CAE 464/517 HVAC Systems Design

Spring 2023

February 02, 2023

Cooling load calculation and examples

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ANNOUNCEMENTS

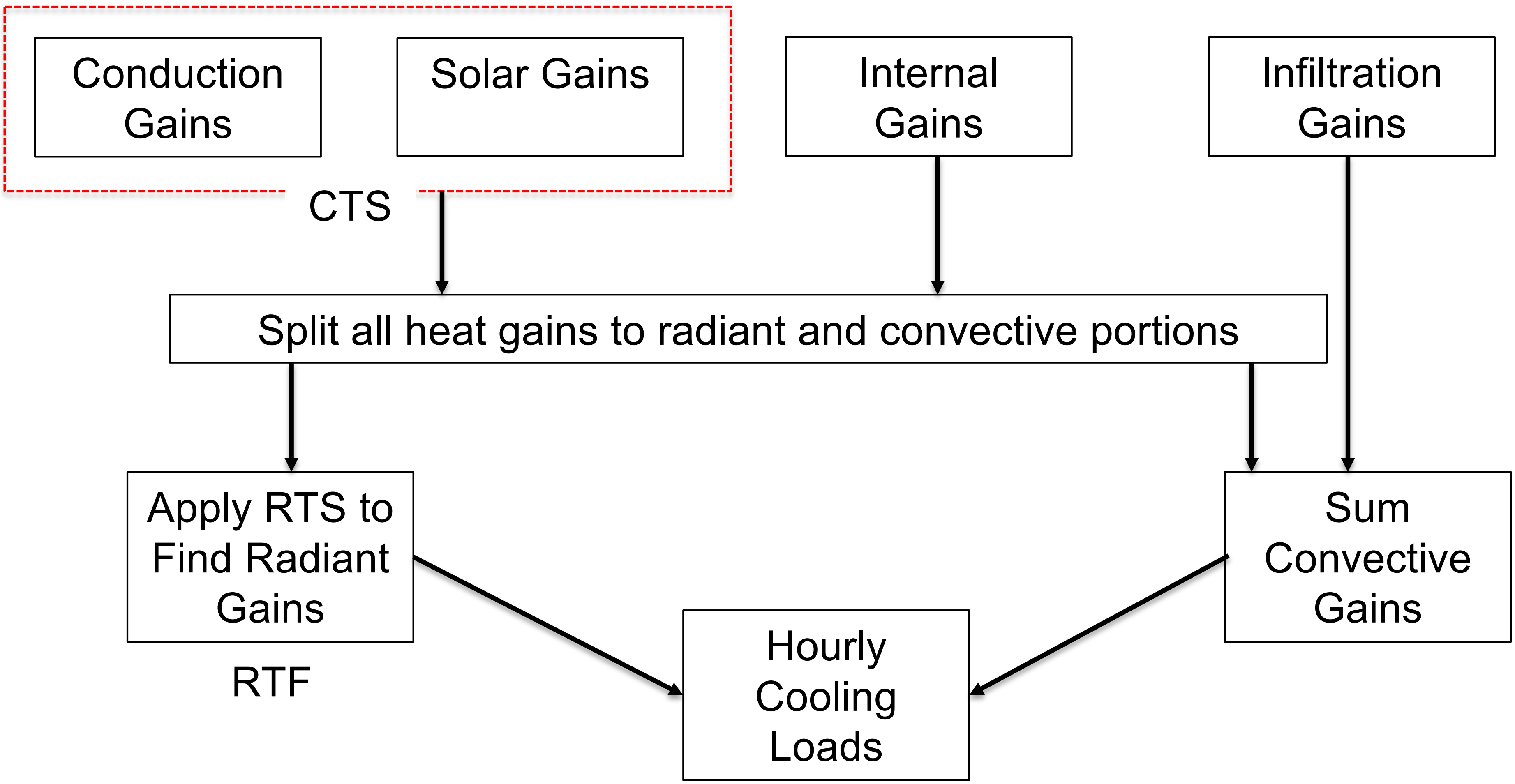
Announcements

- Homework 2 is due tonight (extended deadline)
- Homework 3 is posted
- The project will be distributed soon (working on the Revit model)
- Revit training on Tuesday in class:
  - ❑ Please bring your laptop
  - ❑ We will use Revit 2023 (installed on Apporto and computer lab; also free for educational purposes)

RECAP

Recap

- Radiant Transfer Series Method (RTSM)



CTS = Conduction Transfer Series
RTF = Radiant Transfer Function

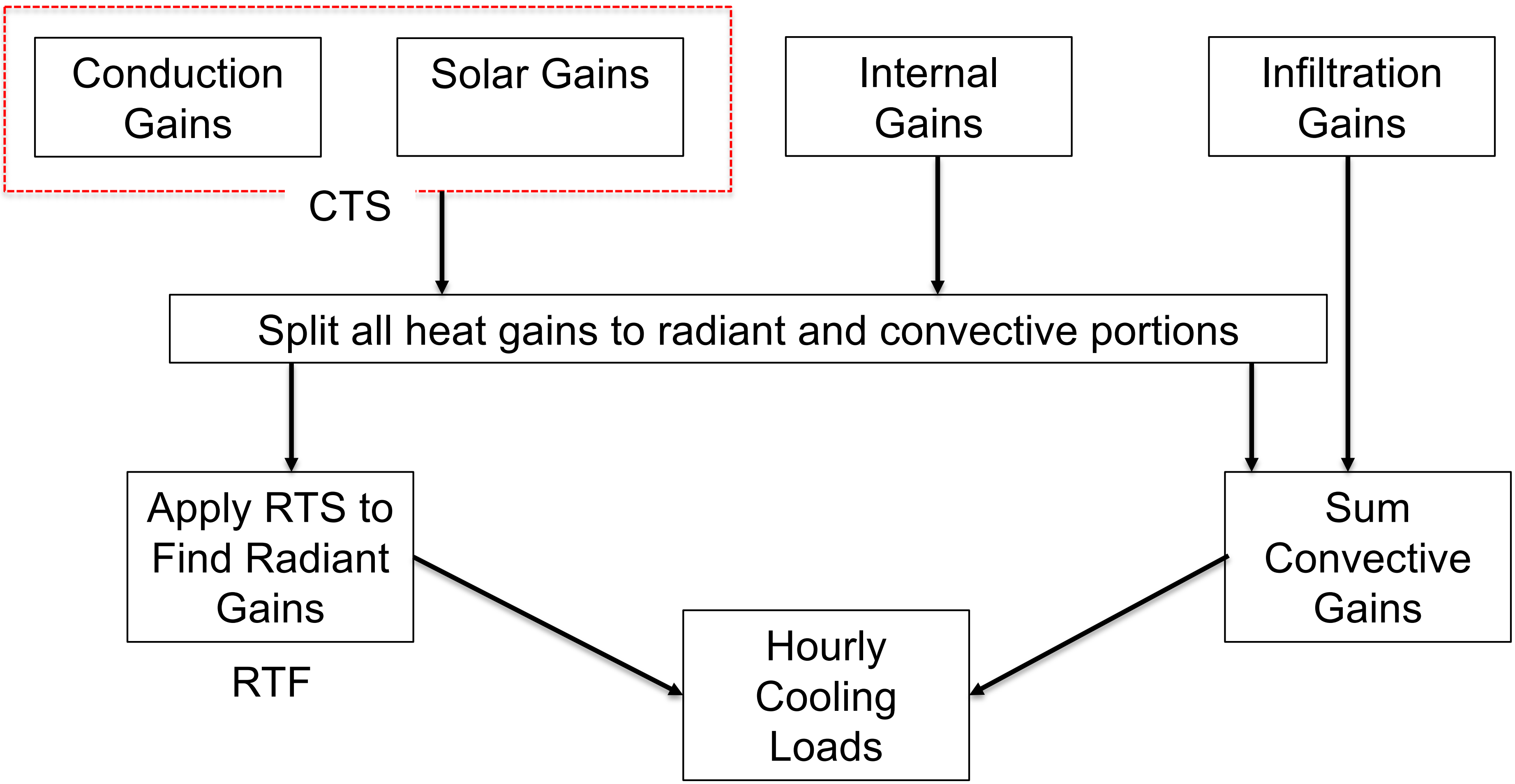
Recap

Recap

COOLING LOAD CALCULATIONS DUE TO ENCLOSURE

CTS

- Radiant Transfer Series Method (RTSM)



CTS = Conduction Transfer Series
RTF = Radiant Transfer Function

CTS

$$q_\theta = \sum_{j=0}^{23} c_j UA(t_{sol-air,\theta-j\delta} - t_{rc})$$

- q_θ: Hourly conductive heat gain Btu/h
- U: Overall heat transfer coefficient for the surface $\frac{Btu}{h.ft^2.F}$
- A: Surface area ft^2
- c_j: j-th conduction time series factor
- $t_{\text{sol-air},\theta-j\delta}$: Sol-air temperature °F
- t_{rc}: Presumed constant room temperature
- θ : The current hour
- δ: The time step (one hour)

CTS

- For example, at 1 pm (13), we write:

$$q_\theta = \sum_{j=0}^{23} c_j UA(t_{e,\theta-j\delta} - t_{rc})$$

$$q_{13} = \sum_{j=0}^{23} c_j UA(t_{e,13-j\delta} - t_{rc}) = [UA]\times \sum_{j=0}^{23} c_j \times(t_{e,13-j\delta} - t_{rc})$$

$$= [UA]\times[c_0\left(t_{sol-air,13} - t_{rc}\right) + c_1\left(t_{sol-air,12} - t_{rc}\right) + c_2\left(t_{sol-air,11} - t_{rc}\right) + \cdots$$

$$\ldots + c_{23}\left(t_{sol-air,14} - t_{rc}\right)]$$

CTS

- For example, at 1 pm (13), we write:

CTS

- Define the sol-air temperature as a proxy for the outdoor surface temperature:

$$\frac{q}{A} = \alpha E_t + h_o(t_o - t_s) - \epsilon \Delta R$$

$$t_{sol-air} = t_o + \frac{\alpha E_t}{h_o} - \frac{\epsilon \Delta R}{h_0}$$

- For horizontal surfaces:
  - ΔR = 20 $\frac{Btu}{h.ft^2}$
  - If ε = 1 and h_o= 3.0 $\frac{Btu}{h.ft^2F}$ the long-wave correction term is about 7°F

CTS

- CTSFs for the very light wall are:
  - ❑ Very large for the first few hours
  - ❑ Nearly zero for the remaining hours
  - ❑ Little stored energy capacity

- Heavier walls have:
  - ❑ Smaller values for the first few hours
  - ❑ Remain non-zero for many hours
  - ❑ Long delay for heavy walls

CTS

- Comparison between different wall assemblies:

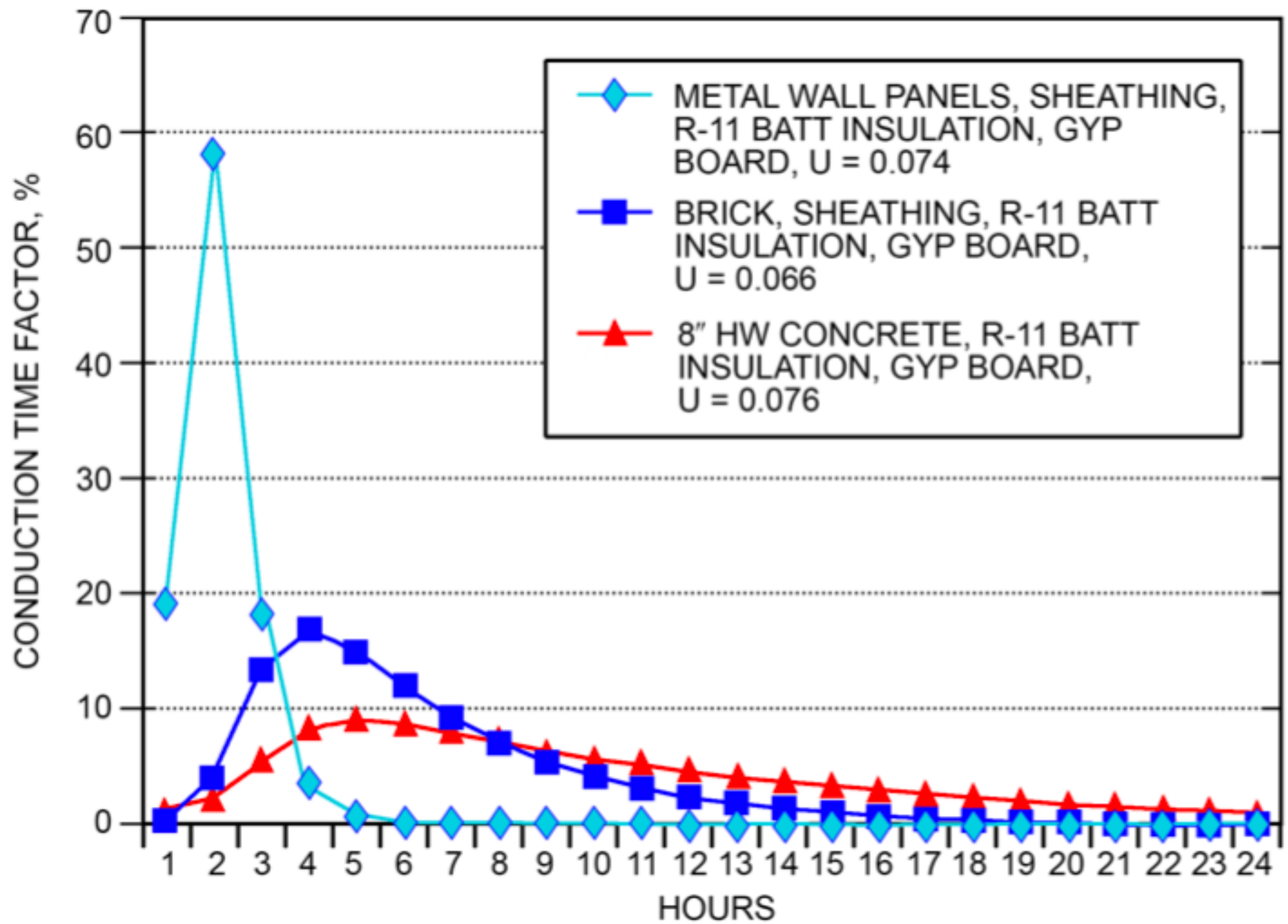


Fig. 9 CTS for Light to Heavy Walls

CTS

- Insulation has limited impacts on CTSs

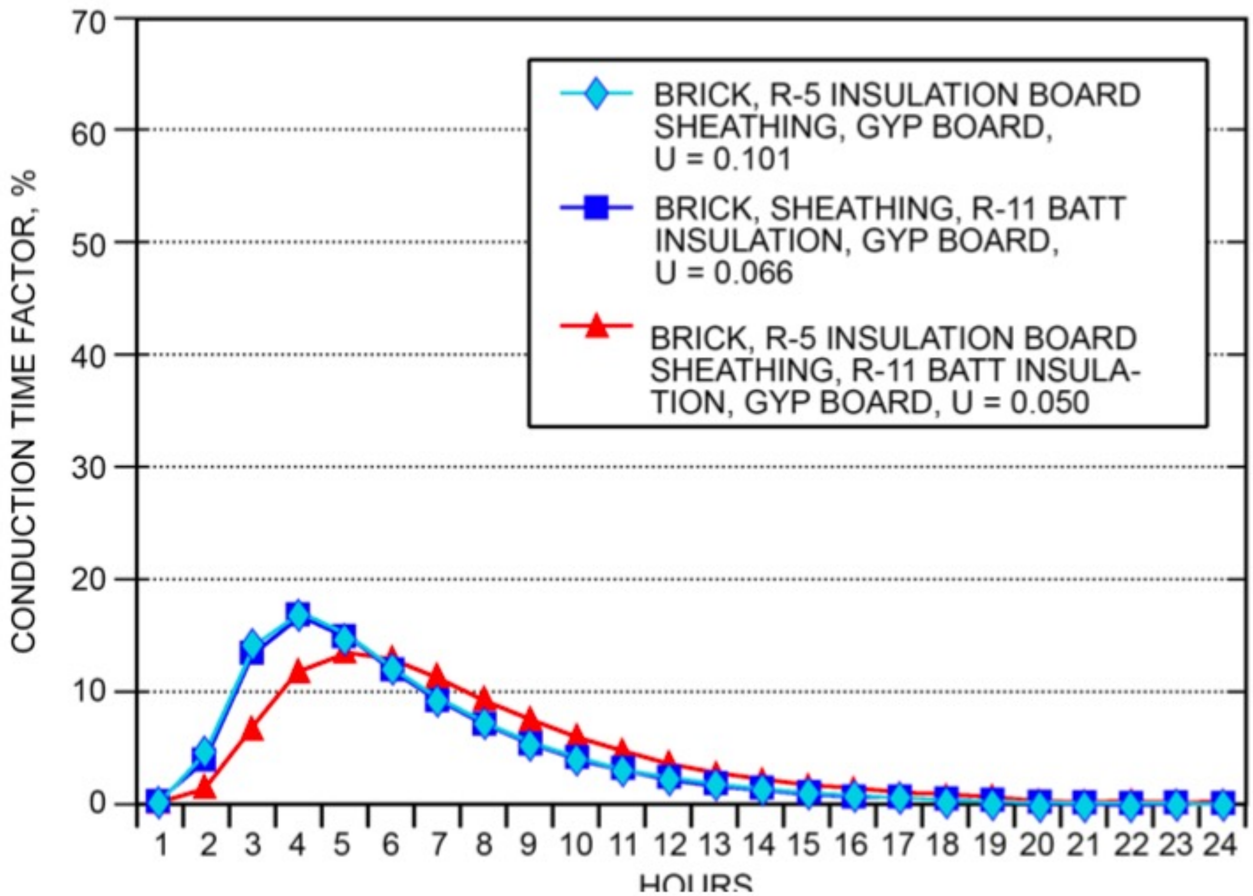


Fig. 10 CTS for Walls with Similar Mass and Increasing Insulation

CTS

Table 16 Wall Conduction Time Series (CTS) (*Continued*)

	Brick Walls								
	Brick, R-5 Insulation Board, Sheathing, Gyp. Board	Brick, R-10 Insulation Board, Sheathing, Gyp. Board	Brick, Sheathing, R-11 Batt Insulation, Gyp. Board	Brick, Sheathing, R-22 Batt Insulation, Gyp. Board	Brick, R-5 Insulation Board, Sheathing, R-11 Batt Insulation, Gyp. Board	Brick, R-5 Insulation Board, Sheathing, R-22 Batt Insulation, Gyp. Board	Brick, R-5 Insulation Board, 8 in. LW CMU	Brick, R-10 Insulation Board, 8 in. LW CMU	Brick, 8 in. LW CMU, R-11 Batt Insulation, Gyp. Board
Wall Number	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**
***U*, Btu/h·ft²·°F**	**0.101**	**0.067**	**0.066**	**0.038**	**0.050**	**0.028**	**0.103**	**0.068**	**0.061**
Total *R*	**9.9**	**14.9**	**15.1**	**26.1**	**20.1**	**36.1**	**9.7**	**14.7**	**16.4**
Hour	**Conduction Time Factors, %**								
0	0.2	0.1	0.2	0.1	0.1	0.4	0.6	0.8	1.6
1	4.8	3.0	4.1	1.6	1.5	0.5	0.8	0.8	1.5
2	13.9	11.1	13.3	8.5	6.8	2.0	2.6	2.1	1.9
3	16.7	15.5	16.6	14.5	11.7	5.3	5.5	4.5	3.3
4	14.9	15.0	14.8	15.2	13.3	8.2	7.6	6.6	5.0
5	12.0	12.7	11.8	13.1	12.7	9.7	8.7	7.9	6.2
6	9.2	10.1	9.2	10.6	11.1	10.1	9.0	8.4	6.9
7	7.0	7.8	7.1	8.3	9.2	9.6	8.7	8.4	7.1
8	5.3	6.0	5.4	6.5	7.5	8.8	8.2	8.0	7.0
9	4.0	4.6	4.2	5.0	5.9	7.8	7.4	7.4	6.7
10	3.0	3.5	3.2	3.9	4.7	6.8	6.6	6.7	6.3
11	2.3	2.6	2.4	3.0	3.6	5.8	5.8	6.0	5.9
12	1.7	2.0	1.9	2.3	2.8	4.9	5.0	5.3	5.4
13	1.3	1.5	1.4	1.8	2.2	4.1	4.3	4.7	5.0
14	1.0	1.1	1.1	1.4	1.7	3.4	3.7	4.1	4.5
15	0.7	0.9	0.8	1.1	1.3	2.8	3.1	3.5	4.1
16	0.5	0.7	0.6	0.8	1.0	2.3	2.6	3.0	3.7
17	0.4	0.5	0.5	0.6	0.8	1.9	2.2	2.6	3.4
18	0.3	0.4	0.4	0.5	0.6	1.5	1.9	2.2	3.0
19	0.2	0.3	0.3	0.4	0.5	1.2	1.6	1.9	2.7
20	0.2	0.2	0.2	0.3	0.4	1.0	1.3	1.6	2.5
21	0.1	0.2	0.2	0.2	0.3	0.8	1.1	1.4	2.2
22	0.1	0.1	0.1	0.2	0.2	0.6	0.9	1.1	2.0
23	0.1	0.1	0.1	0.1	0.2	0.5	0.7	1.0	1.8
Total Percentage	100	100	100	100	100	100	100	100	100
Layer ID from outdoors to indoors (See Table 18)	F01	F01	F01	F01	F01	F01	F01	F01	F01
	M01	M01	M01	M01	M01	M01	M01	M01	M01
	F04	F04	F04	F04	F04	F04	F04	F04	F04
	I01	I01	G03	G03	I01	I01	I01	I01	M03
	G03	I01	I04	I04	G03	I01	M03	I01	I04
	F04	G03	G01	I04	I04	G03	F02	M03	G01
	G01	F04	F02	G01	G01	I04	0	F02	F02
	F02	G01	0	F02	F02	I04	0	0	0
	0	F02	0	0	0	G01	0	0	0
	0	0	0	0	0	F02	0	0	0

CTS

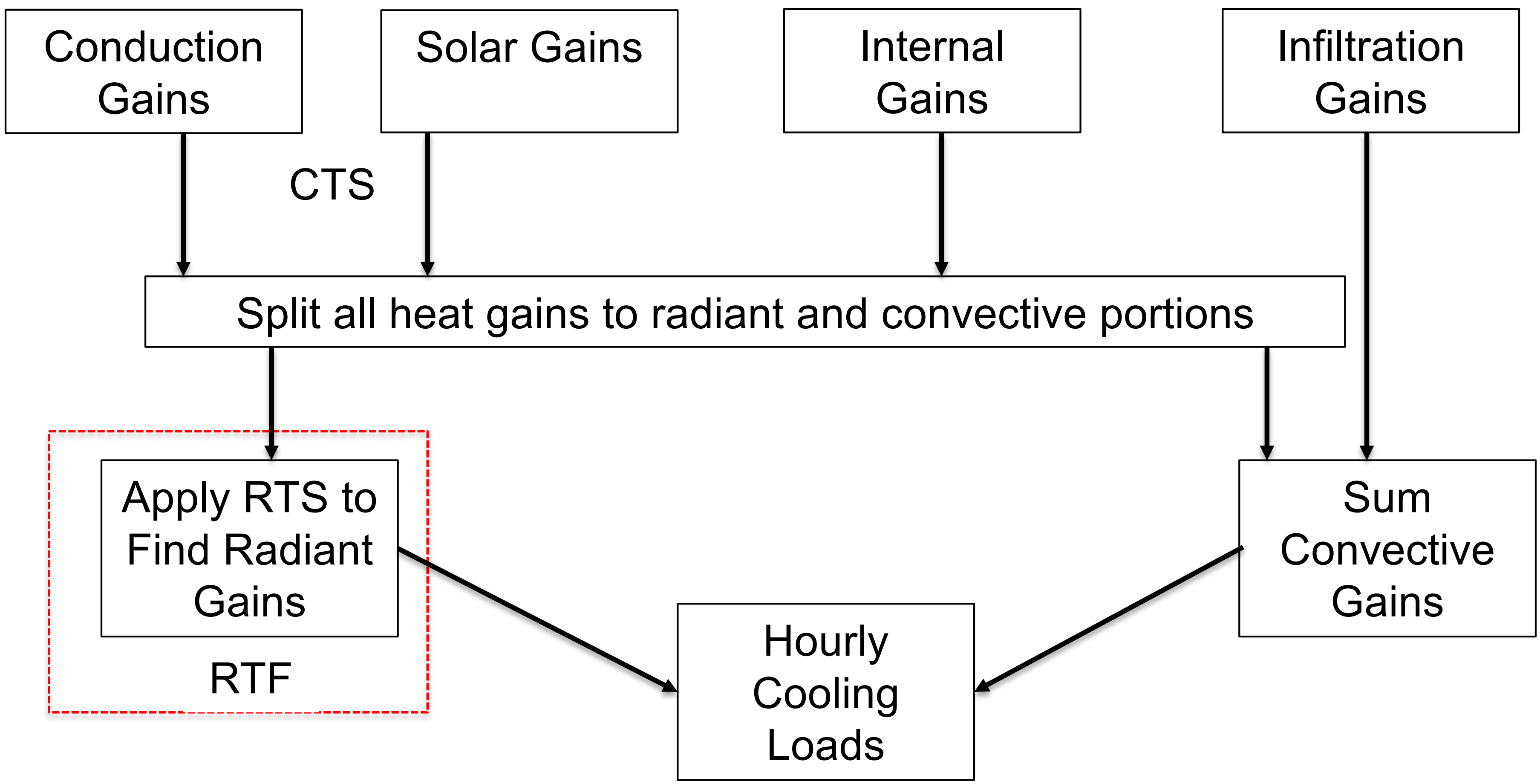
Table 18 Thermal Properties and Code Numbers of Layers Used in Wall and Roof Descriptions for Tables 16 and 17

Layer ID	Description	Thickness, in.	Conductivity, Btu·in/h·ft²·°F	Density, lb/ft³	Specific Heat, Btu/lb·°F	Resistance *R*, ft²·°F·h/Btu	Mass, lb/ft²	Thermal Capacity, Btu/ft²·°F	Notes
F01	Outdoor surface resistance	—	—	—	—	0.25	—	—	1
F02	Indoor vertical surface resistance	—	—	—	—	0.68	—	—	2
F03	Indoor horizontal surface resistance	—	—	—	—	0.92	—	—	3
F04	Wall air space resistance	—	—	—	—	0.87	—	—	4
F05	Ceiling air space resistance	—	—	—	—	1.00	—	—	5
F06	EIFS finish	0.375	5.00	116.0	0.20	0.08	3.63	0.73	6
F07	1 in. stucco	1.000	5.00	116.0	0.20	0.20	9.67	1.93	6
F08	Metal surface	0.030	314.00	489.0	0.12	0.00	1.22	0.15	7
F09	Opaque spandrel glass	0.250	6.90	158.0	0.21	0.04	3.29	0.69	8
F10	1 in. stone	1.000	22.00	160.0	0.19	0.05	13.33	2.53	9

COOLING LOAD CALCULATIONS DUE TO RADIANT HEAT TRANSFER

RTF

- Radiant Transfer Series Method (RTSM)



CTS = Conduction Transfer Series
RTF = Radiant Transfer Function

RTF

$$Q_\theta = r_0 q_\theta + r_1 q_{\theta-\delta} + r_2 q_{\theta-2\delta} + \ \ldots . + r_{23} q_{\theta-23\delta}$$

- Q_θ: Cooling load for the current hour θ
- q_θ: Heat gain for the current hour
- $q_{\theta-n\delta}$: Heat gain n hours ago
- $r_0, r_1, \ldots$: RTFs

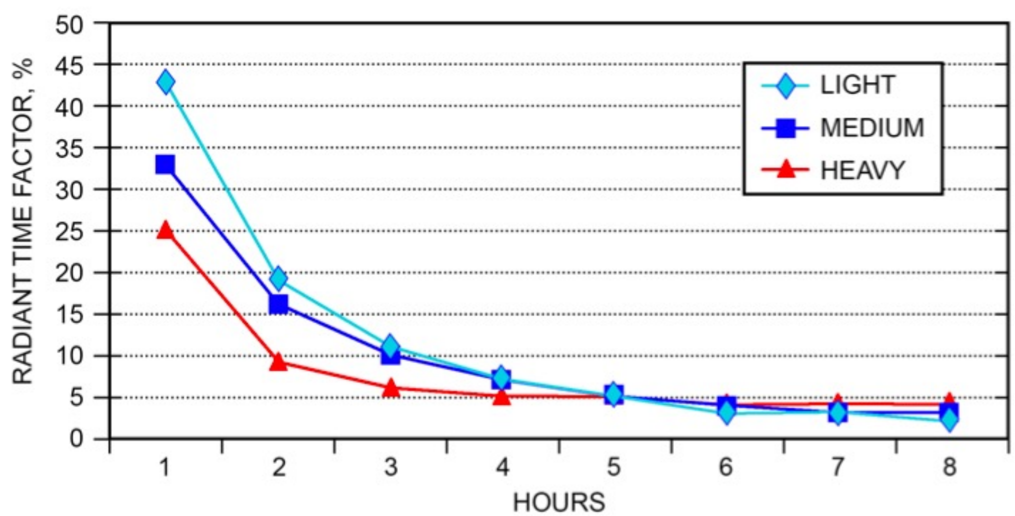
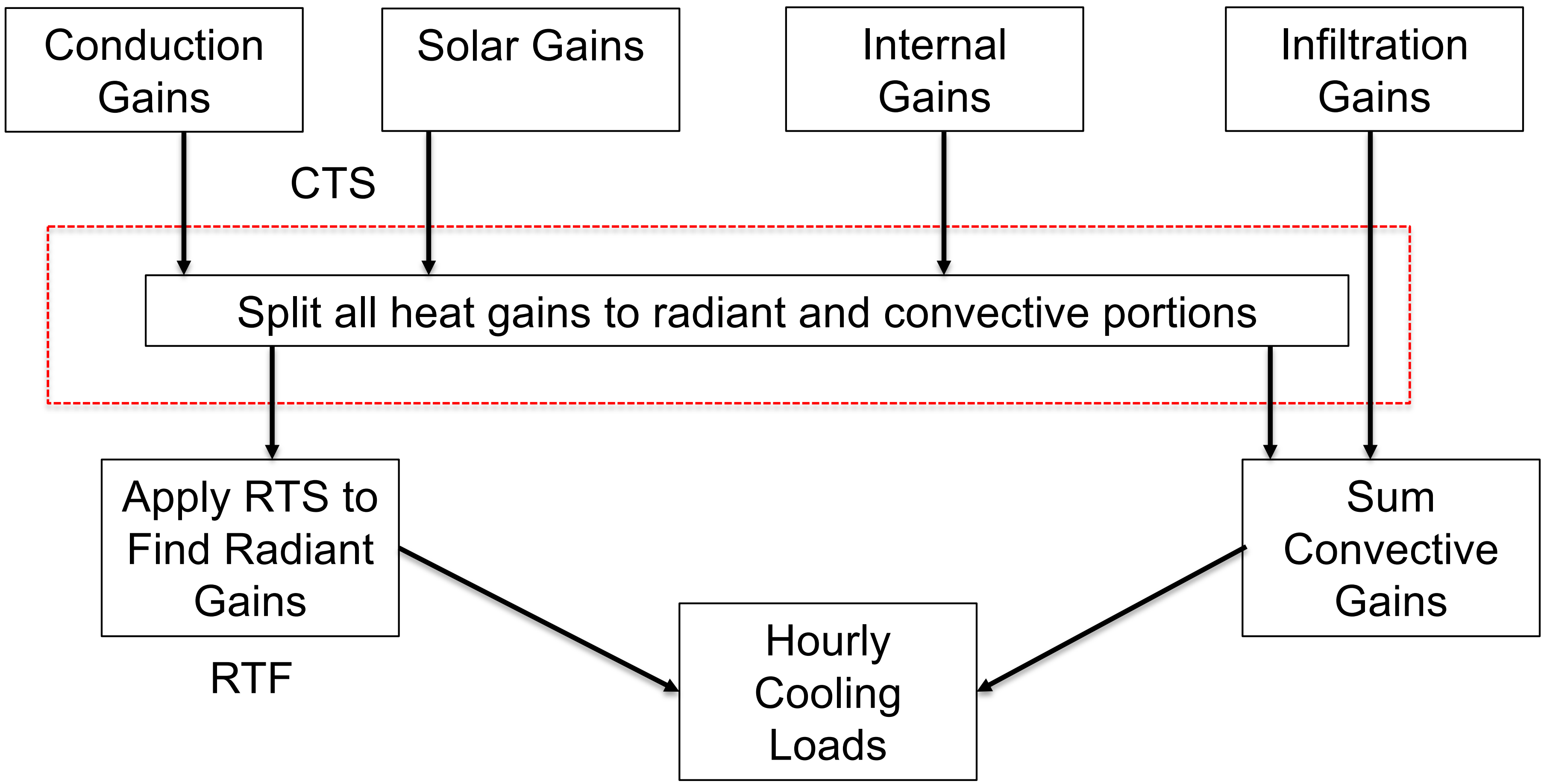


Fig. 11 RTS for Light to Heavy Construction

RTF

- Radiant Transfer Series Method (RTSM)



CTS = Conduction Transfer Series
RTF = Radiant Transfer Function

RTF

Table 14 Recommended Radiative/Convective Splits for Internal Heat Gains

Heat Gain Type	Recommended Radiative Fraction	Recommended Convective Fraction	Comments
Occupants, typical office conditions	0.60	0.40	See Table 1 for other conditions.
Equipment	0.1 to 0.8	0.9 to 0.2	See Tables 6 to 12 for details of equipment heat gain and recommended radiative/convective splits for motors, cooking appliances, laboratory equipment, medical equipment, office equipment, etc.
Office, with fan	0.10	0.90	
Without fan	0.30	0.70	
Lighting			Varies; see Table 3.
Conduction heat gain			
Through walls and floors	0.46	0.54	
Through roof	0.60	0.40	
Through windows	0.33 (SHGC > 0.5) 0.46 (SHGC < 0.5)	0.67 (SHGC > 0.5) 0.54 (SHGC < 0.5)	
Solar heat gain through fenestration			
Without interior shading	1.00	0.00	
With interior shading			Varies; see Tables 14A to 14G in Chapter 15.
Infiltration	0.00	1.00	

Source: Nigusse (2007).

RTF

Table 19 Representative Nonsolar RTS Values for Light to Heavy Construction

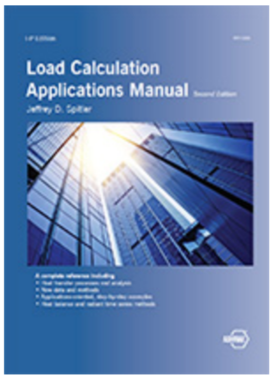
	Light						Medium						Heavy						Interior Zones					
																			Light		Medium		Heavy	
% Glass	With Carpet			No Carpet			With Carpet			No Carpet			With Carpet			No Carpet			With Carpet	No Carpet	With Carpet	No Carpet	With Carpet	No Carpet
	10%	50%	90%	10%	50%	90%	10%	50%	90%	10%	50%	90%	10%	50%	90%	10%	50%	90%						
Hour	Radiant Time Factor, %																							
0	47	50	53	41	43	46	46	49	52	31	33	35	34	38	42	22	25	28	46	40	46	31	33	21
1	19	18	17	20	19	19	18	17	16	17	16	15	9	9	9	10	9	9	19	20	18	17	9	9
2	11	10	9	12	11	11	10	9	8	11	10	10	6	6	5	6	6	6	11	12	10	11	6	6
3	6	6	5	8	7	7	6	5	5	8	7	7	4	4	4	5	5	5	6	8	6	8	5	5
4	4	4	3	5	5	5	4	3	3	6	5	5	4	4	4	5	5	4	4	5	3	6	4	5
5	3	3	2	4	3	3	2	2	2	4	4	4	4	3	3	4	4	4	3	4	2	4	4	4
6	2	2	2	3	3	2	2	2	2	4	3	3	3	3	3	4	4	4	2	3	2	4	3	4
7	2	1	1	2	2	2	1	1	1	3	3	3	3	3	3	4	4	4	2	2	1	3	3	4
8	1	1	1	1	1	1	1	1	1	3	2	2	3	3	3	4	3	3	1	1	1	3	3	4
9	1	1	1	1	1	1	1	1	1	2	2	2	3	3	2	3	3	3	1	1	1	2	3	3
10	1	1	1	1	1	1	1	1	1	2	2	2	3	2	2	3	3	3	1	1	1	2	3	3
11	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	3	3	3	1	1	1	2	2	3
12	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	3	3	3	1	1	1	1	2	3
13	1	1	1	0	1	0	1	1	1	1	1	1	2	2	2	3	3	2	1	1	1	1	2	3
14	0	0	1	0	1	0	1	1	1	1	1	1	2	2	2	3	2	2	1	0	1	1	2	3
15	0	0	1	0	0	0	1	1	1	1	1	1	2	2	2	2	2	2	0	0	1	1	2	3
16	0	0	0	0	0	0	1	1	1	1	1	1	2	2	2	2	2	2	0	0	1	1	2	3
17	0	0	0	0	0	0	1	1	1	1	1	1	2	2	2	2	2	2	0	0	1	1	2	2
18	0	0	0	0	0	0	1	1	1	1	1	1	2	2	1	2	2	2	0	0	1	1	2	2
19	0	0	0	0	0	0	0	1	0	0	1	1	2	2	1	2	2	2	0	0	1	0	2	2
20	0	0	0	0	0	0	0	0	0	0	1	1	2	1	1	2	2	2	0	0	0	0	2	2
21	0	0	0	0	0	0	0	0	0	0	1	1	2	1	1	2	2	2	0	0	0	0	2	2
22	0	0	0	0	0	0	0	0	0	0	1	0	1	1	1	2	2	2	0	0	0	0	1	2
23	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	2	2	1	0	0	0	0	1	2
	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

SPREADSHEETS

Spreadsheets

Supplemental files for *Load Calculation Applications Manual*, Second Edition (I-P and SI Editions)

Thank you for purchasing *Load Calculation Applications Manual*, Second Edition. The zip file linked below provides access to Microsoft® Excel® spreadshe
irradiation, conduction time factor series, and radiant time factors used in the method. The spreadsheets can be adapted to compute cooling loads for a wide ra
C, and D of both the I-P and SI editions of the book.



Load Calculation Applications Manual

The spreadsheets included are:
7-1-solar.xls
7-3_tabulated_CTSF.xls
7-4_generate_CSTF.xls
7-6 RTF_tabulated.xls

Example 7.1 Compute CTSF.xls
Example 7.1 Conduction.xls
Example 7.2 Window.xls
Example 7.3 RTF Generation.xls
Example 7.4 ClgLoad from heat gain.xls
Example 8.1 Compute CTSF.xls
Example 8.1 Compute RTF.xls
Example 8.1 solar.xls
Example 8.1 Conduction HG.xls

B-1_RTSM_IP.xls
B-1_RTSM_SI.xls
C-1_CTSFgen.xls
C-2_RTFgen.xls
D-1 solar.xls

Supplemental Files
(zip file, 226 MB)

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not accessible, please contact the publisher.

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Spreadsheets

Solar Irradiation & Sol-Air Temperature

Latitude Angle	33.64				
Longitude Angle	84.43				
Site Name	USA - GA - ATLANTA MUNICIPAL				
Design Conditions	5%				
Facing Direction	0.0	45.0	90.0	135.0	180.0
Tilt Angle	0.0	90.0			
Time Zone	5	NAE			
DayLightSavings	1				
Months	1	2	3	4	5
DayOfMonth	21				
UnitsOfMeas	IP				
Peak Temperature	62.8	65.9	73.3	79.5	84.3
Daily Range	20.4	21.0	23.0	22.8	20.3
Taub	0.334	0.324	0.355	0.383	0.379
Taud	2.614	2.58	2.474	2.328	2.324

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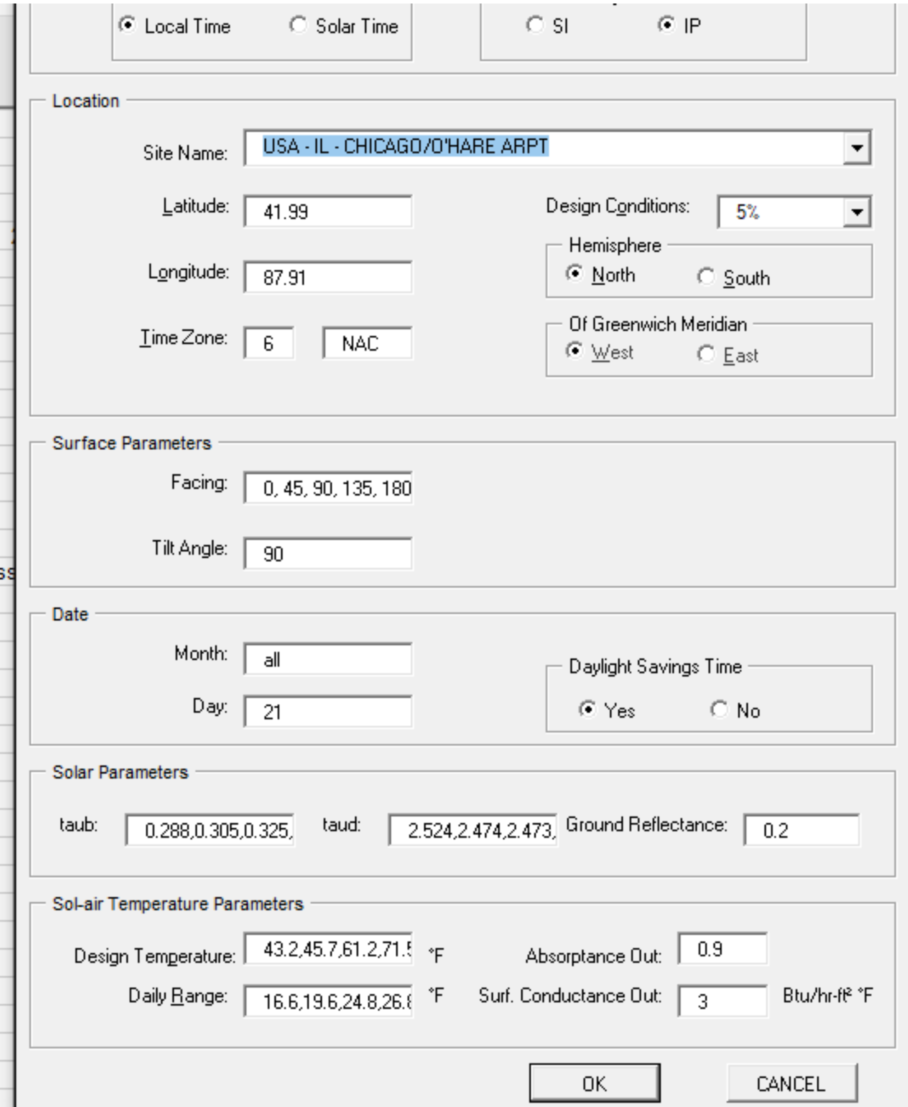


Spreadsheets

Solar Irradiation (Btu/hr-ft²) for January 21, 41.99°N Latitude, 87.91°W Longitude, Time Zone: NAC Standard Time
USA - IL - CHICAGO/O'HARE ARPT, Ground Reflectance: rhog = 0.2

Local Time	N	NE	E	SE	S	SW	W	NW	Horiz
1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8.0	5.7	31.3	120.1	142.4	84.1	5.9	5.7	5.7	22.5
9.0	13.7	15.1	168.7	237.1	173.7	18.6	13.7	13.7	71.0
10.0	19.9	19.9	149.5	264.1	235.0	80.9	19.9	19.9	113.5
11.0	23.9	23.9	97.9	251.5	272.6	147.5	23.9	23.9	141.6
12.0	25.3	25.3	30.8	211.6	286.0	206.7	27.4	25.3	151.9
13.0	24.1	24.1	24.1	153.6	274.9	248.7	92.0	24.1	143.4
14.0	20.4	20.4	20.4	87.3	239.6	264.3	145.7	20.4	116.8
15.0	14.4	14.4	14.4	23.9	180.6	241.9	168.9	15.7	75.5
16.0	6.5	6.5	6.5	6.8	94.3	156.0	129.7	31.8	26.9
17.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
24.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Sol-Air Temperature (°F) for January 21, 41.99°N Latitude, 87.91°W Longitude, Time Zone: NAC Standard Time
USA - IL - CHICAGO/O'HARE ARPT, 5% Design Condition, Surface Color: alpha/ho = 0.3

Local Time	Air Temp.	N	NE	E	SE	S	SW	W	NW	Horiz
1.0	28.6	28.6	28.6	28.6	28.6	28.6	28.6	28.6	28.6	21.6
2.0	27.9	27.9	27.9	27.9	27.9	27.9	27.9	27.9	27.9	20.9
3.0	27.5	27.5	27.5	27.5	27.5	27.5	27.5	27.5	27.5	20.5
4.0	27.0	27.0	27.0	27.0	27.0	27.0	27.0	27.0	27.0	20.0
5.0	26.6	26.6	26.6	26.6	26.6	26.6	26.6	26.6	26.6	19.6
6.0	26.9	26.9	26.9	26.9	26.9	26.9	26.9	26.9	26.9	19.9
7.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	21.0
8.0	30.7	32.4	40.1	66.8	73.5	56.0	32.5	32.4	32.4	30.5
9.0	33.9	38.0	38.5	84.5	105.1	86.1	39.5	38.0	38.0	48.3
10.0	36.8	42.7	42.7	81.6	116.0	107.3	61.0	42.7	42.7	63.8
11.0	39.3	46.4	46.4	68.6	114.7	121.1	83.5	46.4	46.4	74.8
12.0	41.0	48.5	48.5	50.2	104.4	126.8	103.0	49.2	48.5	79.5
13.0	42.3	49.5	49.5	49.5	88.4	124.8	116.9	69.9	49.5	78.3
14.0	43.2	49.3	49.3	49.3	69.4	115.1	122.5	86.9	49.3	71.2
15.0	43.2	47.5	47.5	47.5	50.4	97.4	115.8	93.9	47.9	58.9

INPUT DATA | 33.64°N84.43°W5 | 41.99°N87.91°W6

EXAMPLE (LIGHTING FIXTURES)

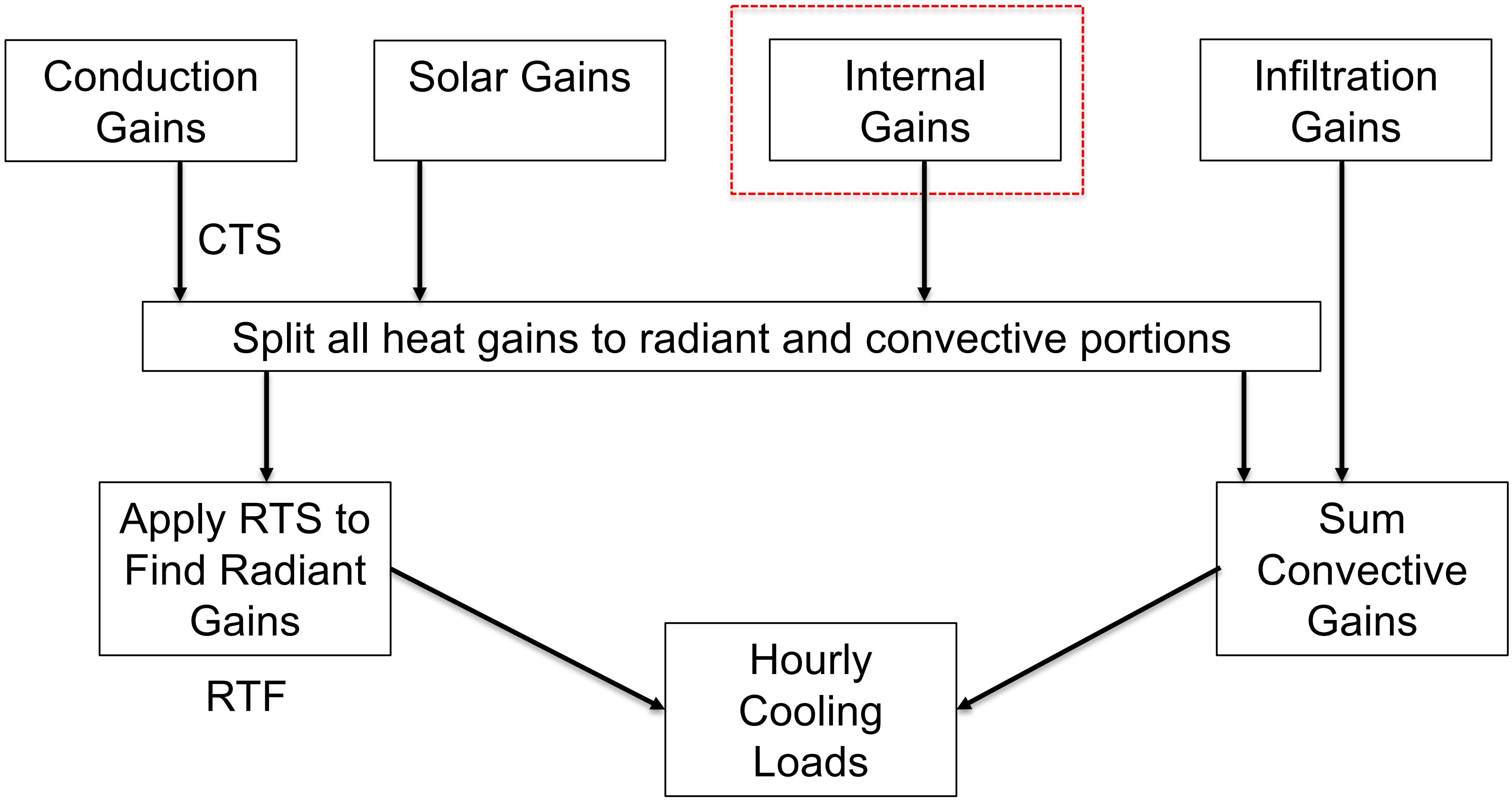
Example (Lighting Fixture)

Example: An interior zone with florescent lighting fixture has a power use of 1000 W. Calculate:

- ❑ The percentage of radiant and convective parts.
- ❑ The associated load at 2 pm?

Internal Loads (Lighting)

- Radiant Transfer Series Method (RTSM)



CTS = Conduction Transfer Series
RTF = Radiant Transfer Function

Example (Lighting Fixture)

Solution: Method 1:

f_{rad}

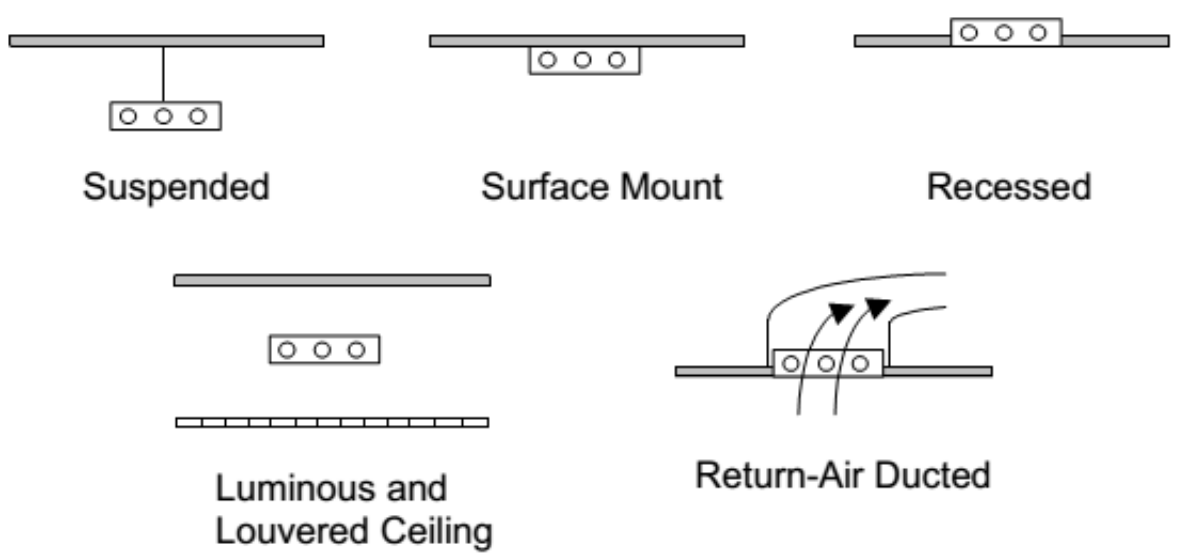
Table 3 Lighting Heat Gain Parameters for Typical Operating Conditions

Luminaire Category	Space Fraction	Radiative Fraction	Notes
Recessed fluorescent luminaire without lens	0.64 to 0.74	0.48 to 0.68	• Use middle values in most situations • May use higher space fraction, and lower radiative fraction for luminaire with side-slot returns • May use lower values of both fractions for direct/indirect luminaire • May use higher values of both fractions for ducted returns
Recessed fluorescent luminaire with lens	0.40 to 0.50	0.61 to 0.73	• May adjust values in the same way as for recessed fluorescent luminaire without lens
Downlight compact fluorescent luminaire	0.12 to 0.24	0.95 to 1.0	• Use middle or high values if detailed features are unknown • Use low value for space fraction and high value for radiative fraction if there are large holes in luminaire's reflector
Downlight incandescent luminaire	0.70 to 0.80	0.95 to 1.0	• Use middle values if lamp type is unknown • Use low value for space fraction if standard lamp (i.e. A-lamp) is used • Use high value for space fraction if reflector lamp (i.e. BR-lamp) is used
Non-in-ceiling fluorescent luminaire	1.0	0.5 to 0.57	• Use lower value for radiative fraction for surface-mounted luminaire • Use higher value for radiative fraction for pendant luminaire

$$f_{conv} = 1 - f_{rad}$$

Example (Lighting Fixture)

Solution: Method 2:



	Field Name	Luminaire Configuration, Fluorescent Lighting				
		Suspended	Surface mount	Recessed	Luminous and louvered ceiling	Return-air ducted
	Return Air Fraction	0.0	0.0	0.0	0.0	0.54
f_{rad}	Fraction Radiant	0.42	0.72	0.37	0.37	0.18
	Fraction Visible	0.18	0.18	0.18	0.18	0.18
f_{conv}	$f_{convected}$	*0.40*	*0.10*	*0.45*	*0.45*	*0.10*

Example (Lighting Fixture)

Table 19 Representative Nonsolar RTS Values for Light to Heavy Construction

% Glass	Light						Medium						Heavy						Interior Zones					
	With Carpet			No Carpet			With Carpet			No Carpet			With Carpet			No Carpet			Light		Medium		Heavy	
	10%	50%	90%	10%	50%	90%	10%	50%	90%	10%	50%	90%	10%	50%	90%	10%	50%	90%	With Carpet	No Carpet	With Carpet	No Carpet	With Carpet	No Carpet
Hour	**Radiant Time Factor, %**																							
0	47	50	53	41	43	46	46	49	52	31	33	35	34	38	42	22	25	28	46	40	46	31	33	21
1	19	18	17	20	19	19	18	17	16	17	16	15	9	9	9	10	9	9	19	20	18	17	9	9
2	11	10	9	12	11	11	10	9	8	11	10	10	6	6	5	6	6	6	11	12	10	11	6	6
3	6	6	5	8	7	7	6	5	5	8	7	7	4	4	4	5	5	5	6	8	6	8	5	5
4	4	4	3	5	5	5	4	3	3	6	5	5	4	4	4	5	5	4	4	5	3	6	4	5
5	3	3	2	4	3	3	2	2	2	4	4	4	4	3	3	4	4	4	3	4	2	4	4	4
6	2	2	2	3	3	2	2	2	2	4	3	3	3	3	3	4	4	4	2	3	2	4	3	4
7	2	1	1	2	2	2	1	1	1	3	3	3	3	3	3	4	4	4	2	2	1	3	3	4
8	1	1	1	1	1	1	1	1	1	3	2	2	3	3	3	4	3	3	1	1	1	3	3	4
9	1	1	1	1	1	1	1	1	1	2	2	2	3	3	2	3	3	3	1	1	1	2	3	3
10	1	1	1	1	1	1	1	1	1	2	2	2	3	2	2	3	3	3	1	1	1	2	3	3
11	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	3	3	3	1	1	1	2	2	3
12	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	3	3	3	1	1	1	1	2	3
13	1	1	1	0	1	0	1	1	1	1	1	1	2	2	2	3	3	2	1	1	1	1	2	3
14	0	0	1	0	1	0	1	1	1	1	1	1	2	2	2	3	2	2	1	0	1	1	2	3
15	0	0	1	0	0	0	1	1	1	1	1	1	2	2	2	2	2	2	0	0	1	1	2	3
16	0	0	0	0	0	0	1	1	1	1	1	1	2	2	2	2	2	2	0	0	1	1	2	3
17	0	0	0	0	0	0	1	1	1	1	1	1	2	2	2	2	2	2	0	0	1	1	2	2
18	0	0	0	0	0	0	1	1	1	1	1	1	2	2	1	2	2	2	0	0	1	1	2	2
19	0	0	0	0	0	0	0	1	0	0	1	1	2	2	1	2	2	2	0	0	1	0	2	2
20	0	0	0	0	0	0	0	0	0	0	1	1	2	1	1	2	2	2	0	0	0	0	2	2
21	0	0	0	0	0	0	0	0	0	0	1	1	2	1	1	2	2	2	0	0	0	0	2	2
22	0	0	0	0	0	0	0	0	0	0	1	0	1	1	1	2	2	2	0	0	0	0	1	2
23	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	2	2	1	0	0	0	0	1	2
	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Example (Lighting Fixture)

$$Q_{14} = Q_{14,radiative} + Q_{14,convective}$$

$$Q_{14,radiative} = f_{rad} \times [r_0 q_{14} + r_1 q_{14-1} + r_2 q_{14-2} + \ \dots . + r_{23} q_{14-23}]$$

$$Q_{14,radiative} = f_{rad} \times [r_0 q_{14} + r_1 q_{13} + r_2 q_{12} + \ \dots . + r_{23} q_{15}]$$

Example (Lighting Fixture)

$$Q_{14,convective} = f_{conv} \times q_{14,conv} = 0.4 \times 1000\ W = 400\ W$$

$$Q_{14,radiative} = (0.42) \times [(0.46)(1000\ W) + (0.19)(1000\ W) + \ldots . + (0)(0.42)(1000\ W) = 420\ W$$

Did we really need to write the series?

Try to solve this exam using a schedule for the lighting fixtures

EXAMPLE (HEATING LOAD)

Example (Heating Load)

Example: Calculate the room heating load for a top floor with the following information:

- The location is Chicago
- Roof area is 100 ft^2
- Each wall area is 50 ft^2
- Window area on each wall is 25 ft^2
- Room height is 9 ft
- Infiltration rate is 1 ACH
- Roof U-value is 0.0799 Btu/h-ft^2-ºF
- Windows U-value is 0.5 Btu/h-ft^2-ºF
- The wall assembly entails: 4’’ brick, wall air space resistance, R-5 1’’ insulation board, 8’’ LW concrete block

Example (Heating Load)

Solution:

- Find the outdoor design condition using Chapter 14

Station	Lat	Long	Elev	Heating DB		Cooling DB/MCWB						Evaporation WB/MCDB				Dehumidification DP/HR/MCDB						Extreme Annual WS			Heat./Cool. Degree-Days	
						0.4%		1%		2%		0.4%		1%		0.4%			1%							
				99.6%	99%	DB / MCWB		DB / MCWB		DB / MCWB		WB / MCDB		WB / MCDB		DP / HR / MCDB			DP / HR / MCDB			1%	2.5%	5%	HDD / CDD 65	
SW GEORGIA REGIONAL	31.536N	84.194W	190	26.6	29.6	96.8	75.9	94.7	75.7	92.7	75.4	79.7	90.4	78.5	88.8	77.2	142.4	83.1	75.9	136.4	82.2	18.4	16.4	14.2	1746	2547
VALDOSTA REGIONAL	30.783N	83.277W	198	27.7	30.8	96.6	76.6	94.5	76.2	92.7	75.8	80.2	90.0	79.2	88.8	77.6	144.6	83.1	76.9	141.1	82.5	16.5	14.0	12.4	1477	2627
Hawaii																									*4 sites, 8 more on CD-ROM*	
HILO INTL	19.719N	155.053W	38	61.6	62.8	85.7	74.0	84.7	73.7	83.9	73.4	76.5	82.0	75.8	81.5	75.0	131.5	79.2	74.0	127.2	78.5	16.7	14.9	12.8	0	3245
HONOLULU INTL	21.324N	157.929W	7	62.5	64.5	89.4	73.8	88.5	73.4	87.7	73.0	77.1	84.5	76.2	83.8	74.9	130.9	81.0	73.7	125.6	80.3	22.5	20.4	18.9	0	4656
KALAELOA	21.317N	158.067W	33	60.4	62.5	90.1	73.4	88.8	73.2	87.9	73.0	77.4	84.9	76.3	84.2	75.1	131.9	81.5	73.5	124.7	80.5	18.2	16.4	14.7	0	4214
KANEOHE MCAS	21.450N	157.768W	24	64.0	65.9	84.9	74.3	84.1	74.1	83.4	73.8	77.0	81.6	76.1	81.3	75.3	132.9	79.8	74.3	128.5	79.5	18.5	16.7	15.4	0	4190
Idaho																									*7 sites, 14 more on CD-ROM*	
BOISE AP	43.567N	116.241W	2814	9.4	15.9	98.6	63.8	95.7	62.8	92.8	61.9	66.1	92.0	64.7	90.2	57.5	78.3	71.5	55.1	71.8	71.6	22.0	19.1	17.1	5414	1007
CALDWELL INDUSTRIAL AP	43.650N	116.633W	2429	9.6	15.7	97.0	66.2	93.1	64.7	90.6	63.8	68.2	92.3	66.4	90.0	59.1	82.0	78.5	56.7	75.0	77.6	22.1	19.2	17.0	5739	692
COEUR D'ALENE AP	47.767N	116.817W	2307	5.8	10.4	91.3	63.1	88.5	62.6	84.2	61.1	66.3	85.6	64.3	83.4	59.2	81.7	72.0	56.8	75.0	70.6	22.3	18.9	16.8	6875	316
IDAHO FALLS REGIONAL	43.516N	112.067W	4729	-6.6	-0.3	92.1	60.9	89.6	60.5	86.7	59.6	64.7	83.2	63.0	81.9	58.7	87.9	71.0	56.2	80.3	68.9	27.2	24.3	20.7	7672	288
LEWISTON-NEZ PERCE CO REGL	46.375N	117.016W	1436	13.0	18.8	98.5	65.3	95.0	64.5	91.4	63.2	67.8	91.9	66.1	89.8	60.0	81.6	72.7	57.7	75.1	72.0	20.9	17.9	15.1	5044	868
MAGIC VALLEY REGIONAL	42.482N	114.487W	4151	7.6	12.0	95.0	62.6	92.2	62.1	89.8	61.6	66.3	88.7	64.7	86.1	58.8	86.4	74.6	56.6	79.6	74.2	27.9	24.6	20.9	6029	775
POCATELLO REGIONAL	42.920N	112.571W	4452	-2.0	3.8	94.9	61.4	91.8	60.8	88.8	60.0	65.2	86.3	63.5	84.5	58.7	86.9	70.7	55.8	78.2	70.5	28.6	25.5	22.6	6941	440
Illinois																									*14 sites, 48 more on CD-ROM*	
ABRAHAM LINCOLN CAPITAL	39.845N	89.684W	594	1.1	6.9	92.6	76.7	90.4	75.6	88.0	74.1	79.5	89.5	77.9	87.3	76.5	141.4	86.2	75.0	134.3	84.3	24.7	21.4	19.1	5328	1144
AURORA MUNICIPAL	41.770N	88.481W	710	-4.9	0.7	90.7	74.1	88.2	73.2	85.5	72.0	77.7	87.1	76.0	84.3	74.8	134.0	83.4	73.1	126.2	81.3	26.0	23.0	19.9	6537	729
CHICAGO MIDWAY INTL	41.786N	87.752W	612	0.5	6.1	91.9	74.7	89.4	73.1	86.6	72.0	77.8	87.8	76.0	85.3	74.9	133.6	84.0	72.9	125.0	82.0	24.4	21.0	19.1	5850	1057
CHICAGO O'HARE INTL	41.995N	87.934W	662	-1.0	4.4	91.3	74.2	88.5	72.9	85.9	71.6	77.5	87.3	75.7	84.7	74.5	132.2	83.5	72.8	124.7	81.4	24.6	21.0	19.1	6190	882
CHICAGO ROCKFORD INTL	42.193N	89.093W	730	-5.4	0.3	90.9	74.4	88.0	72.9	85.4	71.6	77.8	87.0	75.8	84.0	75.0	134.8	83.3	73.2	126.5	81.7	24.5	20.9	18.9	6589	786
DECATUR AP	39.834N	88.866W	675	1.9	7.3	93.1	76.6	90.7	75.5	88.3	74.3	79.4	89.4	77.8	87.5	76.4	141.5	86.0	74.9	134.0	84.1	24.7	21.5	19.6	5388	1105
DUPAGE COUNT AP	41.914N	88.246W	754	-2.5	2.6	90.2	74.6	87.8	73.5	84.6	71.8	77.9	86.8	76.0	84.0	75.0	135.1	83.8	73.1	126.6	81.5	24.8	21.6	19.3	6430	750
GLENVIEW NAS	42.083N	87.817W	653	-0.7	4.8	93.7	75.0	90.2	73.3	87.1	72.1	77.9	90.2	76.2	87.0	74.2	130.7	85.1	72.4	123.1	83.6	20.2	18.0	16.2	6104	909
GREATER PEORIA REGIONAL	40.668N	89.684W	650	-0.9	4.3	92.0	76.5	89.6	75.2	87.0	73.6	79.3	88.3	77.5	86.5	76.6	142.1	85.3	74.8	133.7	83.2	23.1	19.7	17.8	5733	1057
QUAD CITY INTL	41.465N	90.523W	592	-3.5	1.8	92.4	76.2	89.7	74.9	87.1	73.2	79.1	88.8	77.4	86.5	76.3	140.5	85.3	74.6	132.4	83.2	23.9	20.2	18.2	6091	988
QUINCY REGIONAL	39.937N	91.192W	769	0.4	5.6	93.1	76.5	90.3	75.4	87.7	74.1	78.9	89.1	77.5	87.1	76.0	139.6	85.3	74.4	132.3	83.6	24.3	20.7	18.7	5497	1119
SCOTT AFB	38.550N	89.850W	459	7.2	12.1	95.2	77.7	92.7	76.9	90.3	75.9	80.7	90.2	79.2	88.6	78.1	148.5	85.8	76.7	141.4	84.5	22.7	19.6	17.5	4617	1413
ST LOUIS DOWNTOWN AP	38.571N	90.157W	413	8.6	12.7	95.4	76.6	92.7	76.3	90.4	75.2	79.9	90.5	78.3	88.9	77.0	142.9	85.4	75.1	133.9	83.9	20.8	18.6	16.6	4569	1432
U OF ILLINOIS WILLARD AP	40.040N	88.278W	754	-0.4	4.9	91.4	75.5	89.6	74.8	86.9	73.4	79.2	87.8	77.4	85.9	76.7	143.1	85.1	74.8	134.2	82.7	27.5	24.6	21.4	5693	973

Example (Heating Load)

- Find the wall U-value

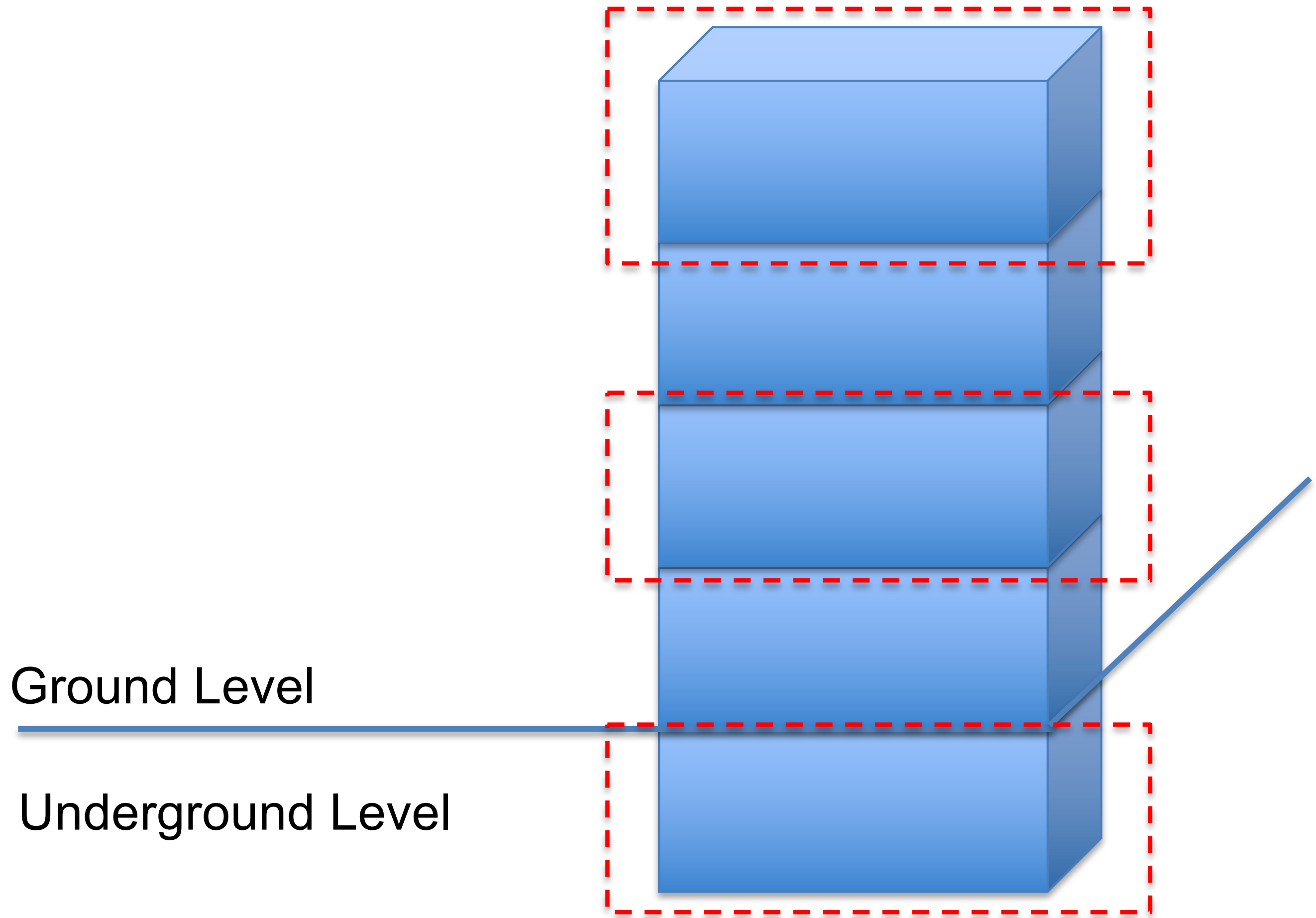
Table 16 Wall Conduction Time Series (CTS) (*Continued*)

	Brick Walls								
	Brick, R-5 Insulation Board, Sheathing, Gyp. Board	Brick, R-10 Insulation Board, Sheathing, Gyp. Board	Brick, Sheathing, R-11 Batt Insulation, Gyp. Board	Brick, Sheathing, R-22 Batt Insulation, Gyp. Board	Brick, R-5 Insulation Board, Sheathing, R-11 Batt Insulation, Gyp. Board	Brick, R-5 Insulation Board, Sheathing, R-22 Batt Insulation, Gyp. Board	Brick, R-5 Insulation Board, 8 in. LW CMU	Brick, R-10 Insulation Board, 8 in. LW CMU	Brick, 8 in. LW CMU, R-11 Batt Insulation, Gyp. Board
Wall Number	21	22	23	24	25	26	27	28	29
U, Btu/h·ft²·°F	0.101	0.067	0.066	0.038	0.050	0.028	0.103	0.068	0.061
Total R	9.9	14.9	15.1	26.1	20.1	36.1	9.7	14.7	16.4

F01
M01
F04
I01
M03
F02
0
0
0
0

Example (Heating Load)

- Understand the heat load calculation components:



Example (Heating Load)

- Calculate the enclosure heat transfer:

$$Q_{wall} = U_{wall} \times A_{wall} \times (t_{room} - t_{99.6\%})$$
$$= (0.103)(4 \times 50) \times (72 - (-1)) = 1503.8 \frac{Btu}{h}$$

$$Q_{win} = U_{win} \times A_{win} \times (t_{room} - t_{99.6\%})$$
$$= (0.5) \times (4 \times 25) \times \big(72 - (-1)\big) = 7300 \frac{Btu}{h}$$

$$Q_{roof} = U_{roof} \times A_{roof} \times (t_{room} - t_{99.6\%})$$
$$= (0.0799) \times (100) \times \big(72 - (-1)\big) = 583.27 \frac{Btu}{hr}$$

Example (Heating Load)

- Calculate the infiltration rate:

$$Q_{infiltration} = q_s = 1.1 \times Q_s \times (t_{room} - t_{99.6\%})$$

$$Infiltration\ rate = \frac{Volume \times ACH}{60} = \frac{100\ ft^2 \times 9 \times 1}{60} = 15\ cfm$$

$$Q_{infiltration} = 1.1 \times 15 \times (72 - (-1)) = 1204.5\ \frac{Btu}{hr}$$

Example (Heating Load)

- Sum all the heat loads:

$$Q_{total} = Q_{wall} + Q_{win} + Q_{roof} + Q_{infiltration}$$

$$Q_{total} = 1503.8 + 7300 + 583.27 + 1204.5 = 10591.57\ \frac{Btu}{hr}$$

EXAMPLE (BUILDING ENCLOSURE)

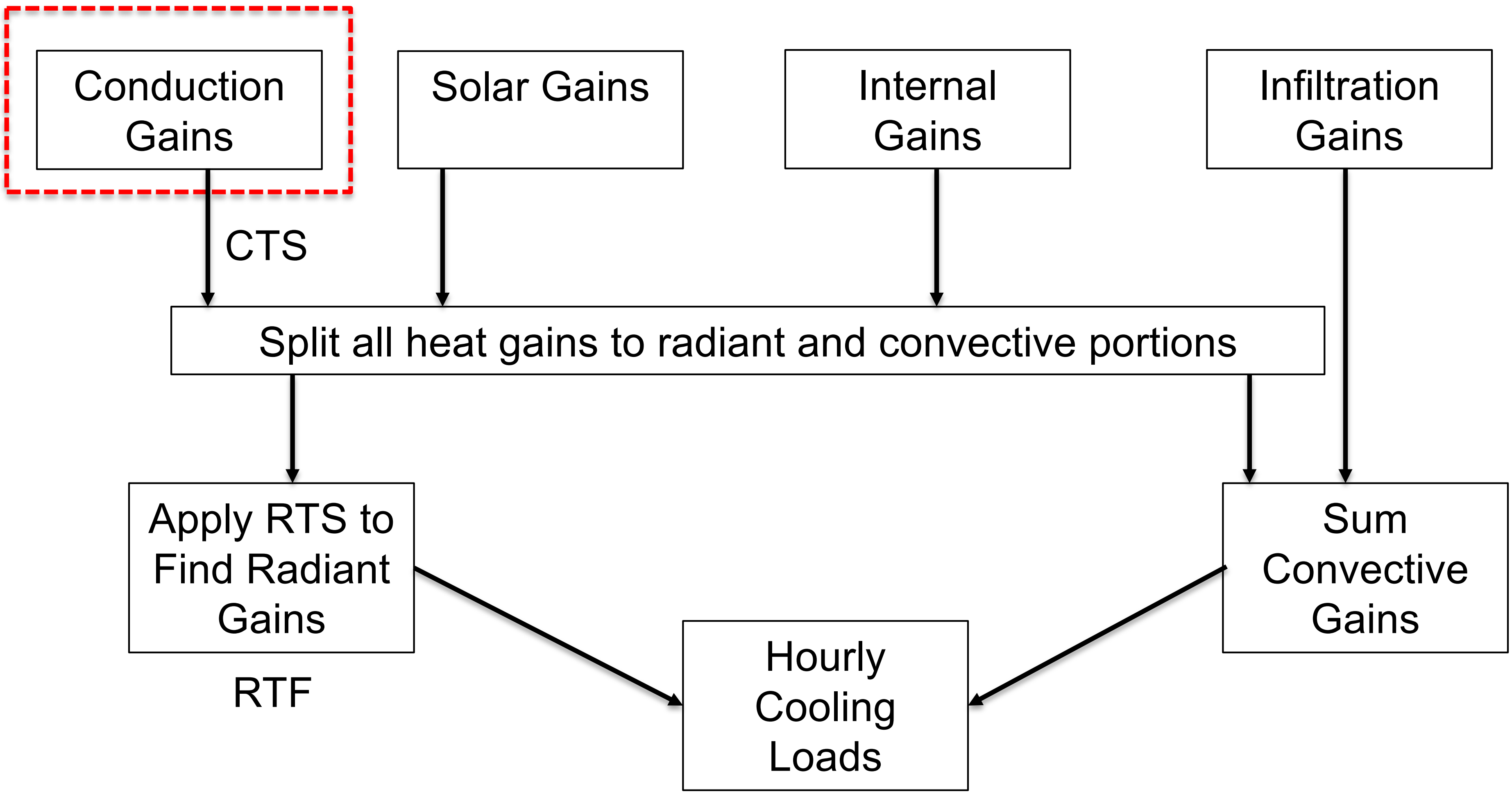
Example (Building Enclosure)

Example: Calculate the radiative and convective cooling load for a south facing wall at 4 pm with the following information

- The location is Chicago
- Wall area is 1000 ft^2
- Wall assembly is Wall #38

Example (Building Enclosure)

- Solution:



CTS = Conduction Transfer Series

RTF = Radiant Transfer Function

Example (Building Enclosure)

Sol-Air Temperature (°F) for July 21, 41.79°N Latitude, 87.75°W Longitude, Time Zone: NAC Daylight Savings Time										
USA - IL - CHICAGO/MIDWAY, 0.4% Design Condition, Surface Color: alpha/ho = 0.3										
Local Time	Air Temp.	N	NE	E	SE	S	SW	W	NW	Horiz
1.0	81.9	81.9	81.9	81.9	81.9	81.9	81.9	81.9	81.9	74.9
2.0	80.8	80.8	80.8	80.8	80.8	80.8	80.8	80.8	80.8	73.8
3.0	80.1	80.1	80.1	80.1	80.1	80.1	80.1	80.1	80.1	73.1
4.0	79.5	79.5	79.5	79.5	79.5	79.5	79.5	79.5	79.5	72.5
5.0	78.9	78.9	78.9	78.9	78.9	78.9	78.9	78.9	78.9	71.9
6.0	78.6	84.3	89.9	89.6	83.5	79.8	79.8	79.8	79.8	74.2
7.0	79.0	94.9	121.5	125.9	105.0	83.1	83.1	83.1	83.1	87.7
8.0	80.4	94.2	133.4	146.5	124.7	88.0	87.5	87.5	87.5	106.6
9.0	83.7	94.2	134.1	155.4	140.2	98.5	93.4	93.4	93.4	127.6
10.0	87.2	99.5	127.3	154.2	149.0	115.2	99.2	99.2	99.2	147.0
11.0	90.4	104.0	115.8	144.6	150.3	129.2	104.6	104.0	104.0	162.4
12.0	93.2	107.8	108.7	129.3	144.8	139.1	115.9	107.8	107.8	172.9
13.0	95.0	109.9	109.9	111.2	133.0	143.2	134.5	112.3	109.9	177.2
14.0	96.5	111.0	111.0	111.0	117.5	142.0	149.2	134.5	112.0	175.7
15.0	97.4	110.9	110.9	110.9	111.4	135.3	157.8	153.1	124.4	168.4
16.0	97.4	109.5	109.1	109.1	109.1	124.1	159.0	165.2	138.7	155.7
17.0	96.2	106.5	105.7	105.7	105.7	109.7	151.8	167.9	147.3	138.5
18.0	94.7	109.0	101.5	101.5	101.5	102.0	137.5	159.6	147.4	119.1
19.0	92.8	108.3	96.6	96.6	96.6	96.6	116.7	136.8	133.2	99.9
20.0	89.9	93.9	90.9	90.9	90.9	90.9	93.3	97.3	97.6	84.8
21.0	87.9	87.9	87.9	87.9	87.9	87.9	87.9	87.9	87.9	80.9
22.0	86.2	86.2	86.2	86.2	86.2	86.2	86.2	86.2	86.2	79.2
23.0	84.5	84.5	84.5	84.5	84.5	84.5	84.5	84.5	84.5	77.5
24.0	83.2	83.2	83.2	83.2	83.2	83.2	83.2	83.2	83.2	76.2

Example (Building Enclosure)

	Brick Walls								
	Brick, 8 in. LW CMU, R-22 Batt Insulation, Gyp. Board	Brick, R-5 Insulation Board, 8 in. HW CMU, Gyp. Board	Brick, R-10 Insulation Board, 8 in. HW CMU, Gyp. Board	Brick, R-5 Insulation Board, Brick	Brick, R-10 Insulation Board, Brick	Brick, R-5 Insulation Board, 8 in. LW Concrete, Gyp. Board	Brick, R-10 Insulation Board, 8 in. LW Concrete, Gyp. Board	Brick, R-5 Insulation Board, 12 in. HW Concrete, Gyp. Board	Brick, R-10 Insulation Board, 12 in. HW Concrete, Gyp. Board
Wall Number	**30**	**31**	**32**	**33**	**34**	**35**	**36**	**37**	**38**
***U*, Btu/h·ft^2·°F**	**0.036**	**0.111**	**0.071**	**0.124**	**0.077**	**0.091**	**0.062**	**0.097**	**0.062**
Total *R*	**27.4**	**9.0**	**14.0**	**8.1**	**13.0**	**11.0**	**16.0**	**10.3**	**16.0**
Hour	**Conduction Time Factors, %**								
0	1.9	1.8	2.0	0.9	1.0	3.3	3.4	3.8	3.9
1	1.8	1.7	1.9	1.3	1.2	3.1	3.3	3.8	3.8
2	1.8	2.4	2.3	3.3	2.8	3.0	3.2	3.7	3.8
3	2.7	3.8	3.4	5.8	5.0	3.1	3.2	3.7	3.8
4	4.0	5.1	4.6	7.3	6.6	3.4	3.4	3.8	3.8
5	5.4	6.0	5.5	8.0	7.5	3.8	3.7	3.9	3.9
6	6.2	6.5	6.1	8.2	7.8	4.2	4.1	4.1	4.0
7	6.7	6.6	6.3	7.9	7.7	4.6	4.4	4.2	4.2
8	6.8	6.6	6.3	7.5	7.4	4.8	4.6	4.3	4.3
9	6.6	6.4	6.2	6.9	6.9	5.0	4.8	4.4	4.4
10	6.4	6.1	6.0	6.2	6.4	5.1	4.9	4.5	4.5
11	6.0	5.7	5.7	5.6	5.8	5.1	5.0	4.5	4.5
12	5.6	5.3	5.4	5.0	5.2	5.1	4.9	4.6	4.5
13	5.2	4.9	5.0	4.4	4.6	5.0	4.9	4.6	4.5
14	4.8	4.6	4.7	3.8	4.1	4.9	4.8	4.5	4.5
15	4.4	4.2	4.3	3.3	3.6	4.7	4.7	4.5	4.5
16	4.0	3.8	4.0	2.9	3.2	4.6	4.6	4.3	4.3
17	3.7	3.5	3.7	2.5	2.8	4.4	4.4	4.3	4.3
18	3.4	3.2	3.4	2.2	2.4	4.2	4.3	4.2	4.2
19	3.1	2.9	3.1	1.9	2.1	4.1	4.1	4.2	4.2
20	2.8	2.6	2.9	1.6	1.8	3.9	4.0	4.1	4.1
21	2.5	2.4	2.6	1.4	1.6	3.7	3.9	4.0	4.1
22	2.3	2.1	2.4	1.2	1.4	3.6	3.7	4.0	4.0
23	2.1	1.9	2.2	1.0	1.2	3.4	3.6	3.9	3.9
Total Percentage	100	100	100	100	100	100	100	100	100

Example (Building Enclosure)

- Write the cooling load equations:

$$Q_{cond,16} = Q_{cond,16,rad} + Q_{cond,16,conv}$$

$$Q_{cond,16,rad} = \mathrm{f_{rad}} \times Q_{cond,16}$$

$$Q_{cond,16,conv} = \mathrm{f_{conv}} \times Q_{cond,16}$$

Example (Building Enclosure)

- Write the cooling load equations:

$$Q_{cond,16,conv} = q_{cond,16}$$

$$Q_{cond,16,conv} = \mathrm{f}_{\mathrm{conv}} \times Q_{cond,16}$$

Example (Building Enclosure)

- Write the cooling load equations:

$$Q_{cond,16,rad} = r_0 \times q_{cond,16,rad} + r_1 \times q_{cond,15,rad}$$

$$+ r_2 \times q_{cond,14,rad} + r_3 \times q_{cond,13,rad}$$

$$+ \cdots + \cdots + \cdots + \cdots$$

$$+ r_{22} \times q_{cond,18,rad} + r_{23} \times q_{cond,17,rad}$$

Example (Building Enclosure)

- Write the cooling load equations:

$$q_\theta = \sum_{j=0}^{23} c_j UA(t_{e,\theta-j\delta} - t_{rc})$$

$$q_{cond,16} = UA[c_0\left(t_{sol-air,16} - t_{setpoint}\right) + c_1\left(t_{sol-air,15} - t_{setpoint}\right)$$

$$+ \ \ldots + \cdots + \cdots$$

$$+ \ \ldots c_{22}\left(t_{sol-air,18} - t_{setpoint}\right) + c_{23}\left(t_{sol-air,17} - t_{setpoint}\right)]$$

SUMMARY

Summary