	—	0.6–2.0	—	0.033	—
Mineral fiber (rock, slag, or glass)					
approx. 3.5 in. (closed sidewall application)	—	2.0–3.5	—	0.077	—
Vermiculite, exfoliated	—	7.0–8.2	0.47	—	0.32
	—	4.0–6.0	0.44	—	—
Metals					
Aluminum (1100)	—	171	1536	—	0.214
Steel, mild	—	489	314	—	0.12
Steel, stainless	—	494	108	—	0.109
Roofing					
Asbestos–cement shingles	—	120	—	4.76	0.24
Asphalt roll roofing	—	70	—	6.50	0.36
Asphalt shingles	—	70	—	2.27	0.30
Built-up roofing	0.375	70	—	3.00	0.35
Slate	0.50	—	—	20.00	0.30
Wood shingles, plain and plastic-film-faced	—	—	—	1.06	0.31
Plastering Materials					
Cement plaster, sand aggregate	—	116	5.0	—	0.20
Sand aggregate	0.375	—	—	13.3	0.20
Sand aggregate	0.75	—	—	6.66	0.20
Gypsum plaster					
Lightweight aggregate	0.50	45	—	3.12	—
Lightweight aggregate	0.625	45	—	2.67	—
Lightweight aggregate on metal lath	0.75	—	—	2.13	—

Table 5-1*a* Typical Thermal Properties of Common Building and Insulating Materials—Design Values[a] *(continued)*

Description	Thickness, in.	Density ρ, lbm/ft^3	Conductivity k, (Btu-in.)/(hr-ft^2-F)	Conductance C, Btu/(hr-ft^2-F)	Specific Heat, Btu/(lbm-F)
Masonry Materials					
Masonry Units					
Brick, fired clay	—	130	6.4–7.8	—	—
	—	120	5.6–6.8	—	0.19
Clay tile, hollow					
1 cell deep	4	—	—	0.90	0.21
2 cells deep	6	—	—	0.66	—
3 cells deep	8	—	—	0.54	—
Concrete blocks					
Normal weight aggregate (sand and gravel), 8 in., 33–36 lb, 126–136 lb/ft^3 concrete, 2 or 3 cores	—	—	—	0.90–1.03	0.22
Lightweight aggregate (expanded shale, clay, slate or slag, pumice), 6 in., 16–17 lb, 85–87 lb/ft^3 concrete, 2 or 3 cores	—	—	—	0.52–0.61	—
Same with vermiculite-filled cores, 8 in., 19–22 lb,	—	—	—	0.33	—
72–86 lb/ft^3 concrete	—	—	—	0.32–0.54	0.21
Same with vermiculite-filled cores	—	—	—	0.19–0.26	—
Concretes					
Sand and gravel or stone aggregate concretes	—	150	10.0–20.0	—	—
(concretes with more than 50%	—	140	9.0–18.0	—	0.19–0.24
quartz or quartzite sand have conductivities in the higher end of the range)	—	130	7.0–13.0	—	—
Limestone concretes	—	120	7.9	—	—
	—	100	5.5	—	—
Cement/lime, mortar, and	—	100	6.7	—	—
stucco	—	80	4.5	—	—
Lightweight aggregate concretes	—	120	6.4–9.1	—	—
Expanded shale, clay, or slate;	—	100	4.7–6.2	—	0.20
expanded slags; cinders; pumice (with density up to 100 lb/ft^3); and scoria (sanded concretes have conductivities in the higher end of the range)	—	80	3.3–4.1	—	0.20

continues

Table 5-1*a* Typical Thermal Properties of Common Building and Insulating Materials—Design Values[a] *(continued)*

Description	Thickness, in.	Density ρ, lbm/ft^3	Conductivity k, (Btu-in.)/(hr-ft^2-F)	Conductance C, Btu/(hr-ft^2-F)	Specific Heat, Btu/(lbm-F)
Siding Materials (on Flat Surface)					
Asbestos–cement shingles	—	120	—	4.75	—
Wood, drop, 1 × 8 in.	—	—	—	1.27	0.28
Aluminum, steel, or vinyl, over sheathing, hollow-backed	—	—	—	1.64	0.29
Insulating-board-backed, nominal 0.375 in.	—	—	—	0.55	0.32
Insulating-board-backed, nominal 0.375 in., foil backed	—	—	—	0.34	—
Architectural (soda–lime float) glass	—	158	6.9	—	0.21
Woods (12% Moisture Content)					
Hardwoods					
Oak	—	41.2–46.8	1.12–1.25	—	0.39
Softwoods					
Hemlock, fir, spruce, pine	—	24.5–31.4	0.74–0.90	—	0.39

[a]Values are for a mean temperature of 75 F and are representative of dry materials for design but may differ depending on installation and workmanship.

Source: Reprinted with permission from *ASHRAE Handbook, Fundamentals Volume*, 1997.

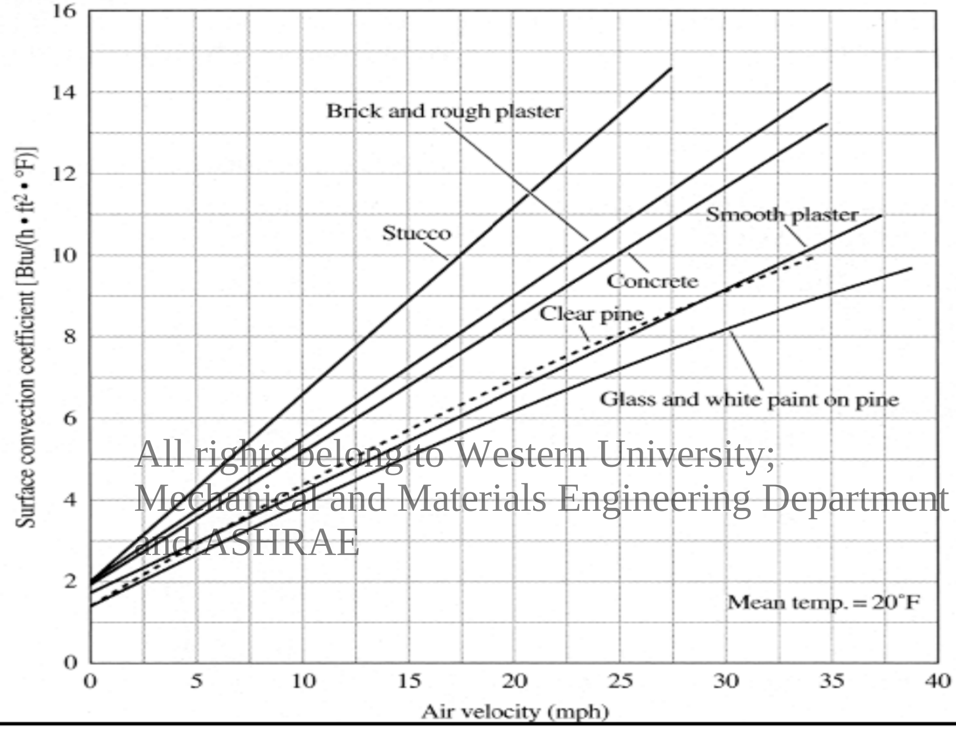
Convection

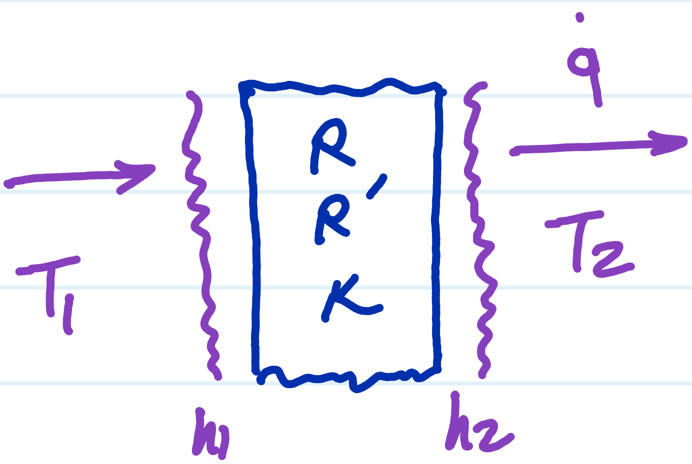
$$\dot{q} = hA\Delta T \qquad R' = \frac{1}{hA} \qquad R = \frac{1}{h}$$

$$C^* = U = \frac{1}{R}$$

IV. Simplified equations for air

(a) Vertical plane surfaces, V of 5 to 30 m/s (room temperature)[c]	McAdams	249	(9-42)	$h' = 7.2V^{0.78}$
(b) Vertical plane surfaces, $V < 5$ m/s (room temperature)[c]	McAdams	249	(9-42)	$h' = 5.62 + 3.9V$

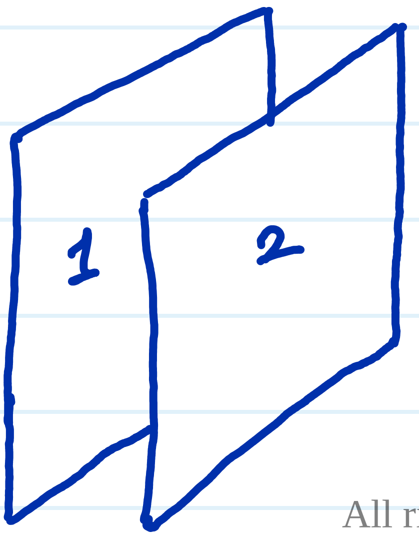




$$R'_{tot} = \frac{1}{h_1 A} + R' + \frac{1}{h_2 A}$$

$$R_{tot} = \frac{1}{h_1} + R + \frac{1}{h_2} \qquad \dot{q} = \frac{\Delta T}{R'_{tot}} \qquad q'' = \frac{\Delta T}{R_{tot}}$$

Radiation



$$q_{12} = \frac{\sigma (T_1^4 - T_2^4)}{\frac{1-\varepsilon_1}{A_1 \varepsilon_1} + \frac{1}{A_1 F_{12}} + \frac{1-\varepsilon_2}{A_2 \varepsilon_2}}$$

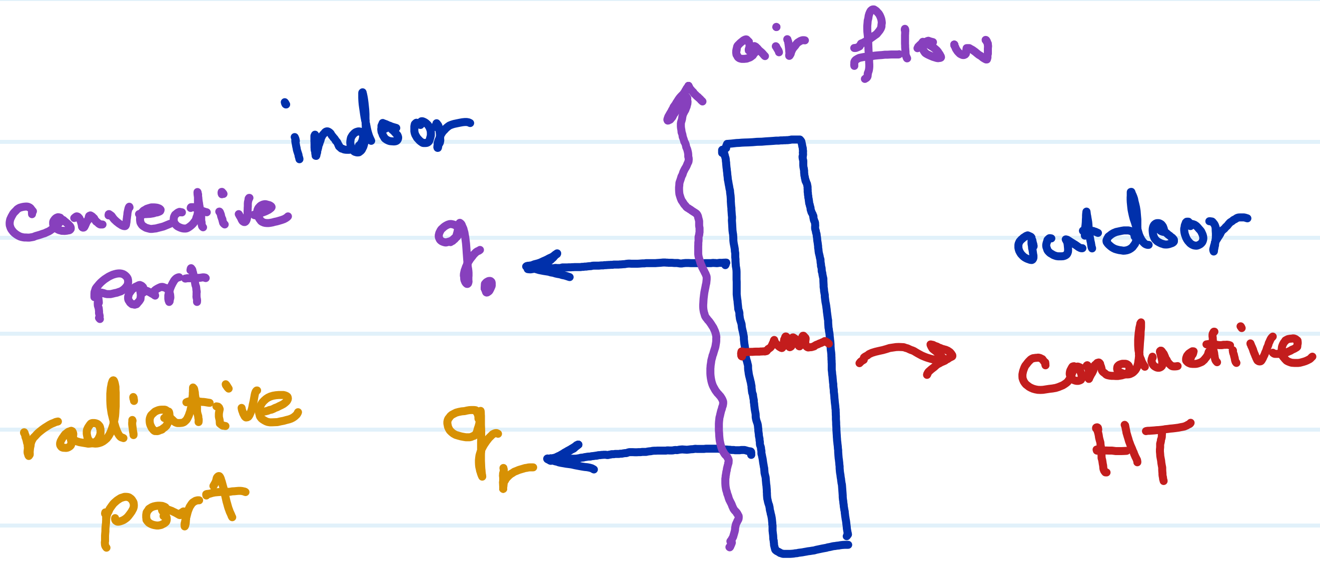
F: Configuration Factor

ε : emittance

σ Boltzman constant

$0.1713 \times 10^{-8} \ \frac{Btu}{hr.ft.F}$

$5.673 \times 10^{-8} \ W/m^2K$



Thermal Radiation cont'd

Table 5-2a Surface Unit Conductances and Unit Resistances for Air[a]

		Surface Emittances											
		$\epsilon = 0.9$				$\epsilon = 0.2$				$\epsilon = 0.05$			
		h		*R*		*h*		*R*		*h*		*R*	
Position of Surface	Direction of Heat Flow	Btu / hr-ft²-F	W / m²-C	hr-ft²-F / Btu	m²-C / W	Btu / hr-ft²-F	W / m²-C	hr-ft²-F / Btu	m²-C / W	Btu / hr-ft²-F	W / m²-C	hr-ft²-F / Btu	m²-C / W
Still Air													
Horizontal	Upward	1.63	9.26	0.61	0.11	0.91	5.2	1.10	0.194	0.76	4.3	1.32	0.232
Sloping—45 degrees	Upward	1.60	9.09	0.62	0.11	0.88	5.0	1.14	0.200	0.73	4.1	1.37	0.241
Vertical	Horizontal	1.46	8.29	0.68	0.12	0.74	4.2	1.35	0.238	0.59	3.4	1.70	0.298
Sloping—45 degrees	Downward	1.32	7.50	0.76	0.13	0.60	3.4	1.67	0.294	0.45	2.6	2.22	0.391
Horizontal	Downward	1.08	6.13	0.92	0.16	0.37	2.1	2.70	0.476	0.22	1.3	4.55	0.800
Moving Air													
(any position) Wind is 15 mph or 6.7 m/s (for winter)	Any	6.0	34.0	0.17	0.029								
Wind is $7\frac{1}{2}$ mph or 3.4 m/s (for summer)	Any	4.0	22.7	0.25	0.044								

[a] Conductances are for surfaces of the stated emittance facing virtual blackbody surroundings at the same temperature as the ambient air. Values are based on a surface–air temperature difference of 10 F and for a surface temperature of 70 F.

Source: Adapted by permission from *ASHRAE Handbook, Fundamentals Volume*, 1989.

Note: 1- the thermal radiation is large factor when natural convection occurs

2- with high air velocity (forced convection) the relative effect of radiation diminishes

3- Radiation appears to be very important in the heat gains through ceiling spaces

$$\frac{1}{E} = \frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2} - 1$$

E. effective emittance of air space

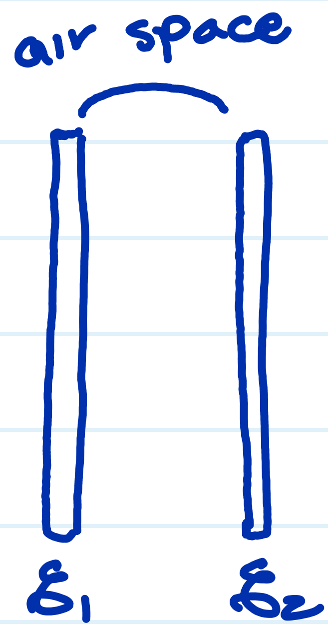


Table 5-2*b* Reflectance and Emittance of Various Surfaces and Effective Emittances of Air Space

Surface	Reflectance, percent	Average Emittance ϵ	Effective Emittance E of Air Space: With One Surface Having Emittance ϵ and Other 0.90	Effective Emittance E of Air Space: With Both Surfaces of Emittance ϵ
Aluminum foil, bright	92–97	0.05	0.05	0.03
Aluminum sheet	80–95	0.12	0.12	0.06
Aluminum coated paper, polished	75–84	0.20	0.20	0.11
Steel, galvanized, bright	70–80	0.25	0.24	0.15
Aluminum paint	30–70	0.50	0.47	0.35
Building materials—wood, paper, glass, masonry, nonmetallic paints	5–15	0.90	0.82	0.82

Source: Adapted by permission from *ASHRAE Handbook, Fundamentals Volume*, 1989.

Table 5-3a Thermal Resistances of Plane Air Spaces[a]

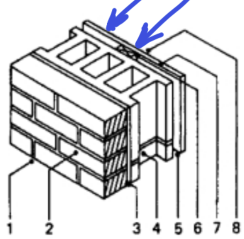
Orientation of Air Space	Direction of Heat Flow	Air Space Mean Temp., F	Air Space Temp. Diff., F	0.5 in. Air Space $E = 0.03^b$	0.05	0.2	0.5	0.82	0.75 in. Air Space 0.03	0.05	0.2	0.5	0.82
Horiz.	Up	90	10	2.13	2.03	1.51	0.99	0.73	2.34	2.22	1.61	1.04	0.75
		50	30	1.62	1.57	1.29	0.96	0.75	1.71	1.66	1.35	0.99	0.77
		50	10	2.13	2.05	1.60	1.11	0.84	2.30	2.21	1.70	1.16	0.87
		0	20	1.73	1.70	1.45	1.12	0.91	1.83	1.79	1.52	1.16	0.93
		0	10	2.10	2.04	1.70	1.27	1.00	2.23	2.16	1.78	1.31	1.02
		−50	20	1.69	1.66	1.49	1.23	1.04	1.77	1.74	1.55	1.27	1.07
		−50	10	2.04	2.00	1.75	1.40	1.16	2.16	2.11	1.84	1.46	1.20
45° Slope	Up	90	10	2.44	2.31	1.65	1.06	0.76	2.96	2.78	1.88	1.15	0.81
		50	30	2.06	1.98	1.56	1.10	0.83	1.99	1.92	1.52	1.08	0.82
		50	10	2.55	2.44	1.83	1.22	0.90	2.90	2.75	2.00	1.29	0.94
		0	20	2.20	2.14	1.76	1.30	1.02	2.13	2.07	1.72	1.28	1.00
		0	10	2.63	2.54	2.03	1.44	1.10	2.72	2.62	2.08	1.47	1.12
		−50	20	2.08	2.04	1.78	1.42	1.17	2.05	2.01	1.76	1.41	1.16
		−50	10	2.62	2.56	2.17	1.66	1.33	2.53	2.47	2.10	1.62	1.30
Vertical	Horiz.	90	10	2.47	2.34	1.67	1.06	0.77	3.50	3.24	2.08	1.22	0.84
		50	30	2.57	2.46	1.84	1.23	0.90	2.91	2.77	2.01	1.30	0.94
		50	10	2.66	2.54	1.88	1.24	0.91	3.70	3.46	2.35	1.43	1.01
		0	20	2.82	2.72	2.14	1.50	1.13	3.14	3.02	2.32	1.58	1.18
		0	10	2.93	2.82	2.20	1.53	1.15	3.77	3.59	2.64	1.73	1.26
		−50	20	2.90	2.82	2.35	1.76	1.39	2.90	2.83	2.36	1.77	1.39
		−50	10	3.20	3.10	2.54	1.87	1.46	3.72	3.60	2.87	2.04	1.56

Thermal Resistance, (F-ft²-hr)/Btu

Example

Table 5-4a Coefficients of Transmission U of Masonry Cavity Walls, Btu/(hr-ft²-F)[a]

two paths



Item	Construction 1 Between Furring	Construction 1 At Furring	Construction 2 Between Furring	Construction 2 At Furring
1. Outside surface (15 mph wind)	0.17	0.17	0.17	0.17
2. Face brick, 4 in.	0.44	0.44	0.44	0.44
3. Cement mortar, 0.5 in.	0.10	0.10	0.10	0.10
4. Concrete block[b]	1.72	1.72	2.99	2.99
5. Reflective air space, 0.75 in. (50 F mean; 30 F temperature difference)	2.77	—	2.77	—
6. Nominal 1 in. × 3 in. vertical furring	—	0.94	—	0.94
7. Gypsum wallboard 0.5 in., foil backed	0.45	0.45	0.45	0.45
8. Inside surface (still air)	0.68	0.68	0.68	0.68
Total thermal resistance R	$R_i = 6.33$	$R_s = 4.50$	$R_i = 7.60$	$R_s = 5.77$

Resistance R (hr-ft²-F)/Btu

table 5.2a

table 5.1

Construction 1: $U_i = 1/6.33 = 0.158$; $U_s = 1/4.50 = 0.222$. With 20% framing (typical of 1 in. × 3 in. vertical furring on masonry @ 16-in. o.c.), $U_{av} = 0.8(0.158) + 0.2(0.222) = 0.171$

Construction 2: $U_i = 1/7.60 = 0.132 U_s = 1/5.77 = 0.173$.
With framing unchanged, $U_{av} = 0.8(0.132) + 0.2(0.173) = 0.140$

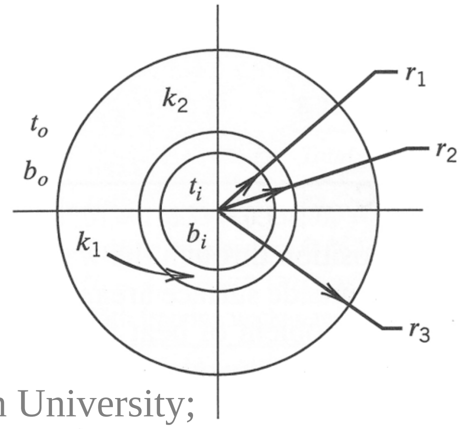
[a] U factor may be converted to W/(m²-C) by multiplying by 5.68.

[b] 8 in. cinder aggregate in construction 1; 6 in. lightweight aggregate with cores filled in construction 2.

Source: Adapted by permission from *ASHRAE Handbook, Fundamentals Volume*, 1977.

The Heat Transfer Through Building Fenestration (Insulated Pipe)

$$R_e' = \frac{1}{h_i A_i} + \frac{\ln(\frac{r_3}{r_2})}{2\pi k_2 L} + \frac{\ln(\frac{r_2}{r_1})}{2\pi k_1 L} + \frac{1}{h_0 A_0}$$



Or:

$$R_e' = \frac{1}{h_i A_i} + \frac{r_3 - r_2}{k_2 A_{m2}} + \frac{r_2 - r_1}{k_1 A_{m1}} + \frac{1}{h_0 A_0}$$

where

$$A_m = \frac{2\pi L(r_0 - r_i)}{\ln(\frac{r_0}{r_i})}$$

Table 5-5a *U*-Factors for Various Fenestration Products[a], Btu/(hr-ft^2-F) (Vertical Installation)

	Frame: Glass Only		Operable (Including Sliding and Swinging Glass Doors)					Fixed
	Center of Glass	Edge of Glass	Aluminum without Thermal Break	Aluminum with Thermal Break	Reinforced Vinyl/ Aluminum-Clad Wood	Wood/ Vinyl	Insulated Fiberglass/ Vinyl	Insulated Fiberglass/ Vinyl
Single Glazing								
$\frac{1}{8}$ in. glass	1.04	1.04	1.27	1.08	0.90	0.89	0.81	0.94
$\frac{1}{4}$ in. acrylic/ polycarb	0.88	0.88	1.14	0.96	0.79	0.78	0.71	0.81
$\frac{1}{8}$ in. acrylic/ polycarb	0.96	0.96	1.21	1.02	0.85	0.83	0.76	0.87
Double Glazing								
$\frac{1}{4}$ in. air space	0.55	0.64	0.87	0.65	0.57	0.55	0.49	0.53
$\frac{1}{2}$ in. air space	0.48	0.59	0.81	0.60	0.53	0.51	0.44	0.48
$\frac{1}{4}$ in. argon space	0.51	0.61	0.84	0.62	0.55	0.53	0.46	0.50
Double Glazing, $e = 0.60$ on surface 2 or 3								
$\frac{1}{4}$ in. air space	0.52	0.62	0.84	0.63	0.55	0.53	0.47	0-51
$\frac{1}{2}$ in. air space	0.44	0.56	0.78	0.57	0.50	0.48	0.42	0.45
$\frac{1}{4}$ in. argon space	0.47	0.58	0.81	0.59	0.52	0.50	0.44	0.47

→ for wind speed of 15 mph.
(mostly winter time)

Table 5-6a Glazing *U*-Factor for Various Wind Speeds

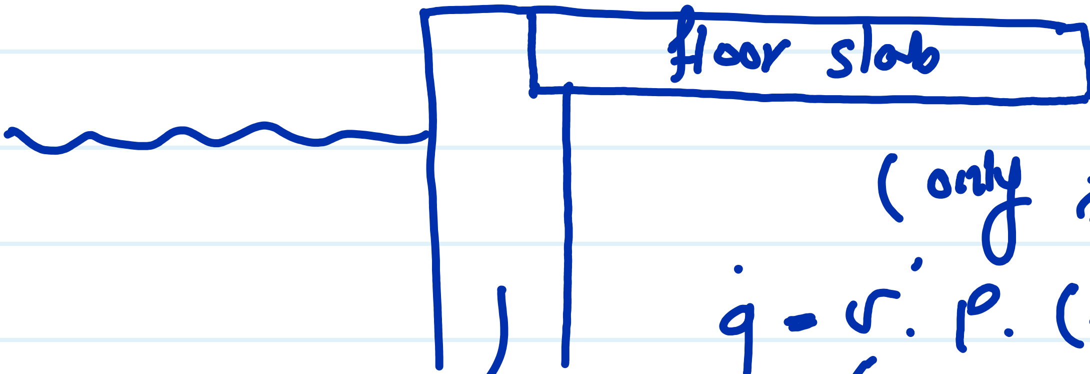
	U-Factor, Btu/(hr-ft²-F)		
Wind Speed	15	7.5	0 mph
	0.10	0.10	0.10
	0.20	0.20	0.19
	0.30	0.29	0.28
	0.40	0.38	0.37
	0.50	0.47	0.45
	0.60	0.56	0.53
	0.70	0.65	0.61
	0.80	0.74	0.69
	0.90	0.83	0.78
	1.00	0.92	0.86
	1.10	1.01	0.94
	1.20	1.10	1.02
	1.30	1.19	1.10

Source: Reprinted with permission from *ASHRAE Handbook, Fundamentals Volume*, 1997.

the effect of lower wind speed (mostly in summer time)

Table 5.7 Transmission Coefficients *U* for Wood and Steel Doors, Btu/(hr-ft²-F)[a]

Nominal Door Thickness, in.	Description	No Storm Door	Wood Storm Door[b]	Metal Storm Door[c]
Wood Doors[d,e]				
$1\frac{3}{8}$	Panel door with $\frac{7}{16}$-in. panels[f]	0.57	0.33	0.37
$1\frac{3}{8}$	Hollow core flush door	0.47	0.30	0.32
$1\frac{3}{8}$	Solid core flush door	0.39	0.26	0.28
$1\frac{3}{8}$	Panel door with $\frac{7}{16}$-in. panels[f]	0.57	0.33	0.36
$1\frac{3}{4}$	Hollow core flush door	0.46	0.29	0.32
$1\frac{3}{4}$	Panel door with $1\frac{1}{8}$-in. panels[f]	0.39	0.26	0.28
$1\frac{3}{4}$	Solid core flush door	0.40	—	0.26
$2\frac{1}{4}$	Solid core flush door	0.27	0.20	0.21
Steel Doors[e]				
$1\frac{3}{4}$	Fiberglass or mineral wool core with steel stiffeners, no thermal break[g]	0.60	—	—
$1\frac{3}{4}$	Paper honeycomb core without thermal break[g]	0.56	—	—
$1\frac{3}{4}$	Solid urethane foam core without thermal break[d]	0.40	—	—
$1\frac{3}{4}$	Solid fire rated mineral fiberboard core without thermal break[g]	0.38	—	—
$1\frac{3}{4}$	Polystyrene core without thermal break (18 gage commercial steel)[g]	0.35	—	—



(only for winter)

$$\dot{q} = U' \cdot P \cdot (t_i - t_o)$$

foundation wall

heat loss coefficient

Table 5-11 Heat-Loss Coefficients for Slab Floor Construction

warmer region

colder regions

		Loss Coefficient					
		2950 Degree-Days[a]		5350 Degree-Days[a]		7433 Degree-Days[a]	
Construction	Insulation	Btu/(hr-ft-F)	W/(m-C)	Btu/(hr-ft-F)	W/(m-C)	Btu/(hr-ft-F)	W/(m-C)
8-in. (200-mm) block wall, brick face	Uninsulated	0.62	1.07	0.68	1.18	0.72	1.25
	R-5.4 (*R*-0.95) slab to footing	0.48	0.83	0.50	0.87	0.56	0.97
4-in. (1000mm) block wall, brick face	Uninsulated	0.80	1.39	0.84	1.45	0.93	1.61
	R-5.4 (*R*-0.95) slab to footing	0.47	0.81	0.49	0.85	0.54	0.94
Metal stud wall, stucco	Uninsulated	1.15	1.99	1.20	2.08	1.34	2.32
	R-5.4 (*R*-0.95) slab to footing	0.51	0.88	0.53	0.92	0.58	1.00
Poured concrete wall, with perimeter ducts	Uninsulated	1.84	3.19	2.12	3.67	2.73	4.74
	R-5.4 (*R*-0.95) slab to footing	0.64	1.11	0.72	1.25	0.90	1.56

[a]Base 65 F. Degree-day data are given in Table 5-10.

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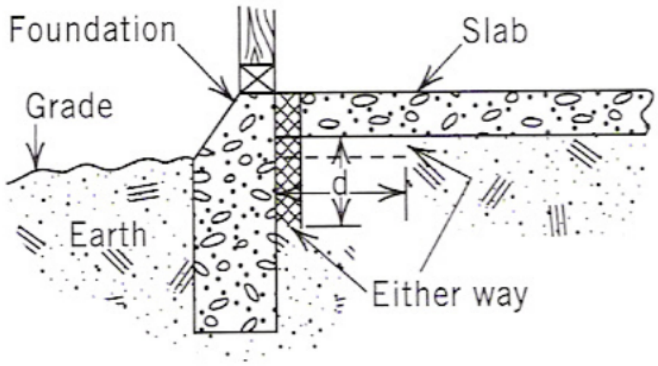

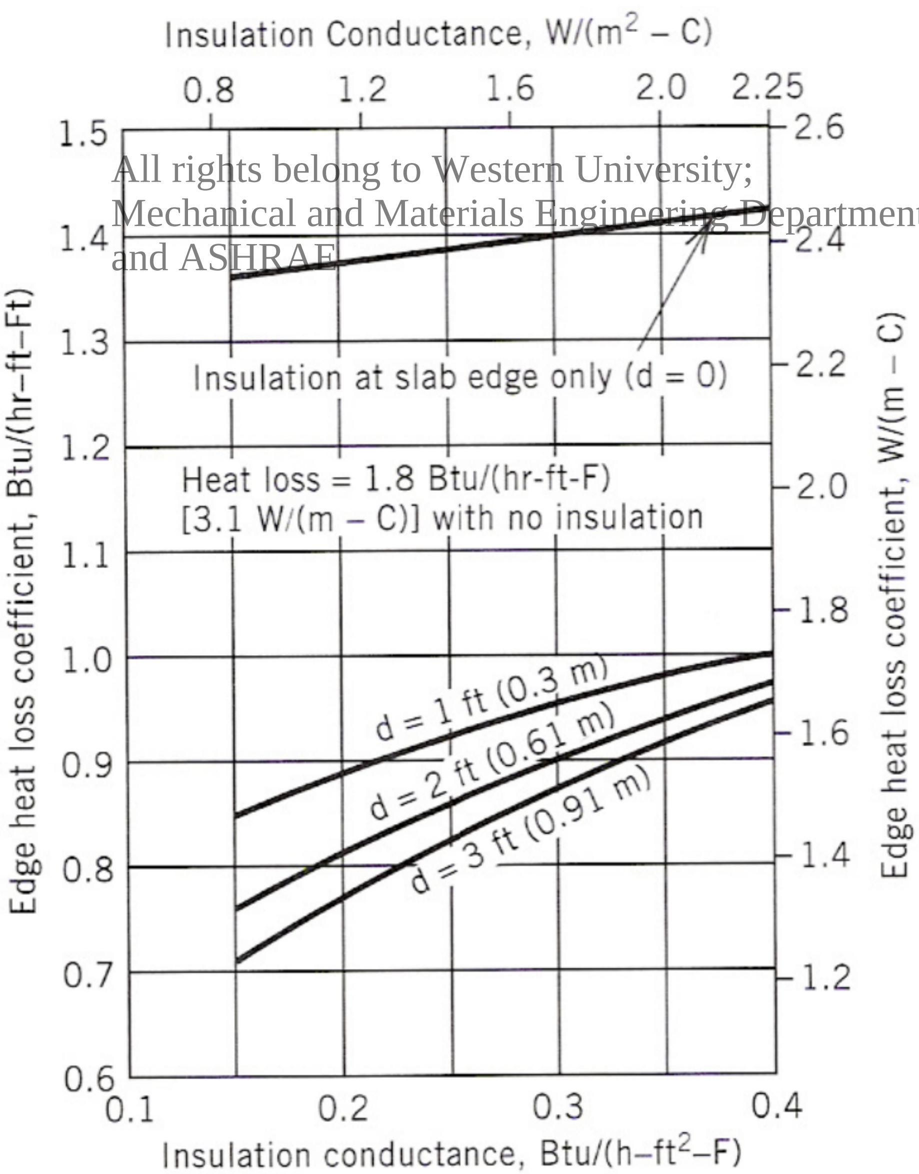

Figure 5-8 Heat loss factors for slab floors on grade. (Rep
Handbook, Systems and Equipment Volume, 2000.)

Concrete floor & walls below grade

Table 5-8 Average Overall Heat-Transfer Coefficients for Basement Walls (Reference 3)

Depth Below Grade, Feet	Depth Below Grade, Meters	Wall Uninsulated, Btu/hr-ft²-F	Wall Uninsulated, W/m²-C	Wall Insulated to Depth of 2 ft Below Grade, R-5, Btu/hr-ft²-F	Wall Insulated to Depth of 2 ft Below Grade, R-0.88, W/m²-C	Wall Insulated to Depth of 2 ft Below Grade, R-10, Btu/hr-ft²-F	Wall Insulated to Depth of 2 ft Below Grade, R-1.76, W/m²-C	Wall Insulated Over Full Inside Surface, R-5, Btu/hr-ft²-F	Wall Insulated Over Full Inside Surface, R-0.88, W/m²-C	Wall Insulated Over Full Inside Surface, R-10, Btu/hr-ft²-F	Wall Insulated Over Full Inside Surface, R-1.76, W/m²-C
4	1.22	0.200	0.035	0.140	0.025	0.130	0.023	0.088	0.015	0.054	0.010
5	1.52	0.180	0.032	0.140	0.025	0.130	0.023	0.082	0.014	0.050	0.009
6	1.83	0.170	0.030	0.140	0.025	0.130	0.023	0.079	0.014	0.048	0.008
7	2.13	0.160	0.028	0.140	0.025	0.130	0.023	0.076	0.013	0.047	0.008

Table 5-9 Heat Loss Through Below-Grade Basement Walls[a]

Basement Depth, ft	Basement Depth, m	Uninsulated		Average Heat Loss Coefficient, Btu/(hr-ft²-F)/Btu or W/(m²-C)[b,c,d]: R-4.17 (hr-ft²-F)/Btu	R-0.73 (m²-C)/W	R-8.34 (hr-ft²-F)/Btu	R-1.47 (m²-C)/W	R-12.5 (hr-ft²-F)/Btu	R-2.20 (m²-C)/W
1	0.3	0.41	2.33	0.152	0.86	0.093	0.53	0.067	0.38
2	0.6	0.316	1.79	0.134	0.76	0.086	0.49	0.063	0.36
3	0.9	0.262	1.49	0.121	0.69	0.080	0.45	0.060	0.34
4	1.2	0.227	1.29	0.110	0.63	0.075	0.43	0.057	0.32
5	1.5	0.200	1.14	1.102	0.58	0.071	0.40	0.054	0.31
6	1.8	0.180	1.02	0.095	0.54	0.067	0.38	0.052	0.29
7	2.1	0.164	0.93	0.089	0.51	0.064	0.36	0.050	0.28

[a] Latta and Boileau, *Canadian Building* (5).
[b] Soil conductivity, 9.6 Btu-in./(hr-ft²-F) or 1.38 W/(m-C).
[c] Average U-factor to the given depth.
[d] $\Delta t = (t_i - t_a - A)$.

Source: Reprinted with permission from *ASHRAE Handbook, Fundamentals Volume,* 1997.

Table 5-10 Heat Loss Through Basement Floors[a,b]

Depth of Basement Wall below Grade		Heat Loss Coefficient, Btu/(hr-ft^2-F) or W/(m^2-C)[b]							
		Shortest Width of Basement							
		ft	m	ft	m	ft	m	ft	m
ft	m	20	6	24	7.3	28	8.5	32	9.7
5	1.5	0.032	0.18	0.029	0.16	0.026	0.15	0.023	0.13
6	1.8	0.030	0.17	0.027	0.15	0.025	0.14	0.022	0.12
7	2.1	0.029	0.16	0.026	0.15	0.023	0.13	0.021	0.12

[a] Latta and Boileau, *Canadian Building* (6).

[b] $\Delta t = (t_i - t_a - A)$.

Source: Reprinted with permission from *ASHRAE Handbook, Fundamentals Volume,* 1997.

Table 5-9 Average Overall Heat-Transfer Coefficients for Uninsulated Basement Floors, 3 ft or More Below Grade (Reference 3)

Wall Uninsulated		Wall Insulated to a Depth of 2 ft Below Grade		Wall Insulated Over Full Inside Surface	
Btu / hr-ft^2-F	W / m^2-C	Btu / hr-ft^2-F	W / m^2-C	Btu / hr-ft^2-F	W / m^2-C
0.025	0.004	0.036	0.006	0.045	0.008

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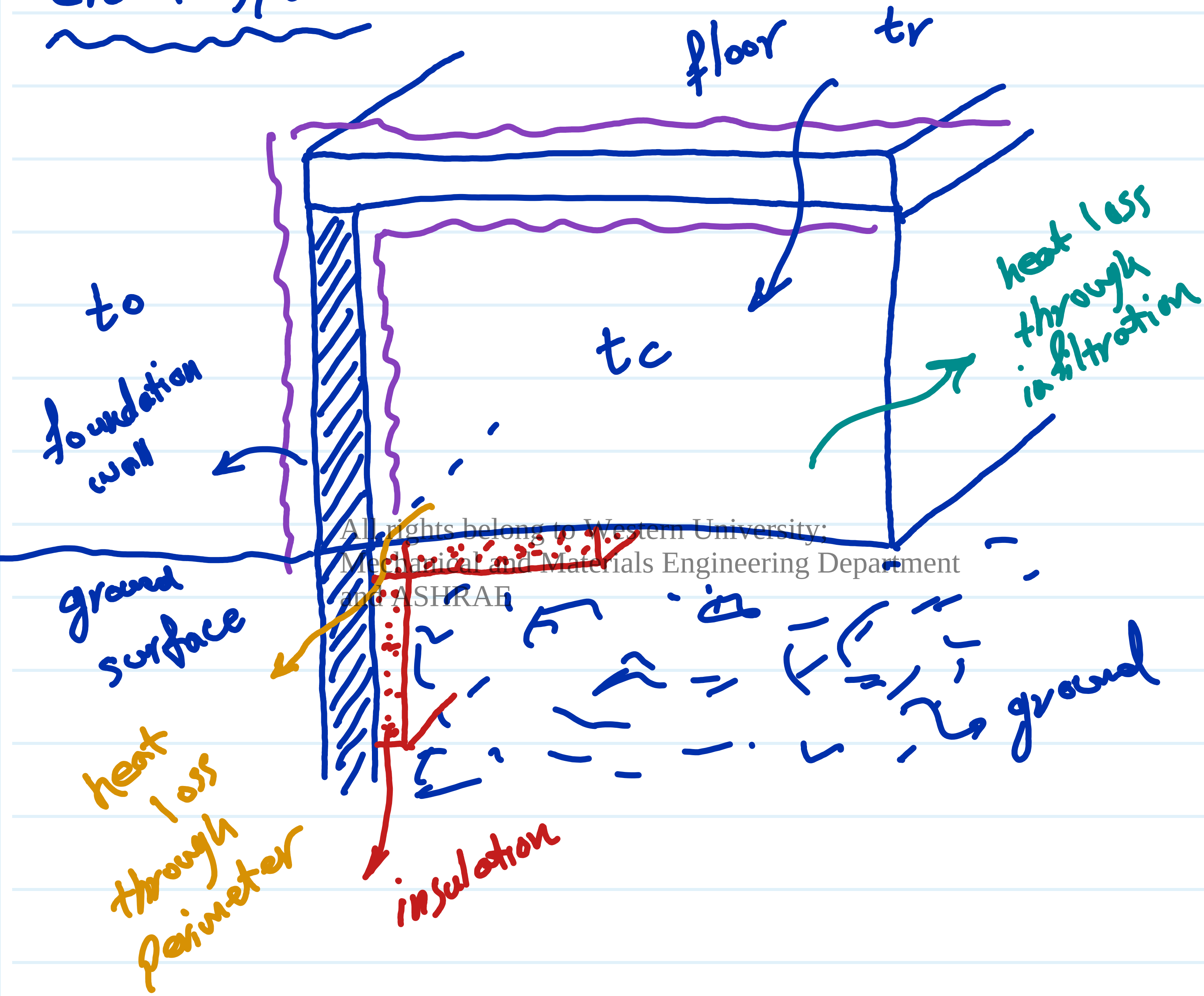
crawl space



$$\dot{q}_{fl} = \dot{q}_{inf} + \dot{q}_{w} + \dot{q}_{p}$$

$$U_{fl} A_{fl} (t_r - t_c) = \dot{m} c_p (t_c - t_o) + U_w A_w (t_c - t_o) + U' P (t_c - t_o)$$