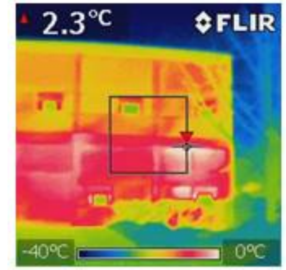
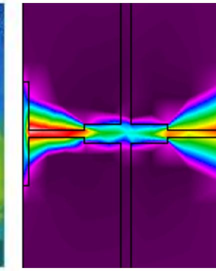
CAE 331/513
Building Science
Fall 2018



November 15, 2018
Cooling load calculations (part 2)

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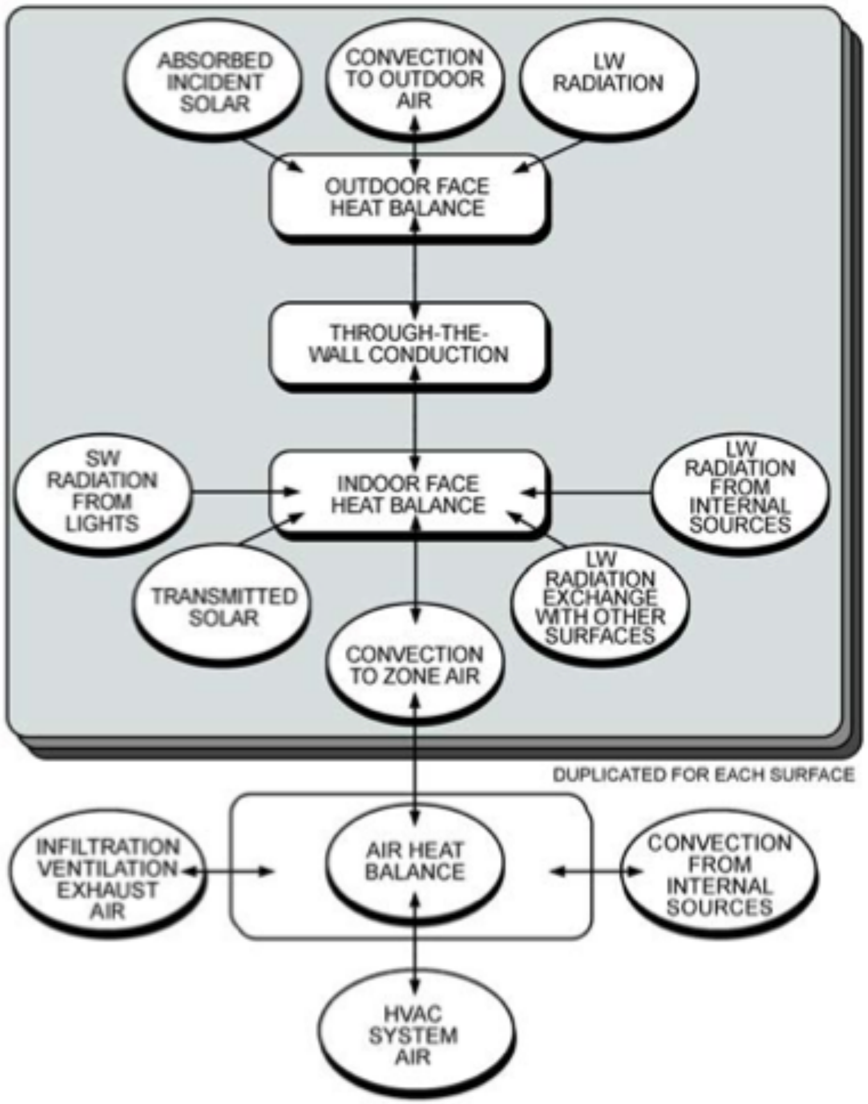
Last time

- Introduced cooling load calculations
  - One method covered so far:
    - Heat balance method (HBM)

- Today and Tuesday Nov 20:
  - Two other cooling load calculation methods
    - Cooling load temperature difference (CLTD) / cooling load factor (CLF)
    - Radiant Time Series (RTS)
  - Introduce Trane Trace 700 for performing load calculations
    - You will use on your HW 6
  - **Tuesday Nov 20th – Alumni 218 computer lab**
    - There will not be an online recording
    - Will be a mixture of lecture + lab activity

Heat balance method (HBM)

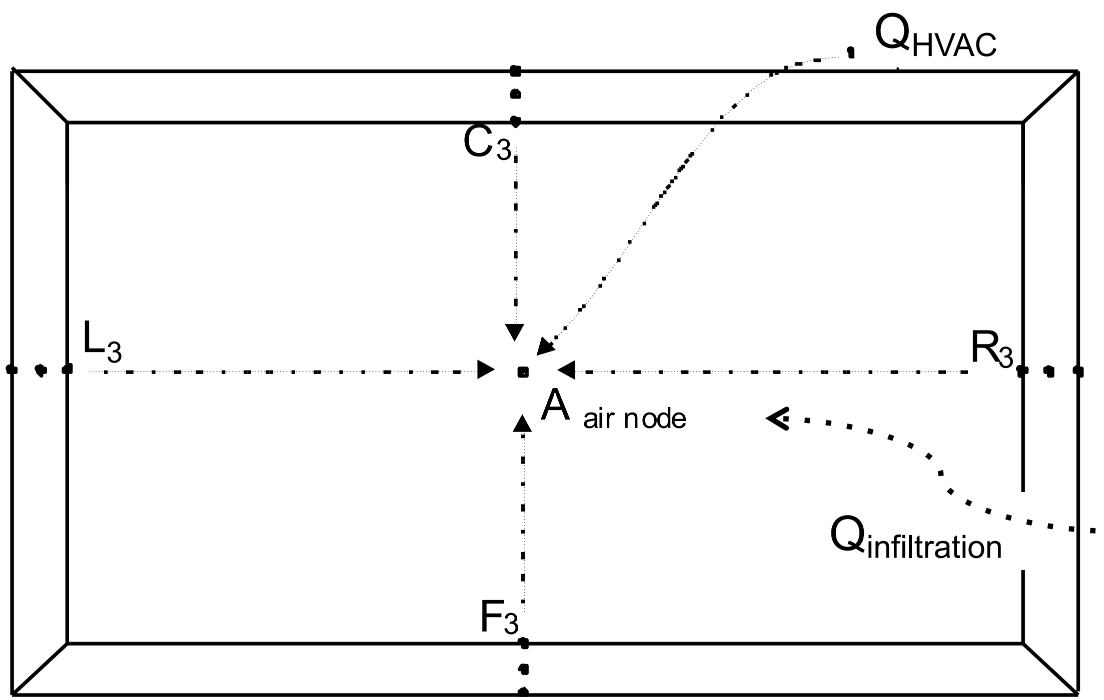


HBM: Indoor air energy balance

- To get the impact on indoor air temperature (and close the system of equations)
  - Write an energy balance on the indoor air node
  - Air impacted directly only by convection (bulk and/or surface)

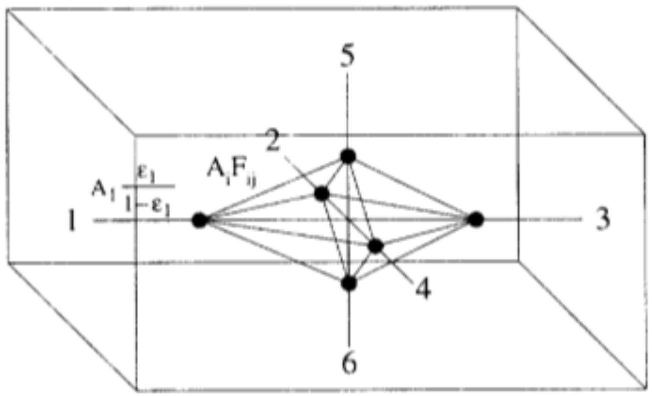
$$(V_{room}\rho_{air}c_{p,air})\frac{dT_{air,in}}{dt} = \sum_{i=1}^{n} h_i A_i \left(T_{i,surf} - T_{air,in}\right) + \dot{m}c_p\left(T_{out} - T_{air,in}\right) + Q_{HVAC}$$

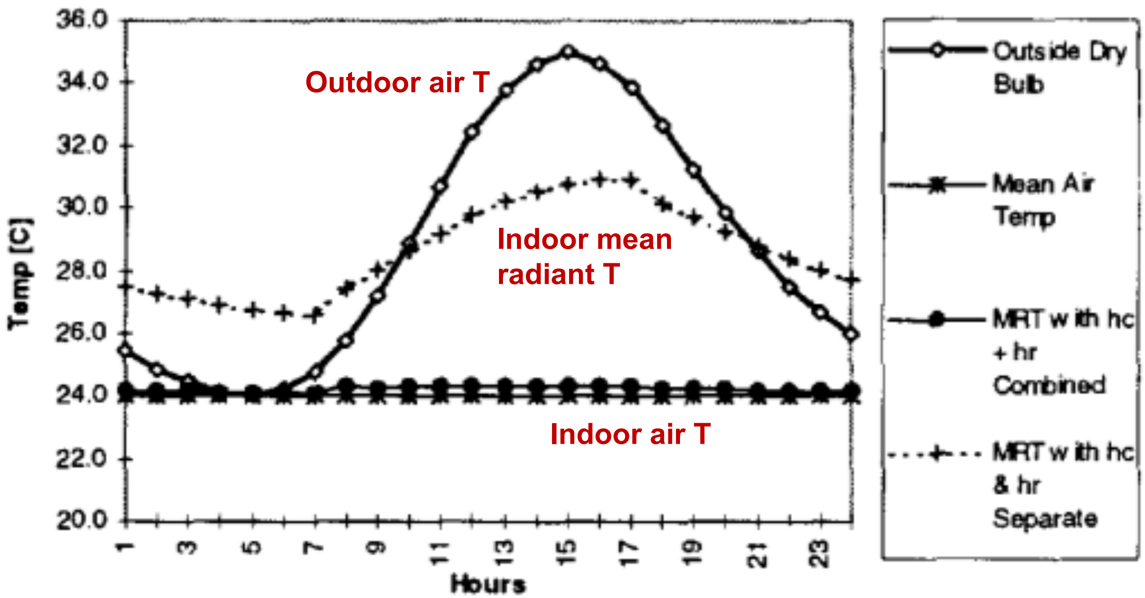
In plain English:
The change in indoor air temperature is equal to the sum of convection from each interior surface plus outdoor air delivery (by infiltration or dedicated outdoor air supply), plus the bulk convective heat transfer delivered by the HVAC system



Using HBM to calculate peak loads

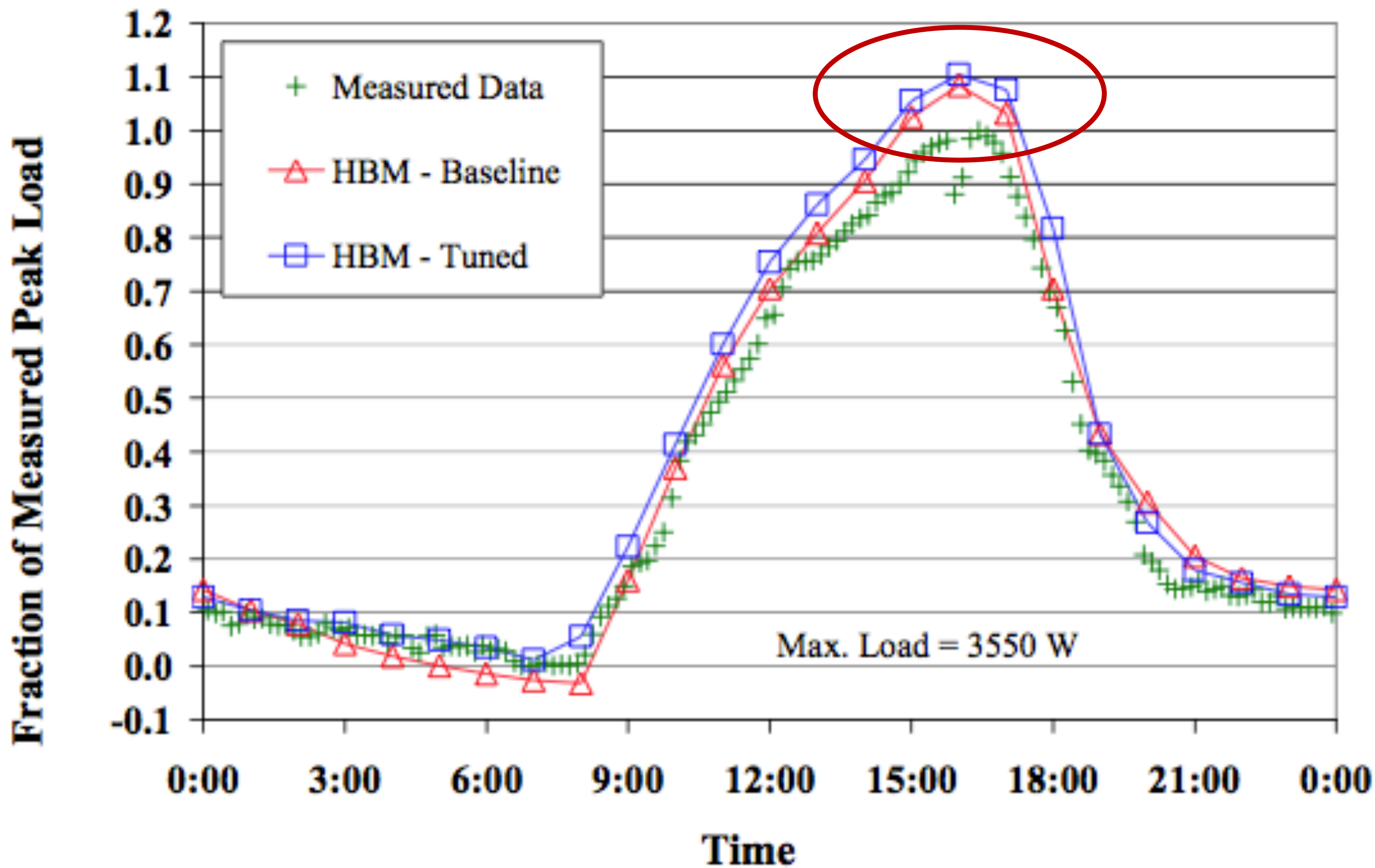
- Tracking indoor and outdoor temperatures for a simple space:





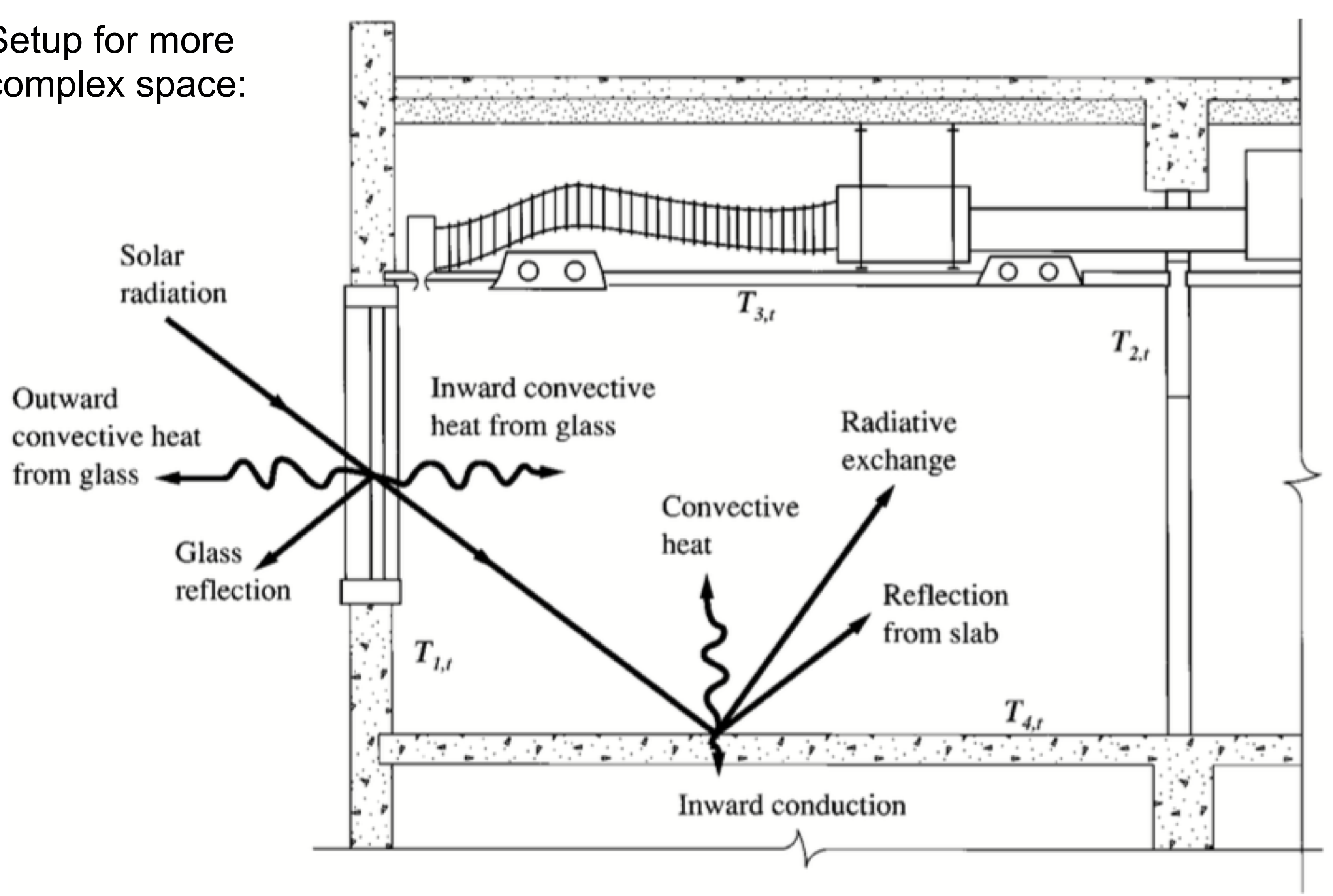
Using HBM to calculate peak loads

- Tracking the cooling load for a simple space:

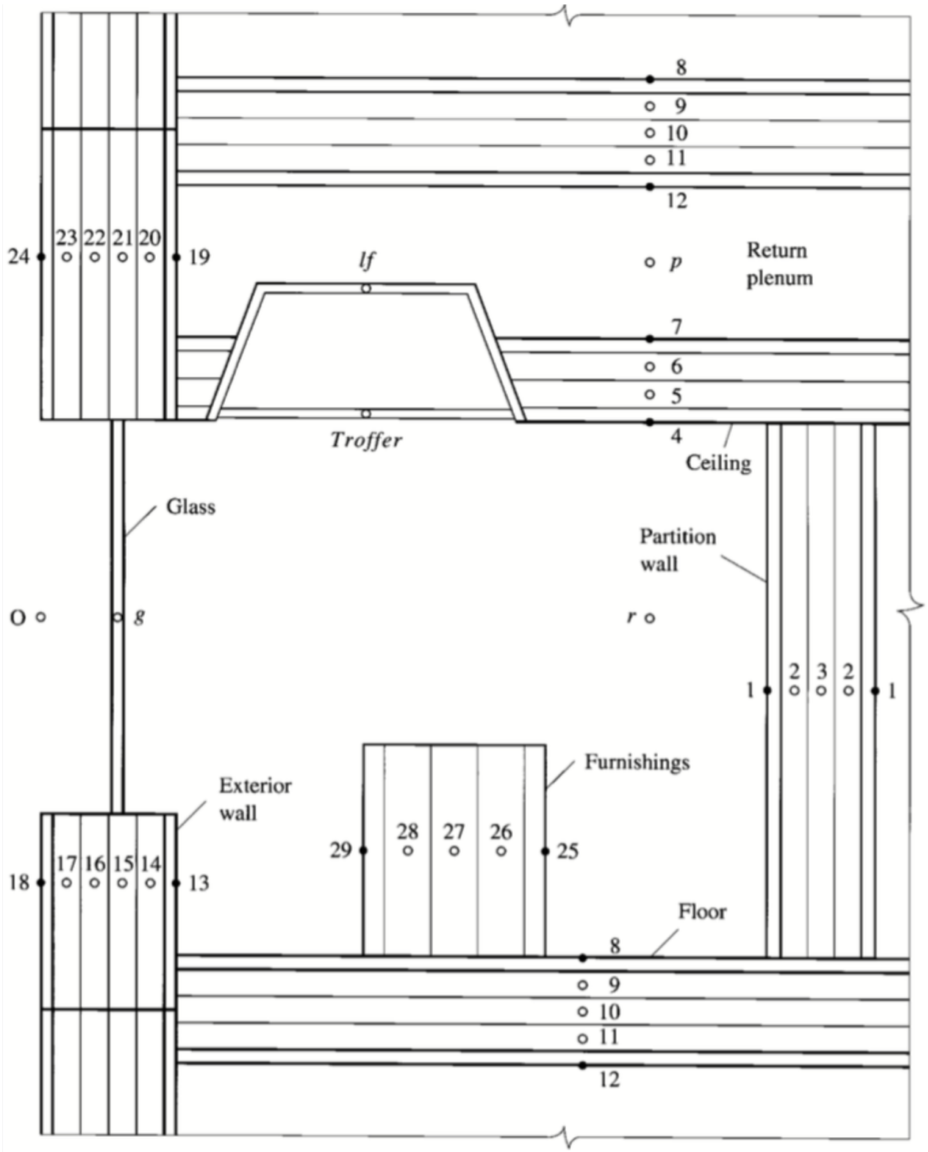


Using HBM to calculate peak loads

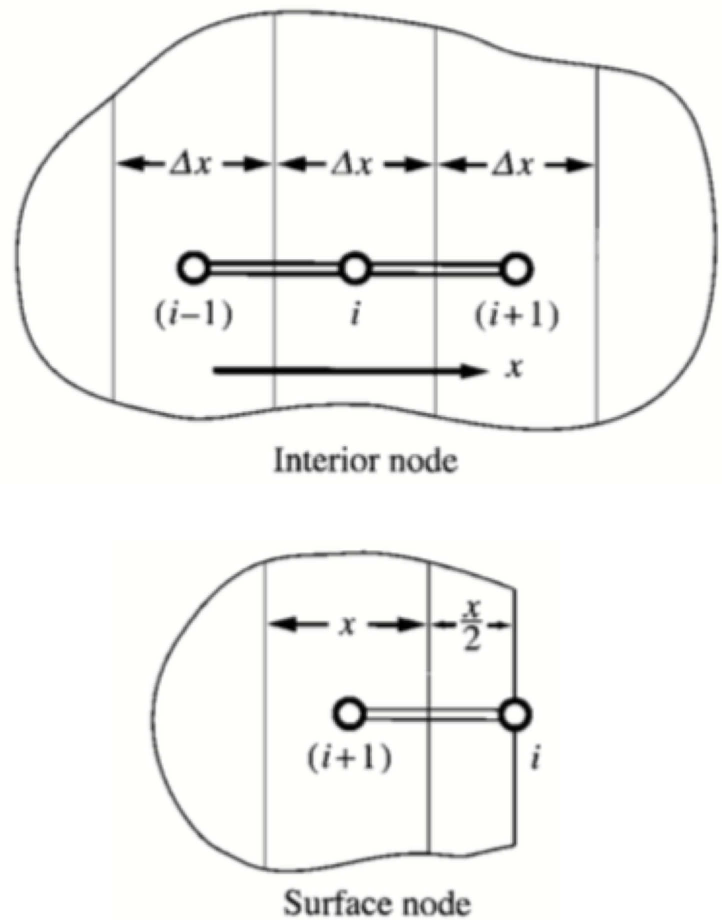
Setup for more complex space:



Using HBM to calculate peak loads: Complex



Setup for more complex space:



Notes on estimating cooling loads

- Frequently, a cooling load must be calculated before every parameter in the conditioned space can be properly or completely defined
  - An example is a cooling load estimate for a new building with many floors of un-leased spaces where detailed partition requirements, furnishings, lighting selection and layout cannot be predefined
  - Potential tenant modifications once the building is occupied also must be considered

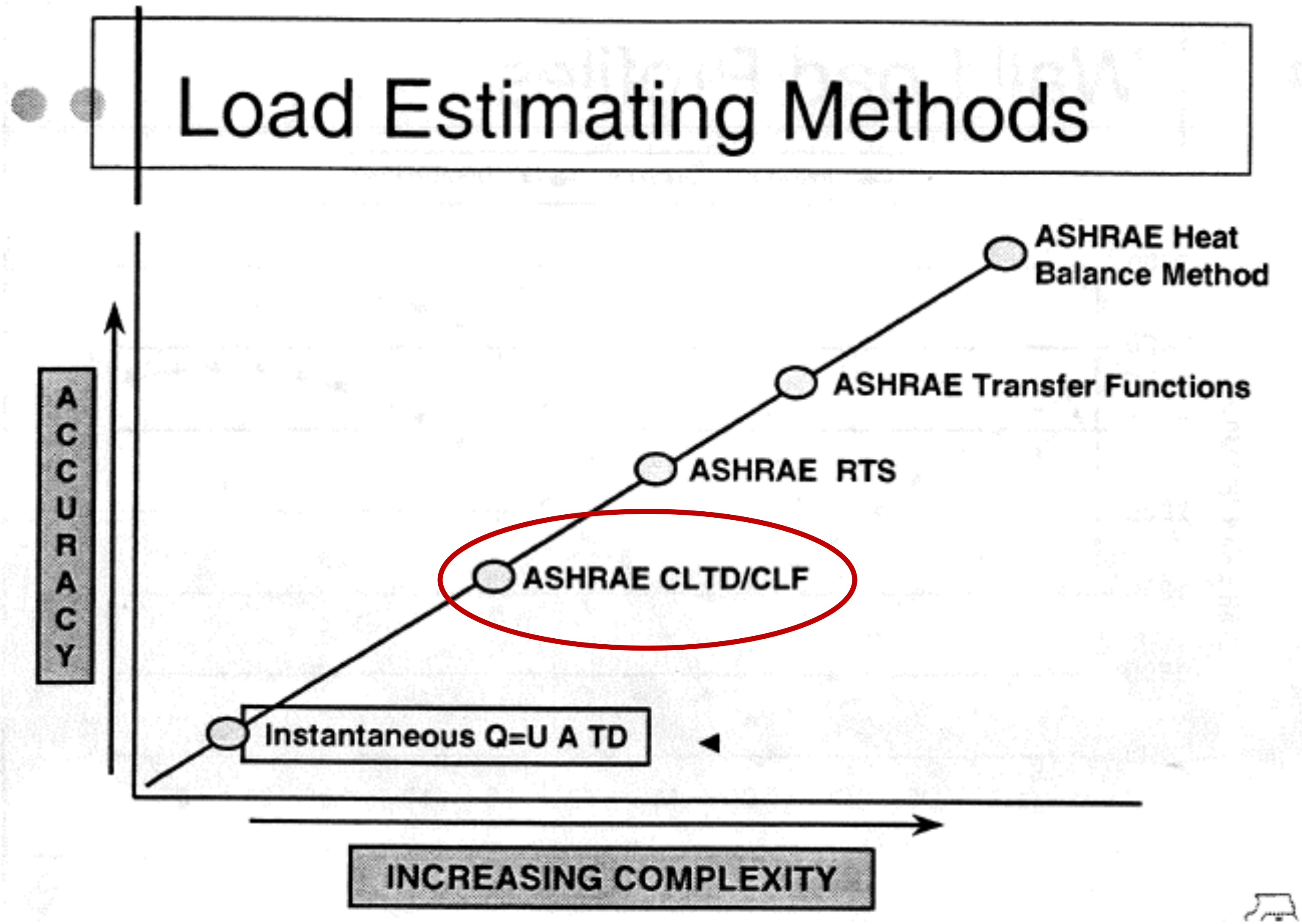
- The total load estimating process requires some engineering judgment that includes a thorough understanding of heat balance fundamentals

Issues with oversizing

- Since getting an accurate cooling load estimate can be difficult (or even impossible at an early design stage) some engineers design conservatively and deliberately oversize systems

- Oversizing a system is problematic because
  - Oversized systems are less efficient, harder to control, and noisier than properly sized systems
  - Oversized systems tend to duty cycle (turn on and off) which reduces reliability and increases maintenance costs
  - Oversized systems take up more space and cost more

Cooling load calculation methods



Simpler method: The ASHRAE CLTD/CLF method

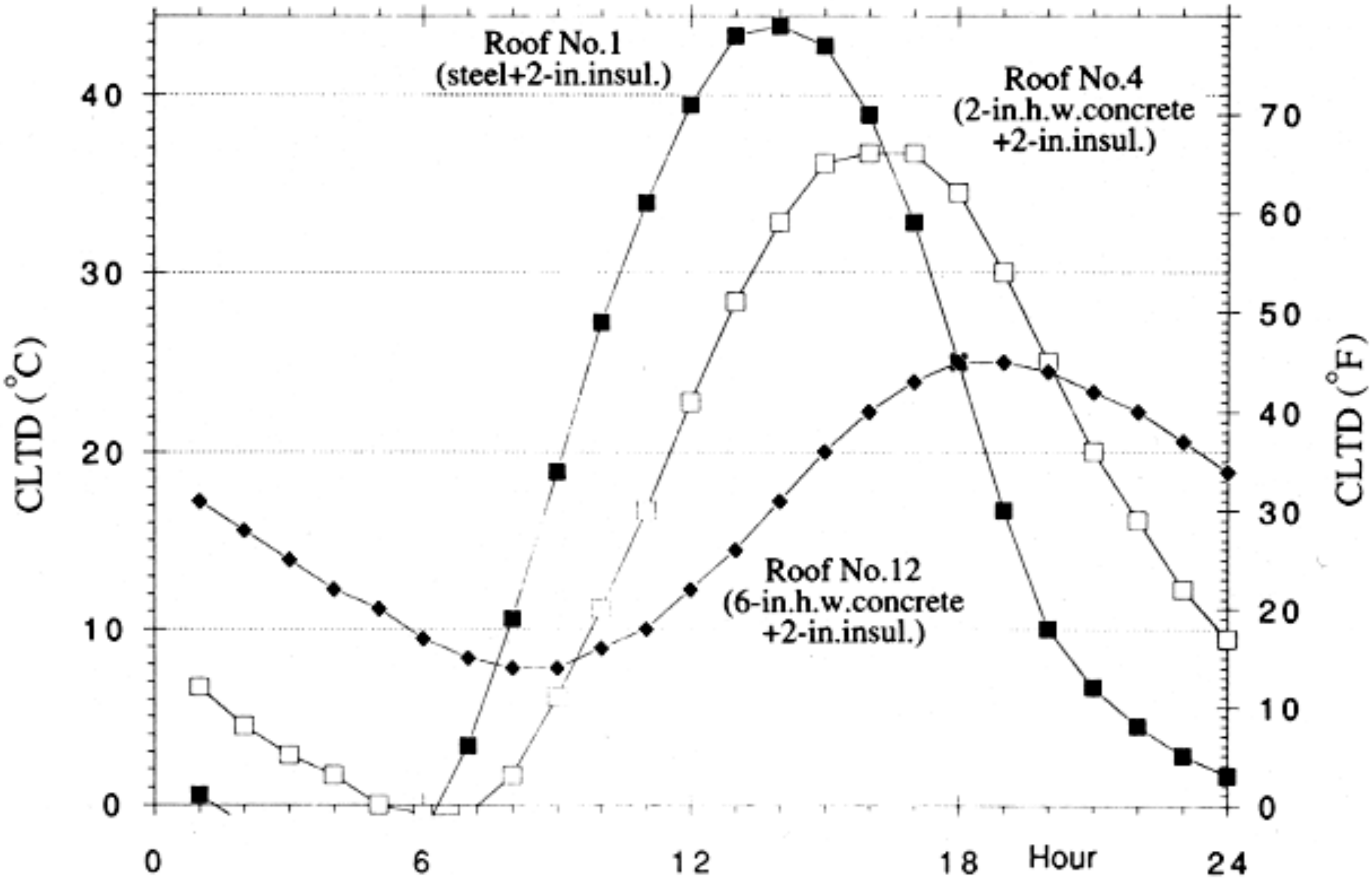
- One method of accounting for periodic responses for conduction and radiation (simpler than others) is the CLTD/CLF method (it's a mouthful)

- CLTD = cooling load temperature difference [K]
  - The temperature difference that gives the same cooling load when multiplied by UA for a given assembly
  - Calculate these "effective ΔT" values for typical constructions and typical temperature patterns
    - Then adjust the conductive load accordingly

Instead of: $$Q_{cooling,conduction} = UA(T_{out} - T_{in})$$

You use: $$Q_{cooling,conduction} = UA(CLTD_t)$$ at hour t

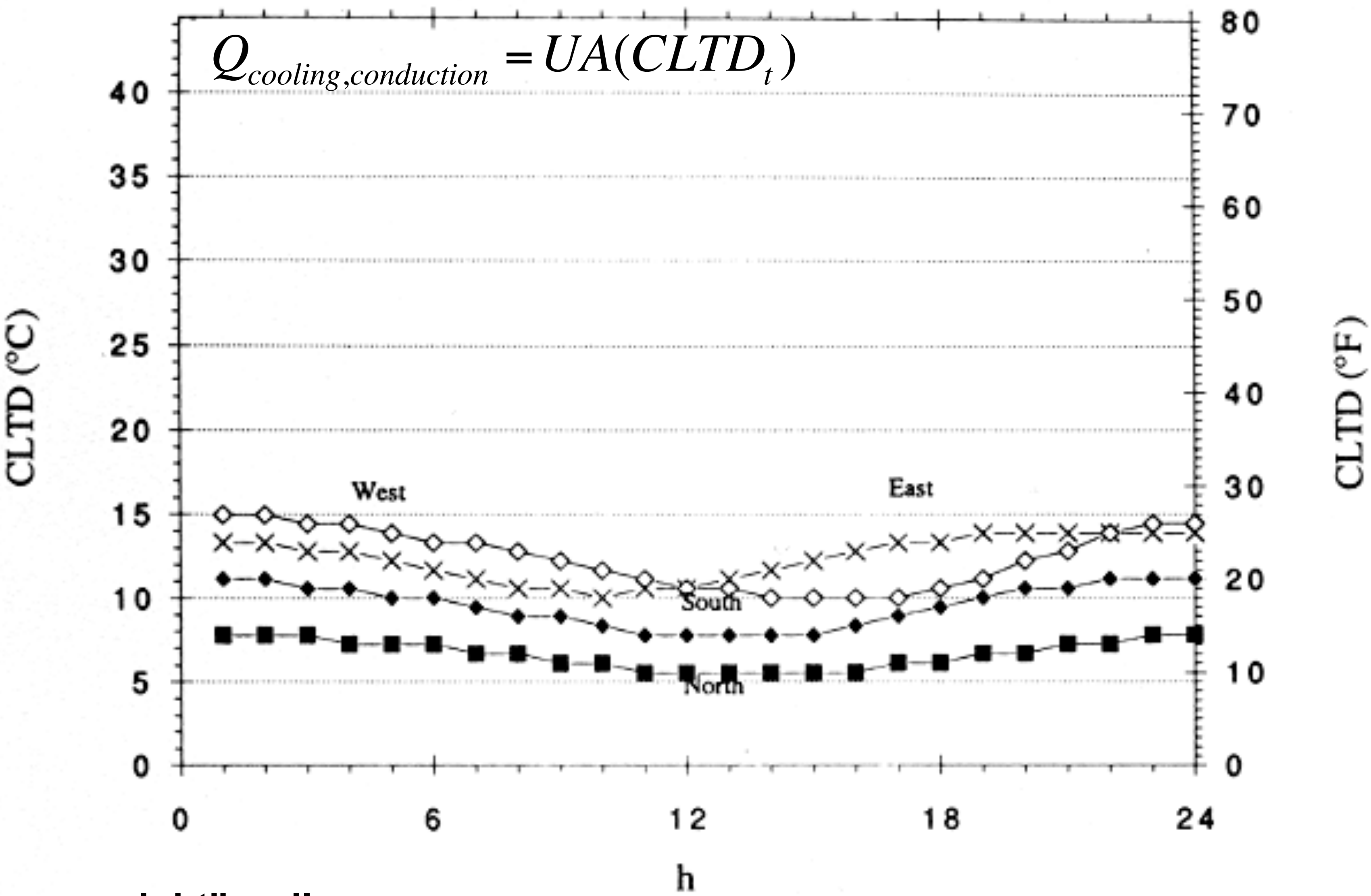
CLTD for typical roof materials



$$Q_{cooling,conduction} = UA(CLTD_t)$$

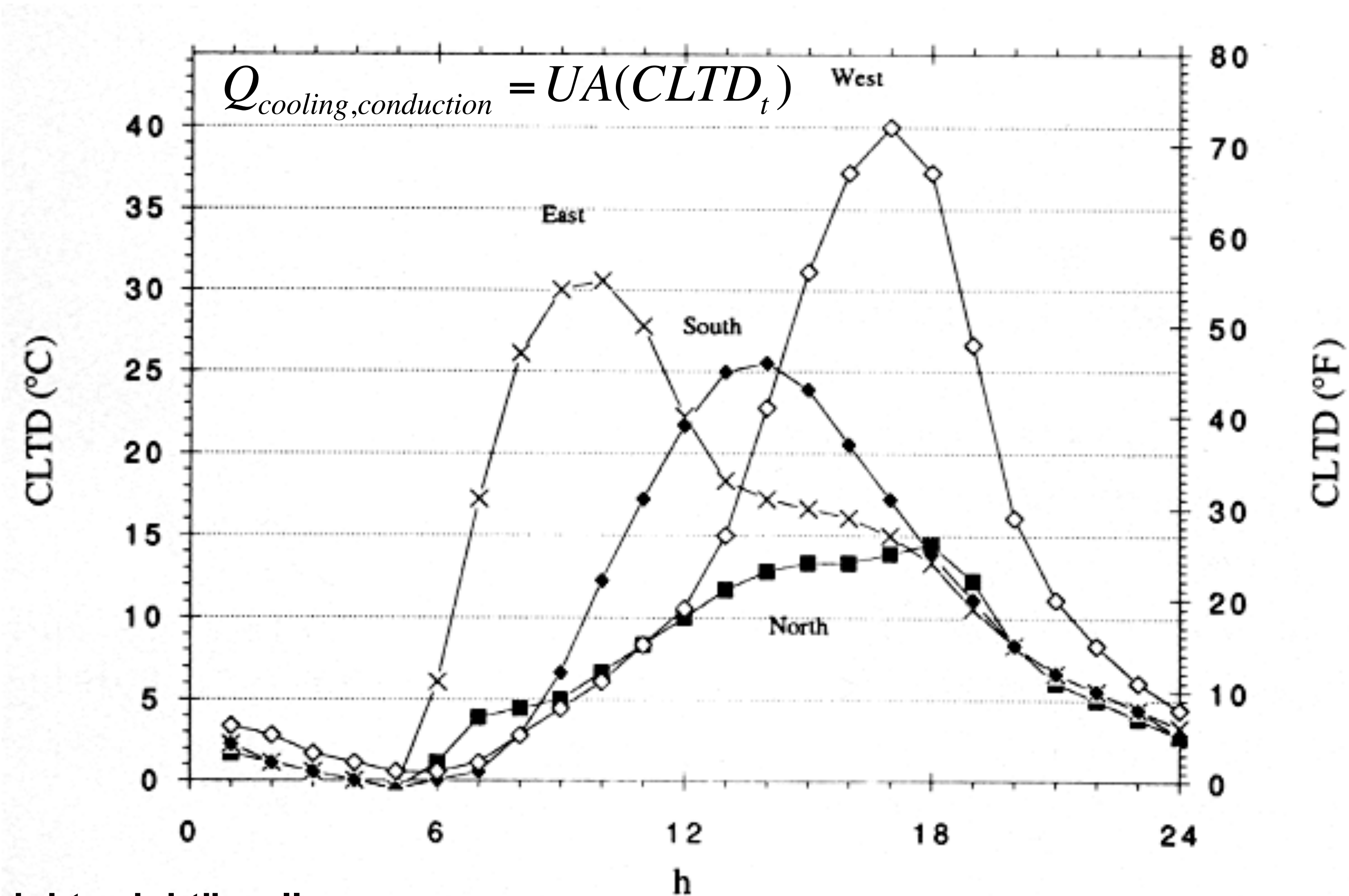
h

CLTD for typical “heavy” or “massive” walls



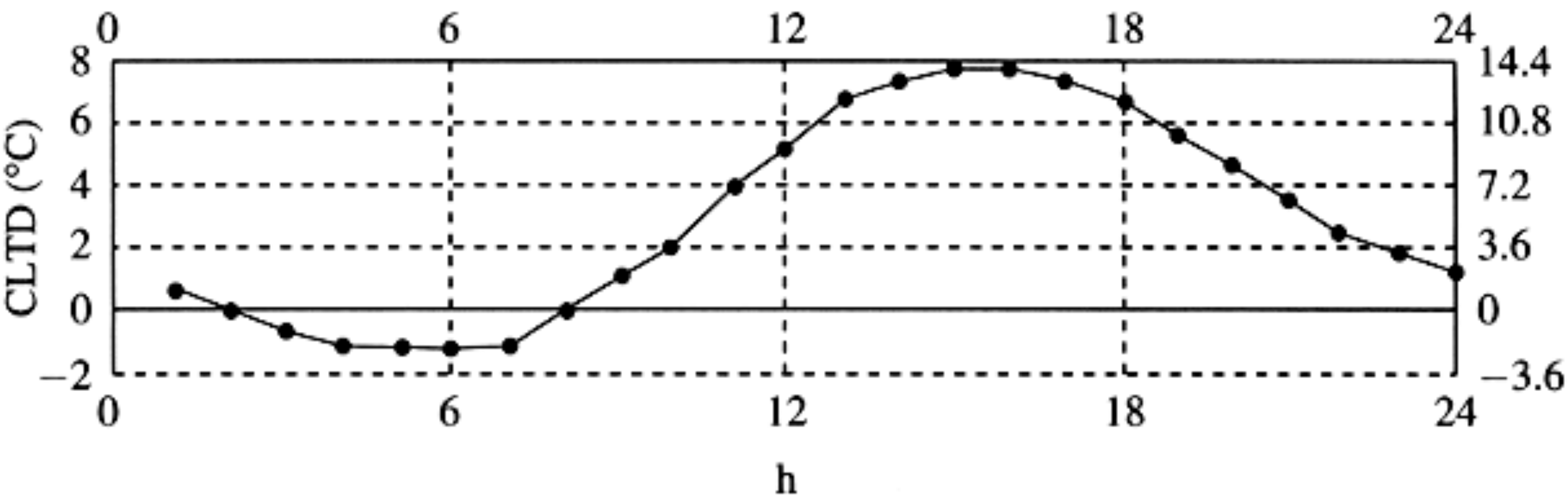
“Heavyweight” walls

CLTD for typical "lightweight" walls



"Lightweight" walls

CLTD for typical glazing



$$Q_{cooling,conduction} = UA(CLTD_t)$$

ASHRAE CLTD/CLF method

- CLF = cooling load factor [dimensionless]
  - Yields the cooling load at hour *t* as a function of maximum daily load
    - Also calculated for common construction materials
    - Just look values up in tables

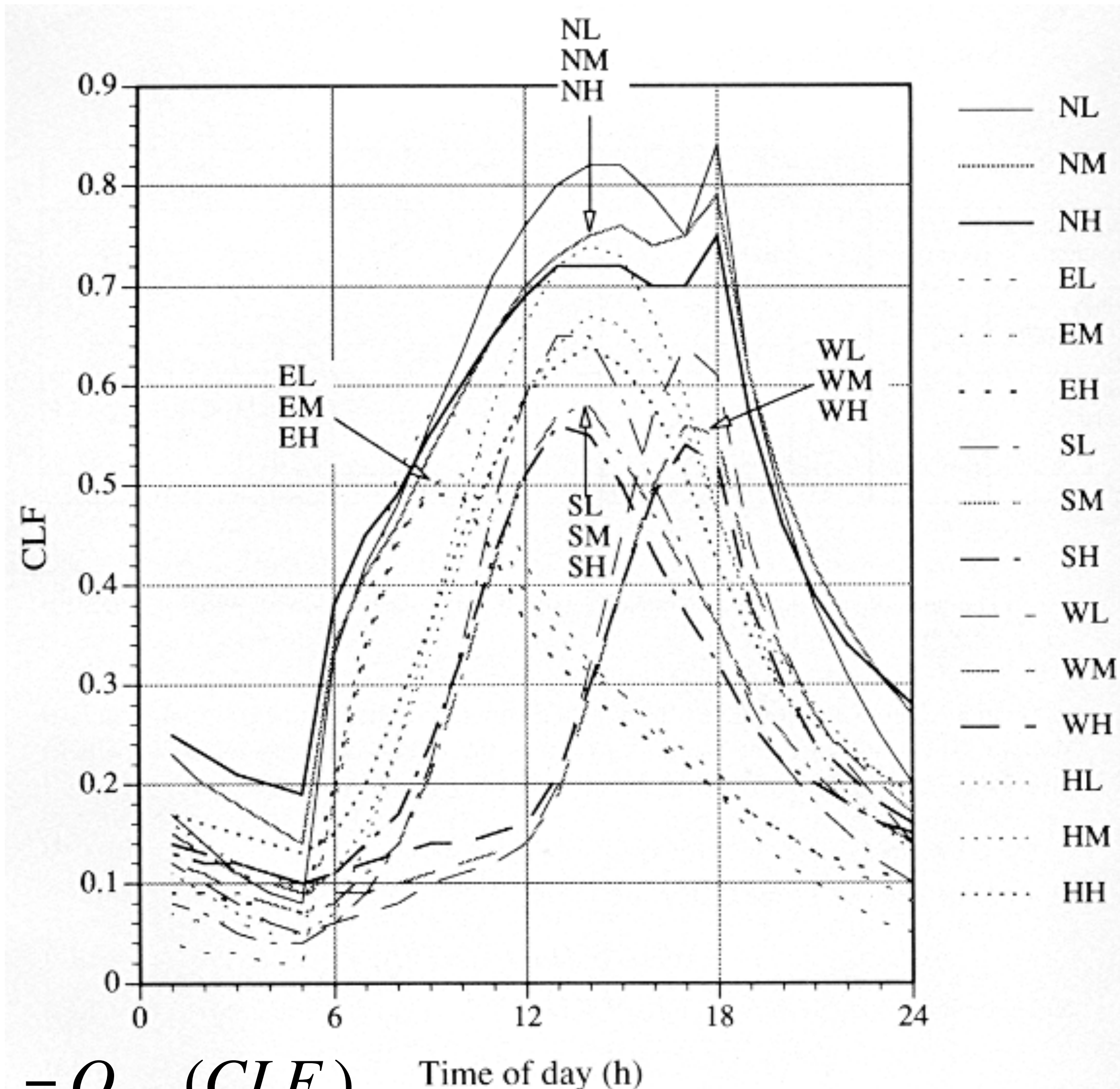
Instead of: $Q_{solar} = \alpha I_{solar} A$

You use: $Q_{cooling,radiation,t} = Q_{\max}(CLF_t)$ at hour t

CLF for typical glazing

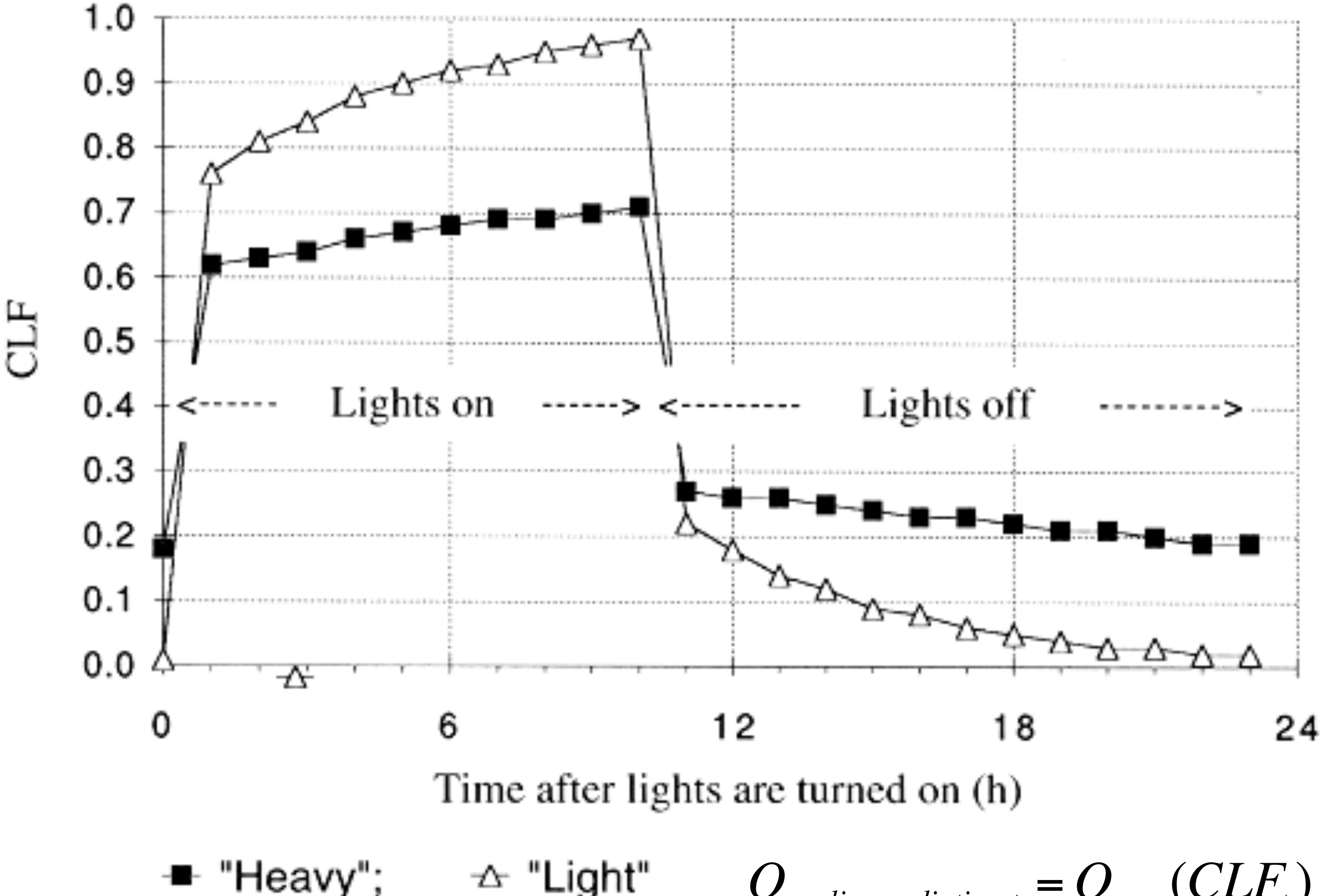
L = light
M = medium
H = heavy

N = north
E = east
W = west
S = south



$$Q_{cooling,radiation,t} = Q_{\max}(CLF_t)$$

CLF for typical internal gains



$$Q_{cooling,radiation,t} = Q_{\max}(CLF_t)$$

Finding peak cooling load with CLTD/CLF method

- To find the peak cooling load you would need to take into account the magnitude of all individual loads around a peak time period (typically within about 3 hours)

- Typically late afternoon or early evening

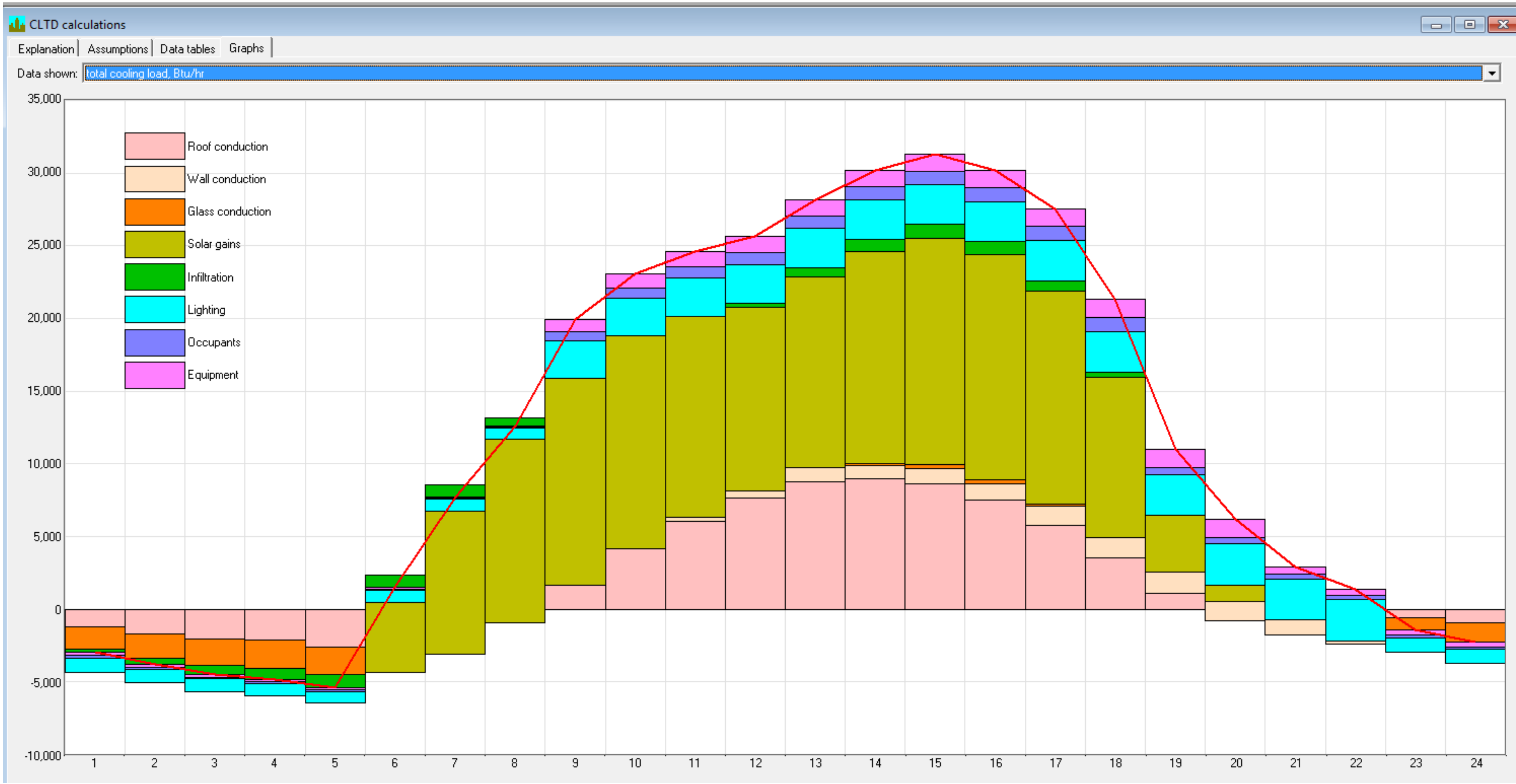
- Use a spreadsheet tool

- For a full example, see older versions of the ASHRAE Handbook of Fundamentals
  - http://www.tagengineering.ca/wp-content/uploads/2015/01/1997-Fundamentals_28.pdf

ASHRAE CLTD/CLF method

Sensible loads					hour t 3p	4p	5p	hour t		
Component and orientation	Construction type		U	A	$CLTD_t$			$\dot{Q}_t=U\times A\times CLTD_t$		
Walls										
Roof										
Glazing conduction										
Glazing solar		A	SC	$SHGF_{max}$	CLF_t			$\dot{Q}_t=A\times SC\times SHGF_{max}\times CLF_t$		
Air exchange		V	$\dot{V}$	T_i	T_o			$\dot{Q}=\rho\times c_p\times\dot{V}\times(T_o-T_i)$ (instantaneous)		
Internal partitions			U	A	ΔT across partition			$\dot{Q}=U\times A\times\Delta T$ (instantaneous)		
Ceiling										
Floor										
Sides										
Ducts										
Internal gains		number	gain /unit	$\dot{Q}$	CLF_t			$\dot{Q}_t=\dot{Q}\times CLF_t$		
Appliances										
Fans										
Lights										
Motors										
People										
TOTAL SENSIBLE										

CLTD/CLF method applied



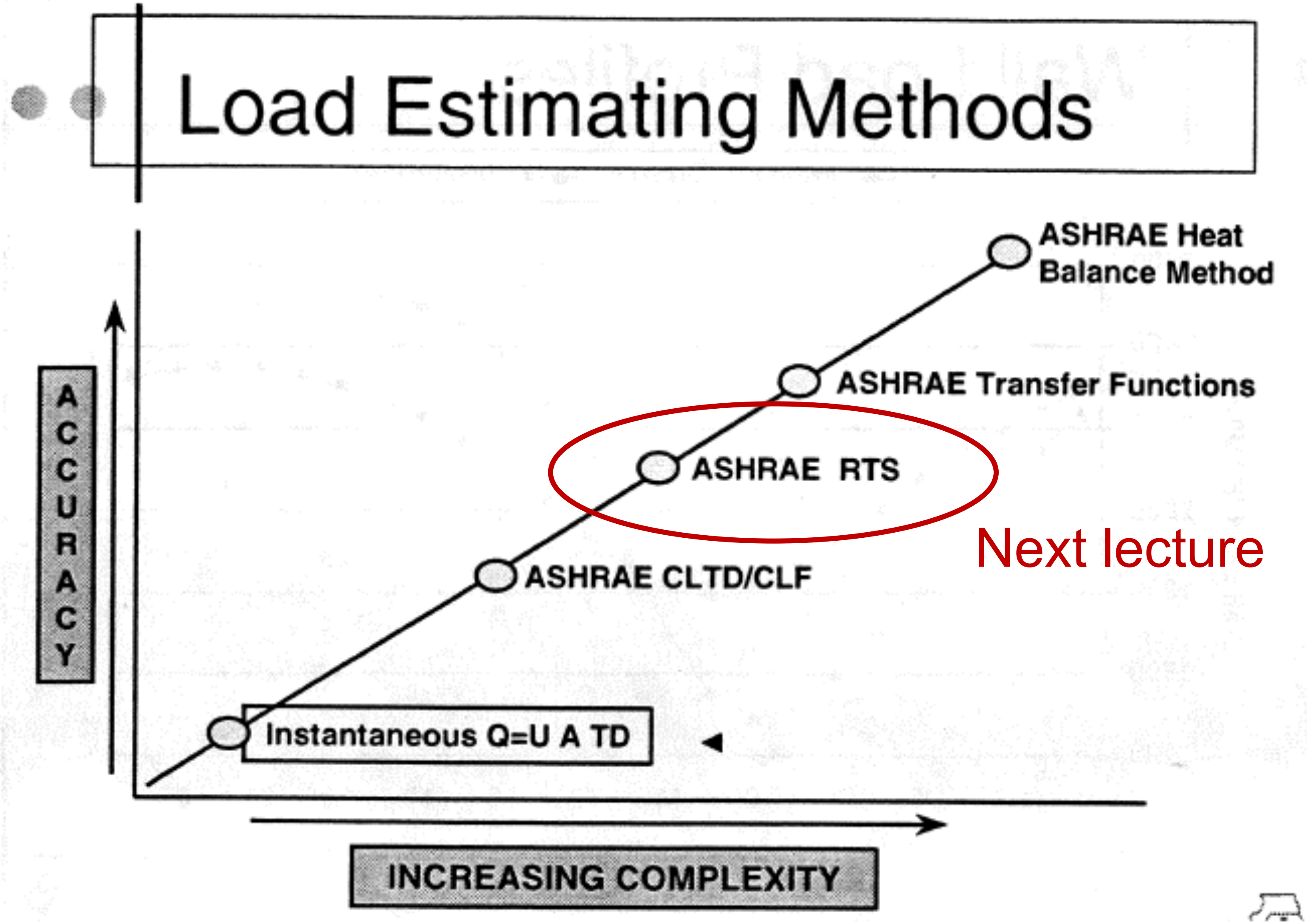
Software tools for load calculations

- These are not done by hand, sometimes by spreadsheet
  - Many use ACCA Manual J

- Most use computer programs

- Big list of programs:
  - http://apps1.eere.energy.gov/buildings/tools_directory/subjects.cfm/pagename=subjects/pagename_menu=whole_building_analysis/pagename_submenu=load_calculation

Cooling load calculation methods



Radiant time-series method (RTS)

- The Radiant Time-Series method (RTS) is a simplified version of the more complete heat balance method that can be implemented in a spreadsheet or software program

- RTS accounts for dynamic elements like outdoor air temperatures, solar radiation, and enclosure heat transfer somewhat more accurately than the CLTD/CLF method
  - Outdoor air temperatures and solar radiation are cyclic with 24 hour peak day periods
  - Enclosure heat capacity will absorb and release heat with a time delay
  - This is accounted for with **“response factors”** for *typical* construction elements

RTS in the ASHRAE Handbook

CHAPTER 18

NONRESIDENTIAL COOLING AND HEATING LOAD CALCULATIONS

Table 26 Summary of RTS Load Calculation Procedures

Equation	Equation No. in Chapter

External Heat Gain

Sol-Air Temperature

$$t_e = t_o + \frac{\alpha E_t}{h_o} - \frac{\varepsilon \Delta R}{h_o} \qquad (30)$$

where

t_e = sol-air temperature, °F
t_o = outdoor air temperature, °F
a = absorptance of surface for solar radiation
E_t = total solar radiation incident on surface, Btu/h·ft^2
h_o = coefficient of heat transfer by long-wave radiation and convection at outer surface, Btu/h·ft^2·°F
ε = hemispherical emittance of surface
ΔR = difference between long-wave radiation incident on surface from sky and surroundings and radiation emitted by blackbody at outdoor air temperature, Btu/h·ft^2; 20 for horizontal surfaces; 0 for vertical surfaces

Wall and Roof Transmission

$$q_\theta = c_0 q_{i,\theta} + c_1 q_{i,\theta\text{-}1} + c_2 q_{i,\theta\text{-}2} + \dots + c_{23} q_{i,\theta\text{-}23} \qquad (32)$$

Equation	Equation No. in Chapter

IAC($\theta.\Omega$) = indoor solar attenuation coefficient for beam solar heat gain coefficient; = 1.0 if no indoor shading device. IAC($\theta.\Omega$) is a function of shade type and, depending on type, may also be a function of beam solar angle of incidence θ and shade geometry

IAC$_D$ = indoor solar attenuation coefficient for diffuse solar heat gain coefficient; = 1.0 if not indoor shading device. IAC$_D$ is a function of shade type and, depending on type, may also be a function of shade geometry

Partitions, Ceilings, Floors Transmission

$$q = UA(t_b - t_i) \qquad (33)$$

where

q = heat transfer rate, Btu/h
U = coefficient of overall heat transfer between adjacent and conditioned space, Btu/h·ft^2·°F
A = area of separating section concerned, ft^2
t_b = average air temperature in adjacent space, °F
t_i = air temperature in conditioned space, °F

RTS simplifying assumptions

- The combined effects of convective and radiative heat transfer to/from the exterior can be modeled by convection to/from an equivalent exterior air temperature called the sol-air temp, $T_{sol\text{-}air}$
  - This means a single combined radiation-convection heat transfer coefficient independent of wind speed, surface temperatures, and sky temperatures must be used for all surfaces

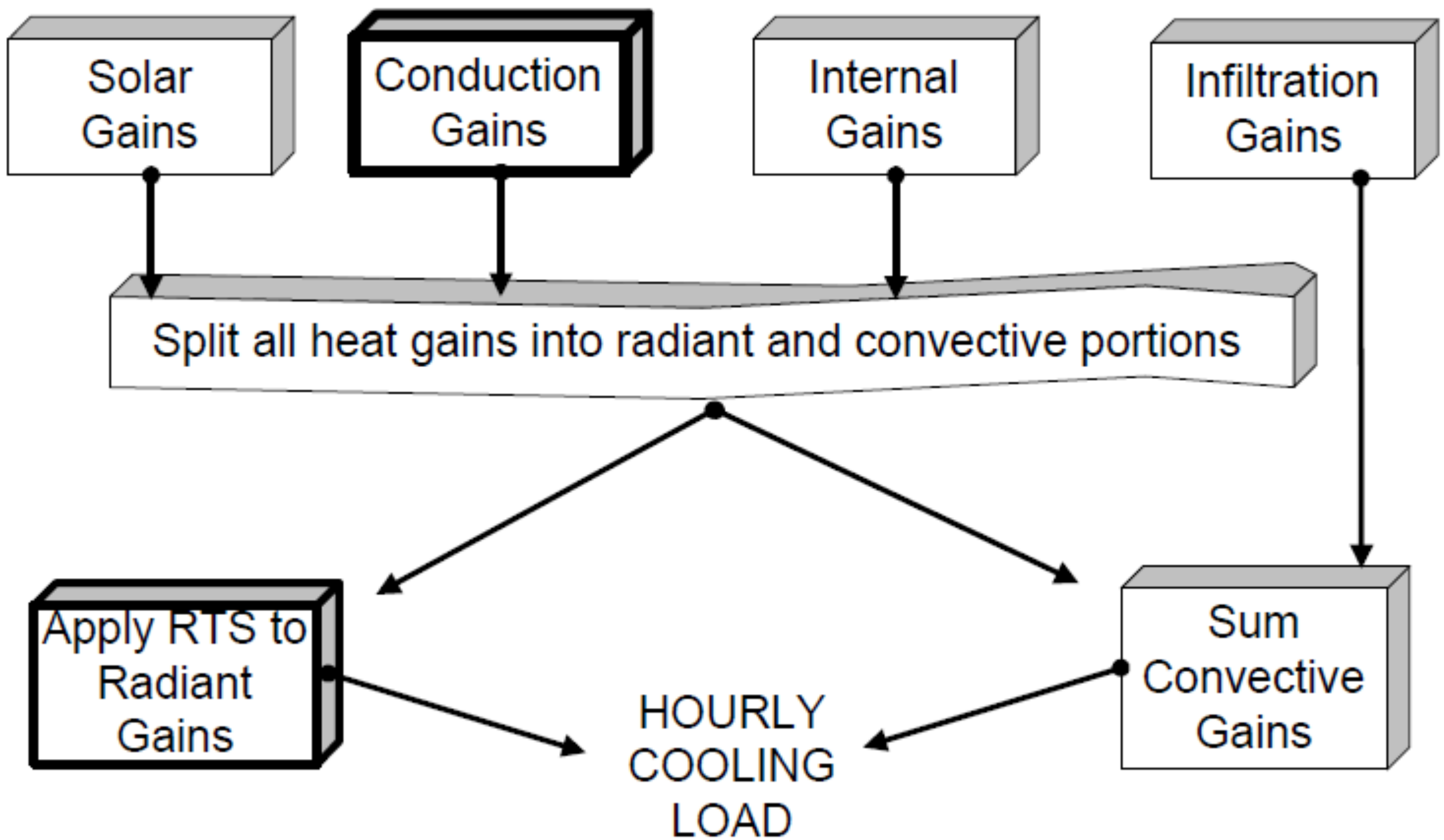
- All interior surface temperatures are assumed to be nearly the same, so all radiation between elements in the interior can be ignored
  - Makes calculations **much simpler**

RTS main idea

The idea behind the radiant time series is this:

- The current heat transfer to/from the interior is equal to:
  - \+ A portion of the **current** convective heat transfer from the outside of the enclosure
  - \+ The **current** solar heat gain through fenestration
  - \+ A portion of the **prior** convective and radiative heat transfer from the outside of the enclosure

RTS procedure



Boxed elements involve response factor calculations

RTS procedure

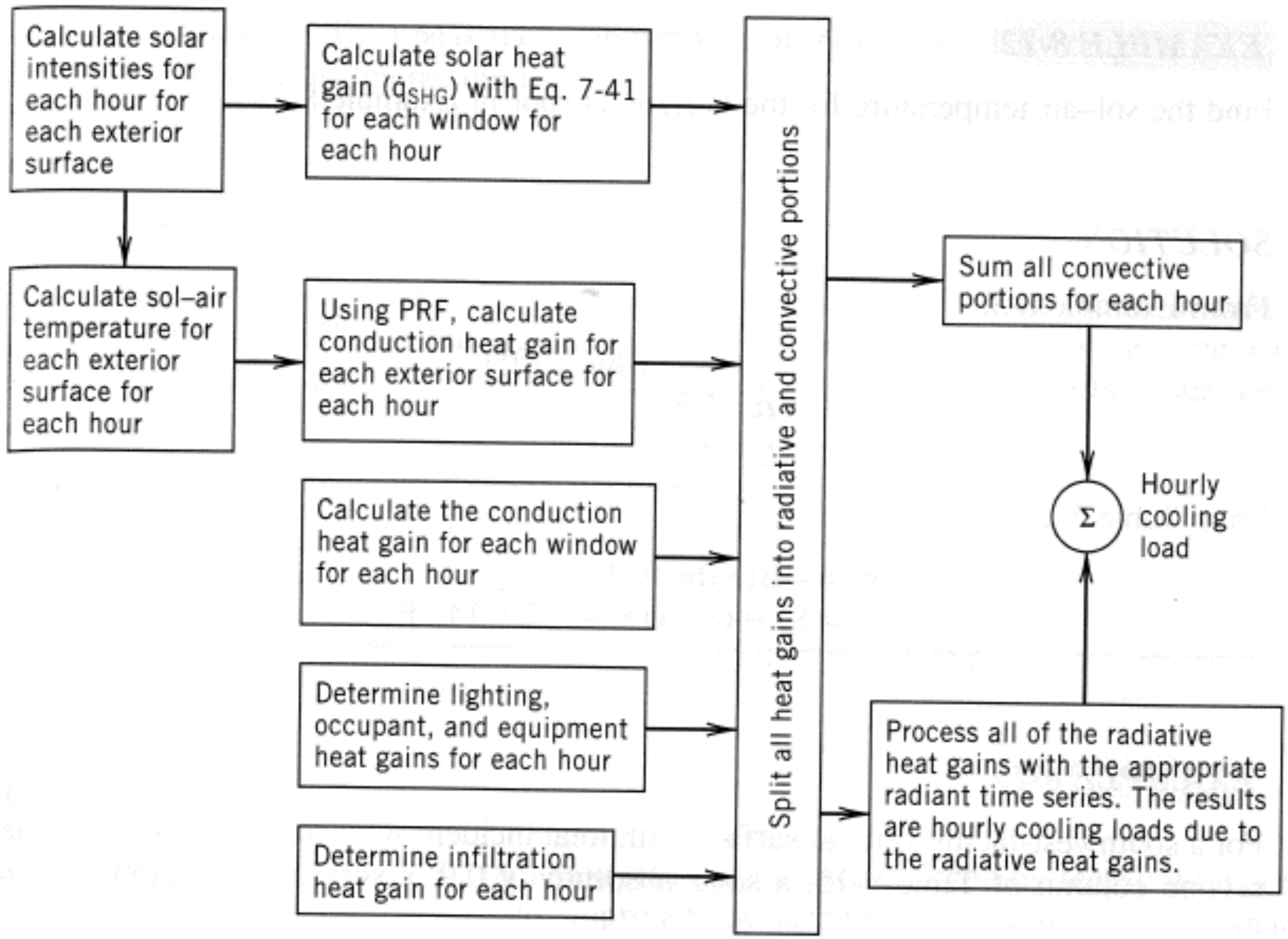


Figure 8-8 Radiant time series method.

RTS procedure

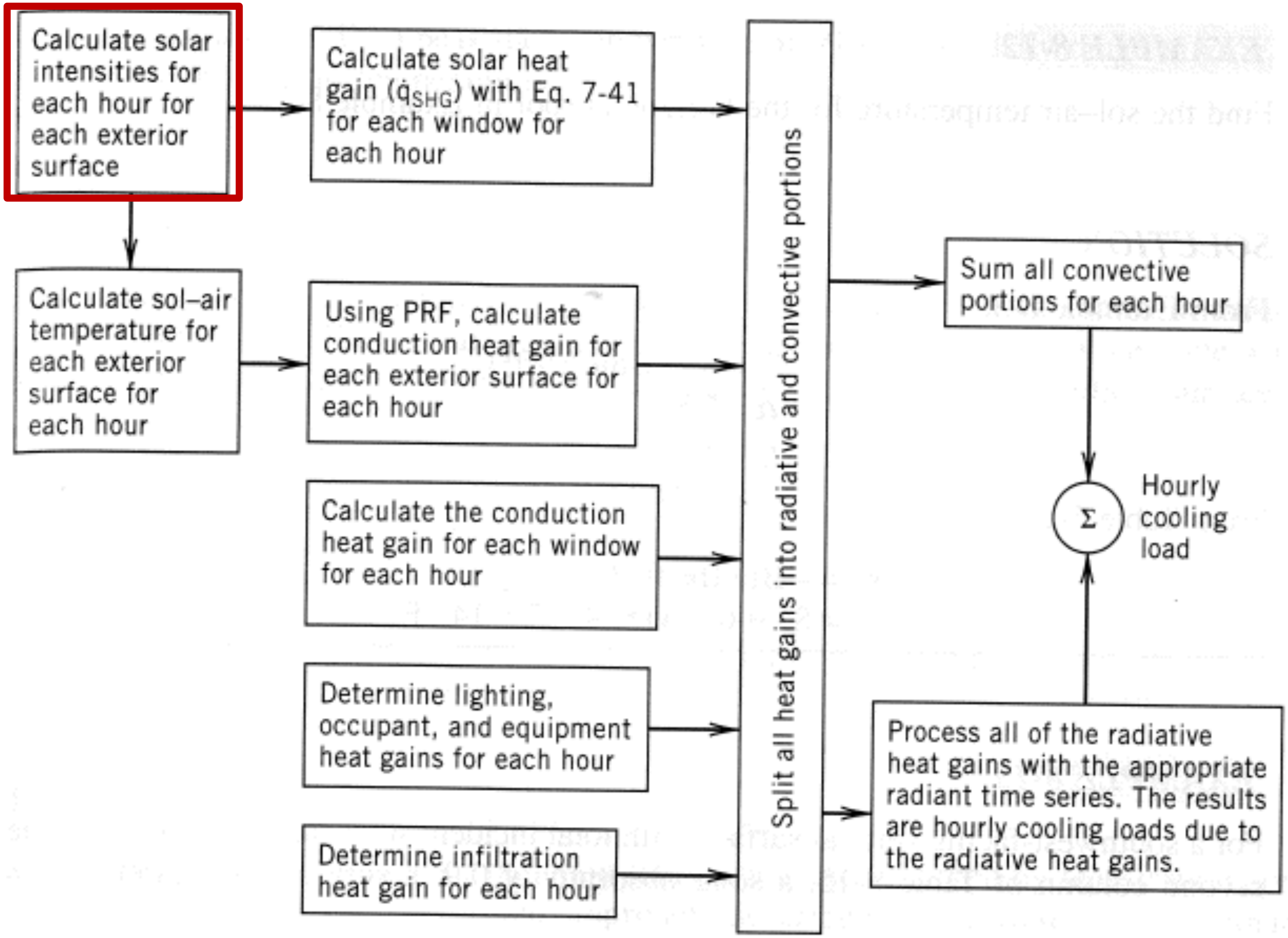
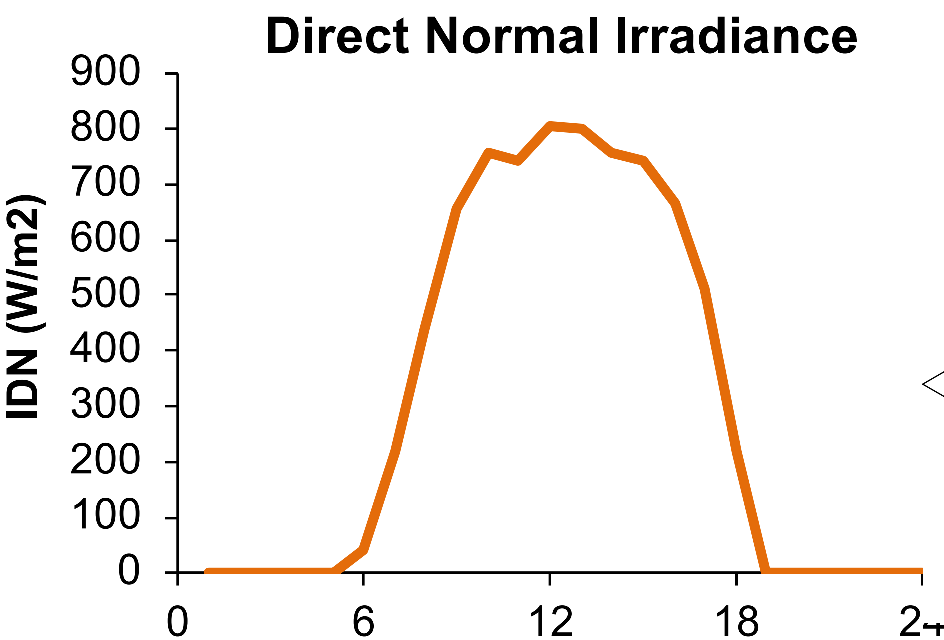
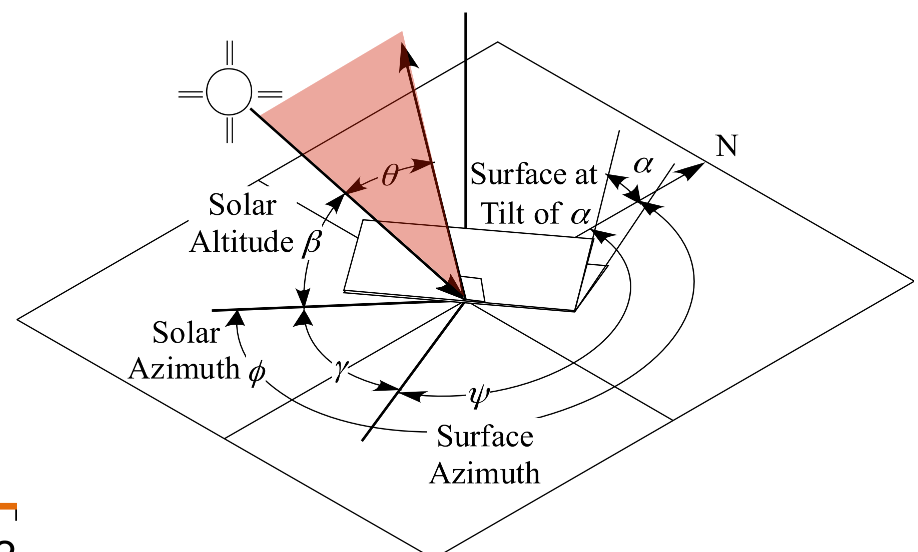


Figure 8-8 Radiant time series method.

Solar intensities

- We can calculate hourly solar intensities based on solar geometry
  - Or download data from the internet
    - http://rredc.nrel.gov/solar/old_data/nsrdb/





$$I_D = I_{DN} \cos\theta$$

RTS procedure

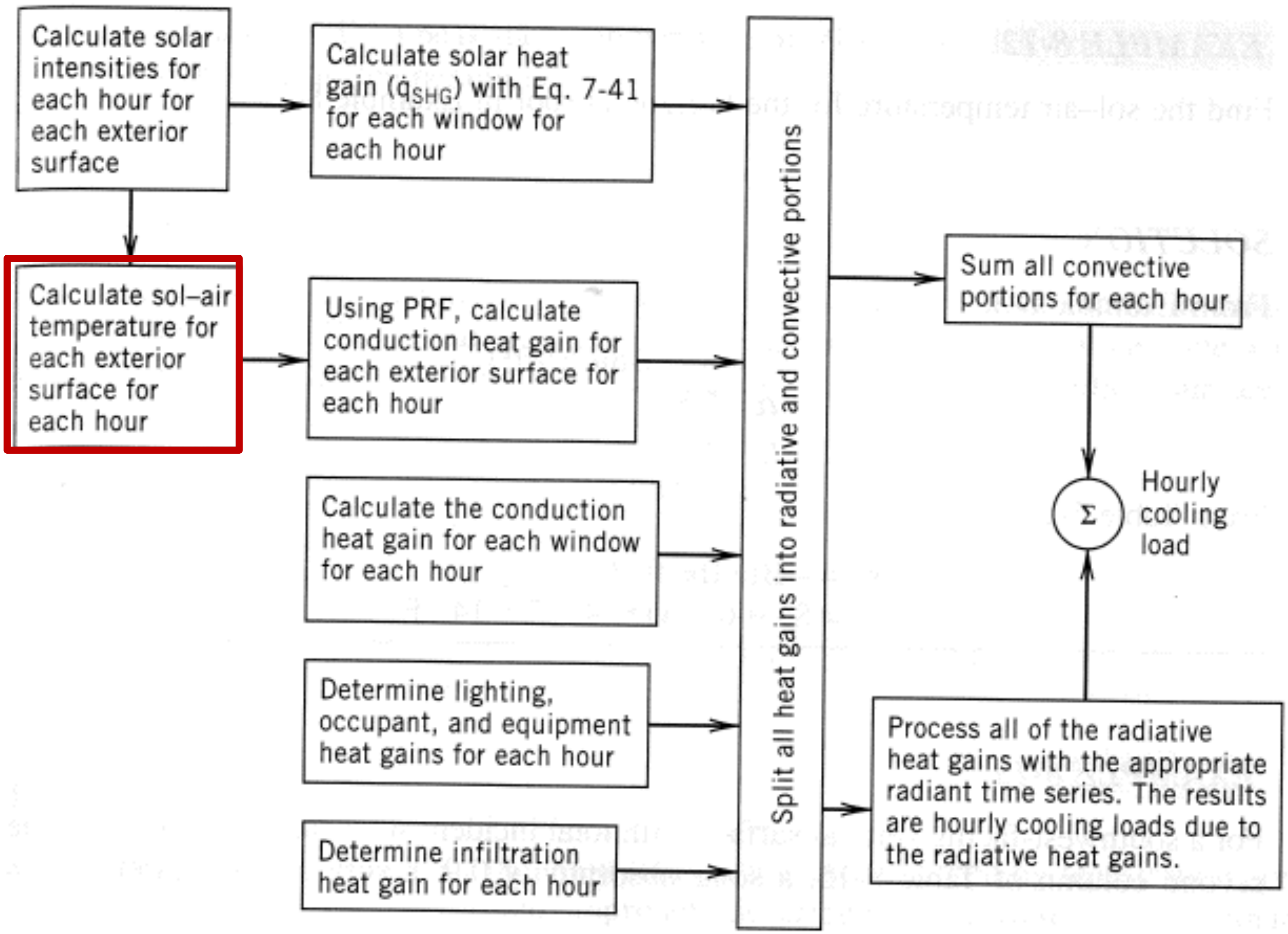


Figure 8-8 Radiant time series method.

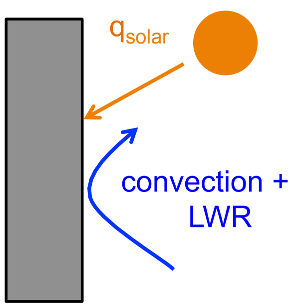
Calculate sol-air temperature

- For each surface, for each hour

Sol-Air Temperature

$$t_e = t_o + \frac{\alpha E_t}{h_o} - \frac{\varepsilon \Delta R}{h_o} \tag{30}$$

where



t_e = sol-air temperature, °F
t_o = outdoor air temperature, °F
a = absorptance of surface for solar radiation
E_t = total solar radiation incident on surface, Btu/h·ft^2
h_o = coefficient of heat transfer by long-wave radiation and convection at outer surface, Btu/h·ft^2·°F
ε = hemispherical emittance of surface
ΔR = difference between long-wave radiation incident on surface from sky and surroundings and radiation emitted by blackbody at outdoor air temperature, Btu/h·ft^2; 20 for horizontal surfaces; 0 for vertical surfaces

RTS procedure

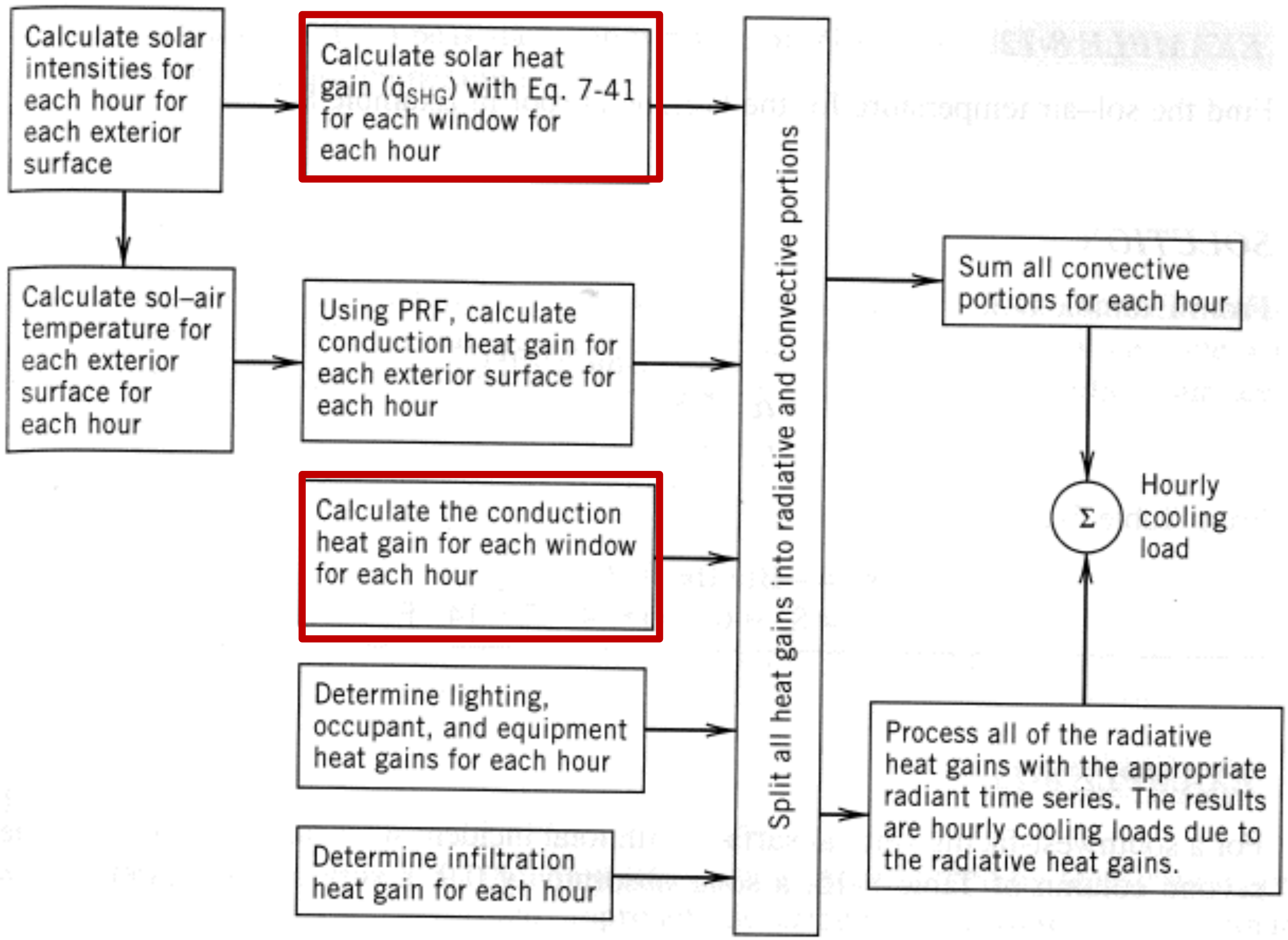


Figure 8-8 Radiant time series method.

Heat gain through windows

- For each window, for each hour of the peak day

Fenestration Transmission

$$q_c = UA(T_{out} - T_{in}) \tag{15}$$

where

q = fenestration transmission heat gain, Btu/h

U = overall U-factor, including frame and mounting orientation from Table 4 of Chapter 15, Btu/h·ft²·°F

A = window area, ft²

T_{in} = indoor temperature, °F

T_{out} = outdoor temperature, °F

- We've done this before!

Solar gain through windows

- For each window, for each hour of the peak day

Fenestration Solar

$$q_b = AE_{t,b}\,\mathrm{SHGC}(\theta)\mathrm{IAC}(\theta,\Omega) \tag{13}$$

$$q_d = A(E_{t,d} + E_{t,r})\langle\mathrm{SHGC}\rangle_D\,\mathrm{IAC}_D \tag{14}$$

where

q_b = beam solar heat gain, Btu/h
q_d = diffuse solar heat gain, Btu/h
A = window area, ft^2
$E_{t,b}$, $E_{t,d}$, and $E_{t,r}$ = beam, sky diffuse, and ground-reflected diffuse irradiance, calculated using equations in Chapter 14
SHGC(θ) = beam solar heat gain coefficient as a function of incident angle θ; may be interpolated between values in Table 10 of Chapter 15
$\langle\mathrm{SHGC}\rangle_D$ = diffuse solar heat gain coefficient (also referred to as hemispherical SHGC); from Table 10 of Chapter 15

- We've done this before!

RTS procedure

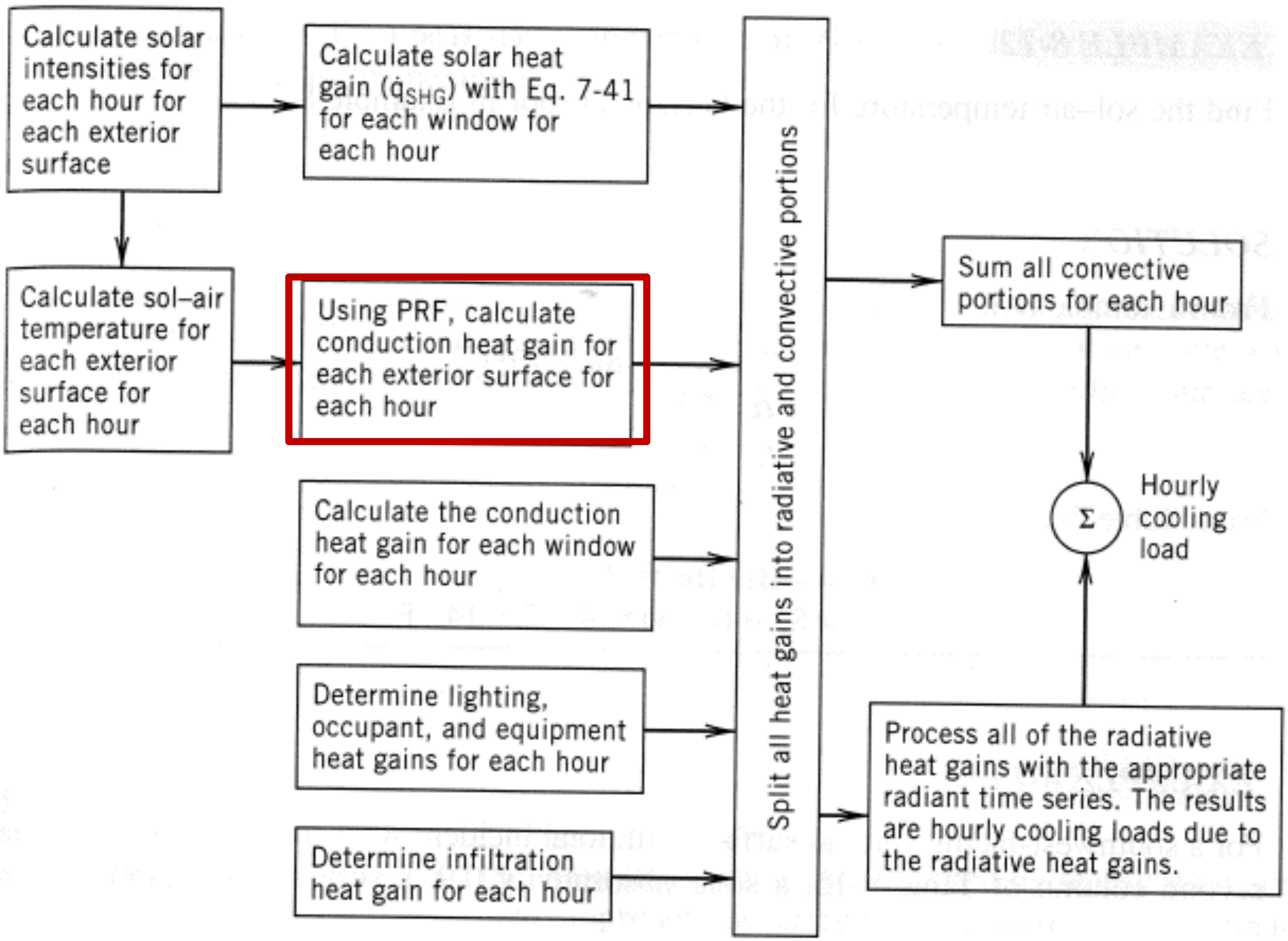


Figure 8-8 Radiant time series method.

Wall and roof conduction heat gains: CTS

- Heat gains to the interior from conduction will be a sum of conduction going on right now + a portion of the heat transferred to the enclosure from earlier times (via storage)

Wall and Roof Transmission

$$q_\theta = c_0 q_{i,\theta} + c_1 q_{i,\theta\text{-}1} + c_2 q_{i,\theta\text{-}2} + \dots + c_{23} q_{i,\theta\text{-}23} \quad (32)$$

$$q_{i,\theta\text{-}n} = UA(t_{e,\theta\text{-}n} - t_{rc}) \quad (31)$$

where

q_θ = hourly conductive heat gain for surface, Btu/h
$q_{i,\theta}$ = heat input for current hour
$q_{i,\theta\text{-}n}$ = conductive heat input for surface n hours ago, Btu/h
c_0, c_1, etc. = conduction time factors
U = overall heat transfer coefficient for surface, $\text{Btu/h}\cdot\text{ft}^2\cdot°\text{F}$
A = surface area, ft^2
$t_{e,\theta\text{-}n}$ = sol-air temperature n hours ago, °F
t_{rc} = presumed constant room air temperature, °F

Finding Conduction Time Series (CTS): C_{0}, C_{1}, etc.

- C_n tells you what fraction of heat gain at this moment will pass through at this moment, and in 1 hour, and in the next hour, and so on…

- C_n depends on the exact details of the enclosure construction (wall or ceiling)
  - Total amount of insulation, density/mass, heat capacity, and the insulation location are all important determinants

- The ASHRAE handbook has a table of U-values and C_n values for 20 common constructions
  - For the RTS method, you are pretty much limited to these enclosure 20 or so construction types

C_n for varying masses of enclosures

- Increasing thermal mass (i.e., heat capacity) increases the delay in heat transmission

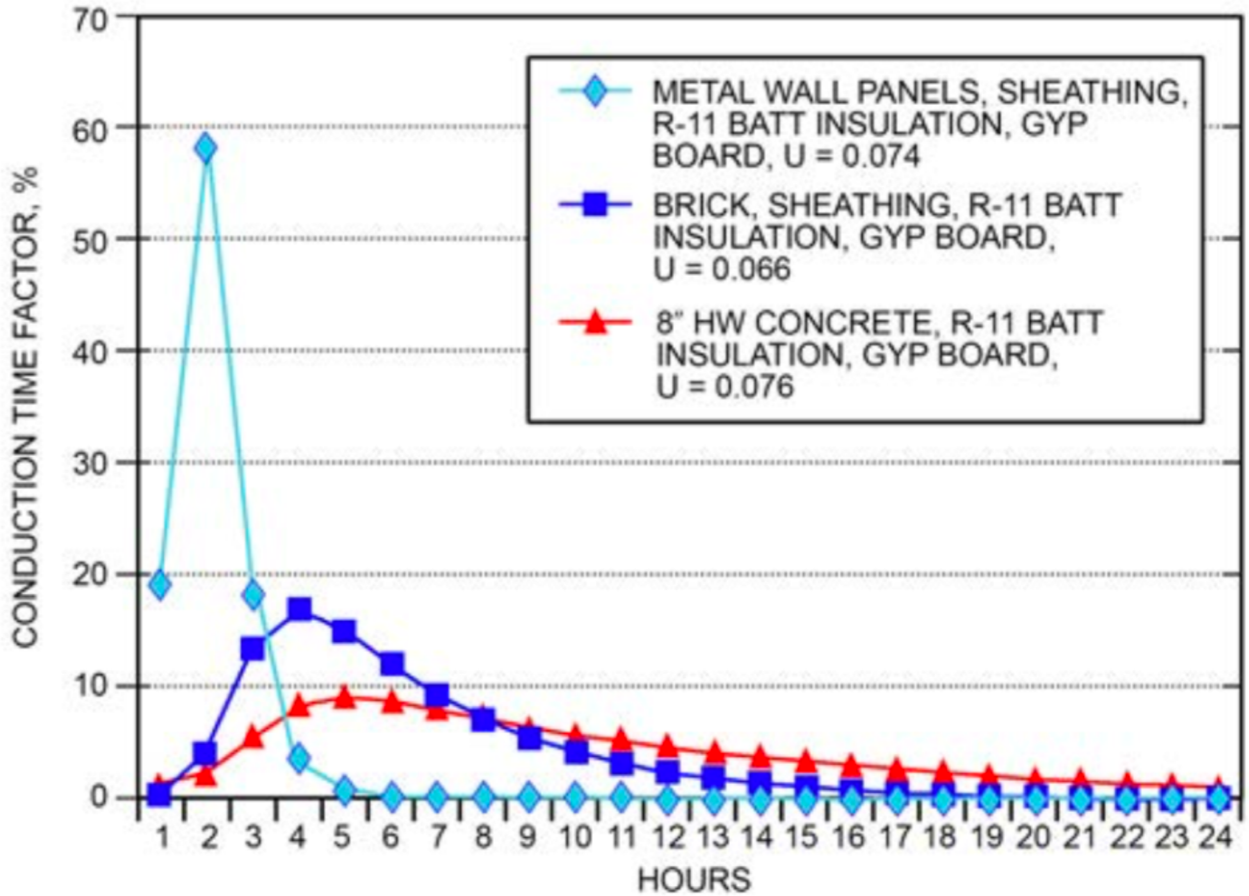


Fig. 9 CTS for Light to Heavy Walls

C_n for same mass with varying insulation

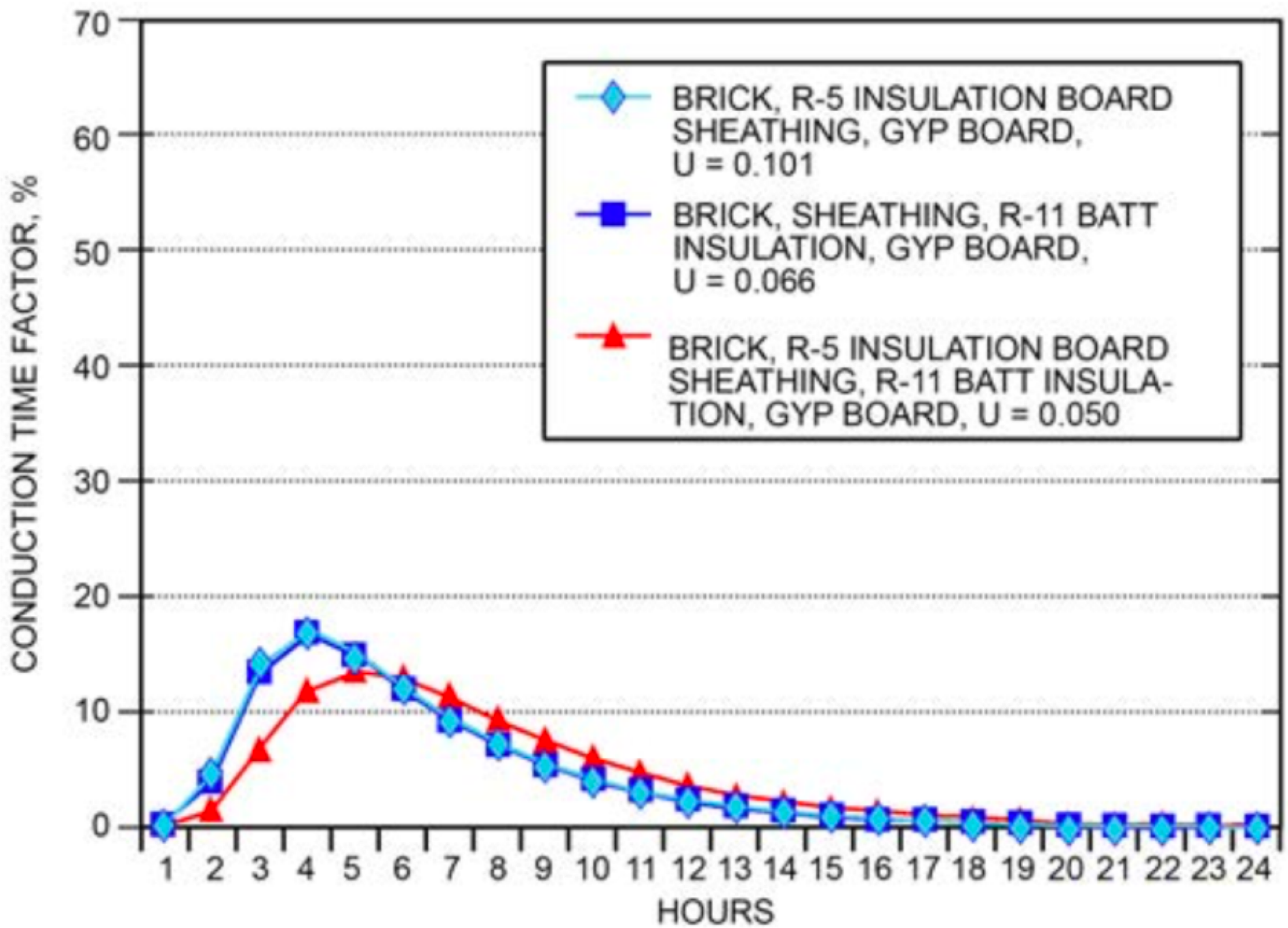


Fig. 10 CTS for Walls with Similar Mass and Increasing Insulation

Wall conduction time series (CTS)

Table 16 Wall Conduction Time Series (CTS)

	Curtain Walls			Stud Walls				EIFS			Brick Walls									
Wall Number =	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
U-Factor, Btu/h·ft^2·°F	0.075	0.076	0.075	0.074	0.074	0.071	0.073	0.118	0.054	0.092	0.101	0.066	0.050	0.102	0.061	0.111	0.124	0.091	0.102	0.068
Total *R*	13.3	13.2	13.3	13.6	13.6	14.0	13.8	8.5	18.6	10.8	9.9	15.1	20.1	9.8	16.3	9.0	8.1	11.0	9.8	14.6
Mass, lb/ft^2	6.3	4.3	16.4	5.2	17.3	5.2	13.7	7.5	7.8	26.8	42.9	44.0	44.2	59.6	62.3	76.2	80.2	96.2	182.8	136.3
Thermal Capacity, Btu/ft^2·°F	1.5	1.0	3.3	1.2	3.6	1.6	3.0	1.8	1.9	5.9	8.7	8.7	8.7	11.7	12.4	15.7	15.3	19.0	38.4	28.4
Hour	**Conduction Time Factors, %**																			
0	18	25	8	19	6	7	5	11	2	1	0	0	0	1	2	2	1	3	4	3
1	58	57	45	59	42	44	41	50	25	2	5	4	1	1	2	2	1	3	4	3
2	20	15	32	18	33	32	34	26	31	6	14	13	7	2	2	2	3	3	4	3
3	4	3	11	3	13	12	13	9	20	9	17	17	12	5	3	4	6	3	4	4
4	0	0	3	1	4	4	4	3	11	9	15	15	13	8	5	5	7	3	4	4
5	0	0	1	0	1	1	2	1	5	9	12	12	13	9	6	6	8	4	4	4
6	0	0	0	0	1	0	1	0	3	8	9	9	11	9	7	6	8	4	4	5
7	0	0	0	0	0	0	0	0	2	7	7	7	9	9	7	7	8	5	4	5
8	0	0	0	0	0	0	0	0	1	6	5	5	7	8	7	7	8	5	4	5
9	0	0	0	0	0	0	0	0	0	6	4	4	6	7	7	6	7	5	4	5
10	0	0	0	0	0	0	0	0	0	5	3	3	5	7	6	6	6	5	4	5

Roof conduction time series (CTS)

Table 17 Roof Conduction Time Series (CTS)

	Sloped Frame Roofs						Wood Deck		Metal Deck Roofs					Concrete Roofs					
Roof Number	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**
U-Factor, Btu/h·ft^2·°F	0.044	0.040	0.045	0.041	0.042	0.041	0.069	0.058	0.080	0.065	0.057	0.036	0.052	0.054	0.052	0.051	0.056	0.055	0.042
Total *R*	22.8	25.0	22.2	24.1	23.7	24.6	14.5	17.2	12.6	15.4	17.6	27.6	19.1	18.6	19.2	19.7	18.0	18.2	23.7
Mass, lb/ft^2	5.5	4.3	2.9	7.1	11.4	7.1	10.0	11.5	4.9	6.3	5.1	5.6	11.8	30.6	43.9	57.2	73.9	97.2	74.2
Thermal Capacity, Btu/ft^2·°F	1.3	0.8	0.6	2.3	3.6	2.3	3.7	3.9	1.4	1.6	1.4	1.6	2.8	6.6	9.3	12.0	16.3	21.4	16.2
Hour	**Conduction Time Factors, %**																		
0	6	10	27	1	1	1	0	1	18	4	8	1	0	1	2	2	2	3	1
1	45	57	62	17	17	12	7	3	61	41	53	23	10	2	2	2	2	3	2
2	33	27	10	31	34	25	18	8	18	35	30	38	22	8	3	3	5	3	6
3	11	5	1	24	25	22	18	10	3	14	7	22	20	11	6	4	6	5	8
4	3	1	0	14	13	15	15	10	0	4	2	10	14	11	7	5	7	6	8
5	1	0	0	7	6	10	11	9	0	1	0	4	10	10	8	6	7	6	8
6	1	0	0	4	3	6	8	8	0	1	0	2	7	9	8	6	6	6	7
7	0	0	0	2	1	4	6	7	0	0	0	0	5	7	7	6	6	6	7
8	0	0	0	0	0	2	5	6	0	0	0	0	4	6	7	6	6	6	6
9	0	0	0	0	0	1	3	5	0	0	0	0	3	5	6	6	5	5	5
10	0	0	0	0	0	1	3	5	0	0	0	0	2	5	5	6	5	5	5
11	0	0	0	0	0	1	2	4	0	0	0	0	1	4	5	5	5	5	5
12	0	0	0	0	0	0	1	4	0	0	0	0	1	3	5	5	4	5	4

RTS procedure

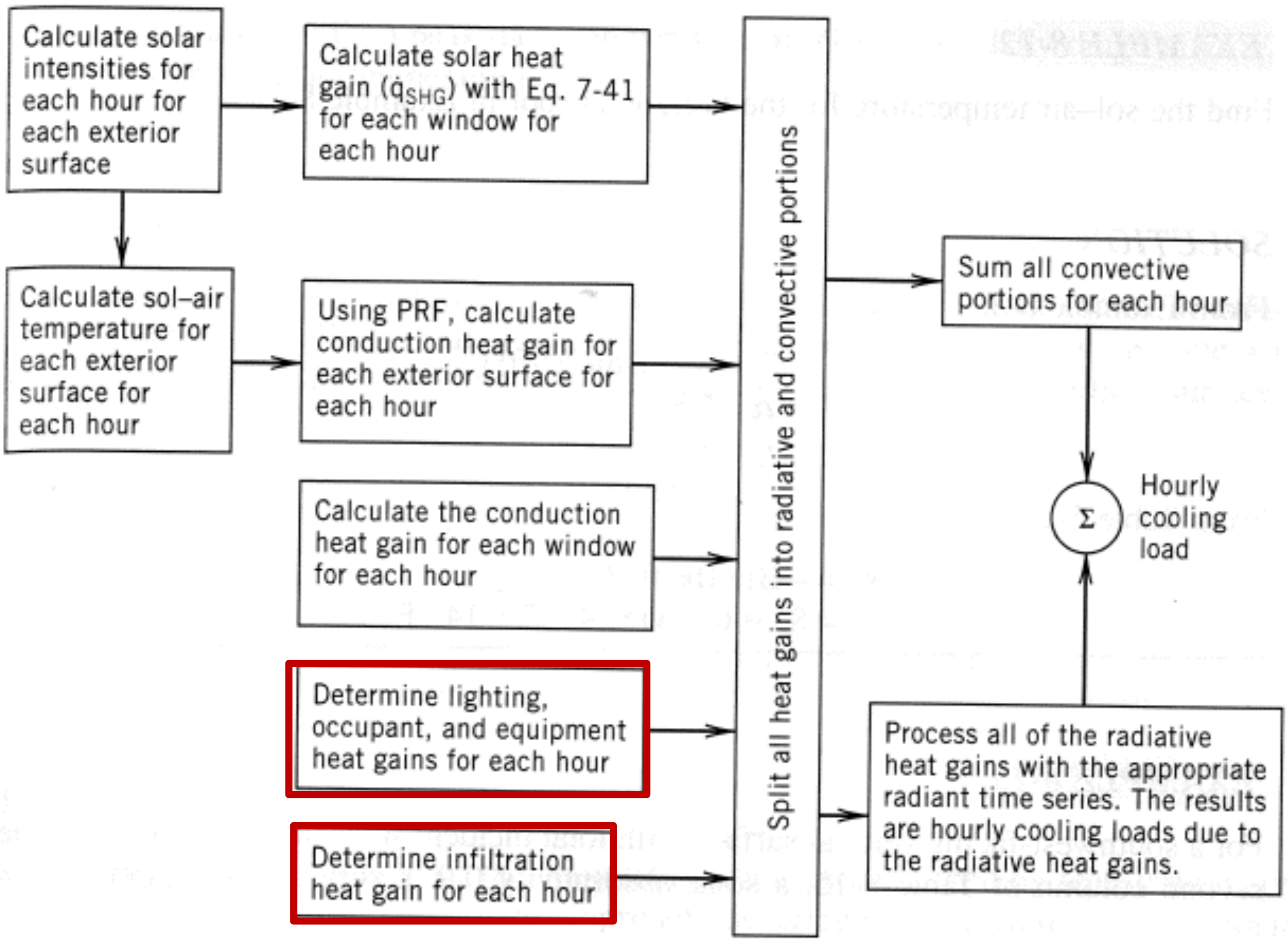


Figure 8-8 Radiant time series method.

Infiltration and internal gains

- We treat infiltration/ventilation gains as instantaneous gains
  - We've already done this
  - We calculate these separately for each hour of the day because the exterior air temperature changes each hour

- We calculate internal gains using methods discussed earlier
  - We calculate these for each hour too because the internal loads will change from hour to hour (need to know or assume schedules of operation)
  - Also need to keep track of the radiative + convective parts

Internal heat gains

Internal Heat Gain

Occupants

$$q_s = q_{s,per} N$$

$$q_l = q_{l,per} N$$

where

q_s = occupant sensible heat gain, Btu/h
q_l = occupant latent heat gain, Btu/h
$q_{s,per}$ = sensible heat gain per person, Btu/h·person; see Table 1
$q_{l,per}$ = latent heat gain per person, Btu/h·person; see Table 1
N = number of occupants

Lighting

$$q_{el} = 3.41 W F_{ul} F_{sa}$$

where

q_{el} = heat gain, Btu/h
W = total light wattage, W
F_{ul} = lighting use factor
F_{sa} = lighting special allowance factor
3.41 = conversion factor

Hooded Cooking Appliances

$$q_s = q_{input} F_U F_R$$

where

q_s = sensible heat gain, Btu/h
q_{input} = nameplate or rated energy input, Btu/h
F_U = usage factor; see Tables 5B, 5C, 5D
F_R = radiation factor; see Tables 5B, 5C, 5D

Infiltration/ventilation heat gains

Ventilation and Infiltration Air Heat Gain

$$q_s = 1.10 Q_s \Delta t \quad (10)$$

$$q_l = 60 \times 0.075 \times 1076 Q_s \Delta W = 4840 Q_s \Delta W \quad (11)$$

where

q_s = sensible heat gain due to infiltration, Btu/h
q_l = latent heat gain due to infiltration, Btu/h
Q_s = infiltration airflow at standard air conditions, cfm
t_o = outdoor air temperature, °F
t_i = indoor air temperature, °F
W_o = outdoor air humidity ratio, lb/lb
W_i = indoor air humidity ratio, lb/lb
1.10 = air sensible heat factor at standard air conditions, Btu/h·cfm
4840 = air latent heat factor at standard air conditions, Btu/h·cfm

Splitting gains into radiative and convective portions

- At each hour, each internal heat gain must be split into radiative parts + convective parts
  - "Delayed" versus "instantaneous"

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 13A to 13G in Chapter 15.
Infiltration	0.00	1.00	

Splitting gains into radiative and convective portions

- We then estimate the cooling load due to the radiative portion of each heat gain by applying a **radiant time series**
  - This is analogous to the periodic response factors (PRF) for conduction based on current and past values of sol-air temperatures, but for internal gains

- Radiant energy is absorbed + reradiated + absorbed + reradiated + absorbed + …
  - We must add up portions of radiation from previous hours to find the total radiant contribution now (kind of like we did with conduction)

Total radiant contribution

$$Q_{r,\theta} = r_0 q_{r,\theta} + r_1 q_{r,\theta-1} + r_2 q_{r,\theta-2} + r_3 q_{r,\theta-3} + \cdots + r_{23} q_{r,\theta-23} \quad (34)$$

where

$Q_{r,\theta}$ = radiant cooling load Q_r for current hour θ, Btu/h
$q_{r,\theta}$ = radiant heat gain for current hour, Btu/h
$q_{r,\theta-n}$ = radiant heat gain n hours ago, Btu/h
r_0, r_1, etc.=radiant time factors

- RTF ($\boldsymbol{r}_{\mathbf{n}}$) depends upon the wavelength (LW vs SW or solar), the mass of the interior of the building, and the interior surface coverings
  - There is a different RTF for transmitted solar light than all the other radiated energy
  - ASHRAE has RTF tables for a number of different constructions with varying amounts of glass and carpet
  - Heavy construction with no carpet has the most contribution by older radiation

Example RTFs

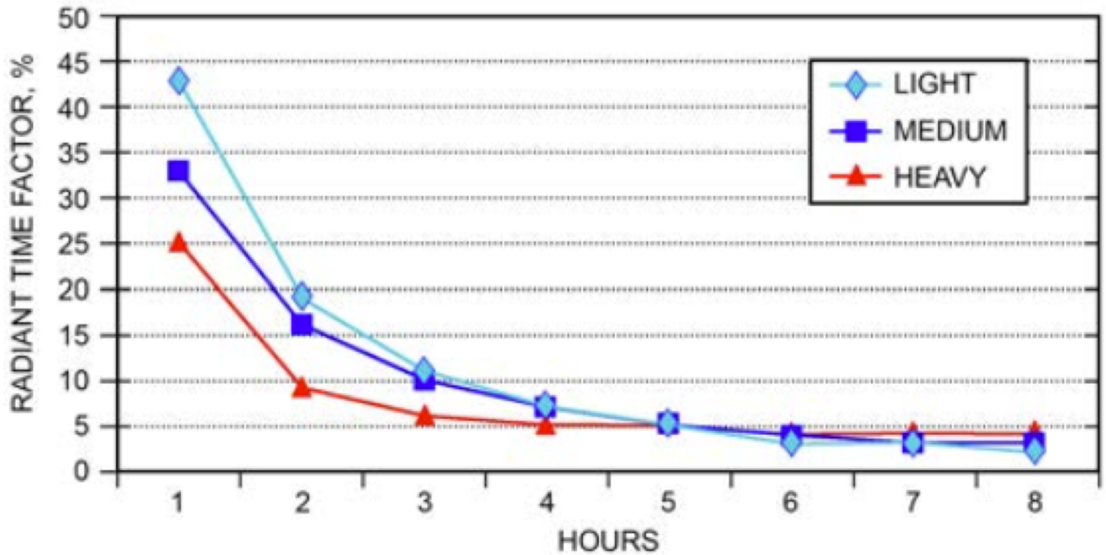


Fig. 11 RTS for Light to Heavy Construction

Table 21 RTS Representative Zone Construction for Tables 19 and 20

Construction Class	Exterior Wall	Roof/Ceiling	Partitions	Floor	Furnishings
Light	Steel siding, 2 in. insulation, air space, 3/4 in. gyp	4 in. LW concrete, ceiling air space, acoustic tile	3/4 in. gyp, air space, 3/4 in. gyp	Acoustic tile, ceiling air space, 4 in. LW concrete	1 in. wood @ 50% of floor area
Medium	4 in. face brick, 2 in. insulation, air space, 3/4 in. gyp	4 in. HW concrete, ceiling air space, acoustic tile	3/4 in. gyp, air space, 3/4 in. gyp	Acoustic tile, ceiling air space, 4 in. HW concrete	1 in. wood @ 50% of floor area
Heavy	4 in. face brick, 8 in. HW concrete air space, 2 in. insulation, 3/4 in. gyp	8 in. HW concrete, ceiling air space, acoustic tile	3/4 in. gyp, 8 in. HW concrete block, 3/4 in. gyp	Acoustic tile, ceiling air space, 8 in. HW concrete	1 in. wood @ 50% of floor area

Example RTFs

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

Table 20 Representative Solar RTS Values for Light to Heavy Construction

% Glass	Light						Medium						Heavy					
	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	53	55	56	44	45	46	52	54	55	28	29	29	47	49	51	26	27	28
1	17	17	17	19	20	20	16	16	15	15	15	15	11	12	12	12	13	13
2	9	9	9	11	11	11	8	8	8	10	10	10	6	6	6	7	7	7
3	5	5	5	7	7	7	5	4	4	7	7	7	4	4	3	5	5	5
4	3	3	3	5	5	5	3	3	3	6	6	6	3	3	3	4	4	4
5	2	2	2	3	3	3	2	2	2	5	5	5	2	2	2	4	4	4
6	2	2	2	3	2	2	2	1	1	4	4	4	2	2	2	3	3	3
7	1	1	1	2	2	2	1	1	1	4	3	3	2	2	2	3	3	3
8	1	1	1	1	1	1	1	1	1	3	3	3	2	2	2	3	3	3

Finally: Instantaneous cooling load

Instantaneous Room Cooling Load

$$Q_s = \sum Q_{i,r} + \sum Q_{i,c}$$

$$Q_l = \sum q_{i,l}$$

where

Q_s = room sensible cooling load, Btu/h

$Q_{i,r}$ = radiant portion of sensible cooling load for current hour, resulting from heat gain element i, Btu/h

$Q_{i,c}$ = convective portion of sensible cooling load, resulting from heat gain element i, Btu/h

Q_l = room latent cooling load, Btu/h

$q_{i,l}$ = latent heat gain for heat gain element i, Btu/h

Convective portion

Convective Portion of Sensible Cooling Load

$$Q_{i,c} = q_{i,c}$$

where $q_{i,c}$ is convective portion of heat gain from heat gain element i, Btu/h.

$$q_{i,c} = q_{i,s}(1 - F_r)$$

where

$q_{i,s}$ = sensible heat gain from heat gain element i, Btu/h

F_r = fraction of heat gain that is radiant; see row for radiant portion for sources of radiant fraction data for individual heat gain elements

Radiative portion

Radiant Portion of Sensible Cooling Load

$$Q_{i,r} = Q_{r,\theta} \tag{34}$$

$$Q_{r,\theta} = r_0 q_{r,\theta} + r_1 q_{r,\theta-1} + r_2 q_{r,\theta-2} + r_3 q_{r,\theta-3} + \cdots + r_{23} q_{r,\theta-23}$$

where

$Q_{r,\theta}$ = radiant cooling load Q_r for current hour θ, Btu/h
$q_{r,\theta}$ = radiant heat gain for current hour, Btu/h
$q_{r,\theta-n}$ = radiant heat gain n hours ago, Btu/h
r_0, r_1, etc. = radiant time factors; see Table 19 for radiant time factors for nonsolar heat gains: wall, roof, partition, ceiling, floor, fenestration transmission heat gains, and occupant, lighting, motor, appliance heat gain. Also used for fenestration diffuse solar heat gain; see Table 20 for radiant time factors for fenestration beam solar heat gain.

$$q_{r,\theta} = q_{i,s} F_r$$

where

$q_{i,s}$ = sensible heat gain from heat gain element i, Btu/h
F_r = fraction of heat gain that is radiant.

RTS Example

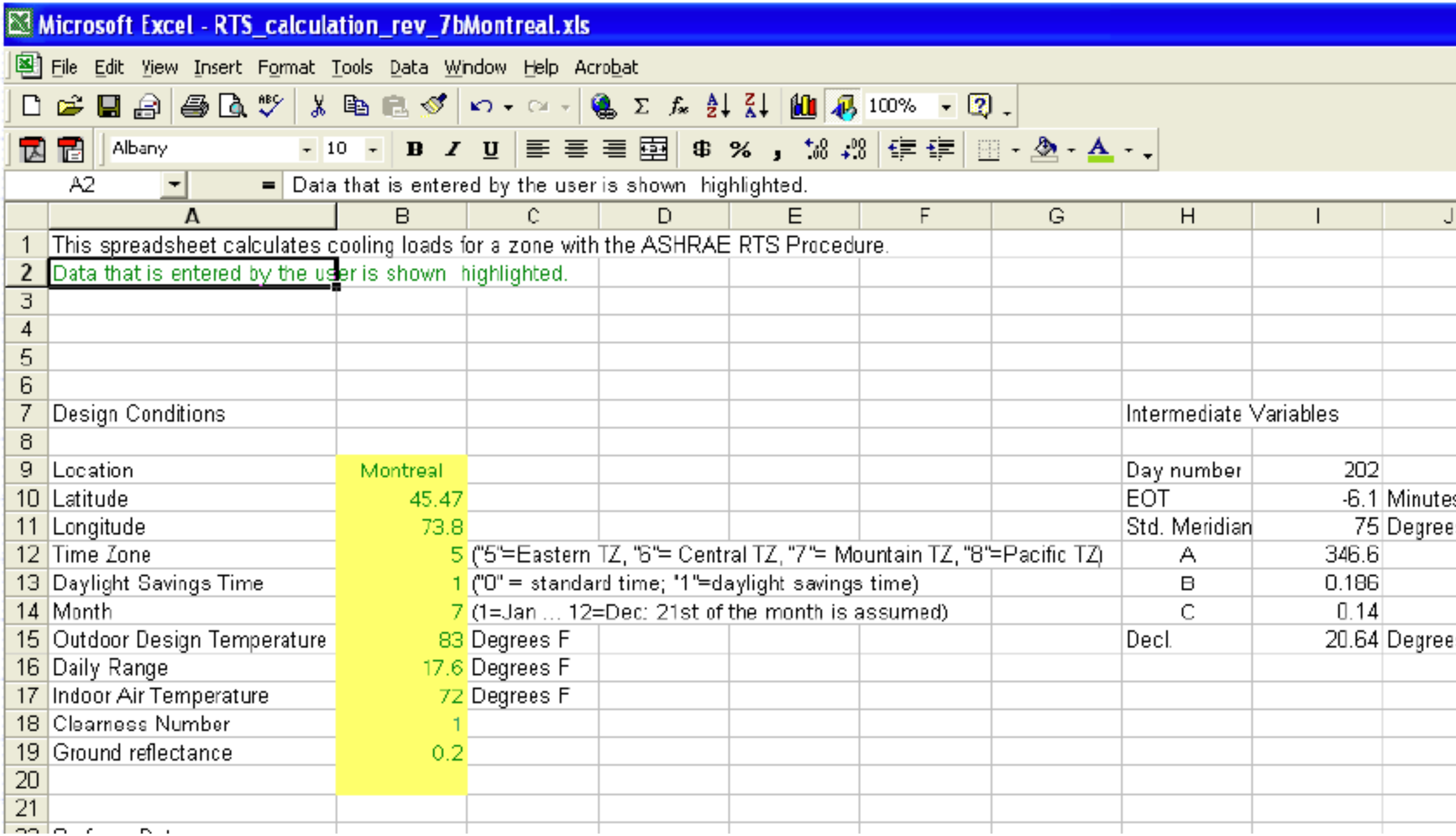
- Page 18.38 has a helpful example using our same corner office in Atlanta

- The next slides also show an older example graphically
  - Note that some of the nomenclature has changed slightly

RTS example

- Outdoor conditions
  - Montreal
  - July 21
  - 83°F dry bulb
    - 17.6°F daily range
  - Ground reflectivity = 0.2
- Indoor conditions
  - Air temperature = 72°F
- Assume only S wall and roof are exposed to outside
  - Wall is 280 ft^2, α=0.9
  - Roof is 900 ft^2, α=0.9
  - Y_{pn} as shown in the next slides
- Other heat gains
  - 10 occupants
  - 1 W/ft^2 equipment gain 8AM to 5 PM
    - 0.2 W/ft^2 5P-8A
  - 1.5 W/ft^2 lighting gain 8AM to 5 PM
    - 0.3 W/ft^2 5P-8A
  - Ignore infiltration
- 80 ft^2 of window on S wall
  - No shading
  - SHGC=0.76, U=0.55

You would create a spreadsheet



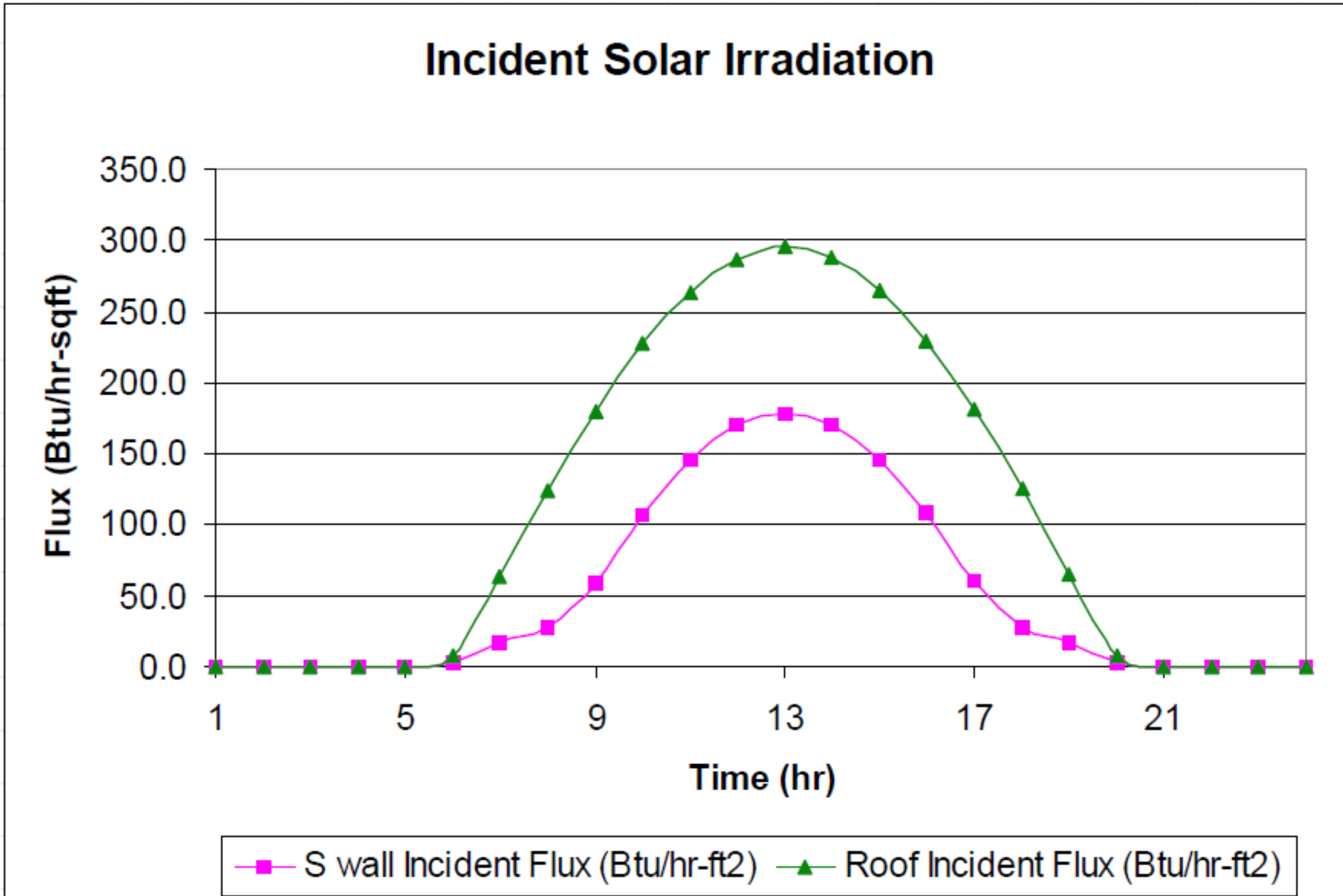
Microsoft Excel - RTS_calculation_rev_7bMontreal.xls

A2 = Data that is entered by the user is shown highlighted.

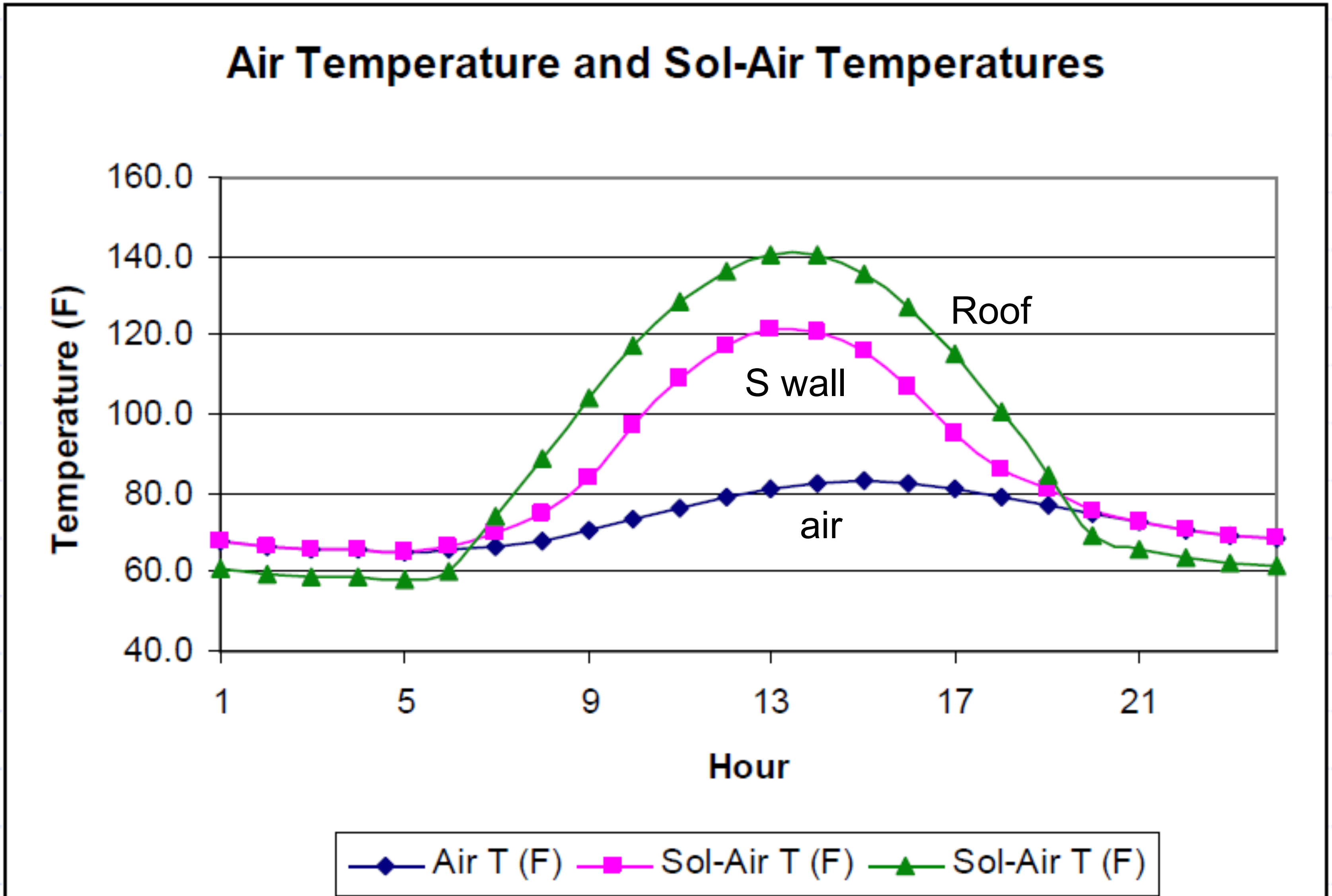
	A	B	C	D	E	F	G	H	I	J
1	This spreadsheet calculates cooling loads for a zone with the ASHRAE RTS Procedure.									
2	Data that is entered by the user is shown highlighted.									
3										
4										
5										
6										
7	Design Conditions							Intermediate Variables		
8										
9	Location	Montreal						Day number	202	
10	Latitude	45.47						EOT	-6.1	Minutes
11	Longitude	73.8						Std. Meridian	75	Degrees
12	Time Zone	5	("5"=Eastern TZ, "6"= Central TZ, "7"= Mountain TZ, "8"=Pacific TZ)					A	346.6	
13	Daylight Savings Time	1	("0" = standard time; "1"=daylight savings time)					B	0.186	
14	Month	7	(1=Jan ... 12=Dec: 21st of the month is assumed)					C	0.14	
15	Outdoor Design Temperature	83	Degrees F					Decl.	20.64	Degrees
16	Daily Range	17.6	Degrees F							
17	Indoor Air Temperature	72	Degrees F							
18	Clearness Number	1								
19	Ground reflectance	0.2								
20										
21										

http://temp-hvac.okstate.edu/sites/default/files/RTS_example_Montreal_ASHRAE_Chapter_6Oct2003.xls

Find incident solar radiation



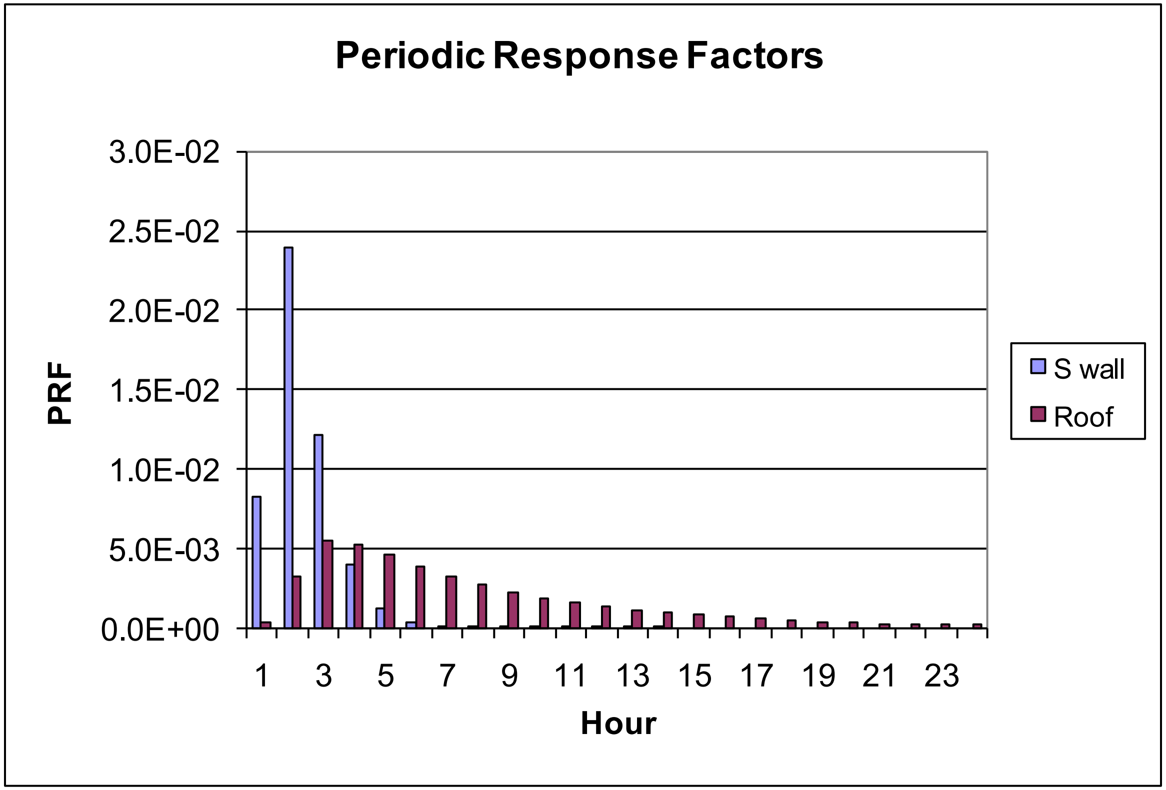
Find sol-air temperatures



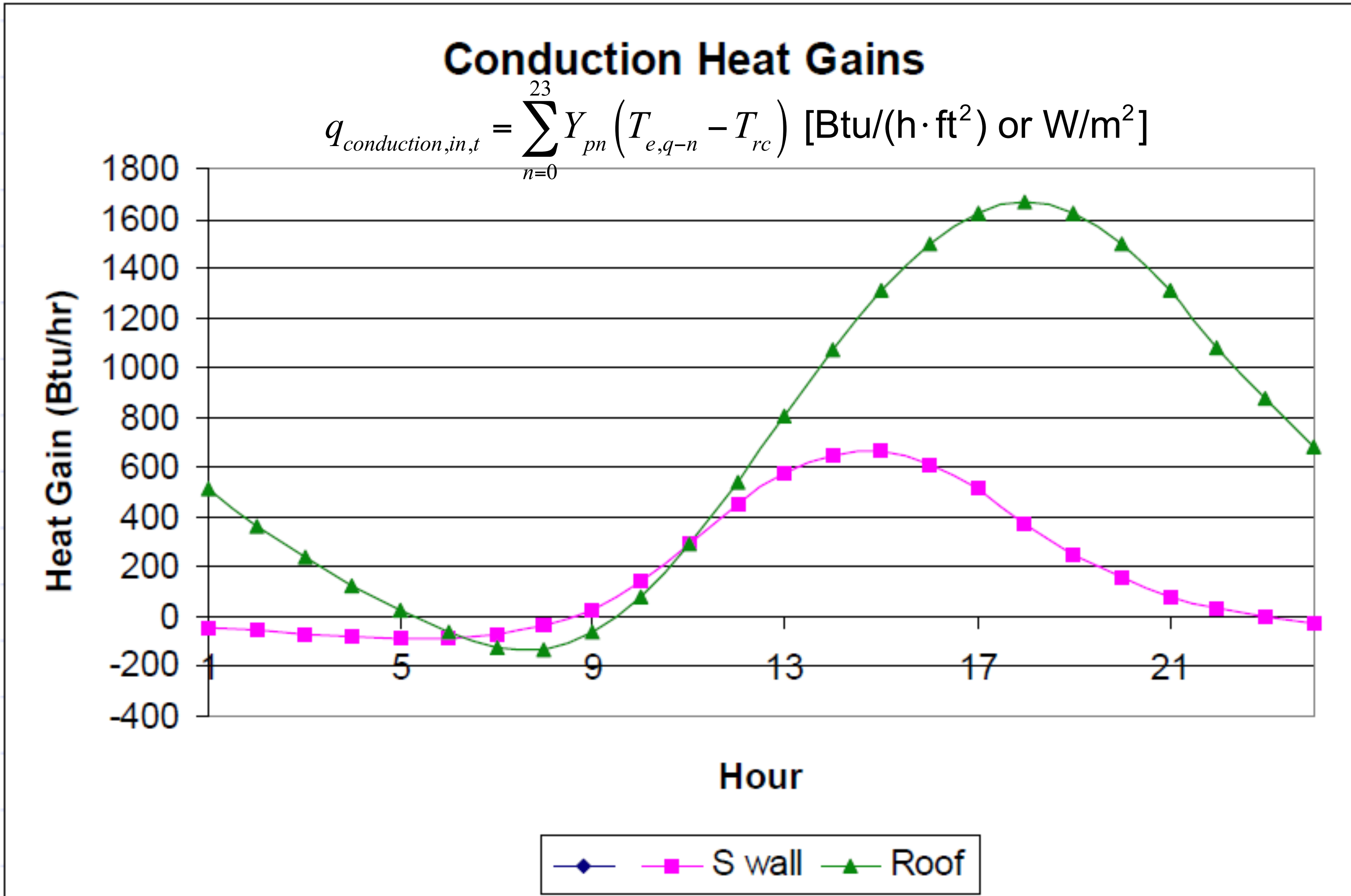
Find periodic response factors for conduction

Ypn		S wall	Roof
1		8.2148E-03	3.5460E-04
2		2.3910E-02	3.2232E-03
3		1.2148E-02	5.5313E-03
4		4.0220E-03	5.3005E-03
5		1.1786E-03	4.5555E-03
6		3.2876E-04	3.8405E-03
7		8.9655E-05	3.2265E-03
8		2.4185E-05	2.7090E-03
9		6.4892E-06	2.2743E-03
10		1.7365E-06	1.9092E-03
11		4.6405E-07	1.6028E-03
12		1.2393E-07	1.3455E-03
13		3.3084E-08	1.1296E-03
14		8.8307E-09	9.4828E-04
15		2.3569E-09	7.9608E-04
16		6.2900E-10	6.6831E-04
17		1.6786E-10	5.6104E-04
18		4.4798E-11	4.7099E-04
19		1.1955E-11	3.9540E-04
20		3.1905E-12	3.3194E-04
21		8.5145E-13	2.7866E-04
22		2.2723E-13	2.3393E-04
23		6.0640E-14	1.9639E-04
24		1.6183E-14	1.6487E-04

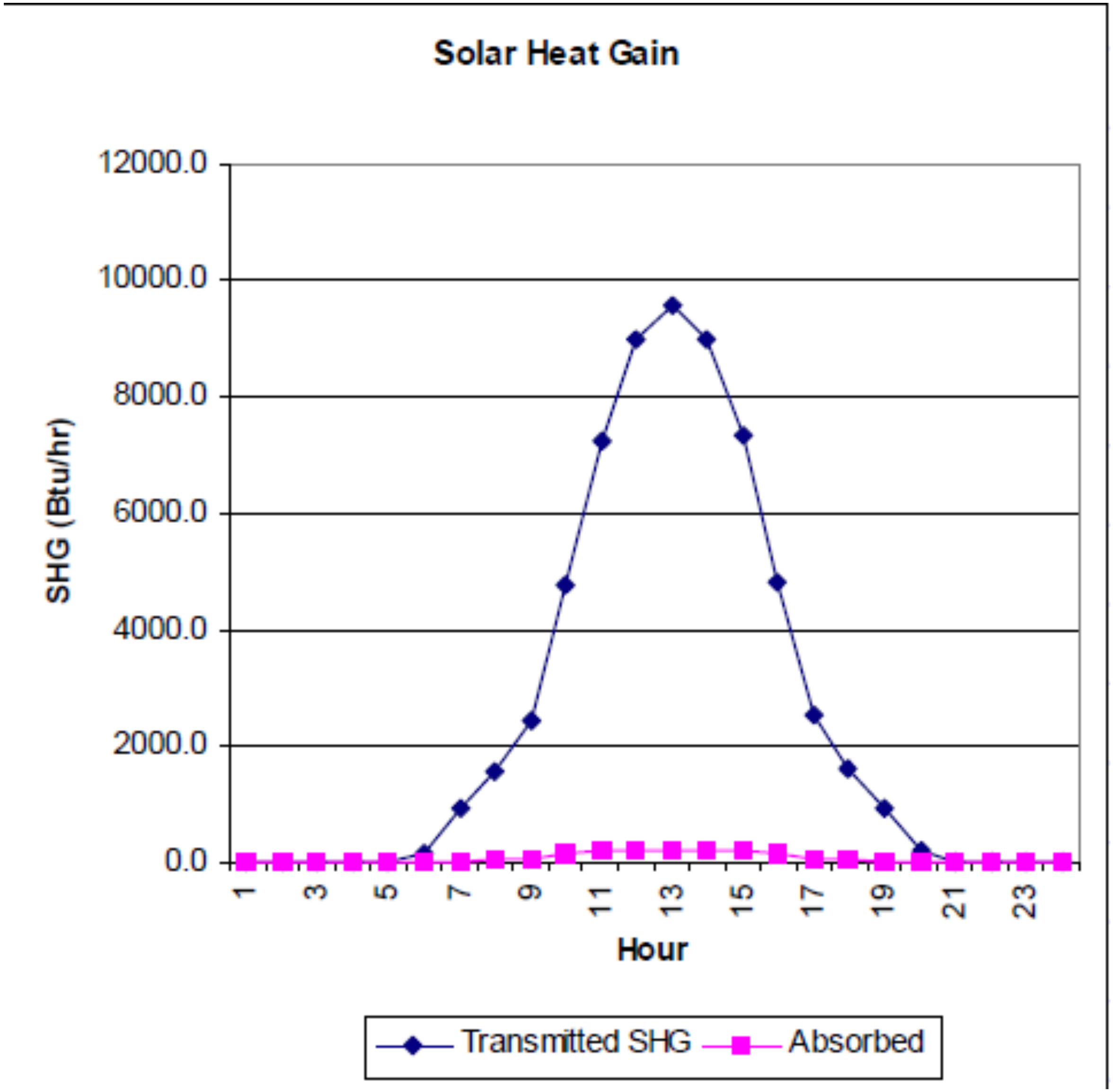
Y_{pn}



Estimate hourly conductive heat gains



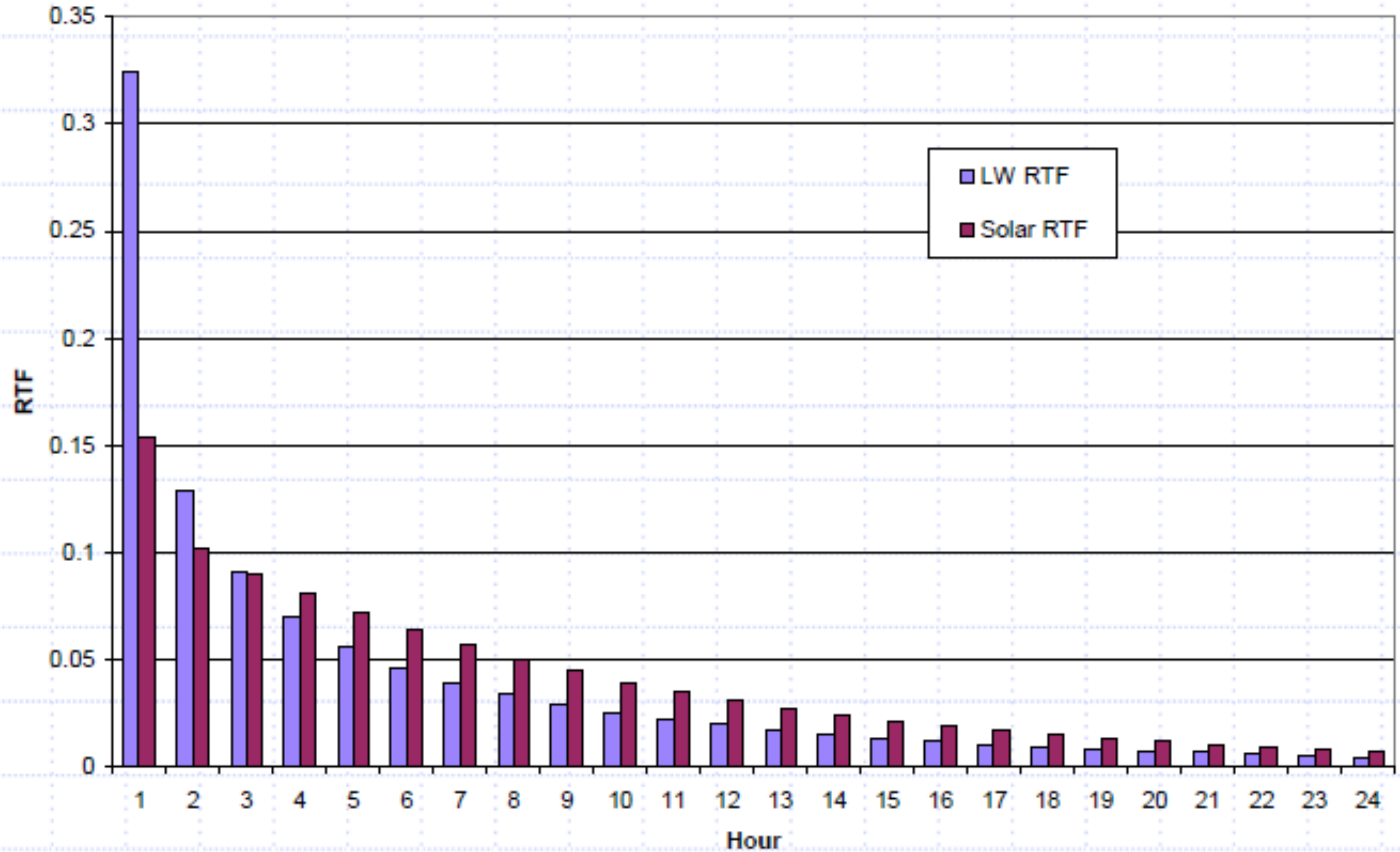
Find solar heat gains



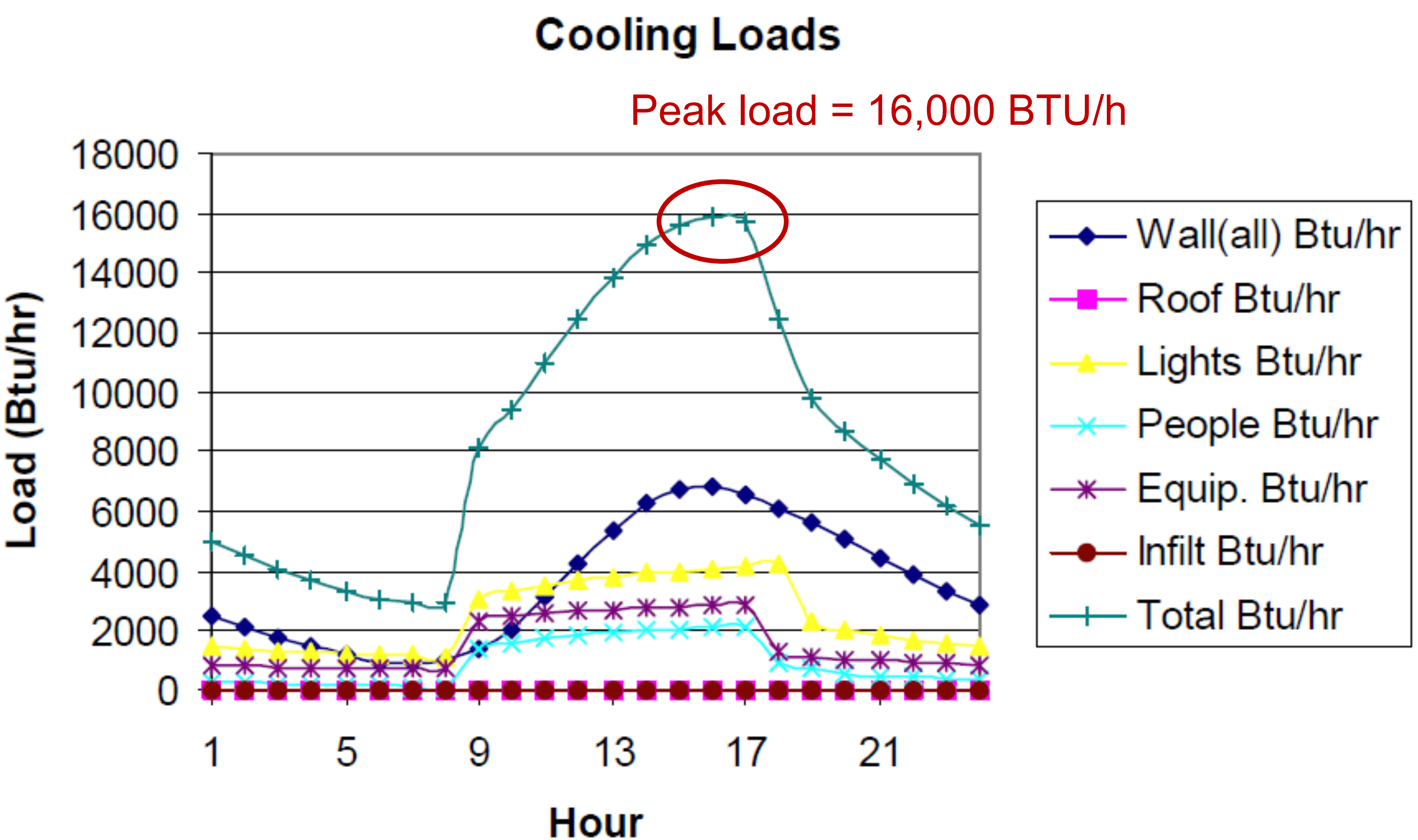
Radiative vs. convective split gains

Heat Gain	**% radiative**	**% convective**
Wall, window conduction	63	37
Roof conduction	84	16
People	70	30
Lighting	67	33
Equipment	20	80
Transmitted solar heat gain	100	0
Absorbed solar heat gain	63	37
Infiltration	0	100

Enter RTFs from ASHRAE



Component hourly cooling loads



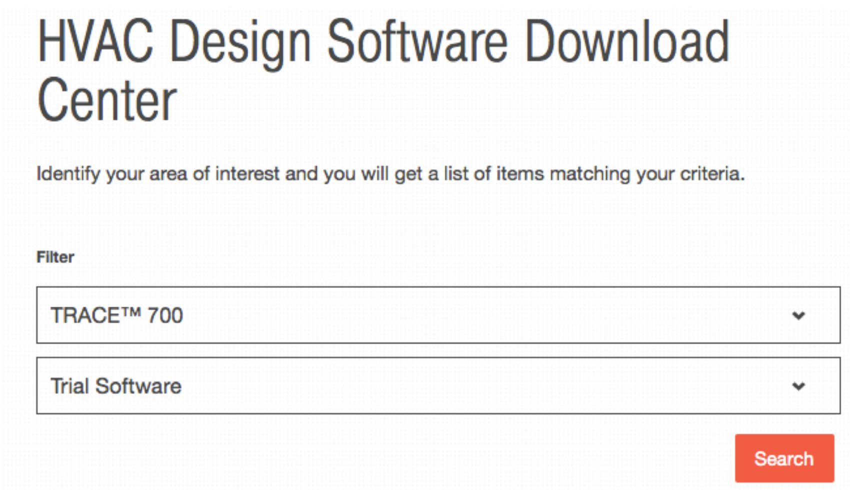
LOAD CALCULATION SOFTWARE

Introduction to load calculation software

Two most commonly used programs for load calculations:

- Trane Trace 700
- Carrier HAP

- Your last HW will involve the use of Trane Trace 700 for load calculations
  - Work in teams
  - Download 30-day trial version here: http://www.trane.com/commercial/north-america/us/en/products-systems/design-and-analysis-tools/download-center/hvac-design-software-download-center.html



Trane Trace 700 help

- In case you need additional help:
  - https://www.youtube.com/watch?v=OWpILURIk60&t=2s
  - https://www.youtube.com/watch?v=wsPWG15Z5lE
  - https://www.youtube.com/watch?v=ije73V5EYdE

Reminder!

Class next week will meet in Alumni 218 Computer Lab

- Tuesday Nov 20th – Alumni 218 computer lab
  - There will not be an online recording
  - Will be a mixture of lecture + lab activity