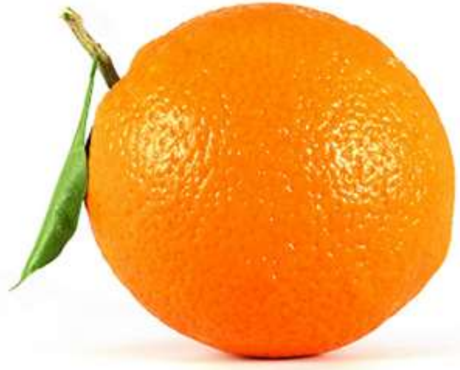
COOLING LOAD ESTIMATION

Principles of Heat Transfer

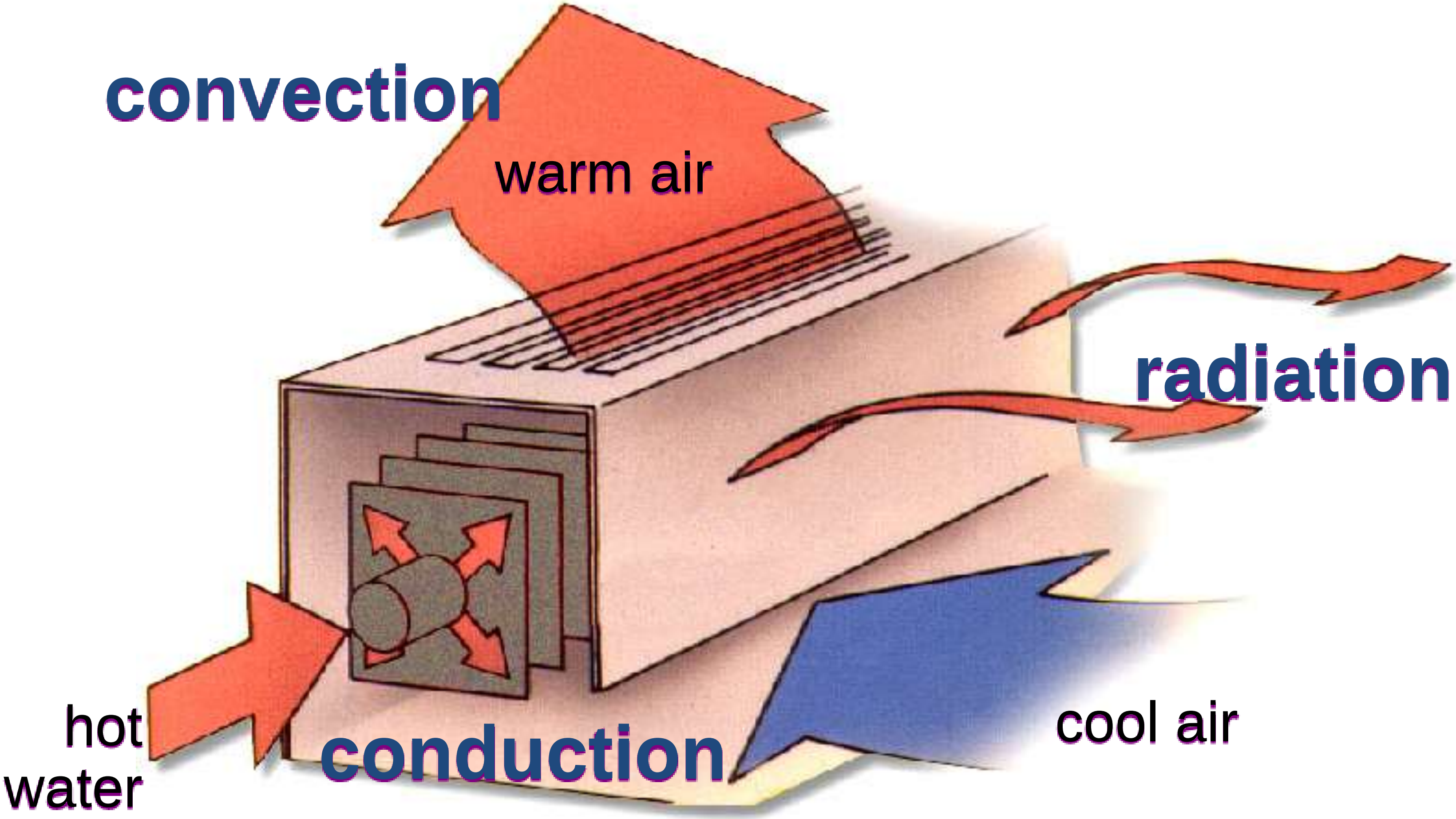
- Heat energy cannot be destroyed.

- Heat always flows from a higher temperature substance to a lower temperature substance.

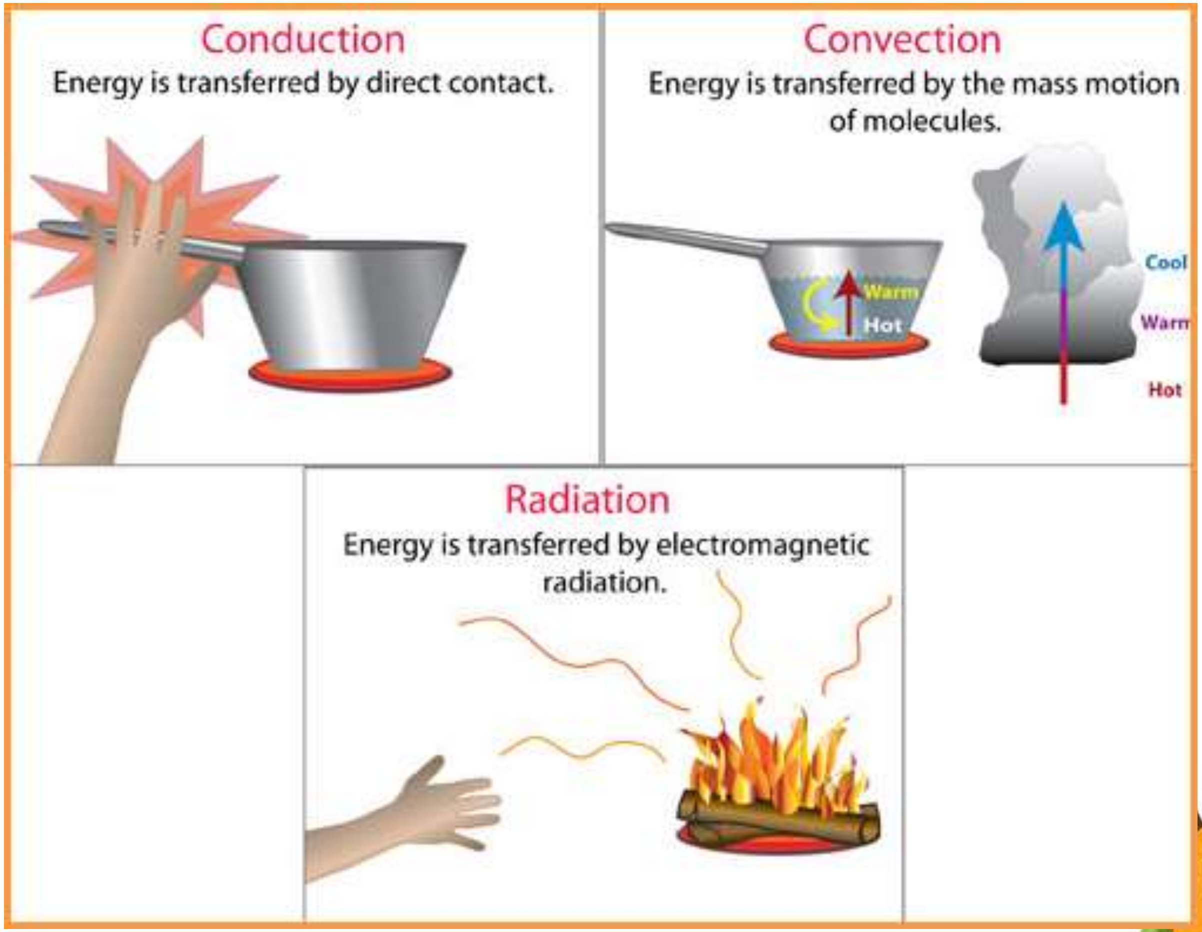
- Heat can be transferred from one substance to another.

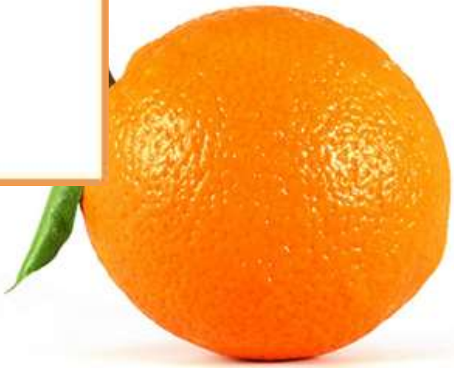


Methods of Heat Transfer

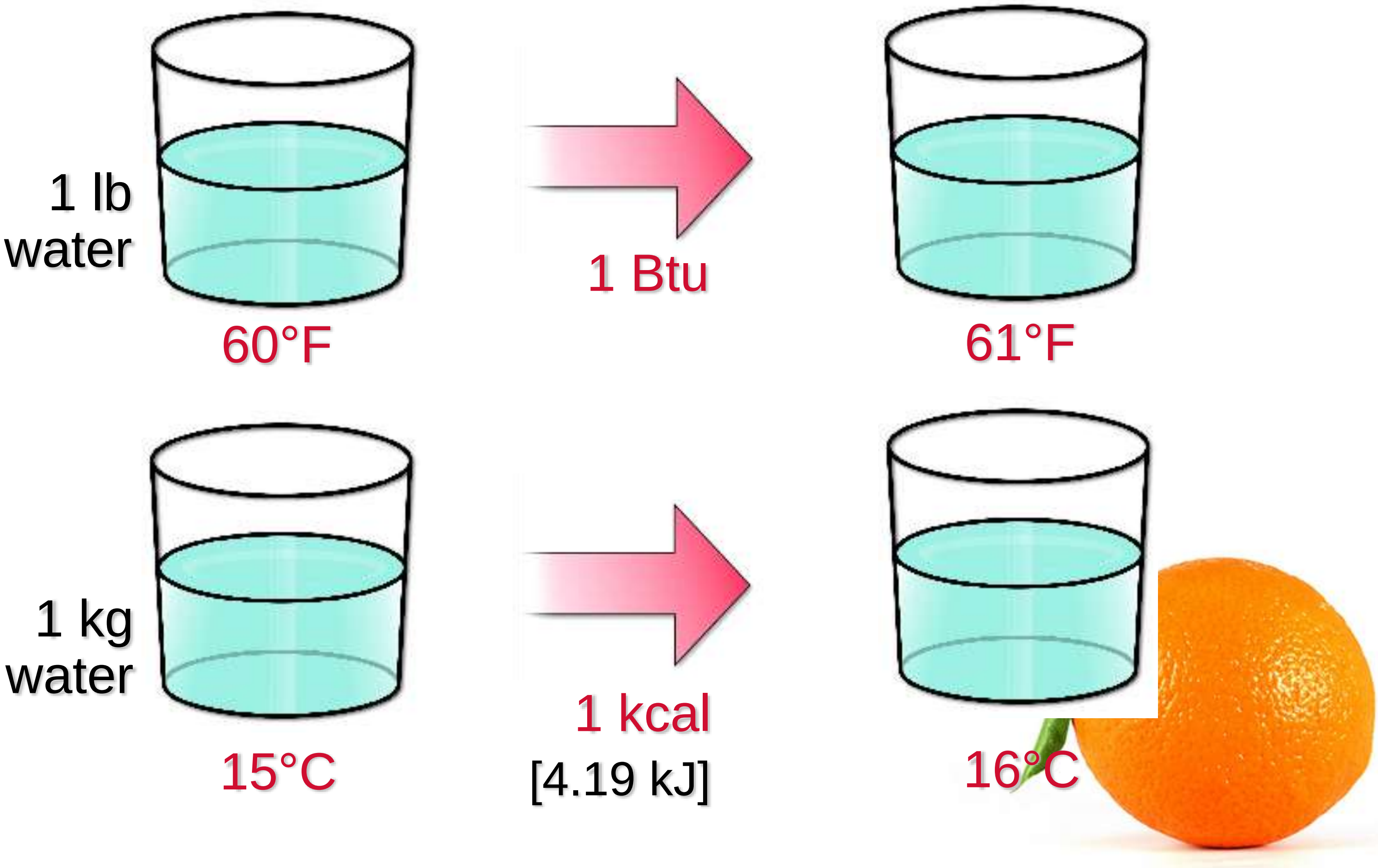


Conduction, Convection & Radiation





Measuring Heat Quantity



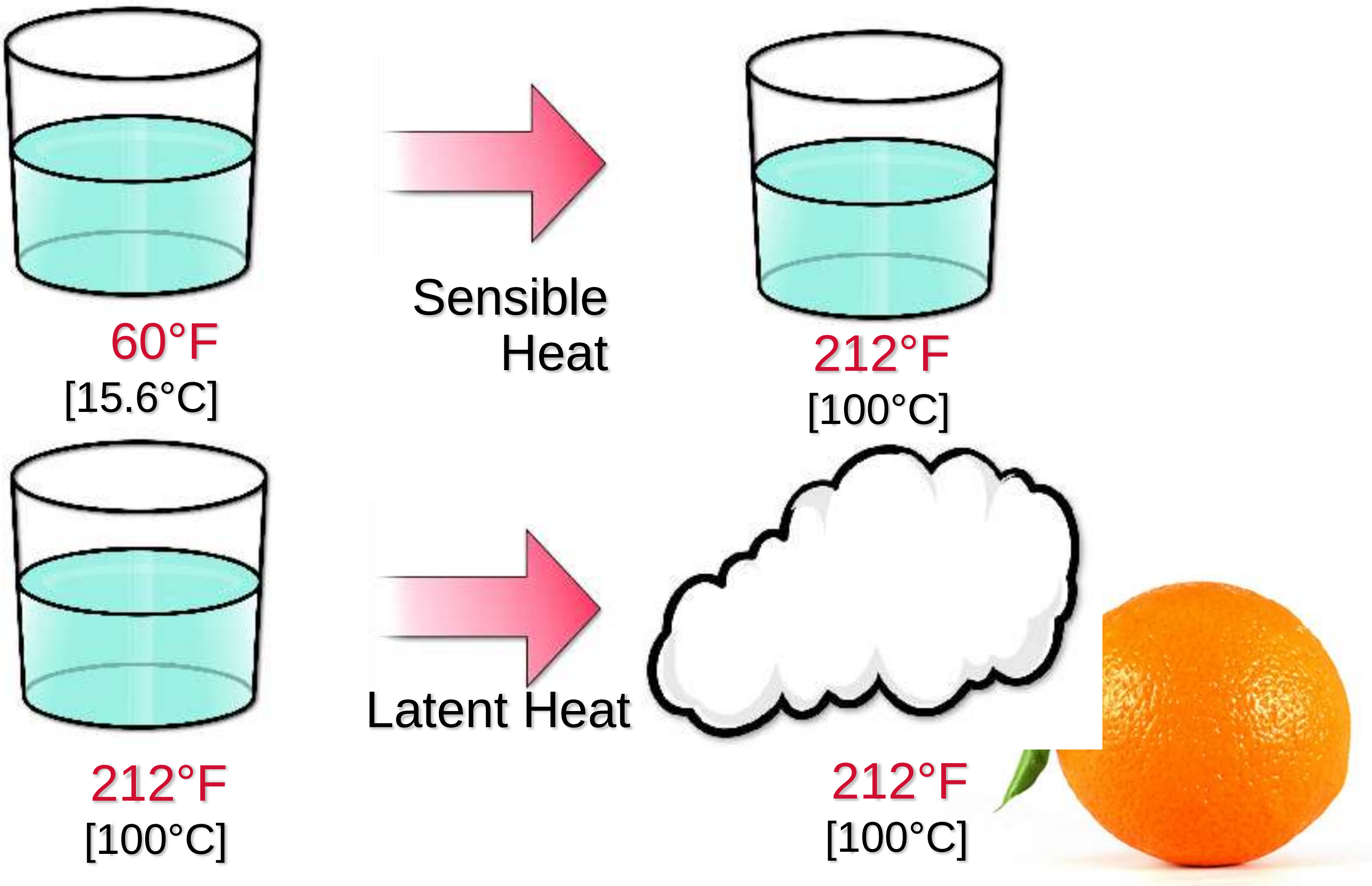
What is BTU?

- BTU refers to British Thermal Unit.

- Unit of Heat Energy in Imperial System or I-P System.

- 1 BTU is the amount of Heat energy required to raise the temperature of 1 lb water by 1^oF.

Sensible Vs Latent Heat



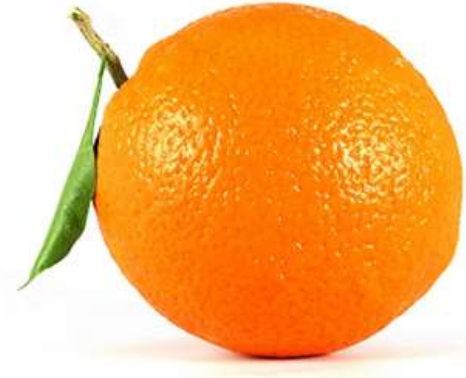
Human Comfort

- Conditions at which most people are likely to feel comfortable most of the time.

- Also called as ***Thermal Comfort.***

- Temperature: 78^{o}F (Summer) – 68^{o}F(Winter).

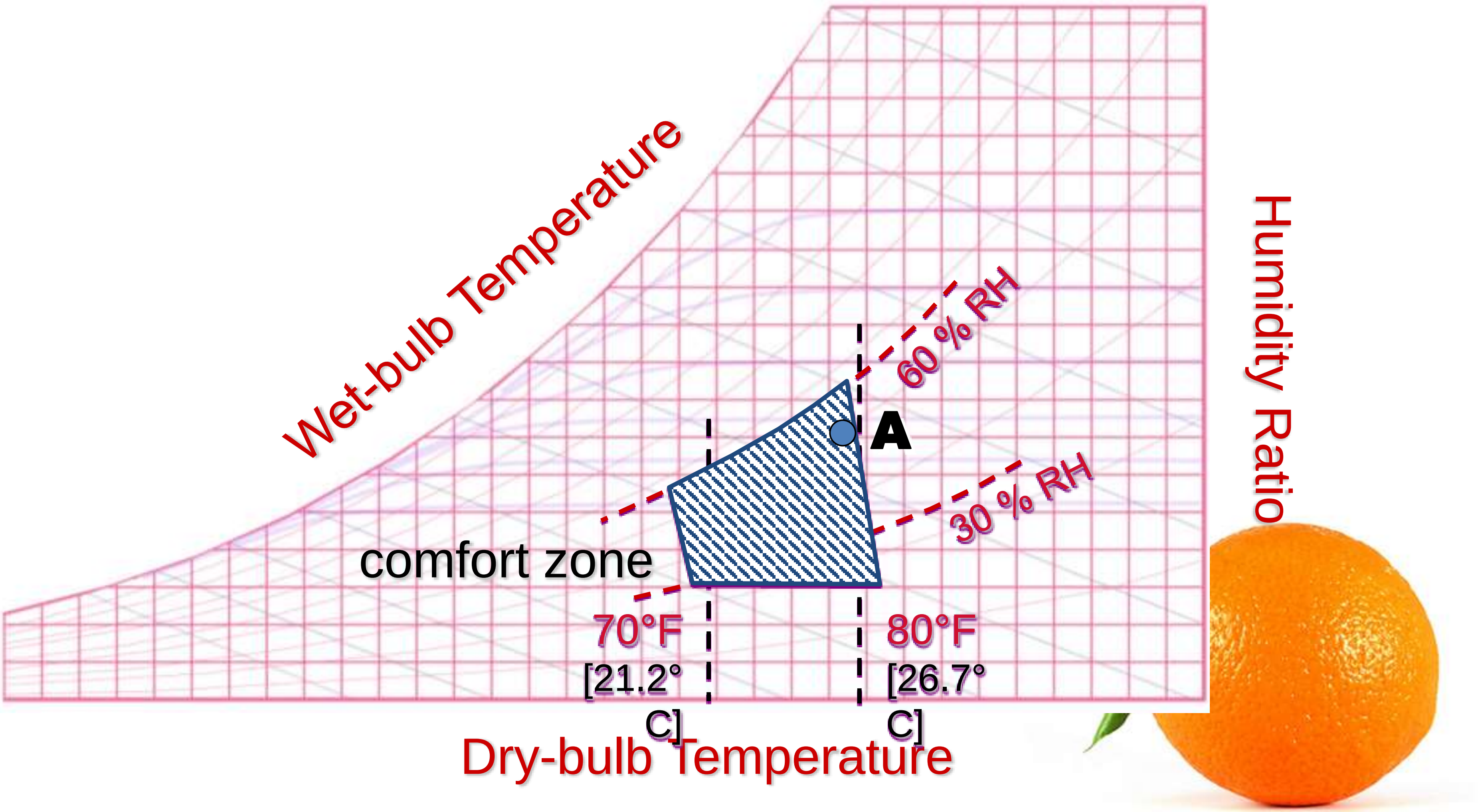
- Relative Humidity: 30 %– 40%.



Factors Affecting Human Comfort

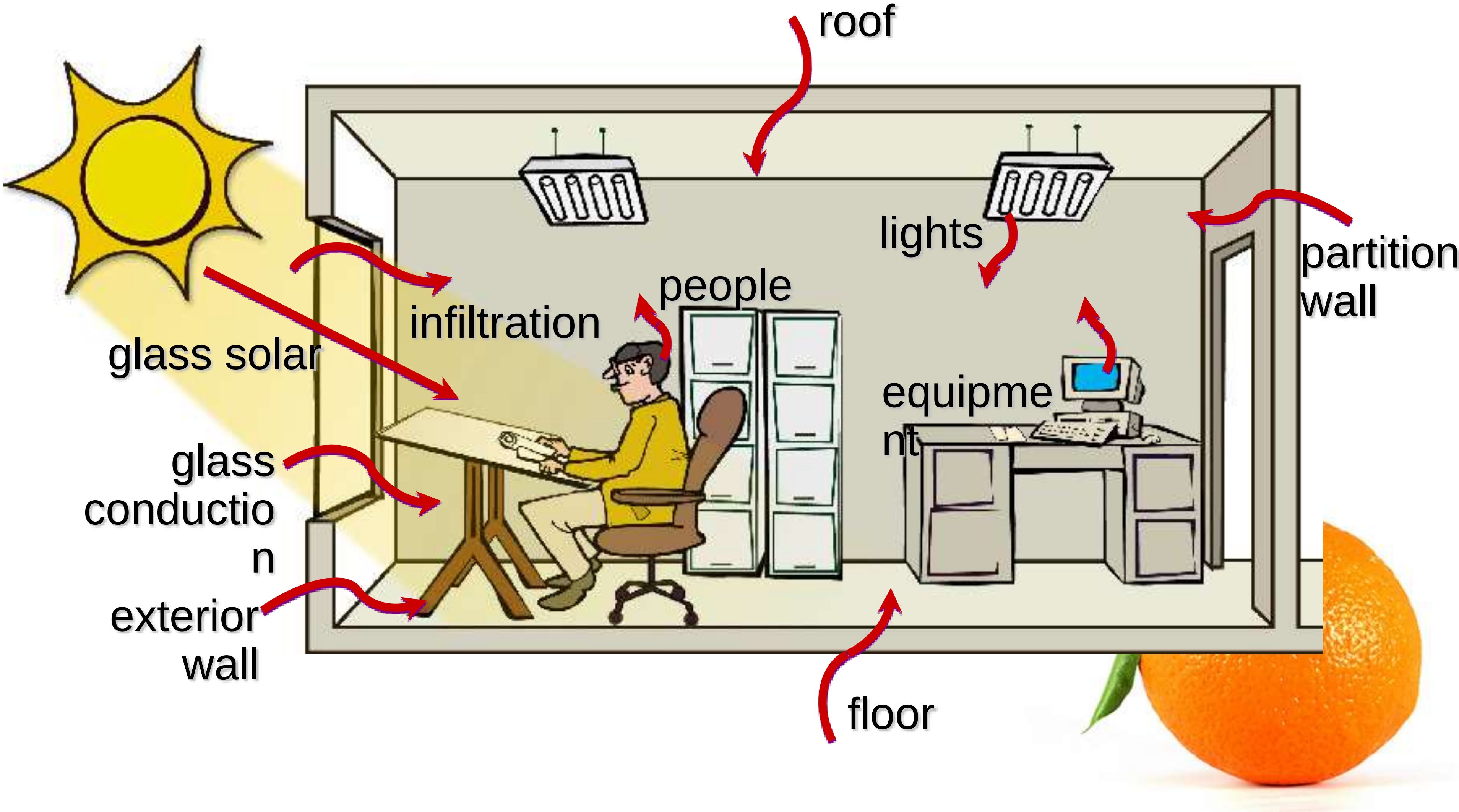
- Dry-bulb temperature
- Humidity
- Air movement
- Fresh air
- Clean air
- Noise level
- Adequate lighting
- Proper furniture and work surfaces

Indoor Design Conditions



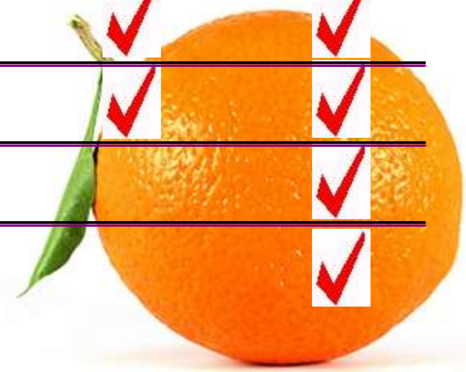
Cooling Load Estimation Procedure

Cooling Load Components

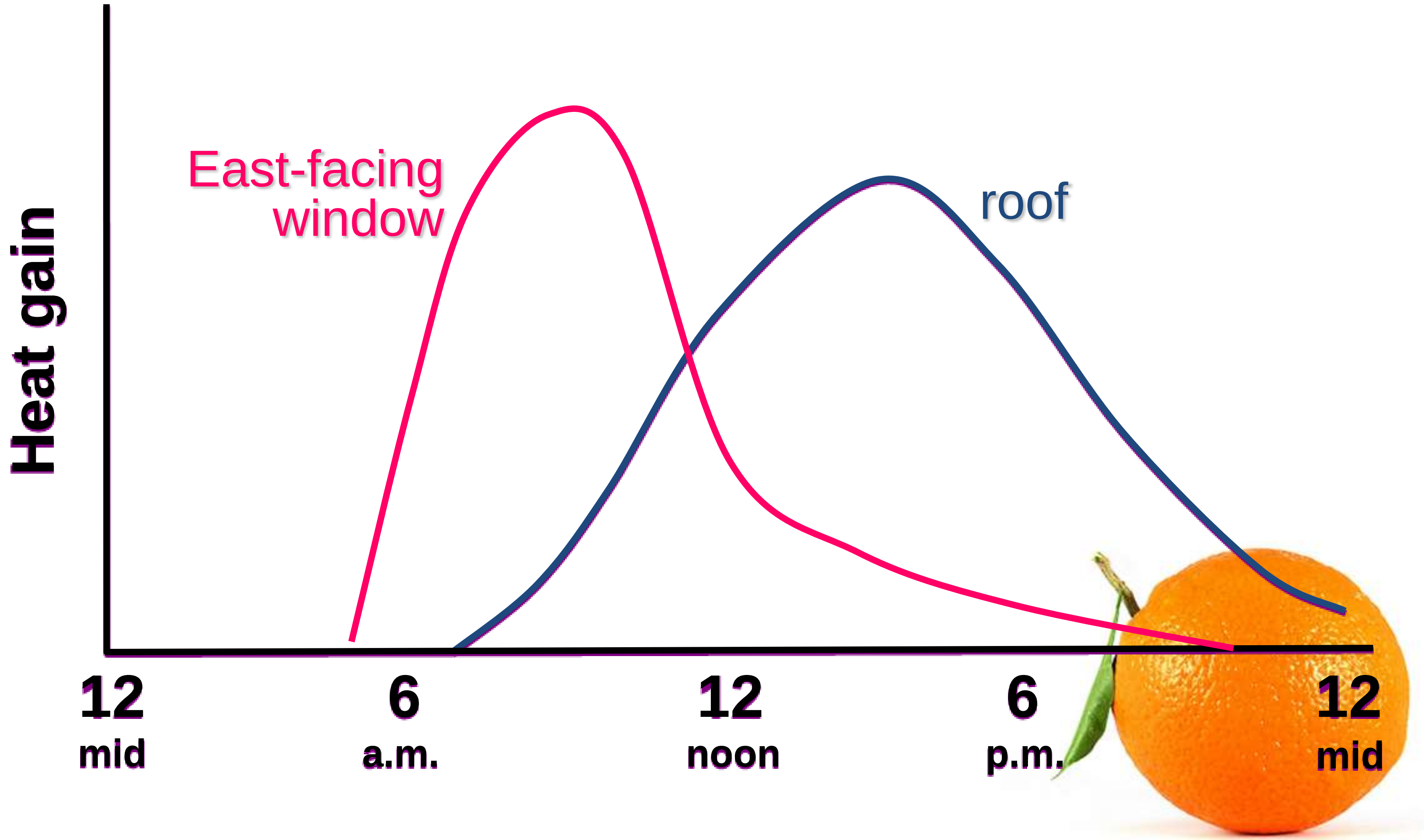


Cooling Load Components

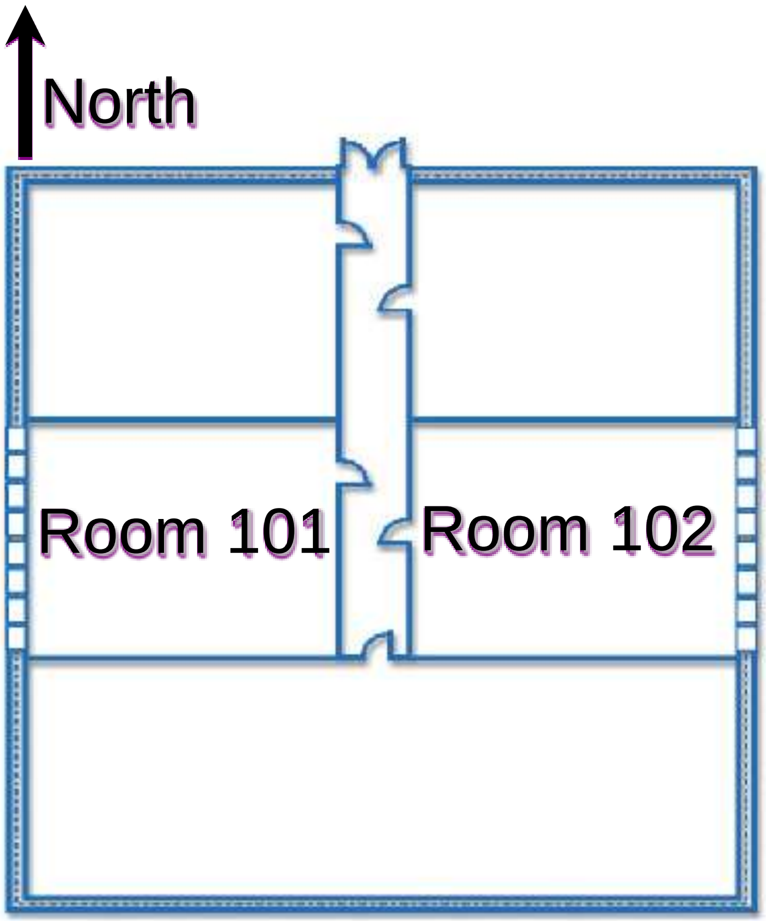
cooling load components	Sensible Load	latent load	space load	coil load
Conduction through roof, walls, windows, and skylights	✓		✓	✓
Solar radiation through windows, skylights	✓		✓	✓
Conduction through ceiling, interior partition walls, and floor	✓		✓	✓
People	✓	✓	✓	✓
Lights	✓		✓	✓
Equipment/ Appliances	✓	✓	✓	✓
Infiltration	✓	✓	✓	✓
Ventilation	✓	✓		✓
System Heat Gains	✓			✓



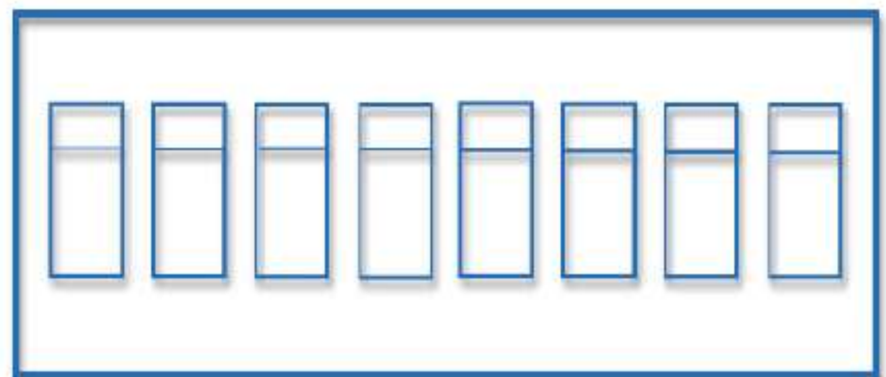
Time of Peak Cooling Load



Example Office Space (Room 101)



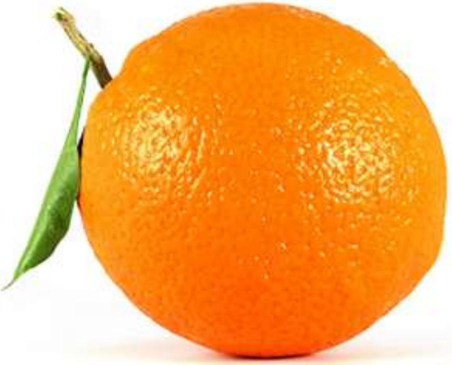
Plan view



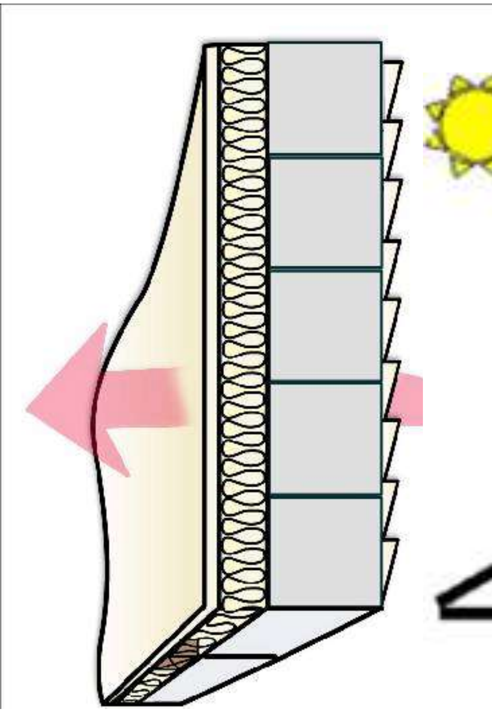
Elevation view (Room 101)

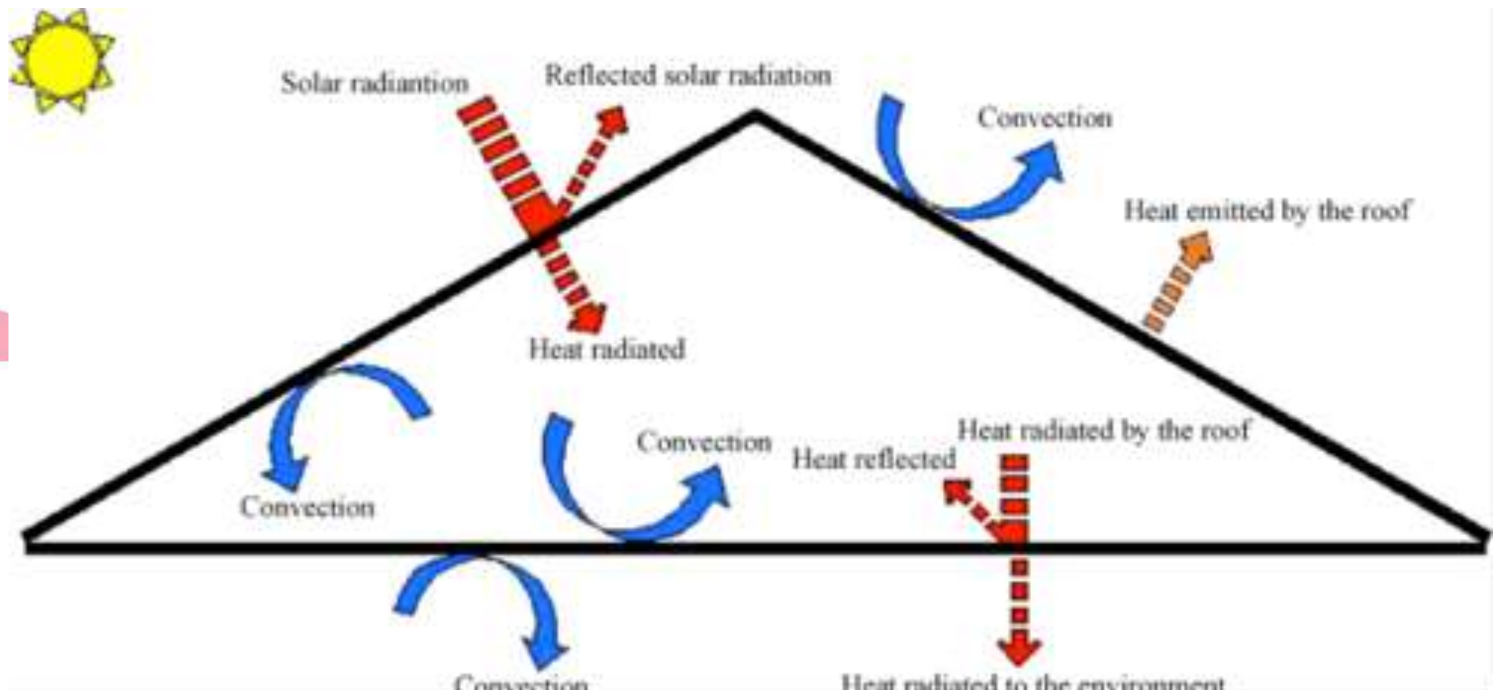
Outdoor Design Conditions

	0.4%		1%		2%	
	DB	WB	DB	WB	DB	WB
St. Louis, Missouri	95°F [35°C]	76°F [25°C]	93°F [34°C]	75°F [24°C]	90°F [32°C]	74°F [23°C]



Heat Conduction through Surfaces





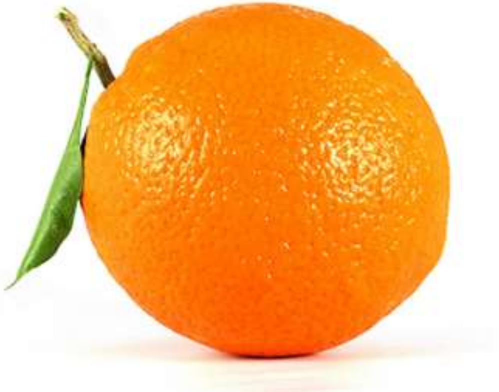
Conduction through a Shaded Wall

$$Q = U \times A \times \Delta T$$

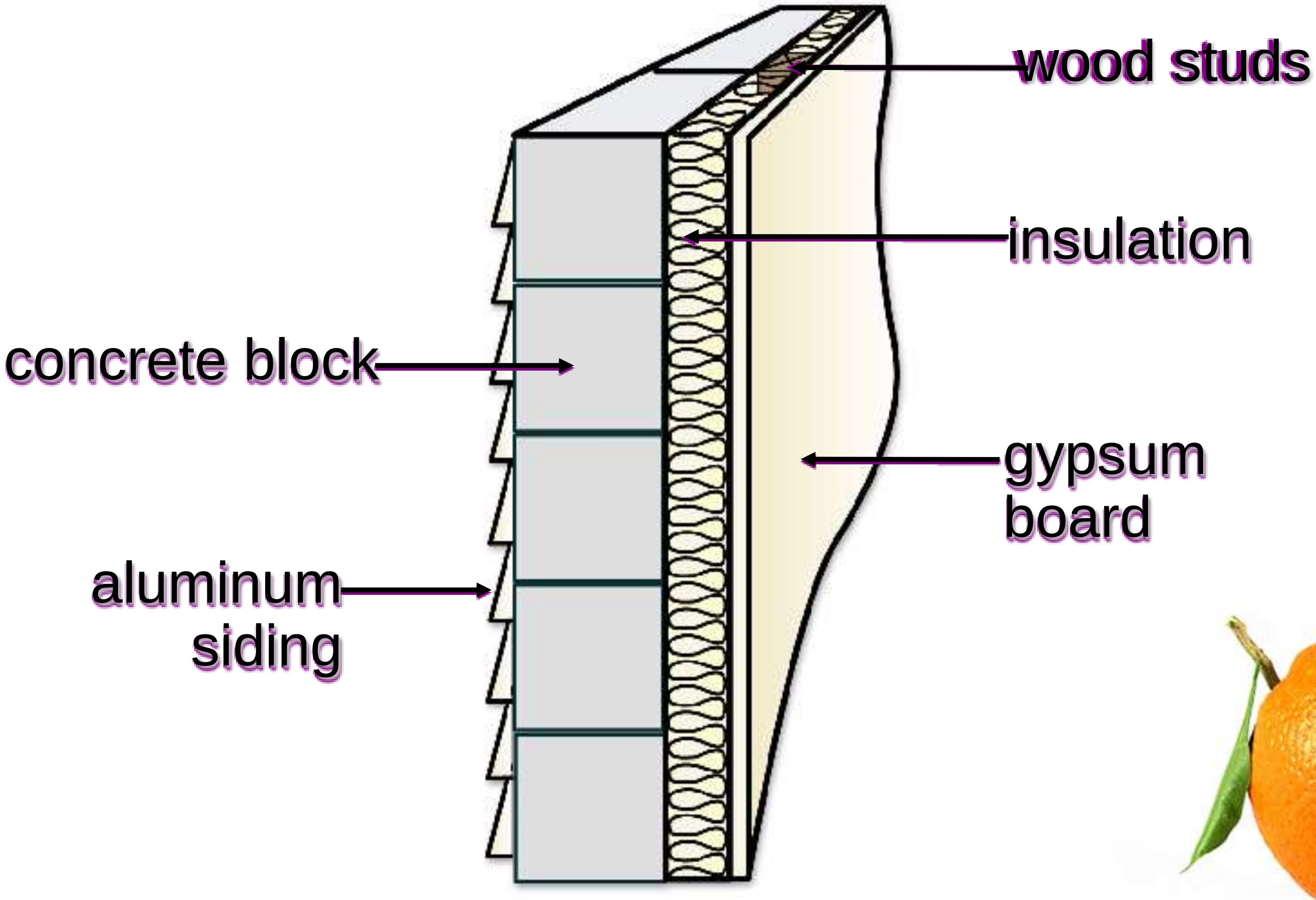
U – Overall heat transfer coefficient of the surface

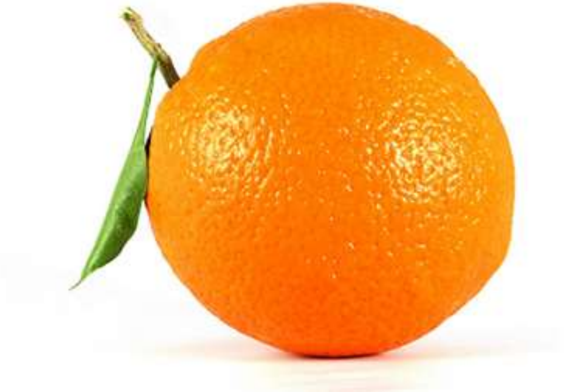
A – Area of the surface

Δ T – Dry bulb temperature difference across the surface



U-factor


wood studs
insulation
concrete block
gypsum
board
aluminum
siding



U-factor for Example Wall

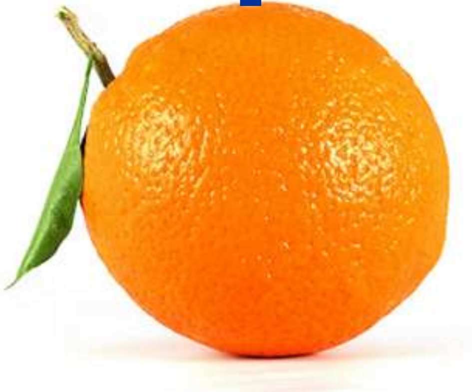
thermal resistance (R)

$R_{outdoor\text{-}air\ film}$	0.25	[0.04]
R_{siding}	0.61	[0.11]
$R_{concrete\ block}$	2.00	[0.35]
$R_{insulation}$	13.00	[2.29]
$R_{gypsum\ board}$	0.45	[0.08]
$R_{indoor\text{-}air\ film}$	0.68	[0.12]
R_{total}	16.99	[2.99]

$$U = \frac{1}{R_{total}}$$

$$U = 0.06\ \text{Btu/hr}\cdot\text{ft}^2\cdot{}^\circ\text{F}$$

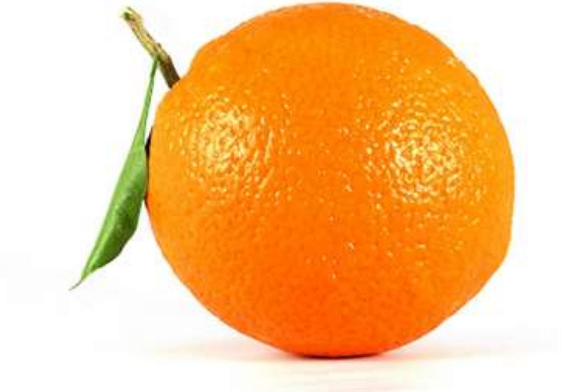
$$[\ U = 0.33\ \text{W/m}^2\cdot{}^\circ\text{K}\ ]$$



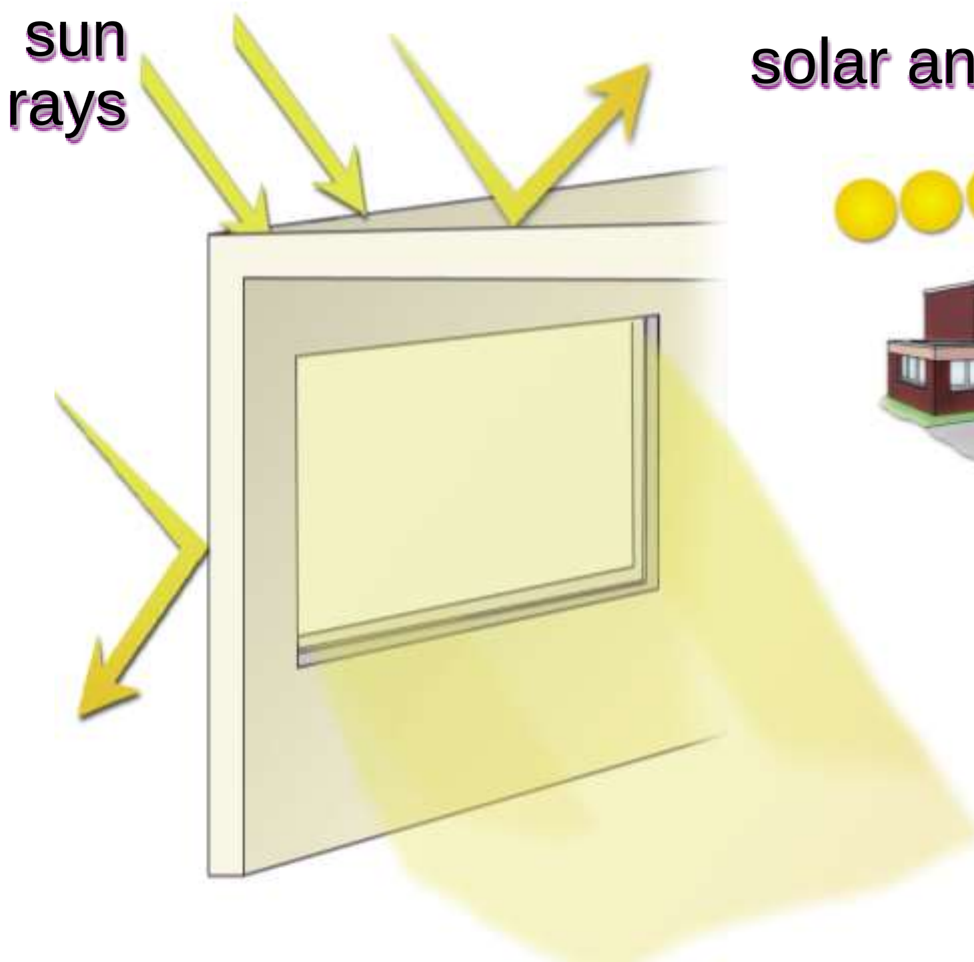
Conduction through a Shaded Wall

$$Q_{wall} = 0.06 \times 380 \times (95 - 78) = 388 \text{ Btu/hr}$$

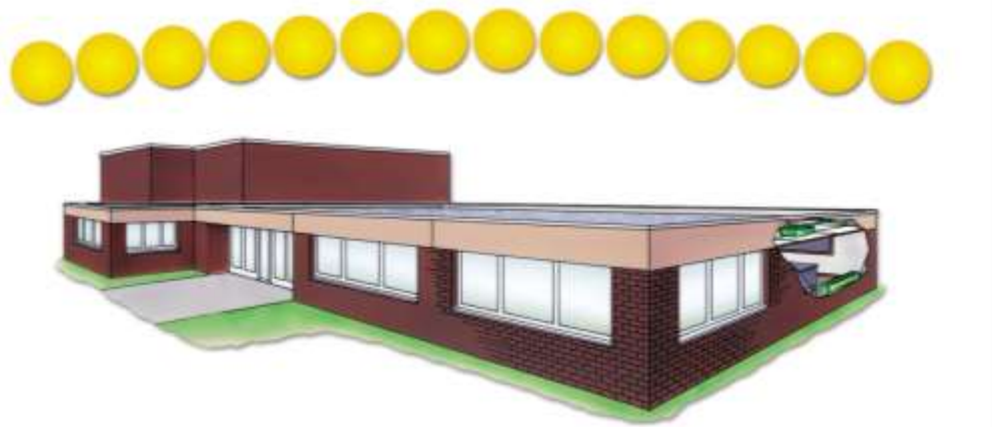
$$\left[\, Q_{wall} = 0.33 \times 36.3 \times (35 - 25.6) = 113 \text{ W} \,\right]$$

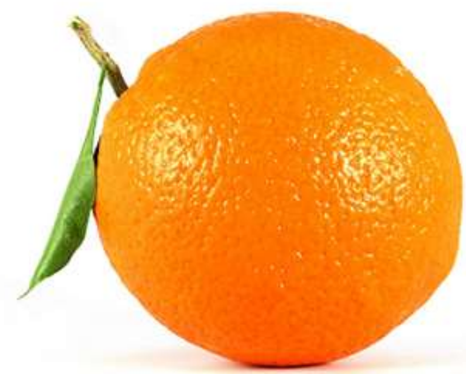


Sunlit Surfaces

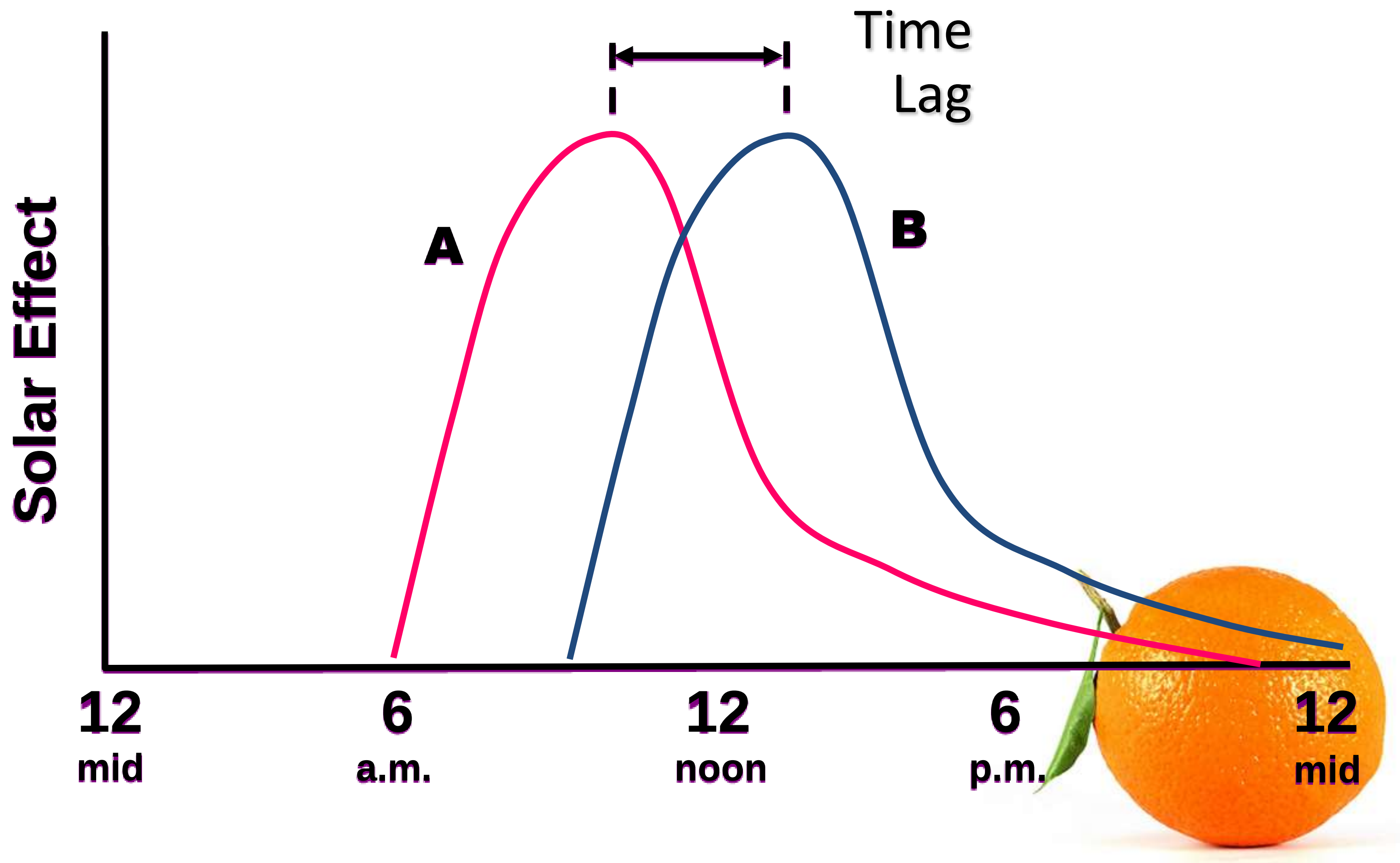


solar angle changes throughout the da





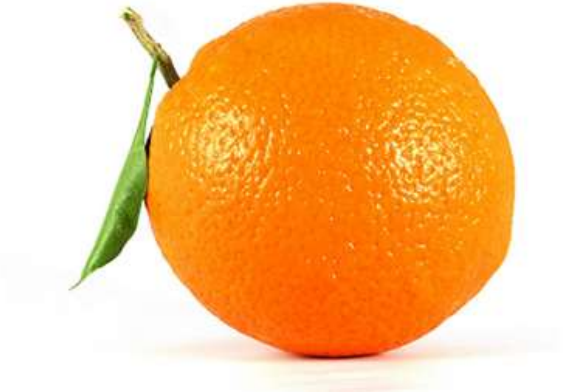
Time Lag



Conduction through Sunlit Surfaces

$$Q = U \times A \times CLTD$$

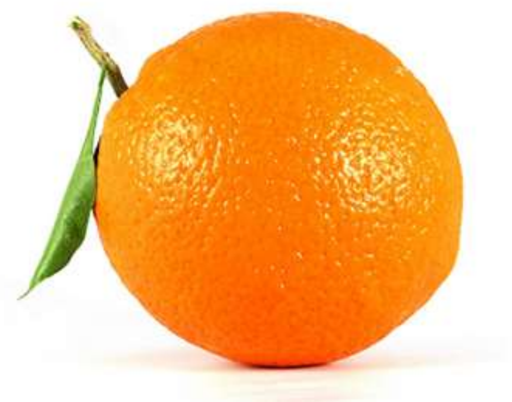
CLTD : Term used to account for the added heat transfer due to the sun shining on exterior walls, roofs, and windows, and the capacity of the wall and roof to store heat.



CLTD Factors for West-Facing Wall

hour

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
CLTD (°F)	35	30	25	21	17	14	11	8	7	6	6	7	8	10	12	16	22	30	37	44	48	48	45	41
CLTD (°C)	19	17	14	12	9	8	6	4	4	3	3	4	4	6	7	9	12	17	21	24	27	27	25	23



Conduction through Sunlit Surfaces

$$Q_{wall} = 0.06 \times 380 \times 22 = 502 \text{ Btu/hr}$$

$$Q_{roof} = 0.057 \times 2700 \times 80 = 12312 \text{ Btu/hr}$$

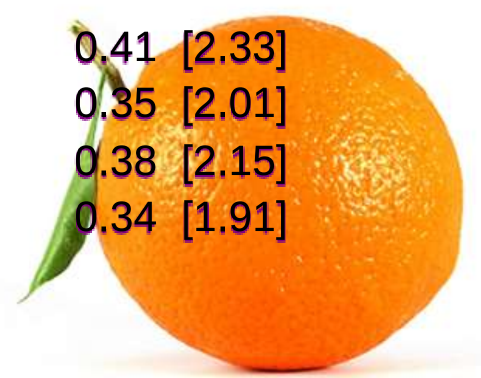
$$[\ Q_{wall} = 0.33 \times 36.3 \times 12 = 144 \text{ W}\ ]$$

$$[\ Q_{roof} = 0.323 \times 250.7 \times 44 = 3563 \text{ W}\ ]$$

U-factors for Windows

fixed frames, vertical installation

	aluminum without thermal break	aluminum with thermal break	wood/vinyl
single glazing			
1/8 in. [3.2 mm] glass	1.13 [6.42]	1.07 [6.07]	0.98 [5.55]
double glazing			
1/4 in. [6.4 mm] air space	0.69 [3.94]	0.63 [3.56]	0.56 [3.17]
1/2 in. [12.8 mm] air space	0.64 [3.61]	0.57 [3.22]	0.50 [2.84]
1/4 in. [6.4 mm] argon space	0.66 [3.75]	0.59 [3.37]	0.52 [2.98]
1/2 in. [12.8 mm] argon space	0.61 [3.47]	0.54 [3.08]	0.48 [2.70]
triple glazing			
1/4 in. [6.4 mm] air spaces	0.55 [3.10]	0.48 [2.73]	0.41 [2.33]
1/2 in. [12.8 mm] air spaces	0.49 [2.76]	0.42 [2.39]	0.35 [2.01]
1/4 in. [6.4 mm] argon spaces	0.51 [2.90]	0.45 [2.54]	0.38 [2.15]
1/2 in. [12.8 mm] argon spaces	0.47 [2.66]	0.40 [2.30]	0.34 [1.91]

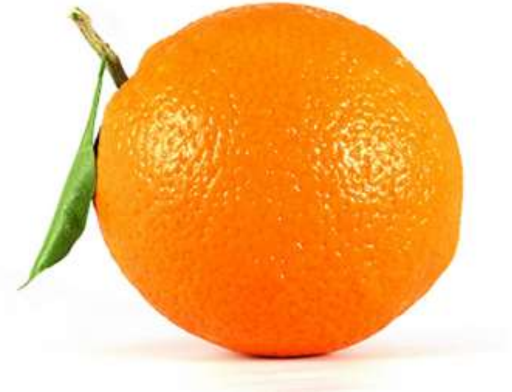


Conduction through Windows

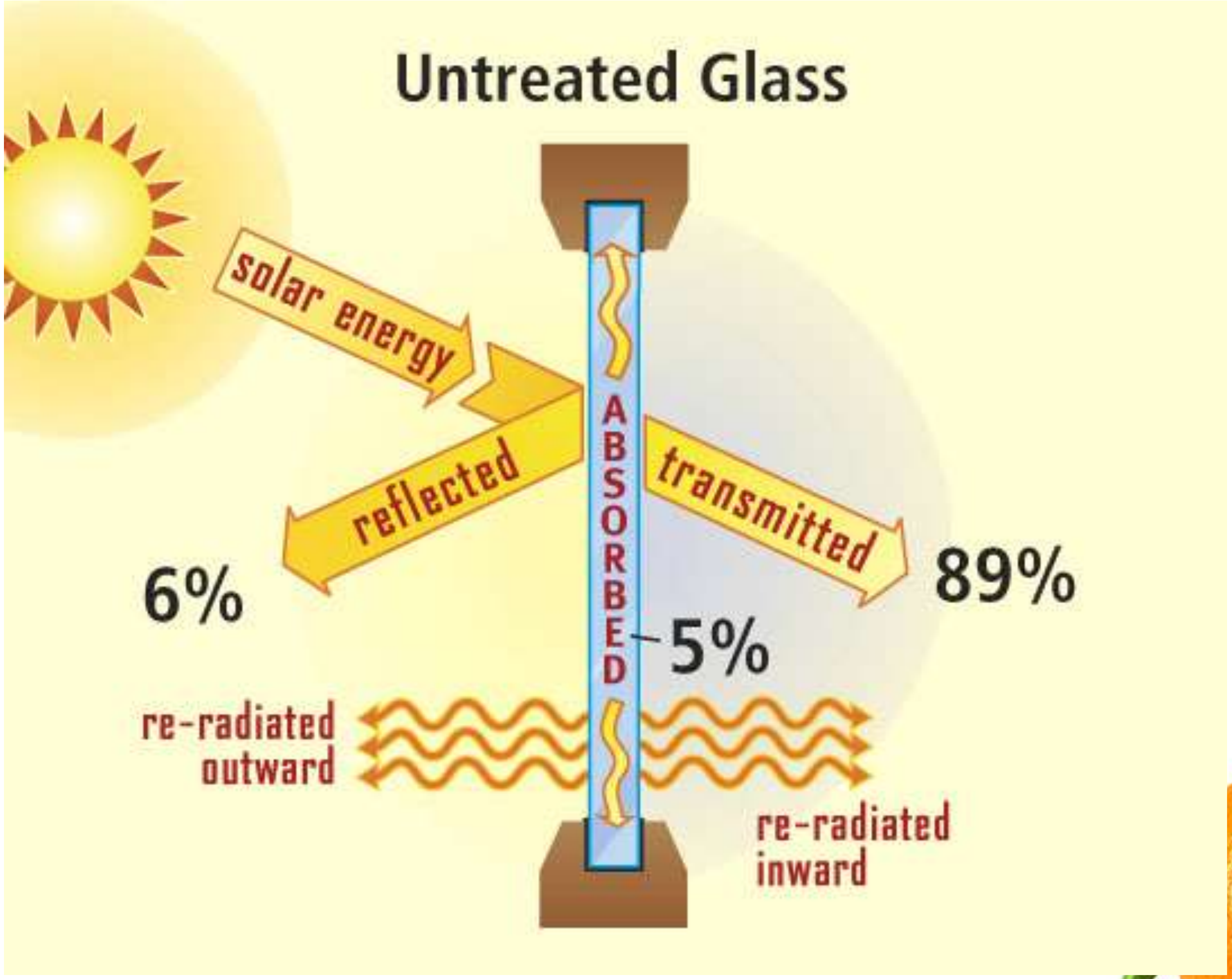
$$Q_{windows} = U \times A \times CLTD$$

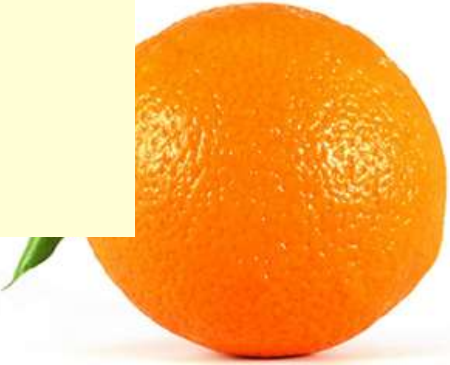
$$Q_{windows} = 0.63 \times 160 \times 13 = 1310 \text{ Btu/hr}$$

$$[\ Q_{windows} = 3.56 \times 14.4 \times 7 = 359 \text{ W}\ ]$$



Solar Radiation through Glass





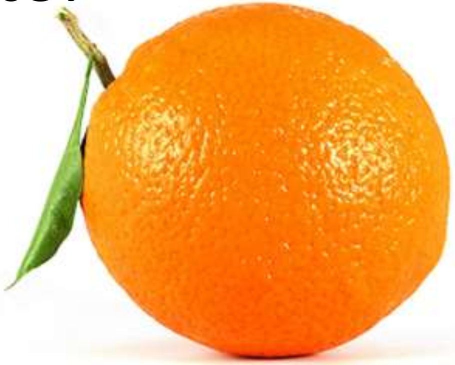
Solar Heat Gain through Glass

$$Q = A \times SC \times SCL$$

Where,

SC – Shading Coefficient

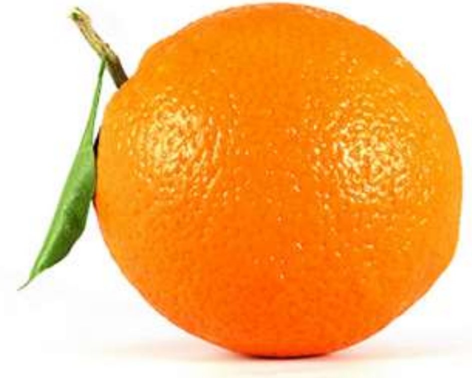
SCL – Solar Cooling Load Factor



Solar Cooling Load Factor (SCL)

- Direction that the window faces
- Time of day
- Month
- Latitude
- Construction of interior partition walls
- Type of floor covering
- Existence of internal shading devices

SCL: A factor used to estimate the rate at which solar heat energy radiates directly into the space, heats up the surfaces and furnishings, and is later released to the space as a sensible heat gain.



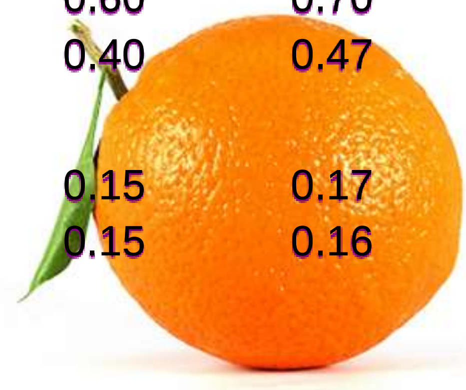
Shading Coefficient (SC) ?

It is an expression used to define how much of the radiant solar energy, that strikes the outer surface of the window, is actually transmitted through the window and into the space.

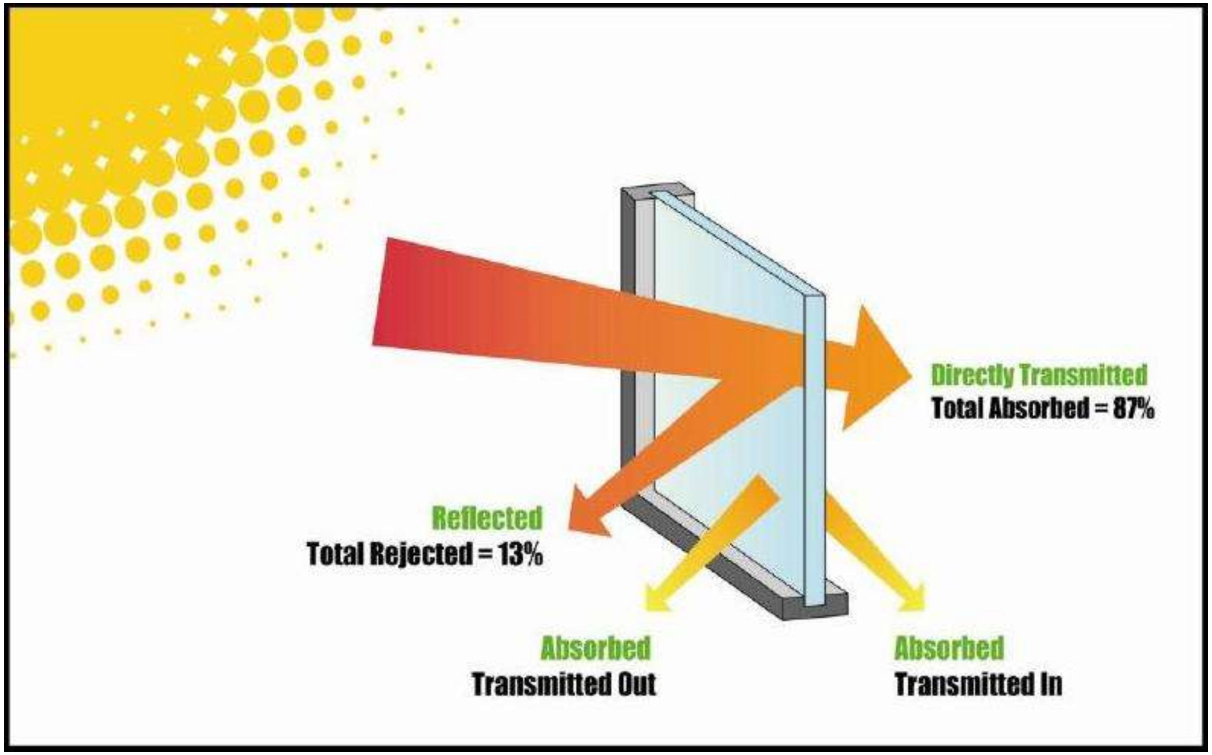
Shading Coefficient (SC)

	shading coefficient at normal incidence			
	aluminum frame		other frames	
	operable	fixed	operable	fixed
uncoated single glazing				
1/4 in. [6.4 mm] clear	0.82	0.85	0.69	0.82
1/4 in. [6.4 mm] green	0.59	0.61	0.49	0.59
reflective single glazing				
1/4 in. [6.4 mm] SS on clear	0.26	0.28	0.22	0.25
1/4 in. [6.4 mm] SS on green	0.26	0.28	0.22	0.25
uncoated double glazing				
1/4 in. [6.4 mm] clear - clear	0.70	0.74	0.60	0.70
1/4 in. [6.4 mm] green - clear	0.48	0.49	0.40	0.47
reflective double glazing				
1/4 in. [6.4 mm] SS on clear - clear	0.20	0.18	0.15	0.17
1/4 in. [6.4 mm] SS on green - clear	0.18	0.18	0.15	0.16

SS = stainless-steel reflective coating



Solar Radiation through Windows



$$Q_{windows} = 160 \times 0.74 \times 192 = 22733 \text{ Btu/hr}$$

$$\left[\ Q_{windows} = 14.4 \times 0.74 \times 605 = 6447 \text{ W}\ \right]$$

Internal Heat Gains

Equipment

People

Appliances

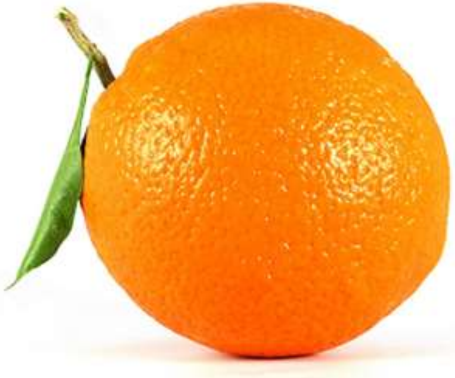
Lights

Heat Generated by People

- Metabolism of the human body normally generates more heat than it needs

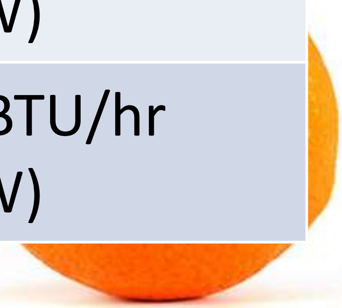
- 60% heat is transferred by convection and radiation to the surrounding environment.

- 40% is released by perspiration and respiration.



Heat Generated by People (Chart)

Level Of Activity	Sensible Heat Gain	Latent Heat Gain
Moderately active work (Office)	250 BTU/hr (75W)	200 BTU/hr (55W)
Standing, light work, walking (Store)	250 BTU/hr (75W)	200 BTU/hr (55W)
Light bench work (Factory)	275 BTU/hr (80W)	475BTU/hr (140W)
Heavy work (Factory)	580BTU/hr(170W)	870BTU/hr (255W)
Exercise (Gymnasium)	710BTU/hr (210W)	1090BTU/hr (315W)

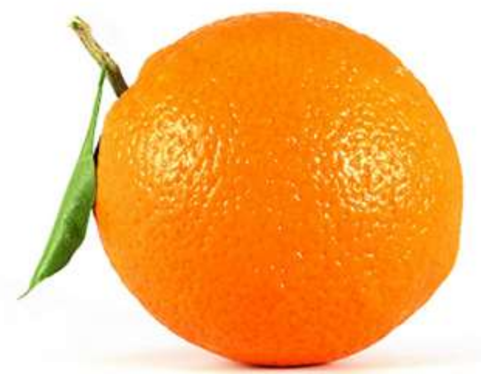


CLF Factors for People

Total hours in space	Hours after people enter space											
	1	2	3	4	5	6	7	8	9	10	11	12
2	0.65	0.74	0.16	0.11	0.08	0.06	0.05	0.04	0.03	0.02	0.02	0.01
4	0.65	0.75	0.81	0.85	0.24	0.17	0.13	0.10	0.07	0.06	0.04	0.03
6	0.65	0.75	0.81	0.85	0.89	0.91	0.29	0.20	0.15	0.12	0.09	0.07
8	0.65	0.75	0.81	0.85	0.89	0.91	0.93	0.95	0.31	0.22	0.17	0.13
10	0.65	0.75	0.81	0.85	0.89	0.91	0.93	0.95	0.96	0.97	0.33	0.24

Note: CLF – Cooling Load Factor

Capacity of a space to absorb and store heat.



Heat Gain from People

Q_S = No: of people x Sensible heat gain per person x CLF

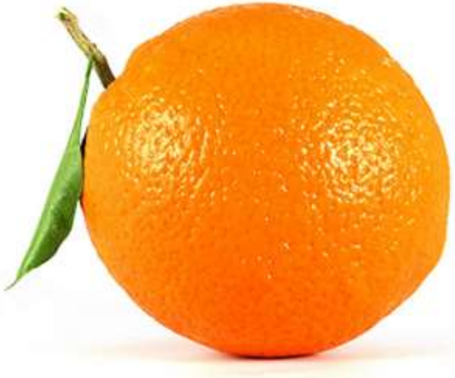
$Q_{sensible} = 18 \times 250 \times 1.0 = 4500$ Btu/hr

Q_L = No: of people $\times$ Latent heat gain/ person

$Q_{latent} = 18 \times 200 = 3600$ Btu/hr

$[\ Q_{sensible} = 18 \times 75 \times 1.0 = 1350\ \text{W}\ ]$

$[\ Q_{latent} = 18 \times 55 = 990\ \text{W}\ ]$



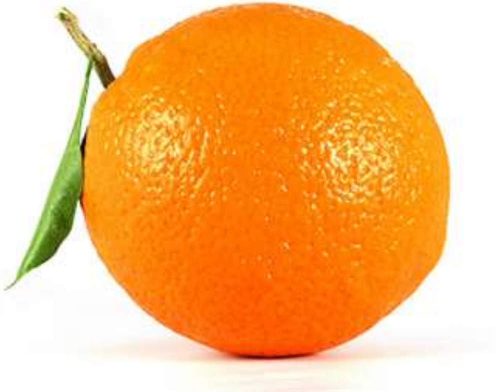
Heat Gain from Lighting

$$Q = \text{Btu/hr} \times \text{Ballast factor} \times \text{CLF}$$

$$[\ Q = \text{watts} \times \text{Ballast factor} \times \text{CLF}\ ]$$

Ballast factor = 1.2 for fluorescent lights

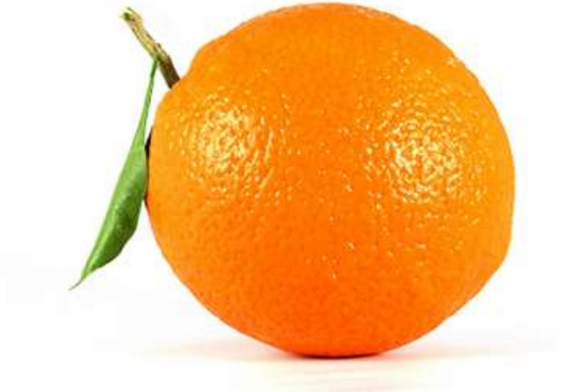
Ballast factor = 1.0 for incandescent lights



Heat Gain from Lighting

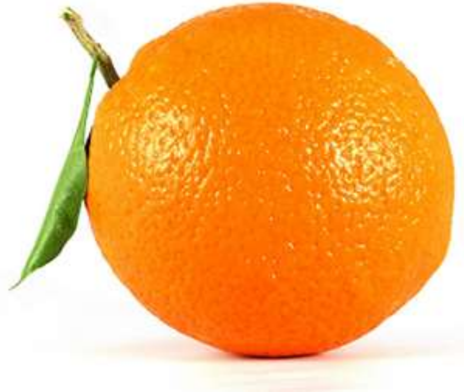
$$Q_{lights} = 5400 \times 3.41 \times 1.2 \times 1.0 = 22097 \text{ Btu/hr}$$

$$\left[\ Q_{lights} = 5400 \times 1.2 \times 1.0 = 6480 \text{ W}\ \right]$$

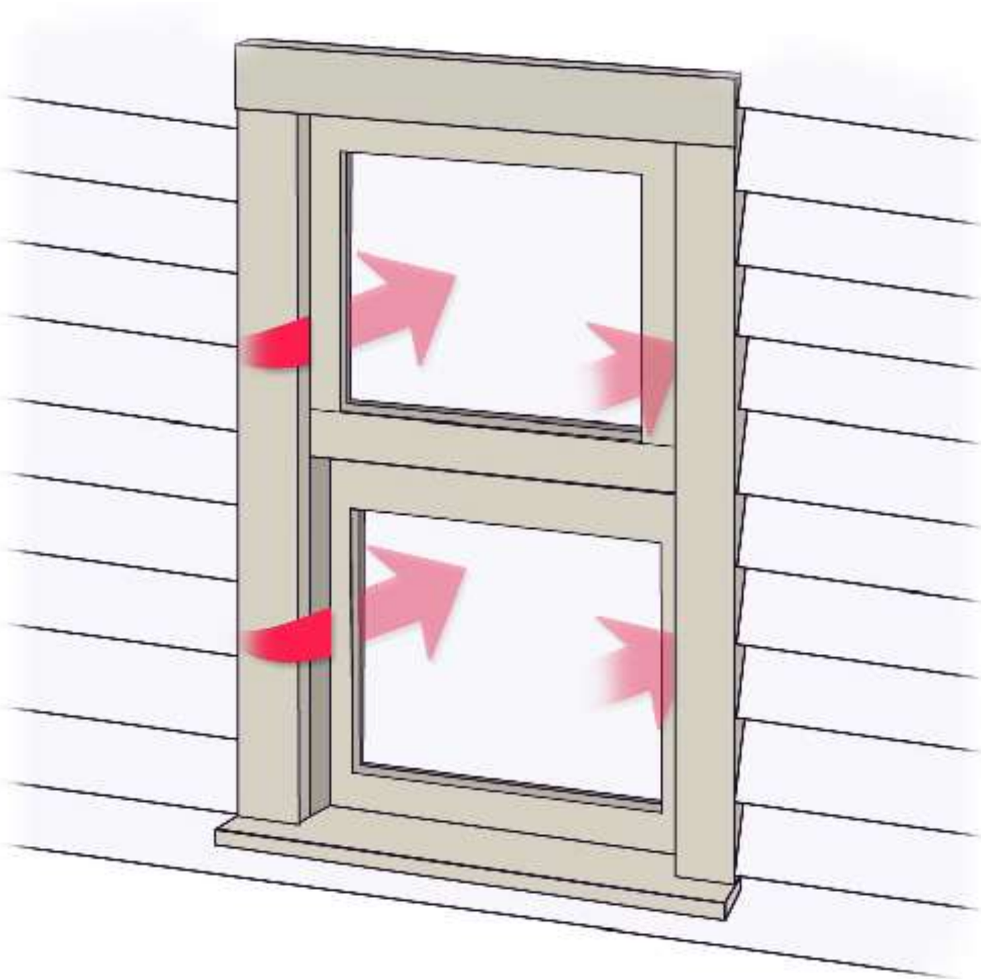


Heat generated by equipment

Equipment	Sensible Heat Gain	Latent Heat Gain
Coffee maker	3580 BTU/hr (1050W)	1540 BTU/hr (450W)
Printer	1000 BTU/hr (292W)	
Typewriter	230 BTU/hr (67W)	

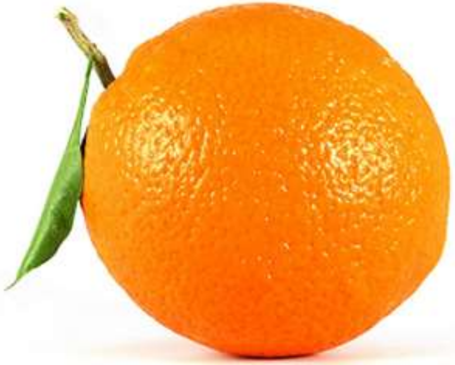


Infiltration



Methods of Estimating Infiltration

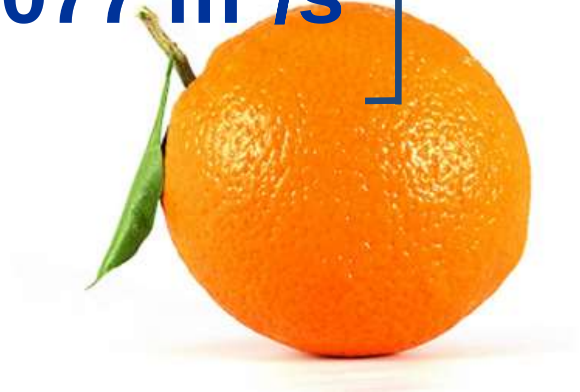
- Air change method
- Crack method
- Effective leakage-area method



Infiltration Airflow

$$\text{Infiltration airflow} = \frac{32400 \times 0.3}{60} = 162 \text{ CFM}$$

$$\left[\text{Infiltration airflow} = \frac{927.6 \times 0.3}{3600} = 0.077 \text{ m}^3/\text{s}\right]$$



Heat Gain from Infiltration

$$Q_{sensible} = 1.085 \times \text{airflow} \times \Delta T$$

$$Q_{latent} = 0.7 \times \text{airflow} \times \Delta W$$

$$\left[\ Q_{sensible} = 1210 \times \text{airflow} \times \Delta T\ \right]$$

$$\left[\ Q_{latent} = 3010 \times \text{airflow} \times \Delta W\ \right]$$

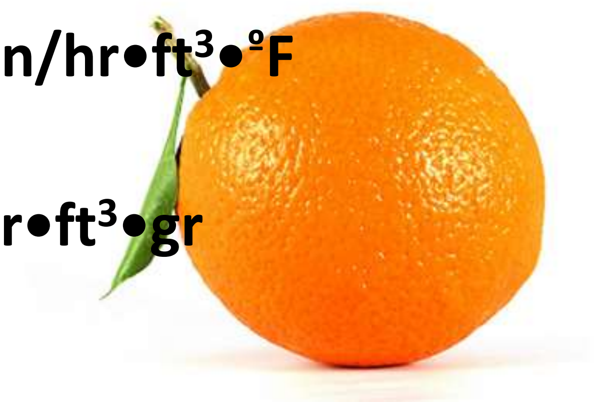
ΔW = (Outdoor Humidity Ratio – Indoor Humidity Ratio)

Air Flow – Quantity of air infiltrating the place

ΔT = (Outdoor D.B.T – Indoor D.B.T)

Density x Specific Heat = 1.085 (1210) Btu•min/hr•ft^3•ºF [J/m^3•ºK]

Latent Heat Factor = 0.7 (3010) Btu•min•lb/hr•ft^3•gr [J•kg/m^3•g]



Heat Gain from Infiltration

$$Q_S = 1.085 \times 162 \times (95 - 78) = 2{,}988 \text{ Btu/hr}$$

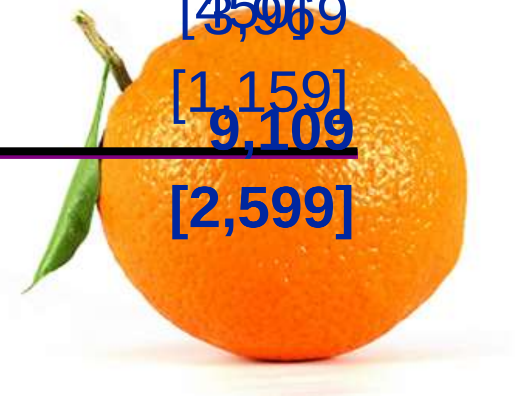
$$Q_L = 0.7 \times 162 \times (105 - 70) = 3{,}969 \text{ Btu/hr}$$

$$\left[\, Q_S = 1{,}210 \times 0.077 \times (35 - 25.6) = 876 \text{ W} \,\right]$$

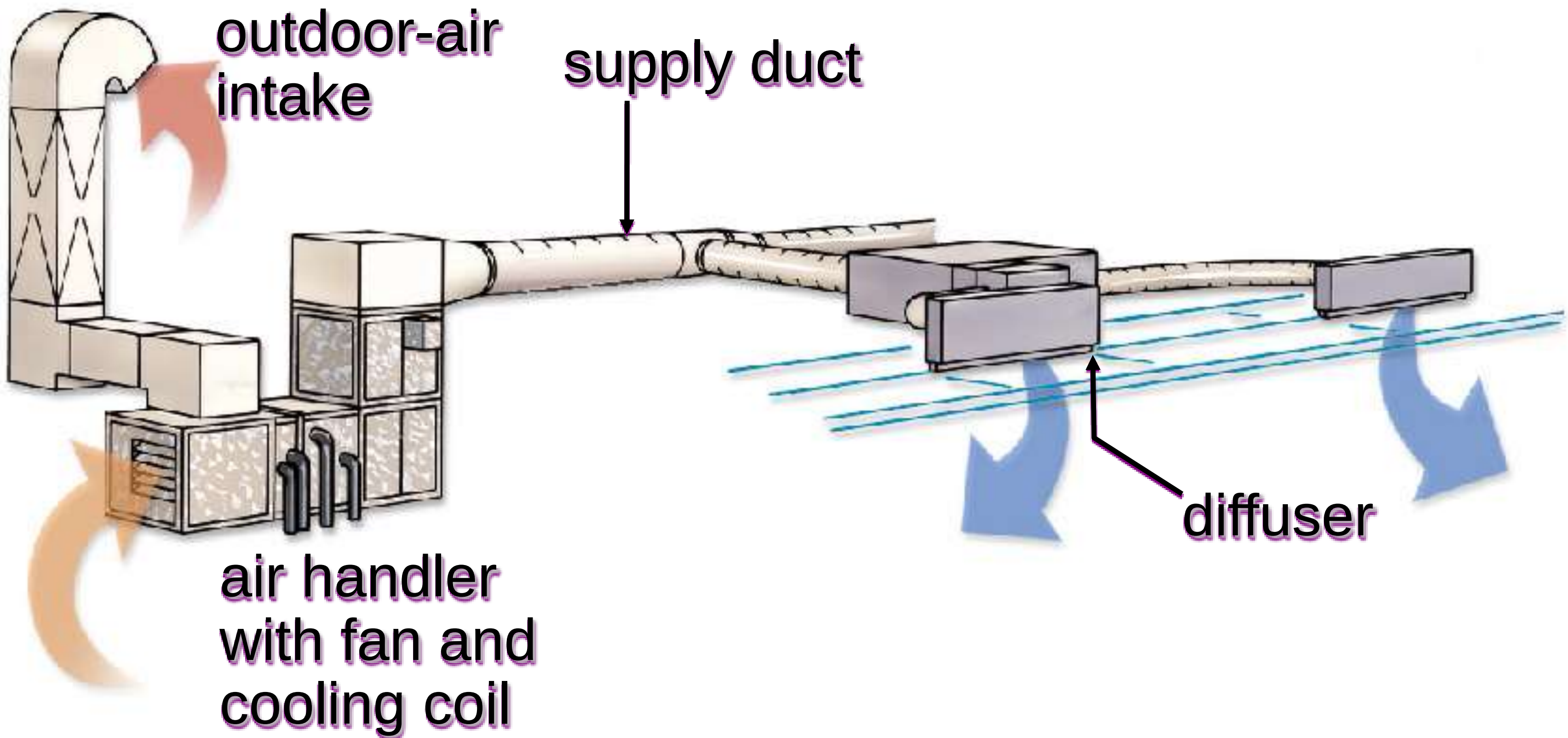
$$\left[\, Q_L = 3{,}010 \times 0.077 \times (15 - 10) = 1{,}159 \text{ W} \,\right]$$

Summary of Space Cooling Loads

space load components	**sensible load** Btu/hr [W]	**latent load** Btu/hr [W]
conduction through roof	12,312 [3,563]	
conduction through exterior wall	502 [144]	
conduction through windows	1,310 [359]	
solar radiation through windows	22,933 [6,447]	
people	4,600 [1,350]	3,600 [990]
lights	21,797 [6,480]	
equipment	8,184 [2,404]	1,540 [450]
infiltration	2,988 [876]	3,969 [1,159]
Total space cooling load	**74,626 [21,623]**	**9,109 [2,599]**

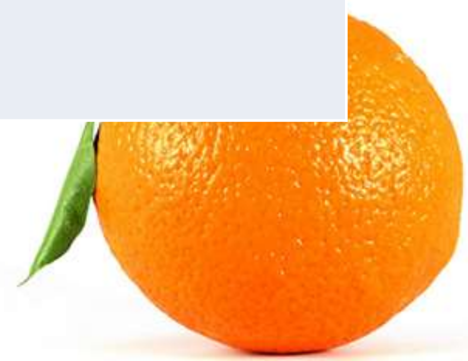


Ventilation



Outdoor Air Requirements

Type of Space	Outdoor Air/ person	Outdoor Air/ ft2 (m2)
Auditorium	15 CFM (0.008 m^3/s)	
Class rooms	15 CFM (0.008 m^3/s)	
Locker rooms		0.5 CFM (0.0025 m^3/s)
Office space	20 CFM (0.01 m^3/s)	
Public restrooms	50 CFM (0.025 m^3/s)	
Smoking lounge	60 CFM (0.03 m^3/s)	



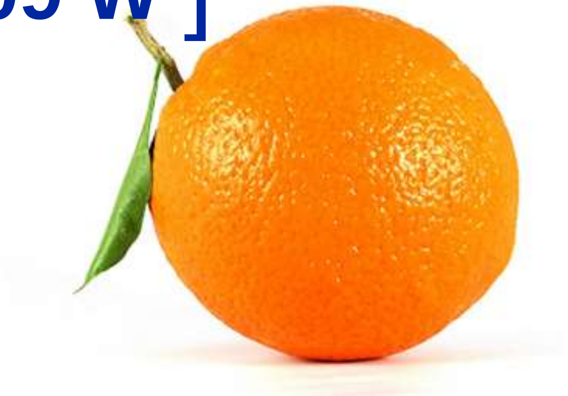
Cooling Load Due to Ventilation

$$Q_S = 1.085 \times 360 \times (95 - 78) = 6640 \text{ Btu/hr}$$

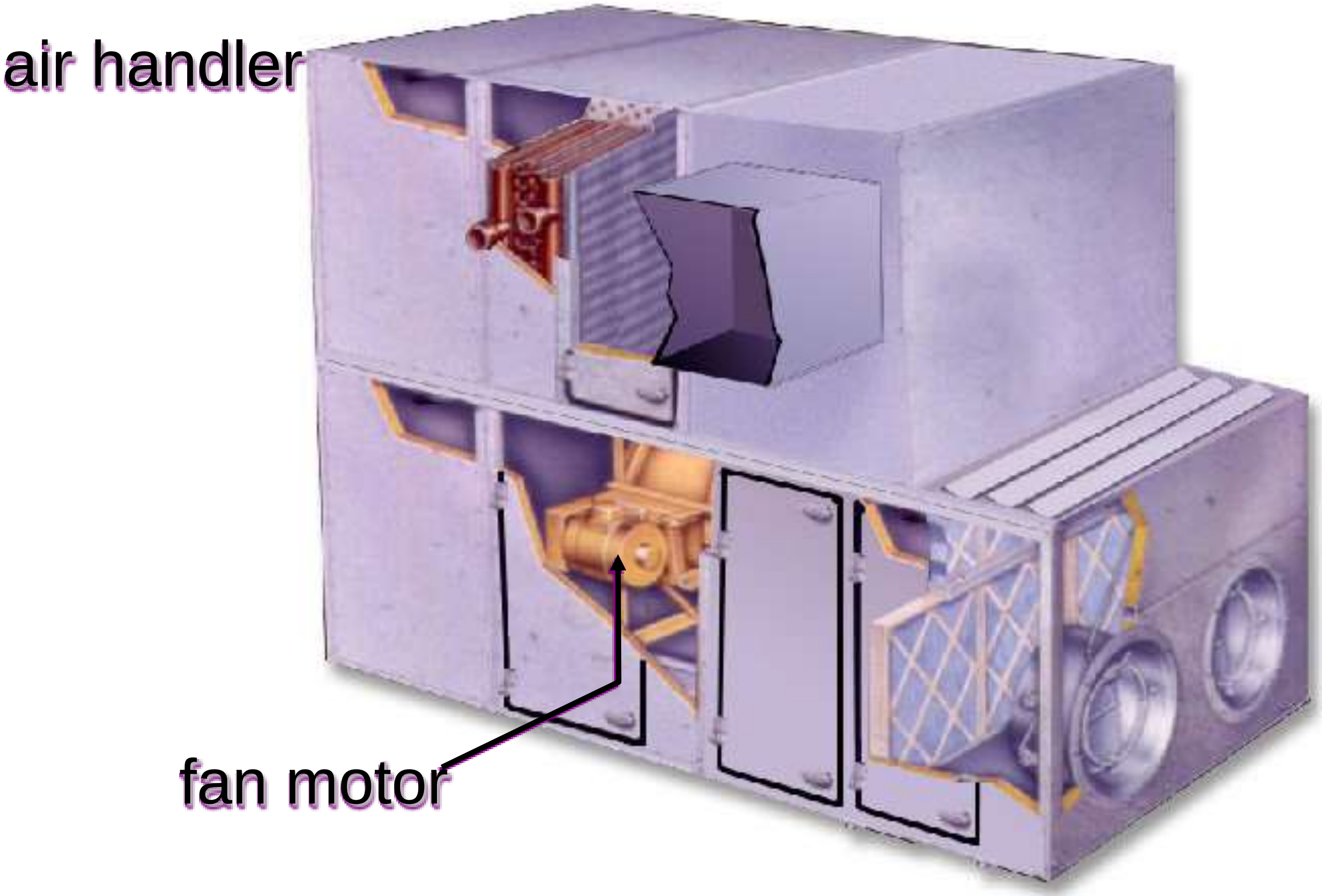
$$Q_L = 0.7 \times 360 \times (105 - 70) = 8820 \text{ Btu/hr}$$

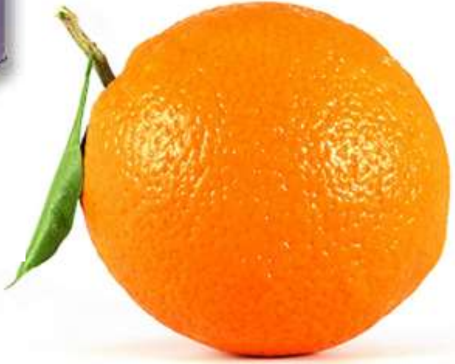
$$\left[\ Q_S = 1210 \times 0.18 \times (35 - 25.6) = 2047 \text{ W}\ \right]$$

$$\left[\ Q_L = 3010 \times 0.18 \times (15 - 10) = 2709 \text{ W}\ \right]$$

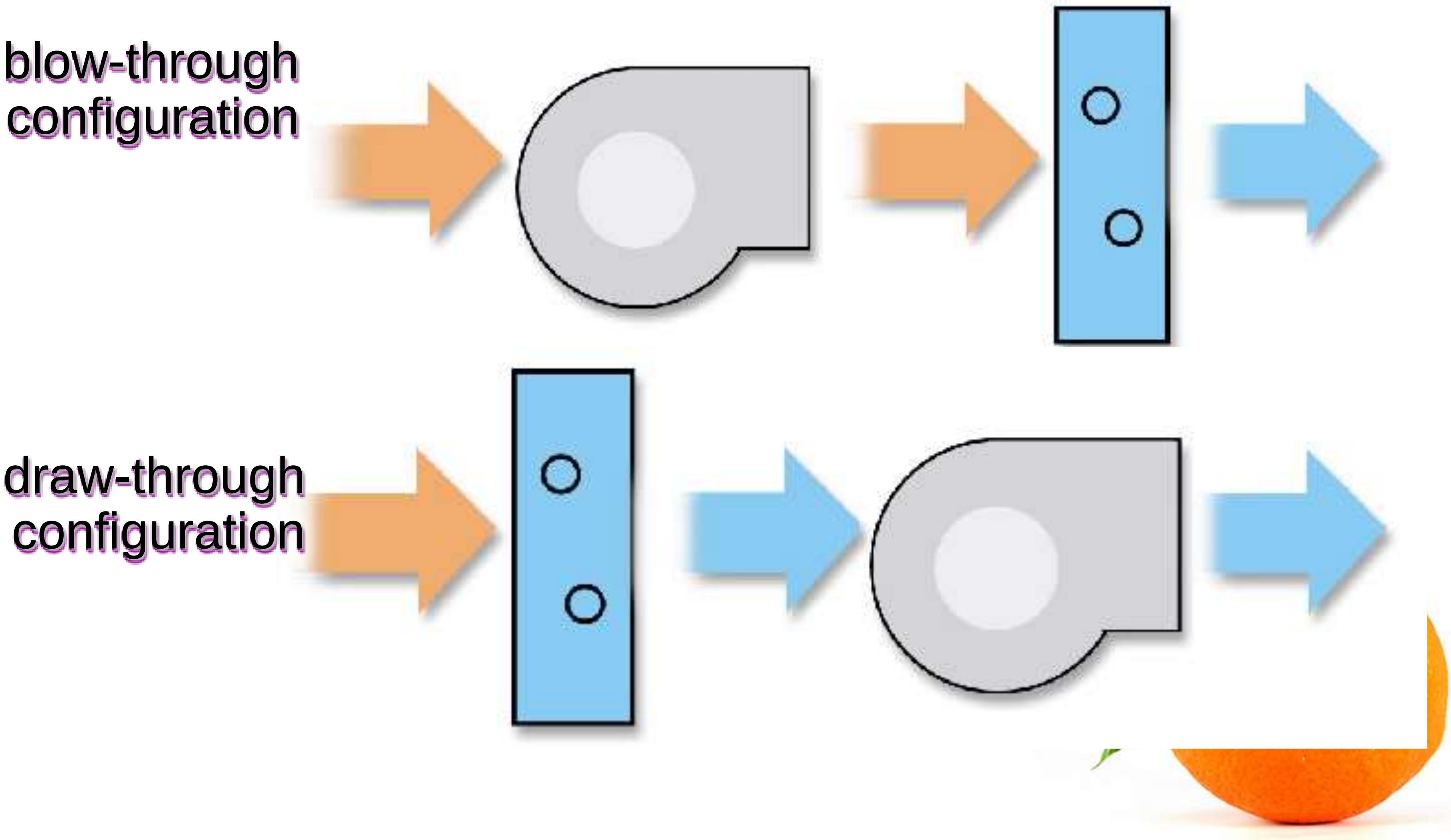


System Heat Gains





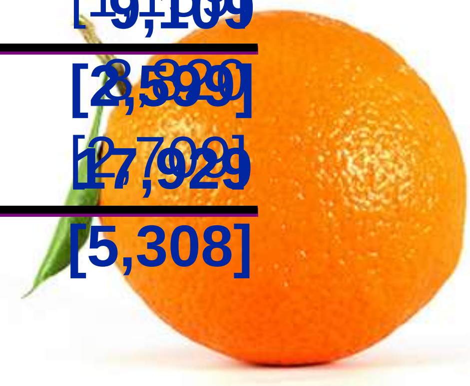
Components of Fan Heat



Heat Gain in Ductwork

Summary of Cooling Loads

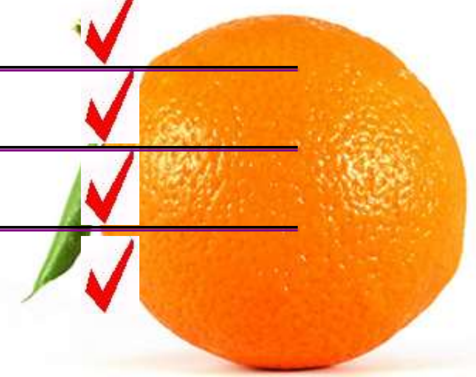
	sensible load Btu/hr	sensible load [W]	latent load Btu/hr	latent load [W]
	12,312			
conduction through roof	[illegible]	[illegible]		
conduction through exterior wall	[illegible]	[illegible]		
conduction through windows	[illegible]	[illegible]		
solar radiation through windows	[illegible]	[illegible]	3,600	
people	[illegible]	[illegible]		[990]
lights	[illegible]	[illegible]	1,540	
equipment	[illegible]	[illegible]	[illegible]	[illegible]
infiltration		[876]		[illegible]
total space cooling load	**74,626**	**[illegible]**	**9,109**	**[illegible]**
ventilation	[illegible]	[illegible]	[illegible]	[illegible]
total coil cooling load	**81,266**	**[23,670]**	**17,929**	**[5,308]**



Psychometric Analysis

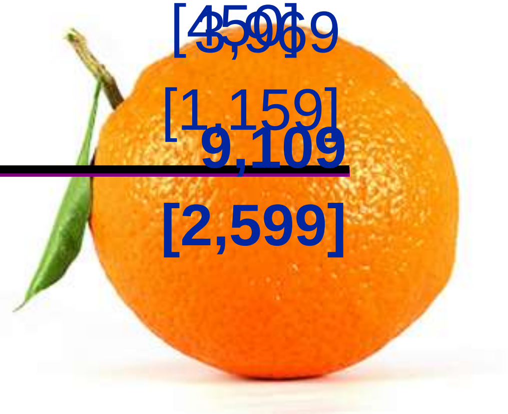
Space Load versus Coil Load

	space load	coil load
conduction through roof, walls, windows, and skylights	✓	✓
solar radiation through windows, skyligh	✓	✓
conduction through ceiling, interior partition walls, and floor	✓	✓
people	✓	✓
lights	✓	✓
equipment and appliances	✓	✓
infiltration	✓	✓
ventilation		✓
system heat gains		✓



Space Sensible and Latent Loads

space load components	**sensible load** Btu/hr [W]	**latent load** Btu/hr [W]
conduction through roof	12,312 [3,563]	
conduction through exterior wall	502 [144]	
conduction through windows	1,310 [359]	
solar radiation through windows	22,733 [6,447]	
people	4,500 [1,350]	3,600 [990]
lights	21,097 [6,480]	
equipment	8,184 [2,404]	1,540 [450]
infiltration	2,988 [876]	3,969 [1,159]
total space cooling load	**74,626 [21,623]**	**9,109 [2,599]**

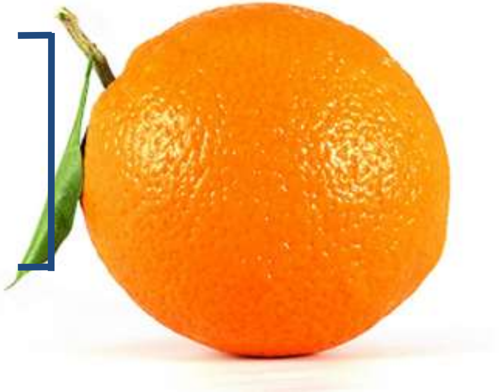


Sensible Heat Ratio (SHR)

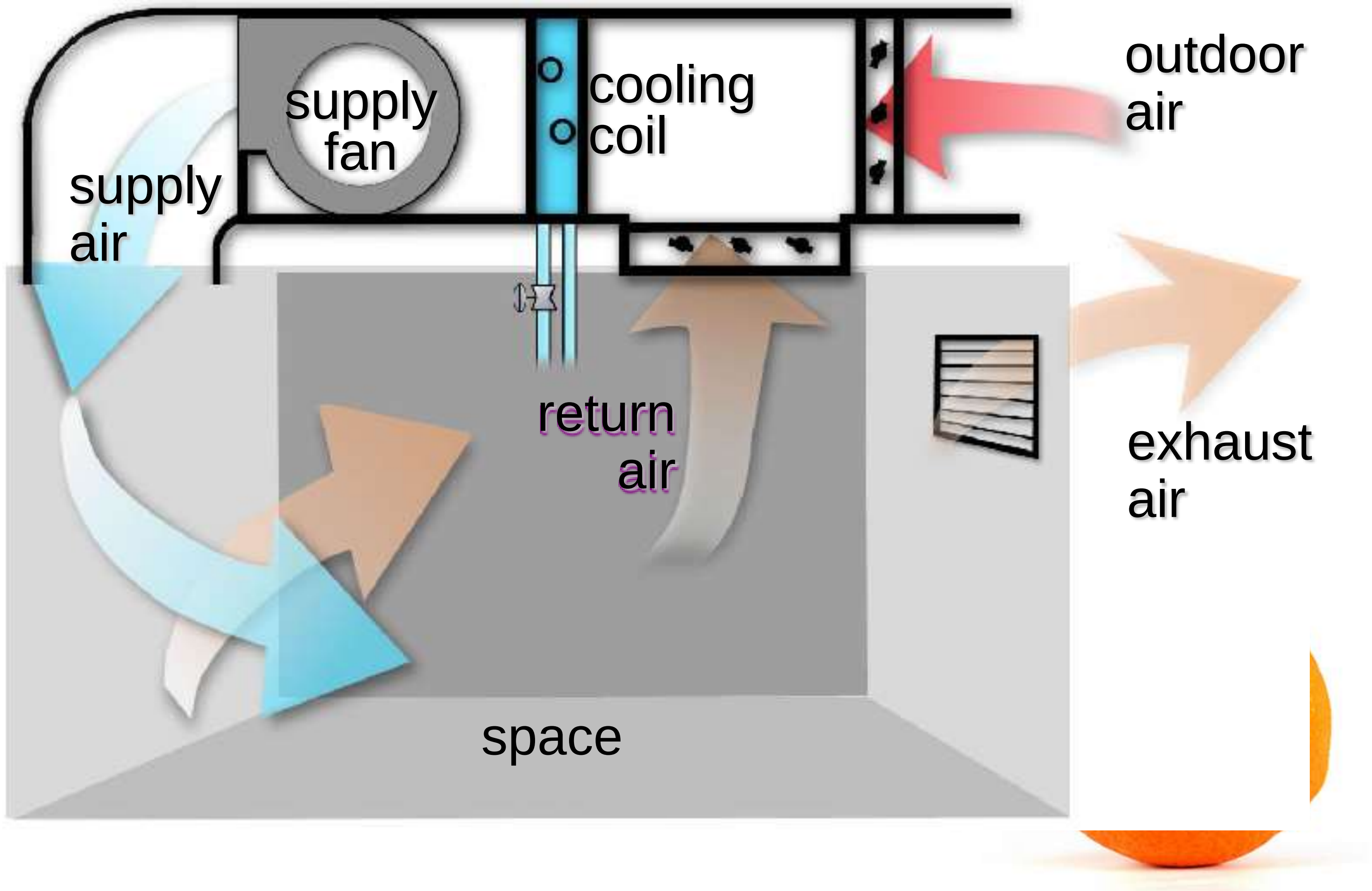
$$SHR = \frac{\text{sensible heat gain}}{\text{sensible heat gain + latent heat gain}}$$

$$SHR = \frac{74{,}626}{74626 + 9109} = 0.89$$

$$\left[SHR = \frac{21623}{21623 + 2599} = 0.89 \right]$$



Single-Space Analysis



Determine Supply Airflow

$$\text{supply airflow} = \frac{\text{sensible heat gain}}{1.085 \times (\text{room DB} - \text{supply DB})}$$

$$\left[\text{supply airflow} = \frac{\text{sensible heat gain}}{1{,}210 \times (\text{room DB} - \text{supply DB})}\right]$$

Determine Supply Airflow

$$\text{supply airflow} = \frac{74{,}626}{1.085 \times (78 - 55)} = 2{,}990 \text{ cfm}$$

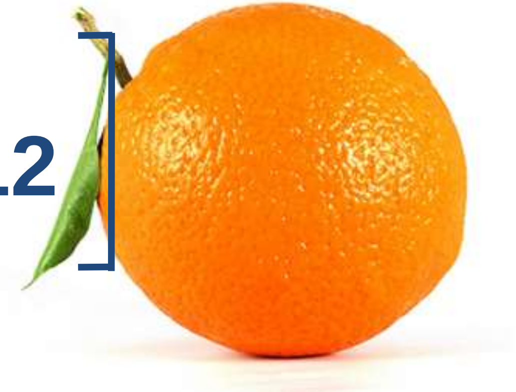
$$\left[\text{supply airflow} = \frac{21{,}623}{1{,}210 \times (25.6 - 12.8)} = 1.40 \text{ m}^3/\text{s}\right]$$

Calculate Entering Coil Conditions

$$\%\ \text{outdoor air} = \frac{\text{ventilation airflow}}{\text{total supply airflow}}$$

$$\%\text{OA} = \frac{360\ \text{cfm}}{2990\ \text{cfm}} = 0.12$$

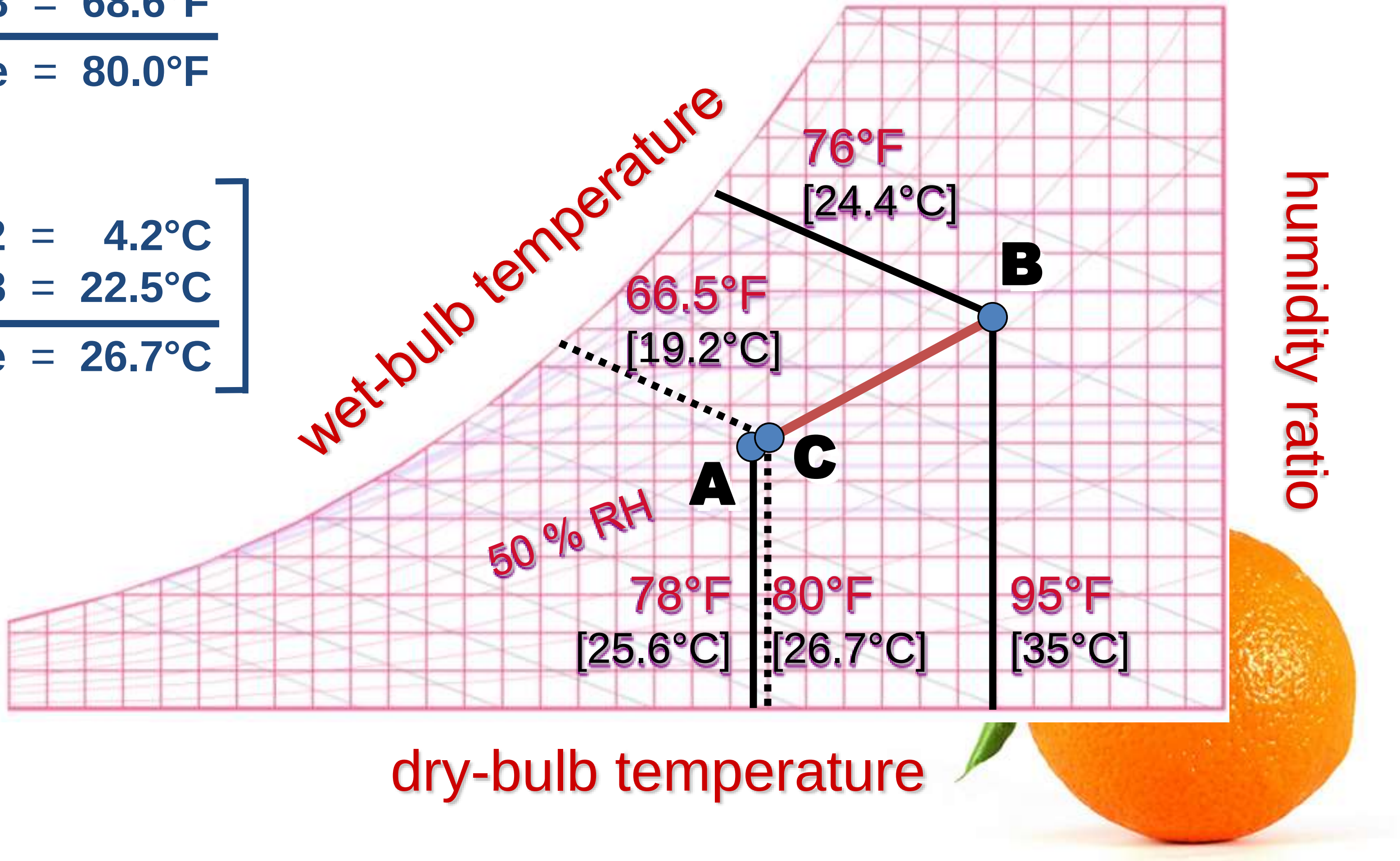
$$\left[\%\text{OA} = \frac{0.18\ \text{m}^3/\text{s}}{1.40\ \text{m}^3/\text{s}} = 0.12\right]$$



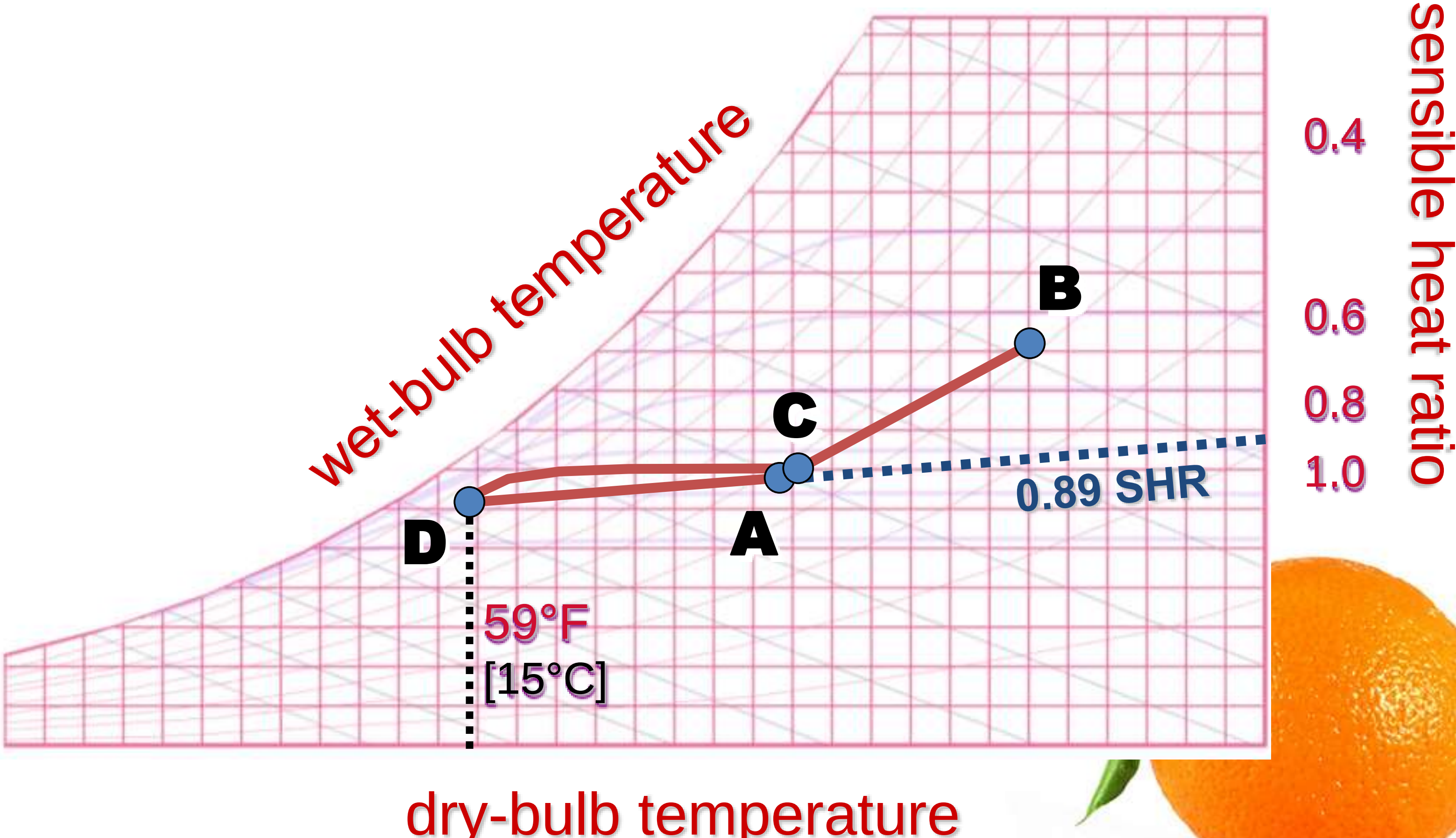
Calculate Entering Coil Conditions

95°F	× 0.12	=	11.4°F
78°F	× 0.88	=	68.6°F
	mixture	=	80.0°F

[
35°C	× 0.12	=	4.2°C
25.6°C	× 0.88	=	22.5°C
	mixture	=	26.7°C
]



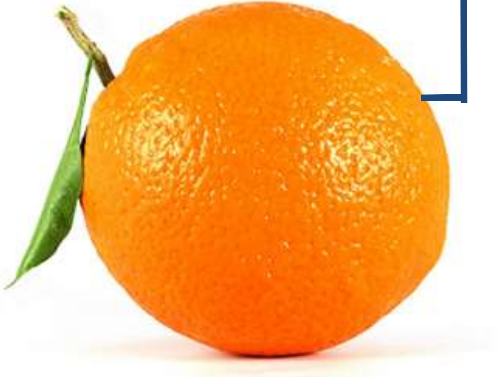
Determine Supply Air Temperature



Recalculate Supply Airflow

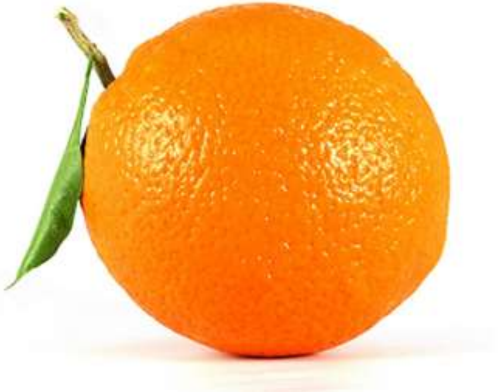
$$\text{supply airflow} = \frac{74{,}626}{1.085 \times (78 - 59)} = 3{,}620 \text{ cfm}$$

$$\left[\text{supply airflow} = \frac{21{,}623}{1{,}210 \times (25.6 - 15)} = 1.69 \text{ m}^3/\text{s}\right]$$

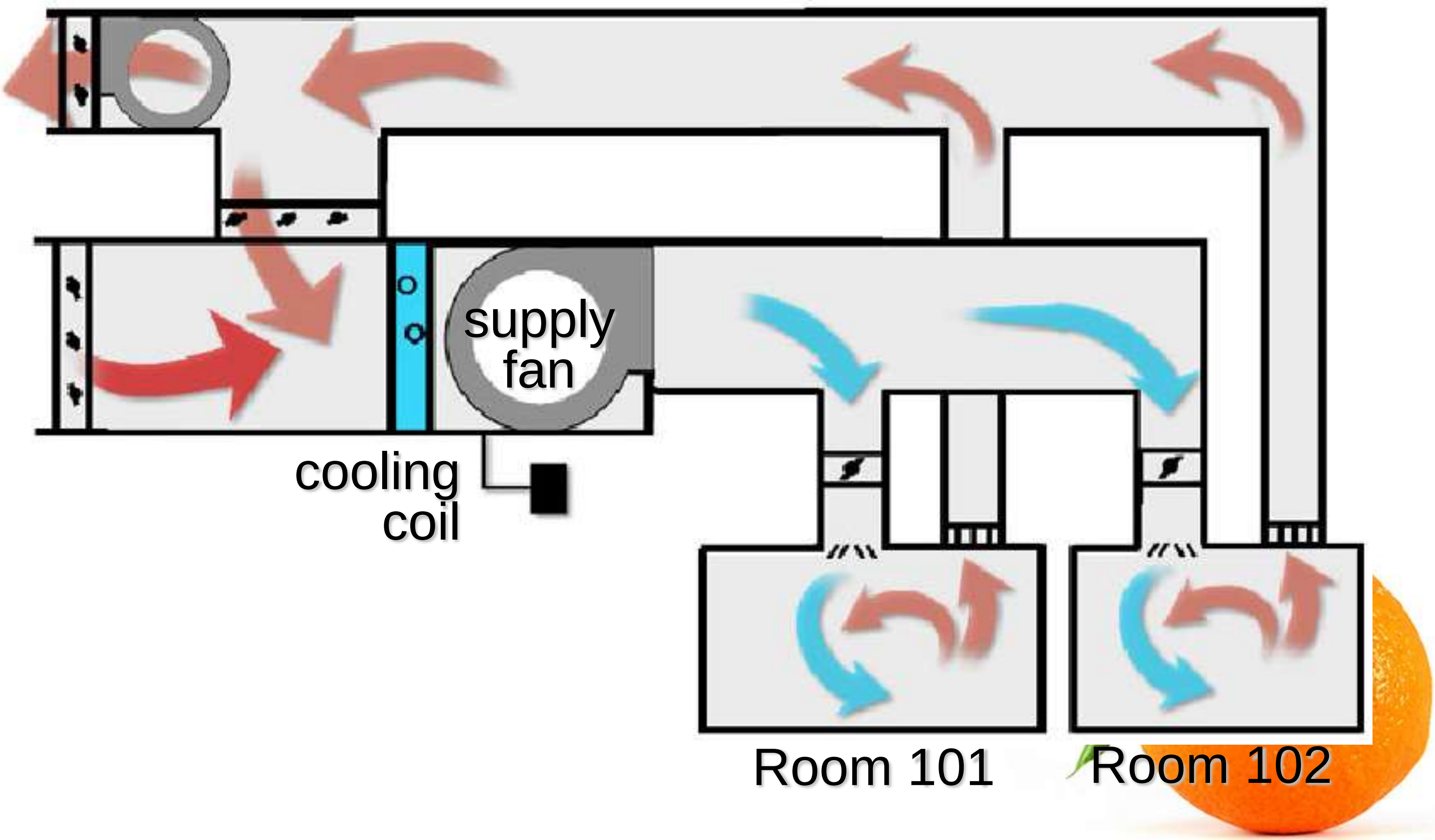


Total Cooling Load on Coil

	Room 101	
	Btu/hr	[W]
total space sensible load	74,626	[21,623]
total space latent load	9,109	[2,599]
ventilation	15,460	[4,756]
total coil cooling load	**99,195**	**[28,978]**

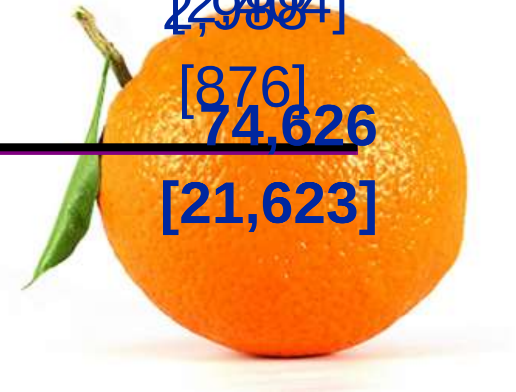


Multiple-Space Analysis



Room 101 (Faces West)

space sensible load components	8 a.m. Btu/hr [W]	4 p.m. Btu/hr [W]
	2,616	12,312
conduction through roof	[740]	[3,563] 502
conduction through exterior wall	160 [48]	1,310 [144]
conduction through windows	202 [51] 3,552	22,733 [359]
solar radiation through windows	[1,012] 4,500	[6,447] 4,500
people	[1,350] 22,097	[1,350] 22,097
lights	[6,480] 8,184	[6,480] 8,184
equipment	[2,404] 2,988	[2,404] 2,988
infiltration	[876] 44,299	[876] 74,626
total space sensible load	**[12,961]**	**[21,623]**



Room 102 (Faces East)

space sensible load components	**8 a.m.** Btu/hr [W]		**4 p.m.** Btu/hr [W]	
conduction through roof	2,616	[740]	12,312	[3,563]
conduction through exterior wall	160	[48]	844	[252]
conduction through windows	202	[51]	1,310	[359]
solar radiation through windows	21,667	[6,138]	3,078	[874]
people	4,500	[1,350]	4,500	[1,350]
lights	21,697	[6,480]	21,697	[6,480]
equipment	8,184	[2,404]	8,184	[2,404]
infiltration	2,988	[876]	2,988	[876]
total space sensible load	**62,414**	**[18,087]**	**55,313**	**[16,158]**

"Sum-of-Peaks" versus "Block"

space sensible load	**8 a.m.** Btu/hr [W]	**4 p.m.** Btu/hr [W]
Room 101 (faces west)	44299 [12961]	**74626** **[21623]**
Room 102 (faces east)	**62414** **[18087]**	55313 [16158]

sum-of-peaks = 74626 + **62414** = **137040 Btu/hr**

[21623 + 18087 = 39710 W]

block = 74626 + **55313** = **129939 Btu/hr**

[21623 + 16158 = 37781 W]

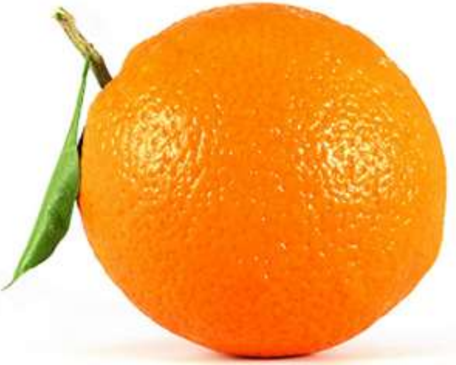
“Sum-of-Peaks” versus “Block”

- Sum-of-peaks

  supply airflow = 6,648 CFM [3.10 m^3/s]

- Block

  supply airflow = 6,303 CFM [2.95 m^3/s]



"Block" Cooling Load

loads at 4 p.m.	Room 101 Btu/hr [W]	Room 102 Btu/hr [W]
total space sensible load	74626 [21623]	55313 [16158]
total space latent load	9109 [2599]	9109 [2599]
ventilation	15460 [4756]	15460 [4756]
Total coil cooling load	**99195 [28978]**	**79882 [23513]**

Block cooling load (4 p.m.) = **99195** + **79882** = **179077 Btu/hr**

[28978 + 23513 = 52491 W]