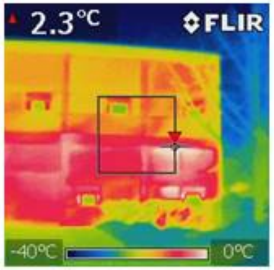
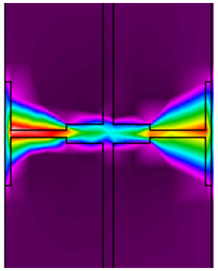
CAE 331/513
Building Science
Fall 2016





Week 14: November 22, 2016
Cooling load calculations

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Graduate student projects

- Your 8-page single-spaced final report is due to me by Thursday December 1 at 11:59 pm
- You do not have to present the work orally (we ran out of time in the semester)

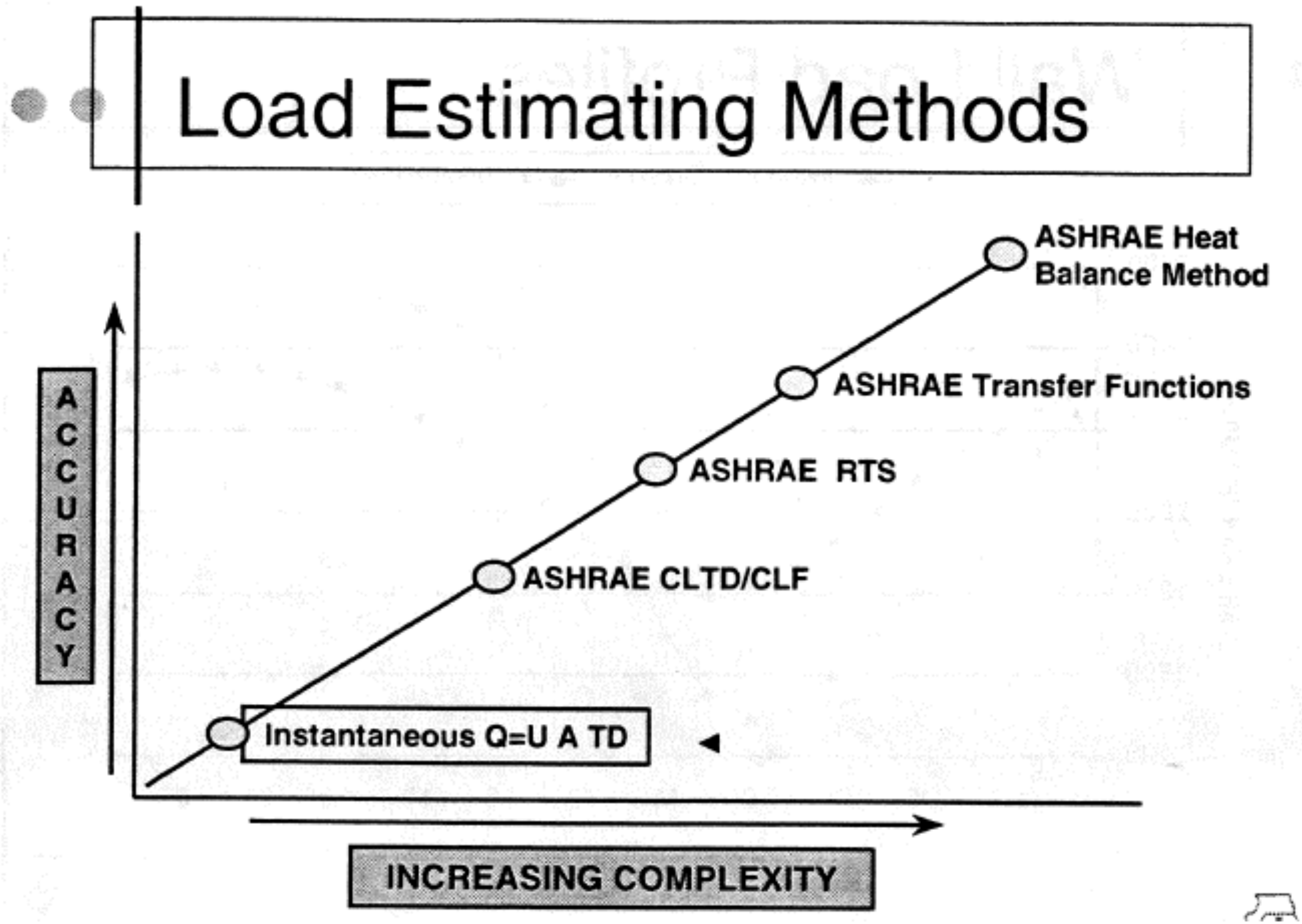
Jaurez, Ibrane R.	Onsite renewables
Jittasirinuwat, Vitoon	Cost of achieving LEED
Unzueta Ramos, Andoni I.	Air distribution systems
Zhang, Pangyan	Kitchen ventilation
Liu, Yang	Insulation location
Mandefro, Surafeal B.	Thermal mass

Last time

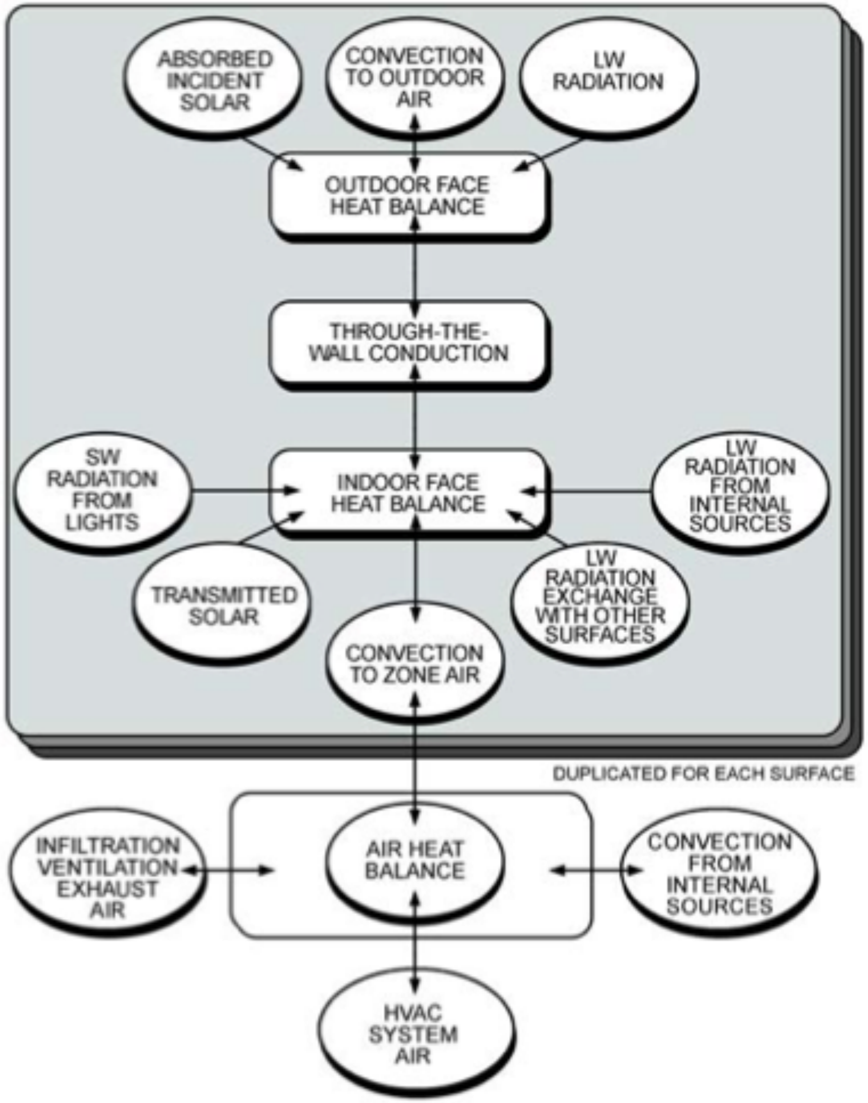
- Introduced cooling load calculations
  - Two methods covered so far:
    - Heat balance method (HBM)
    - Cooling load temperature difference (CLTD) / cooling load factor (CLF)

- Today:
  - One last cooling load calculation method
    - Radiant Time Series (RTS)
  - Introduce Trane Trace 700 for performing load calculations
    - Assign HW 6

Cooling load calculation methods

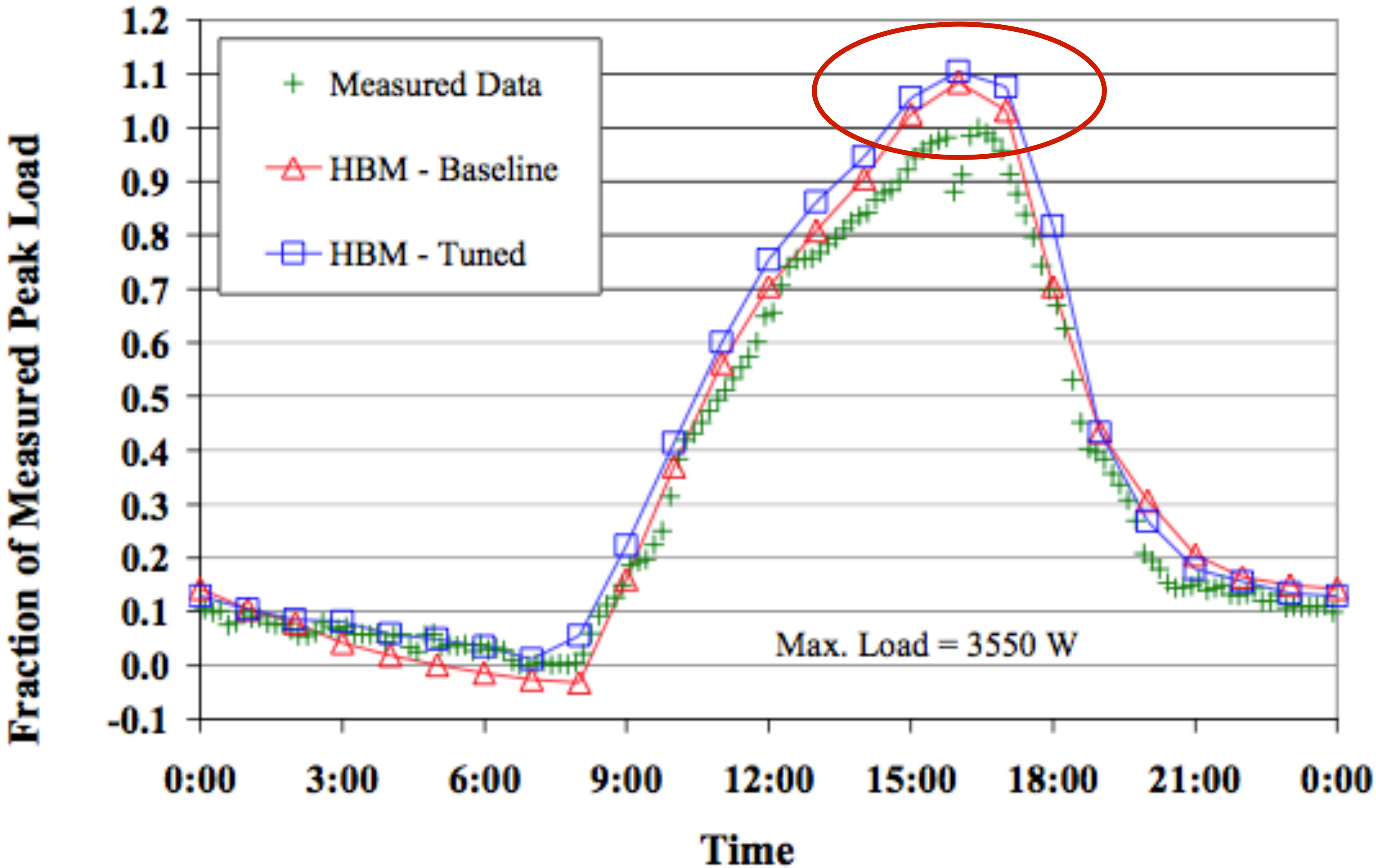


Heat balance method



Using HBM to calculate peak loads

- Tracking the cooling load for a simple space:



Simpler method: The ASHRAE CLTD/CLF method

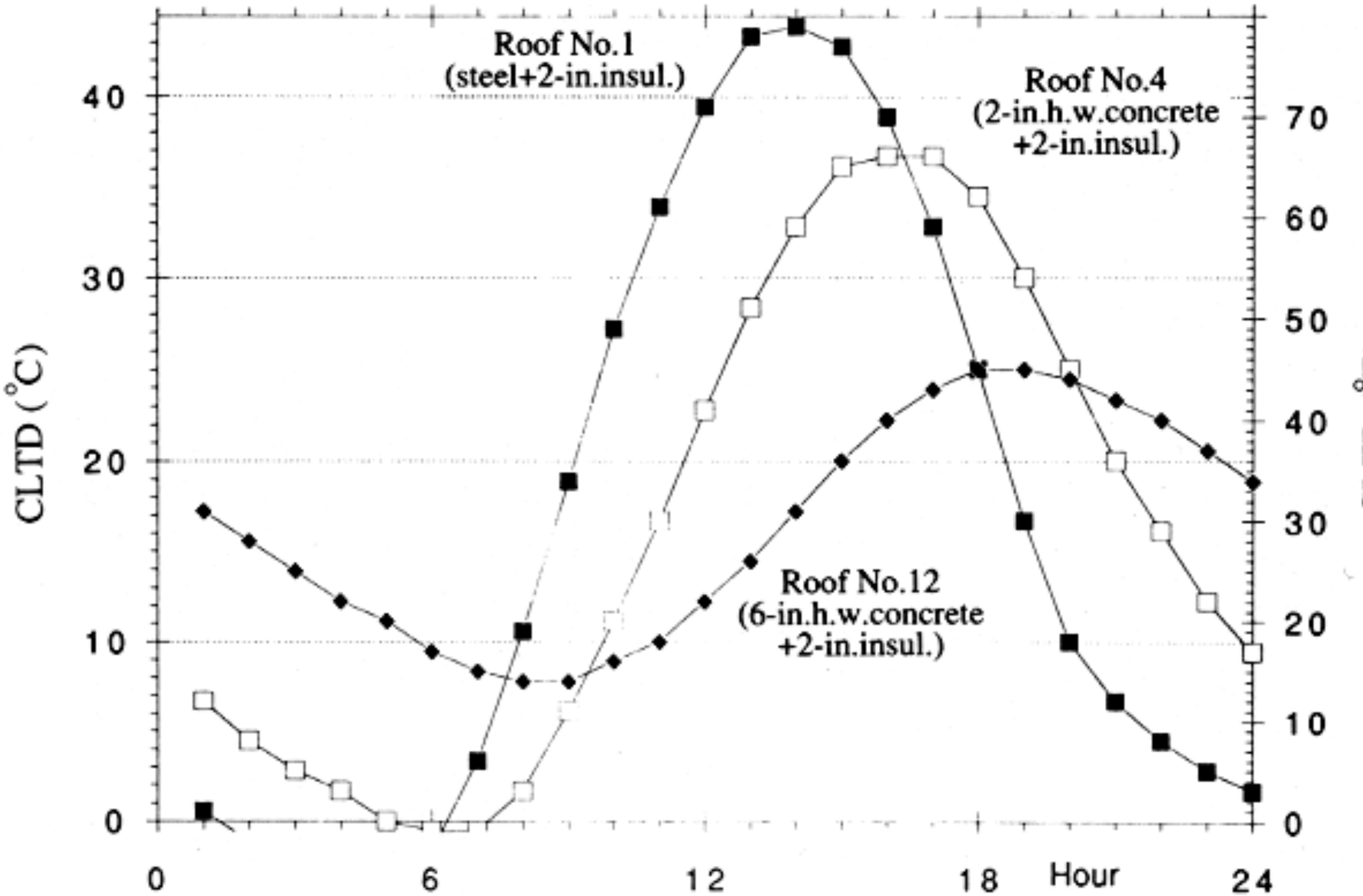
- One method of accounting for periodic responses for conduction and radiation (simpler than others) is the CLTD/CLF method (it's a mouthful)

- 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 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

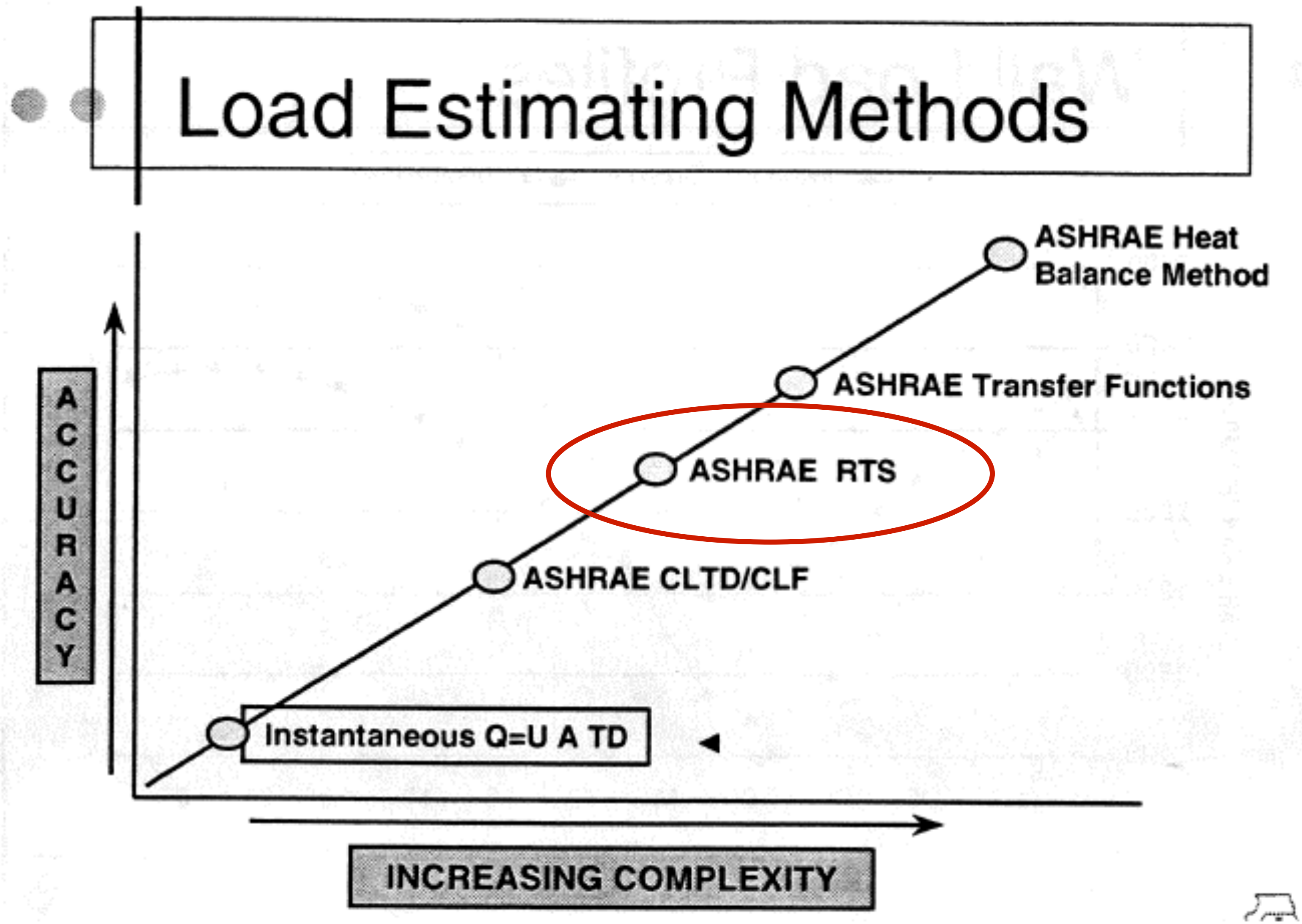
CLTD for typical roof materials



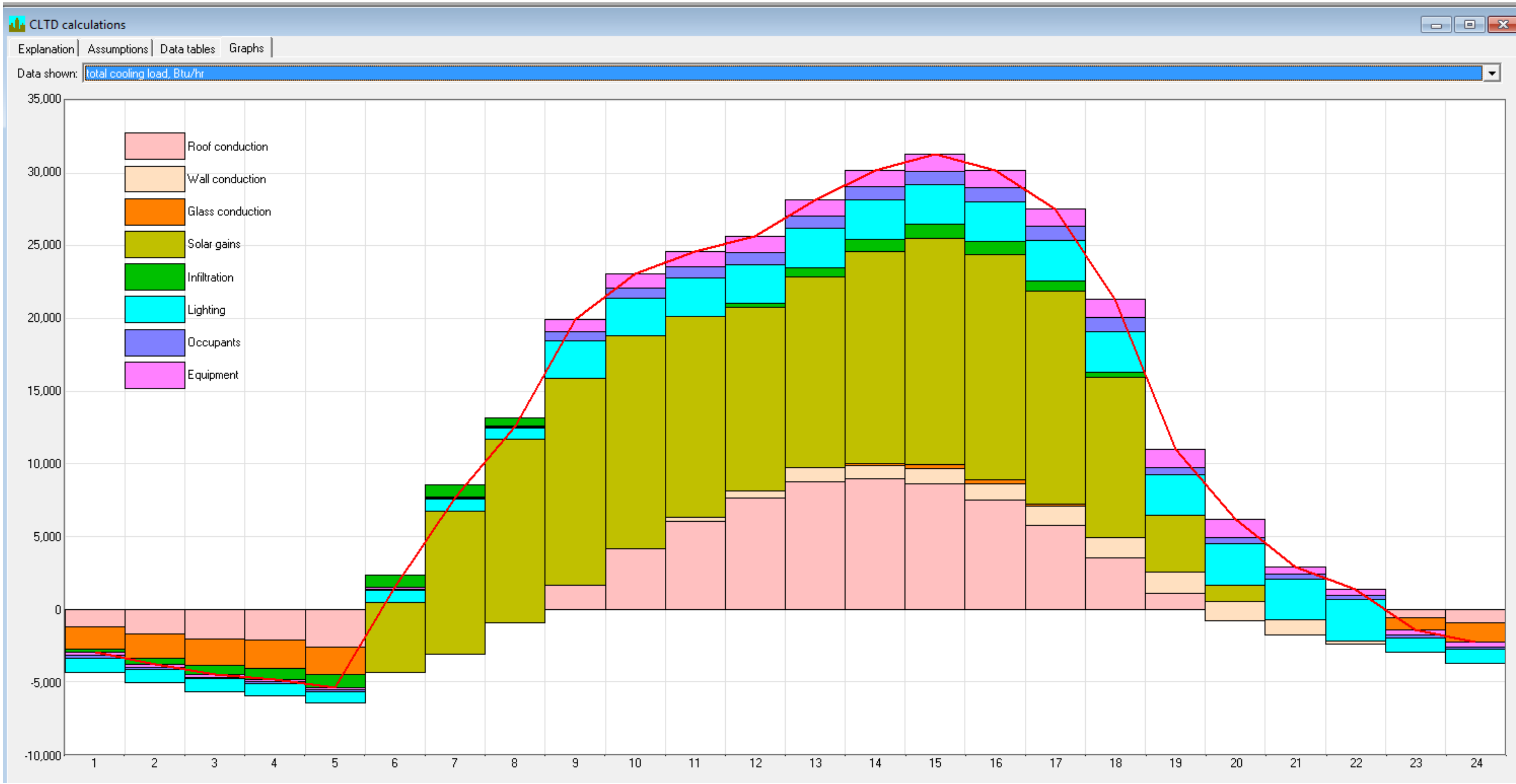
$$Q_{cooling,conduction} = UA(CLTD_t)$$

h

Cooling load calculation methods



CLTD/CLF method applied: HCB tool



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 similar software

- RTS accounts for dynamic elements like outdoor air temperatures, solar radiation, and enclosure heat transfer
  - 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 simplifying assumptions

- The combined effects of convective and radiative heat transfer to/from 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 temps and sky temps, must be used for all surfaces

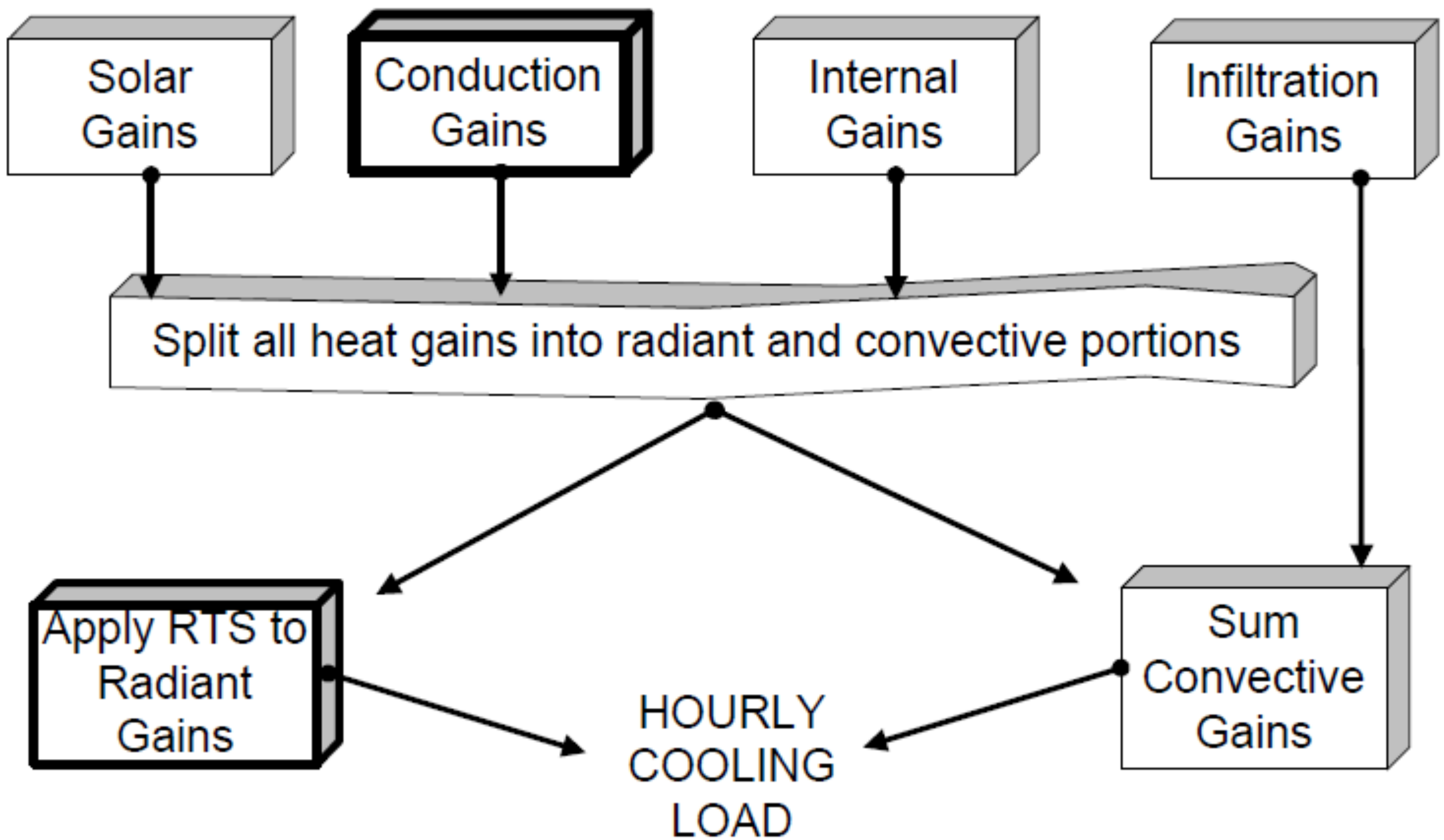
- All interior surface temperatures are assumed to be nearly the same, so all radiation between elements in the interior can be ignored
  - Makes calculations much simpler

RTS main idea

The idea behind the radiant time series is this:

- The current heat transfer to/from the interior is equal to:
  + Part of the current convective heat transfer from the outside of the enclosure
  + Current solar heat gain through fenestration
  + Part of the earlier convective and radiative heat transfer from the outside of the enclosure

RTS procedure



RTS procedure

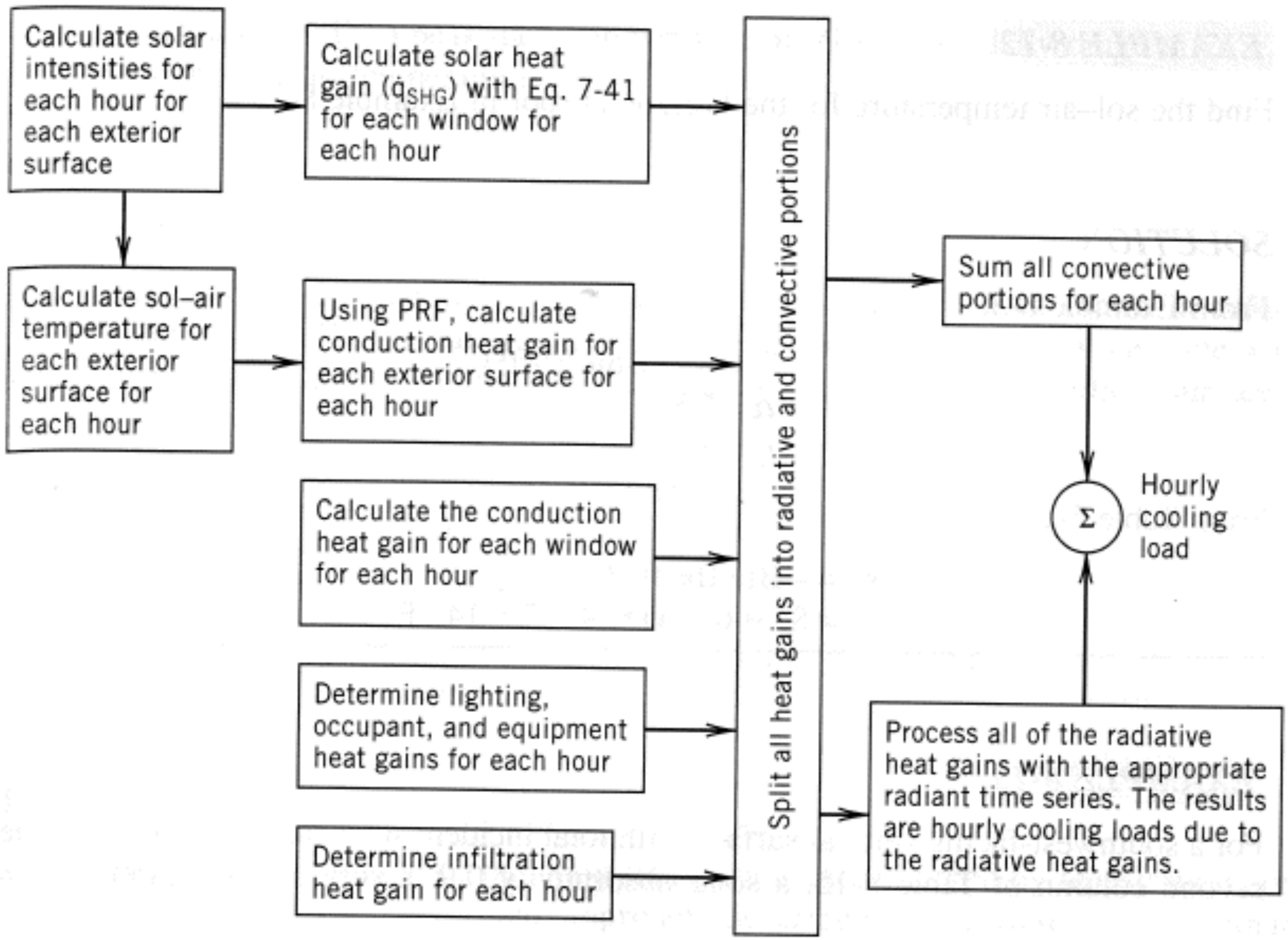


Figure 8-8 Radiant time series method.

RTS procedure

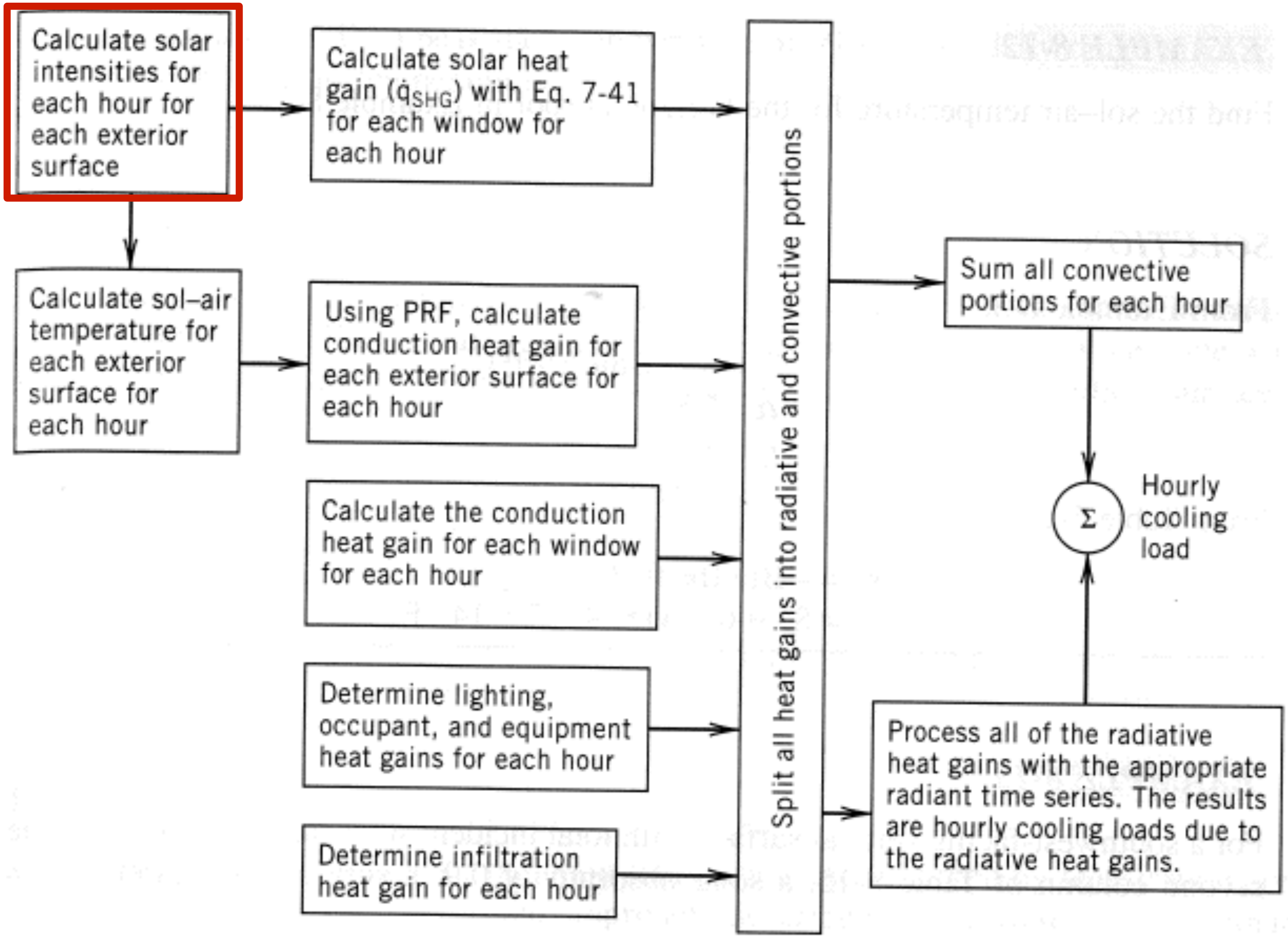
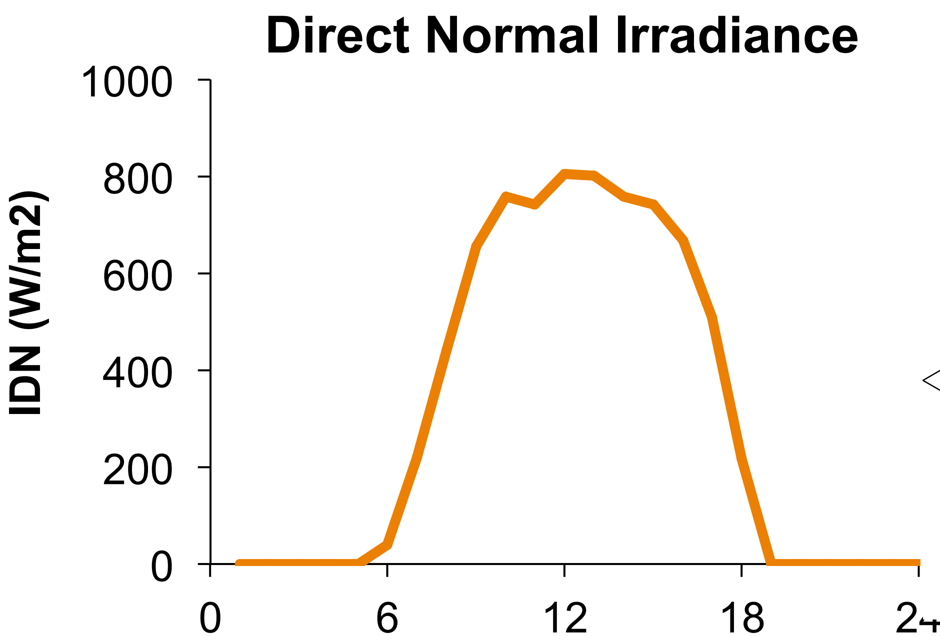
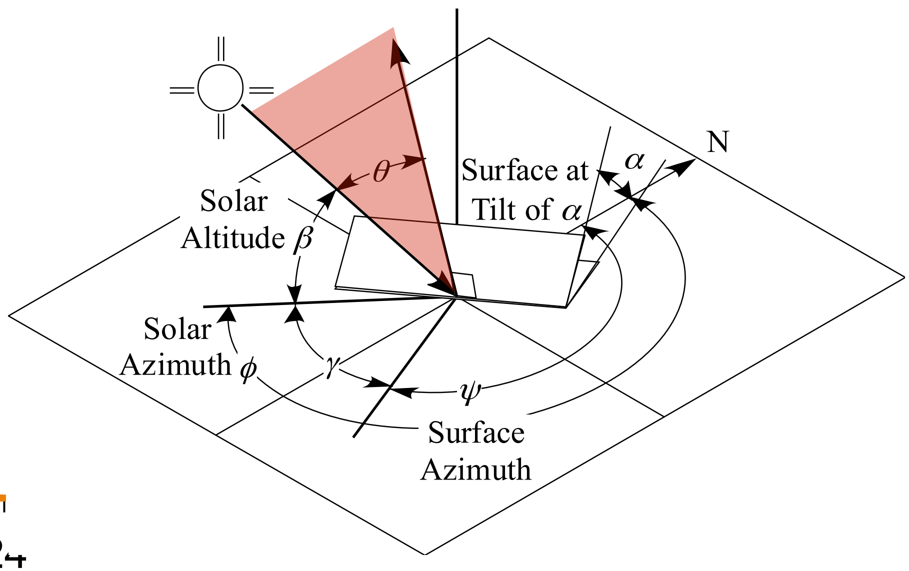


Figure 8-8 Radiant time series method.

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

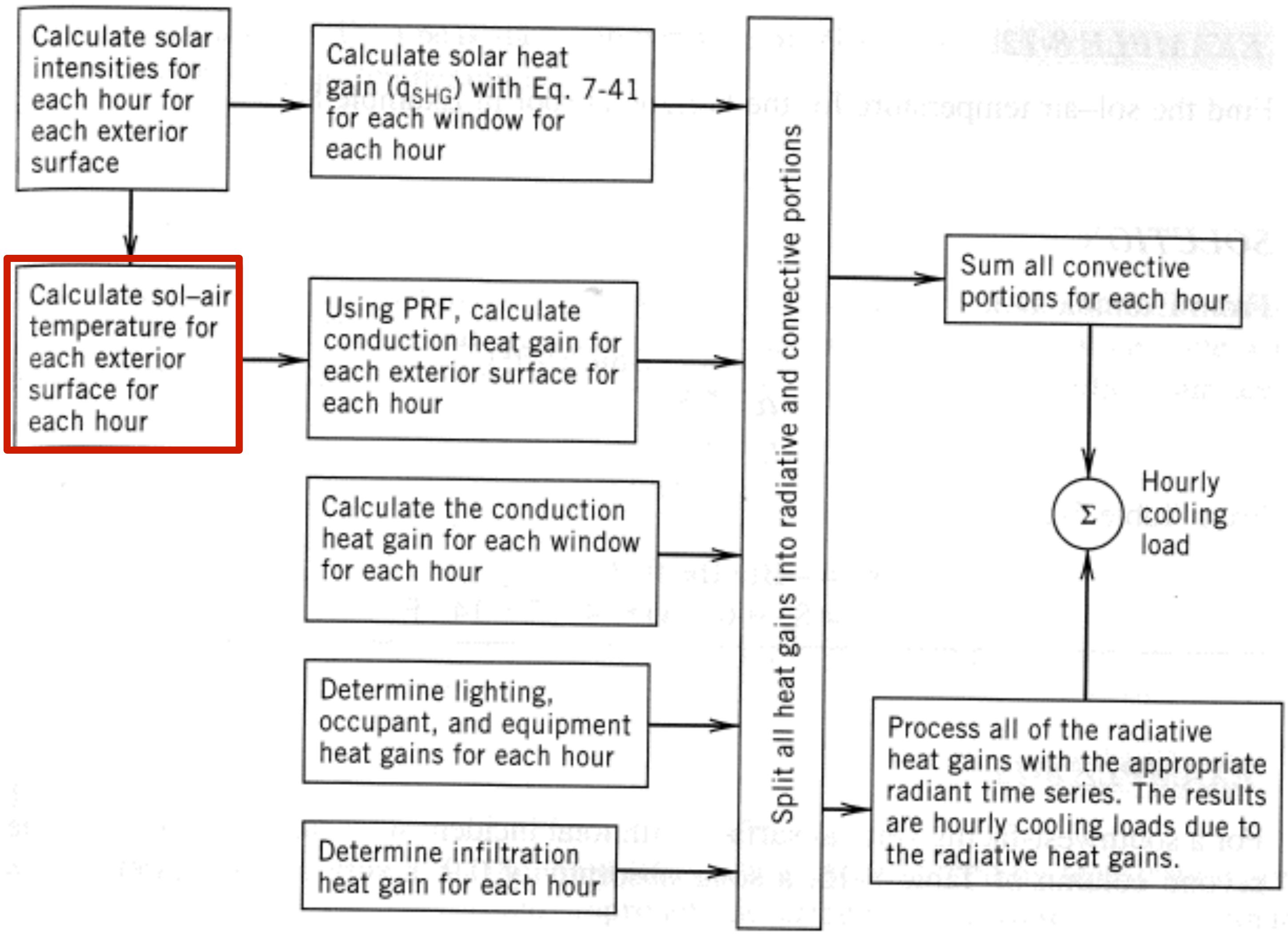


Figure 8-8 Radiant time series method.

Calculate sol-air temperature

- For each surface, for each hour

$$T_{sol-air} = T_{air,out} + \alpha \frac{I_{solar}}{h_{ext,conv+rad}} - \varepsilon \frac{\delta R}{h_{ext,conv+rad}}$$

$\varepsilon\delta R \approx 7$°F for horizontal surfaces

$\varepsilon\delta R \approx 0$°F for vertical surfaces

RTS procedure

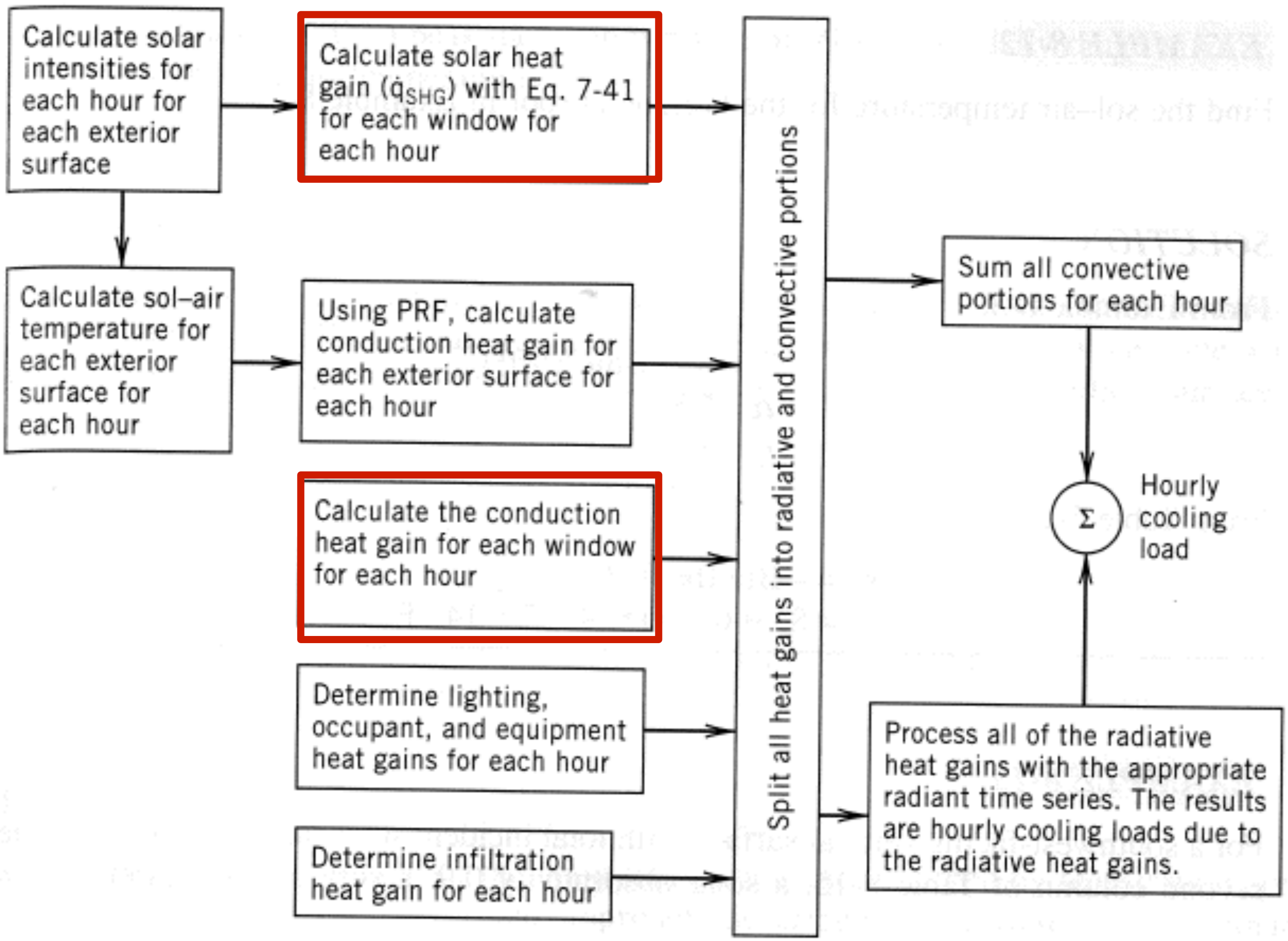


Figure 8-8 Radiant time series method.

Heat gain through windows

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

$$q_{window} = U_{pf}\left(T_{out} - T_{in}\right) + I_{solar}SHGC(IAC)$$

- We've done this before

RTS procedure

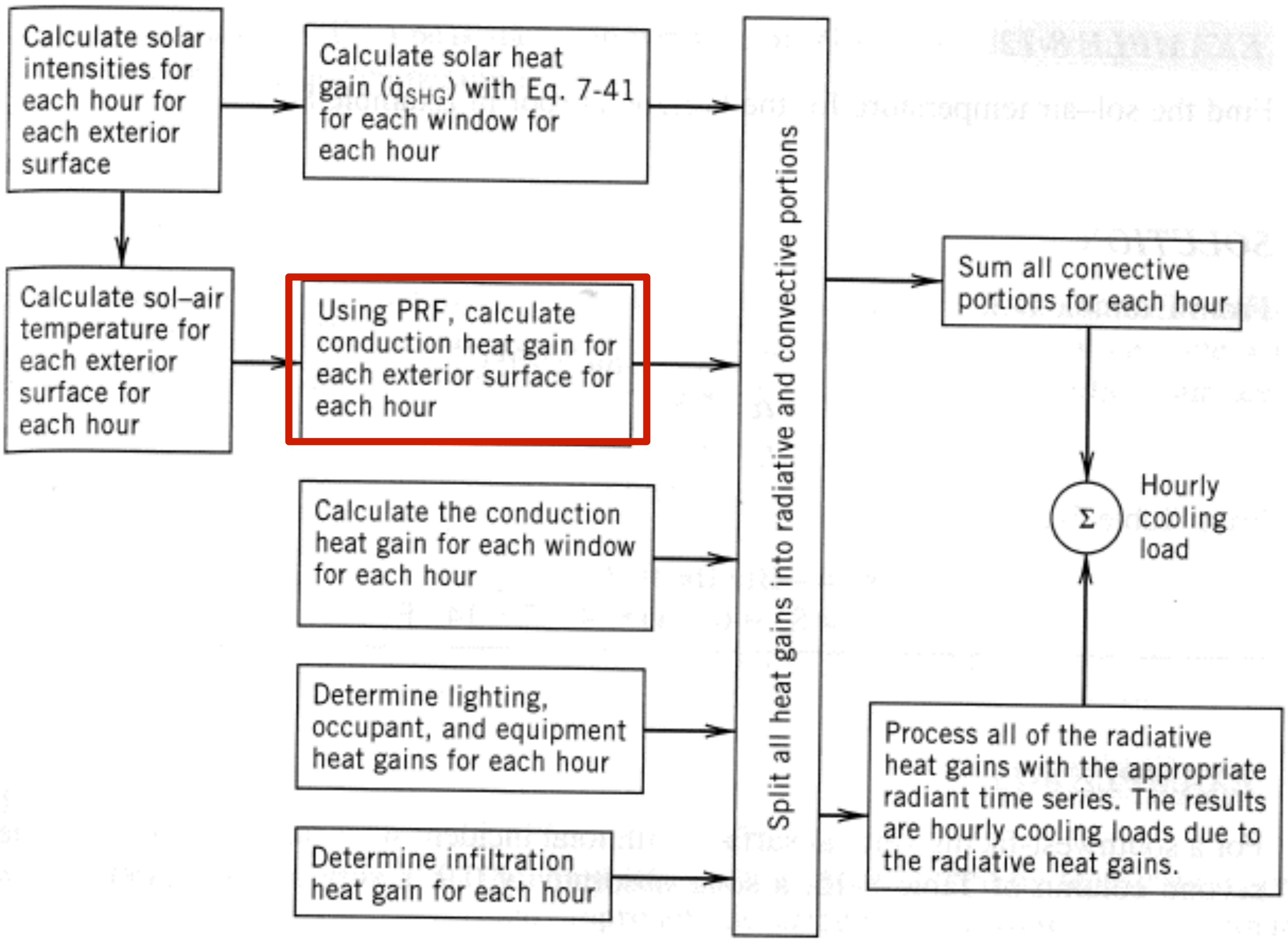


Figure 8-8 Radiant time series method.

Conduction heat gains and "PRF"

- Heat gains to the interior from conduction will be a sum of conduction going on right now + part of the heat transferred to the enclosure from earlier times
- For example:

$$q(n)=C_0U(T_e(n) - T_i(n)) + C_1U(T_e(n\text{-}1) - T_i(n\text{-}1)) + \ldots + C_{23}U(T_e(n\text{-}23) - T_i(n\text{-}23))$$

where $T_e = T_{sol\text{-}air}$

- We call C_n the **conduction time series**
- $Y_{pn} = C_n U$ is the periodic response factor (PRF) in [W/m^{2}K]
- U is just the U-value of the element in [W/m^{2}K]

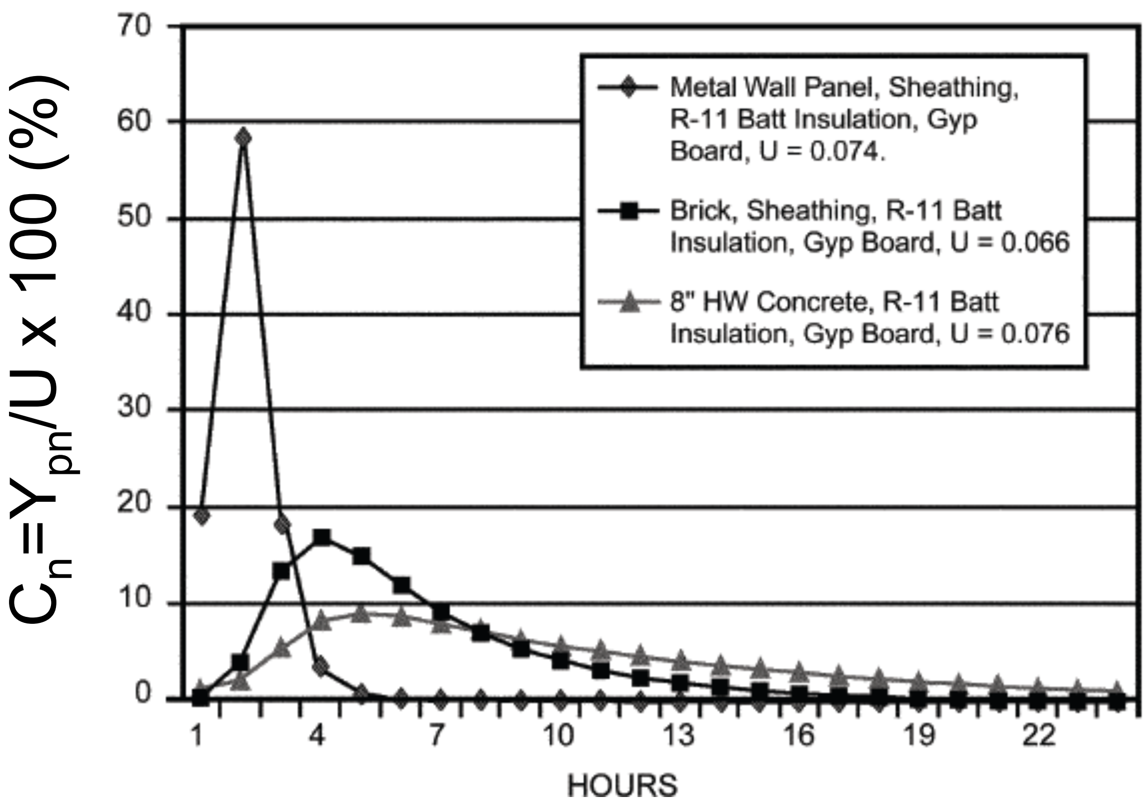
Finding Y_{pn} and C_n

- C_n and Y_{pn} depend on the exact details of the enclosure construction (wall or ceiling)
  - Overall insulation, mass, heat capacity and the insulation location both are important

- 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 constructions

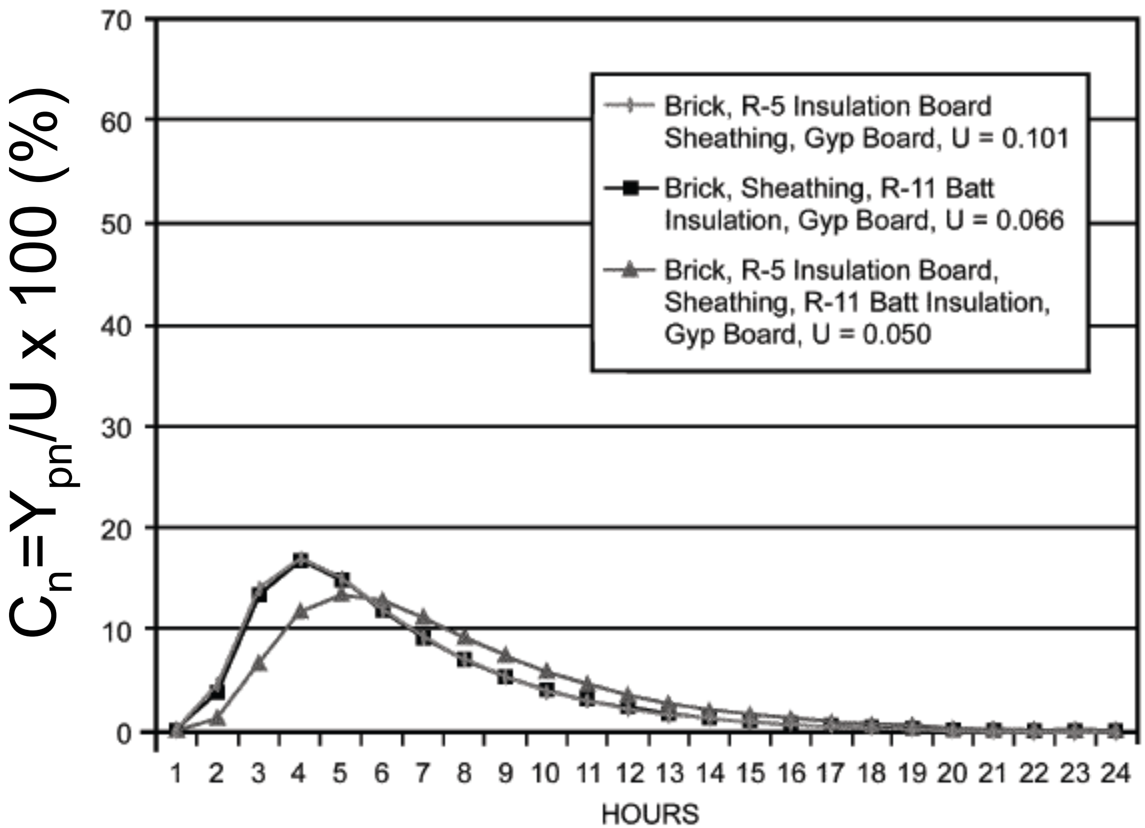
C_n for varying masses of enclosures

- Increasing mass (heat capacity) increases the delay in heat transmission



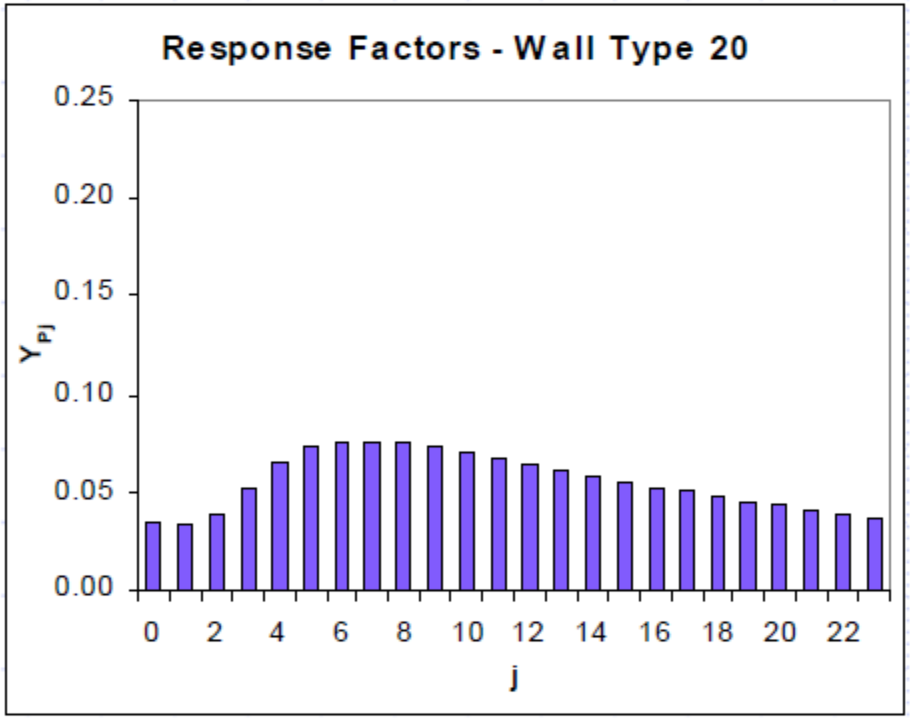
C_n for varying insulation

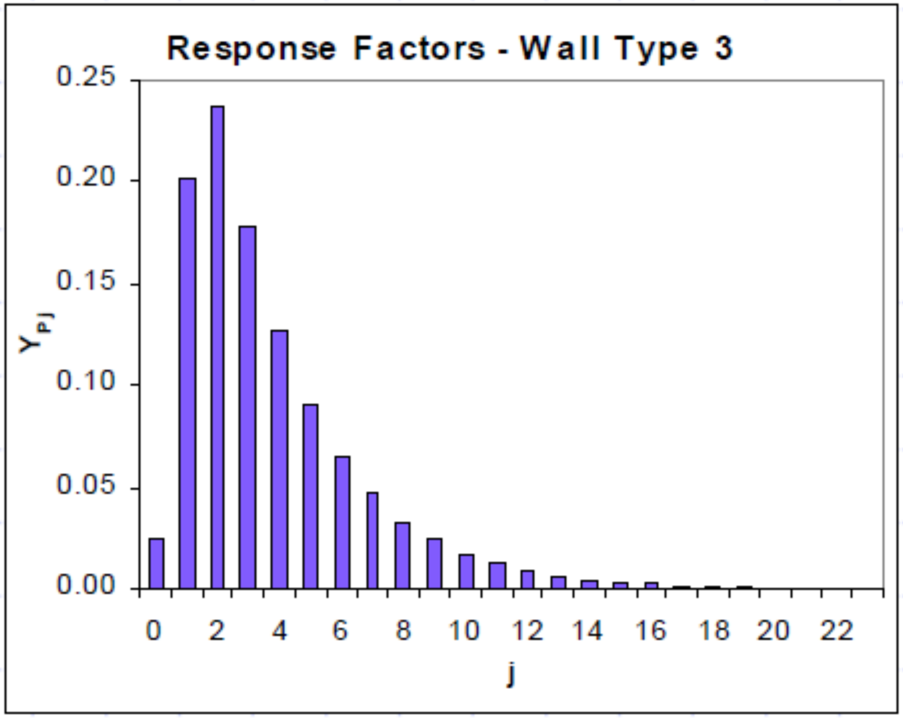
- Interior and exterior insulation have smaller effects on this brick wall



Y_{pn} for two different walls

- Type 20: Brick + 8” concrete + R11 insulation + gypsum board
- Type 3: 1” stone + R10 insulation + gypsum board





Conduction heat gains and "PRF"

- Once we have Y_{pn} we can estimate the heat conduction into the room at the current time as:

$$q_{conduction,in,t} = \sum_{n=0}^{23} Y_{pn}\left(T_{e,q-n} - T_{rc}\right) \text{ [Btu/(h}\cdot\text{ft}^2\text{) or W/m}^2\text{]}$$

where

$T_{e,q-n}$ =the sol-air temp n hours ago

T_{rc} = constant interior room temp

Y_{pn} = periodic response function

Conduction heat gains and "PRF": Expanded

- To use the previous equation we need to know the sol-air temp for the previous 24 hours
- The calculation for 8 am would look like this:

$$q_{conduction,in,8am} = Y_{p0}\left(T_{e,8am} - T_{rc}\right) + Y_{p1}\left(T_{e,7am} - T_{rc}\right) + Y_{p2}\left(T_{e,6am} - T_{rc}\right) + Y_{p3}\left(T_{e,5am} - T_{rc}\right) + Y_{p4}\left(T_{e,4am} - T_{rc}\right) + Y_{p5}\left(T_{e,3am} - T_{rc}\right) + \cdots + Y_{p22}\left(\underline{T_{e,11am}} - T_{rc}\right) + Y_{p23}\left(\underline{T_{e,10am}} - T_{rc}\right) + Y_{p24}\left(\underline{T_{e,9am}} - T_{rc}\right)$$

The underlined times are from the day before

RTS procedure

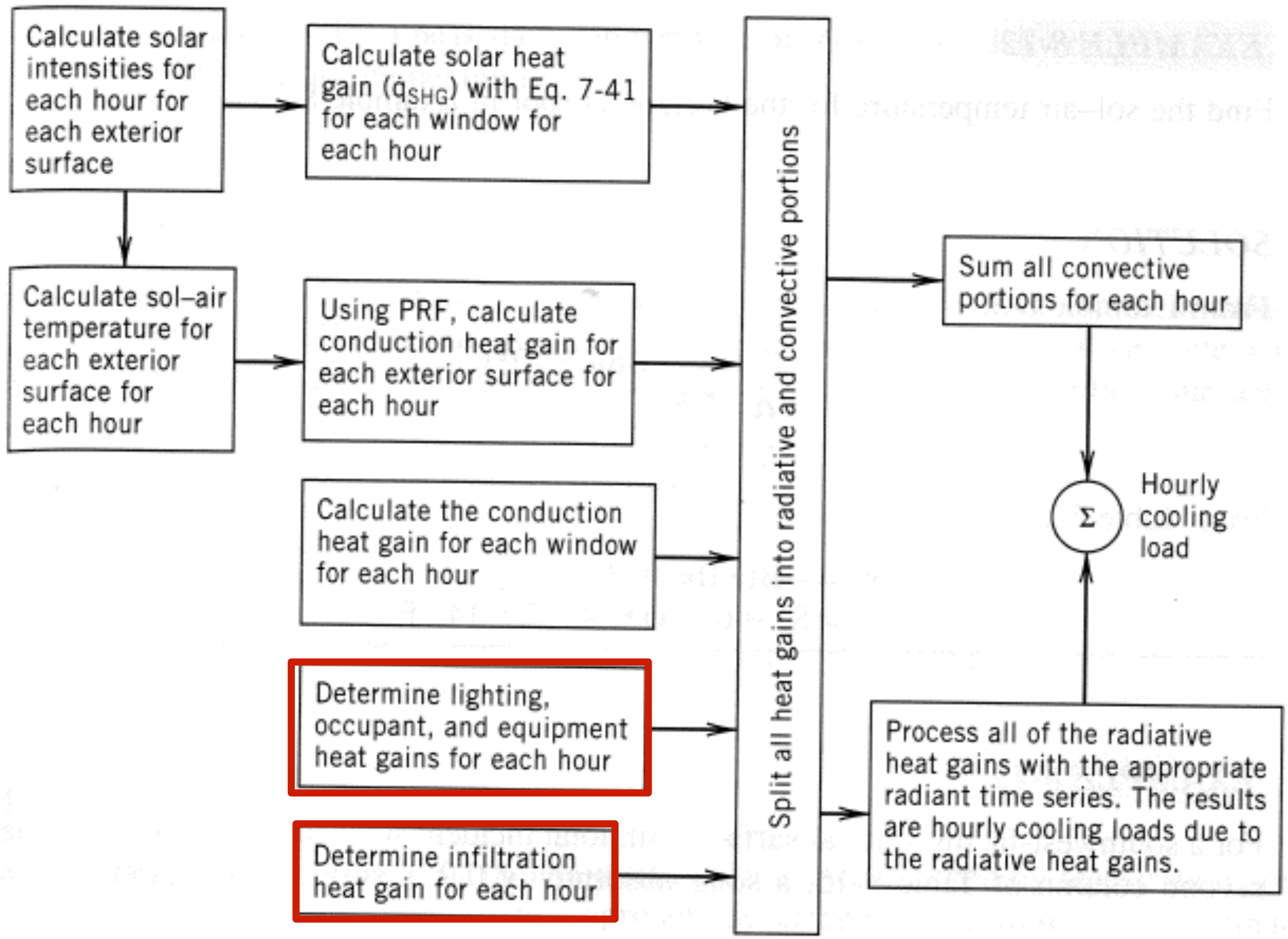


Figure 8-8 Radiant time series method.

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 schedules)
  - Also need to keep track of the radiative + convective parts

Splitting gains into radiative and convective portions

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

Table 14 Recommended Radiative/Convective Splits f

Heat Gain Type	Recommended Radiative Fraction	Recommended Convective Fraction
Occupants, typical office conditions	0.6	0.4
Equipment	0.1 to 0.8	0.9 to 0.2
Office, with fan	0.10	0.9
Without fan	0.3	0.7
Lighting		
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	1.0	0.0
With interior shading		
Infiltration	0.0	1.0

Splitting gains into radiative and convective portions

- Convection is considered instantaneous
- 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
- 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

$$Q_{cooling,t} = \sum_{n=0}^{23} r_n Q_{t-n\delta} \quad \text{[Btu/h] or [W]}$$

where

$Q_{cooling,t}$ = radiative cooling load at current hour, Btu/hr or W

$Q_{t-n\delta}$ = radiative heat gain n hours ago, Btu/hr or W

$r_n = n^{th}$ radiant time factor (RTF)

- RTF depends upon the wavelength (LW vs SW or solar), the mass of the enclosure, and the 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

Table 19 Representative Nonsolar RTS Values for Light to Heavy Construc

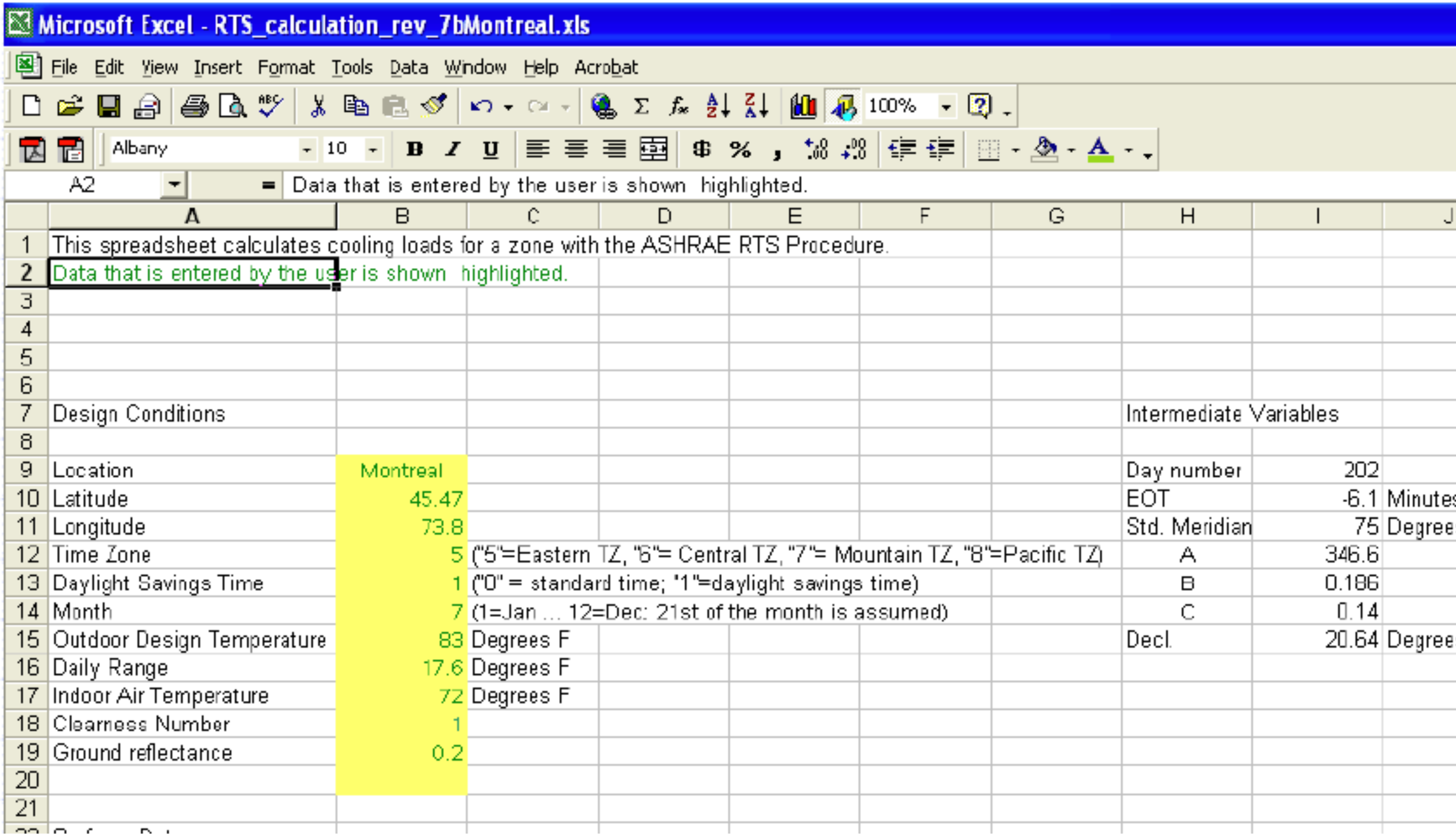
	Light						Medium						Heavy					
	With Carpet			No Carpet			With Carpet			No Carpet			With Carpet			No Carpet		
% Glass	10%	50%	90%	10%	50%	90%	10%	50%	90%	10%	50%	90%	10%	50%	90%	10%	50%	90%
Hour	Radiant Time Factor, %																	
0	47	50	53	41	43	46	46	49	52	31	33	35	34	38	42	22	25	28
1	19	18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

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

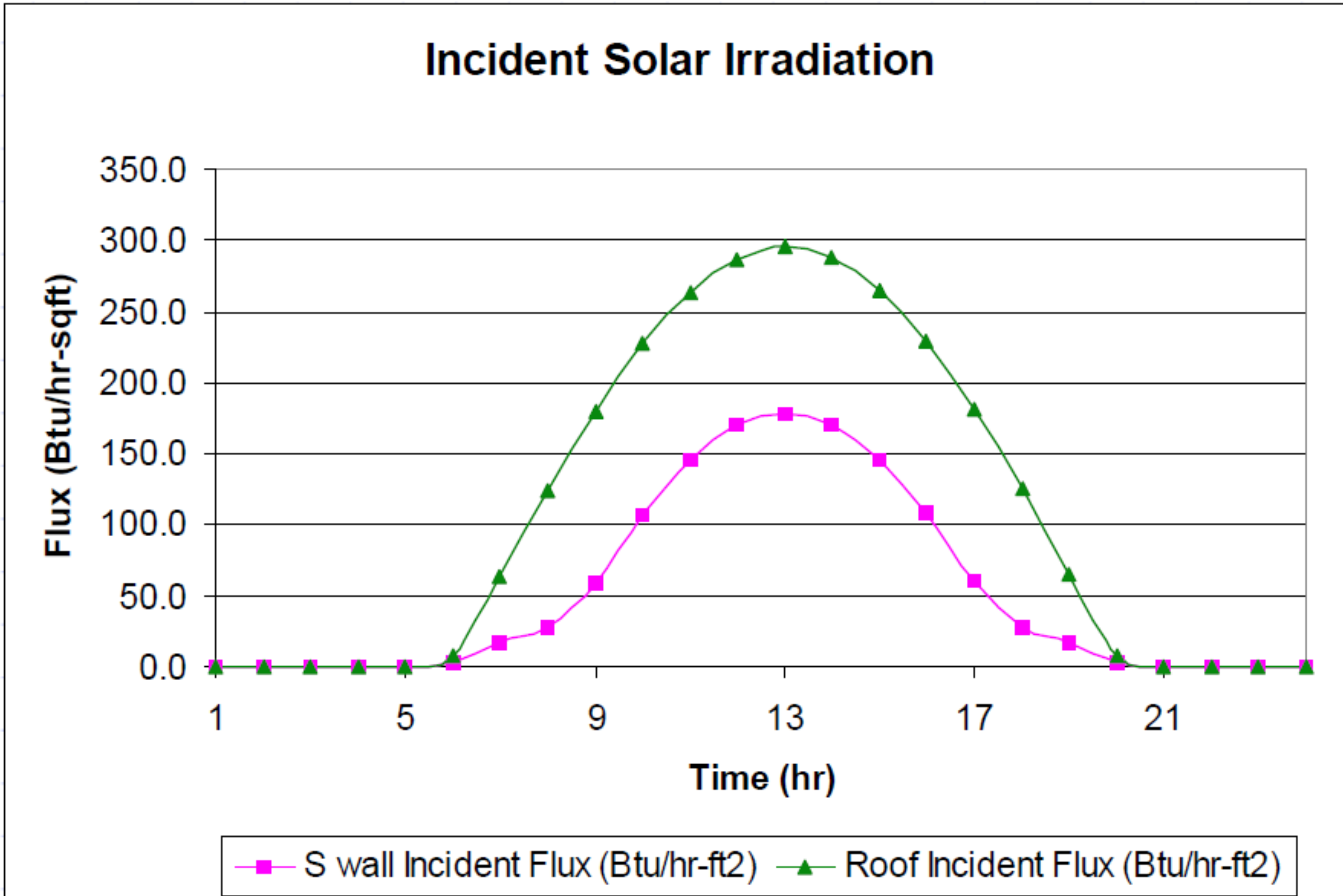
You would create a spreadsheet



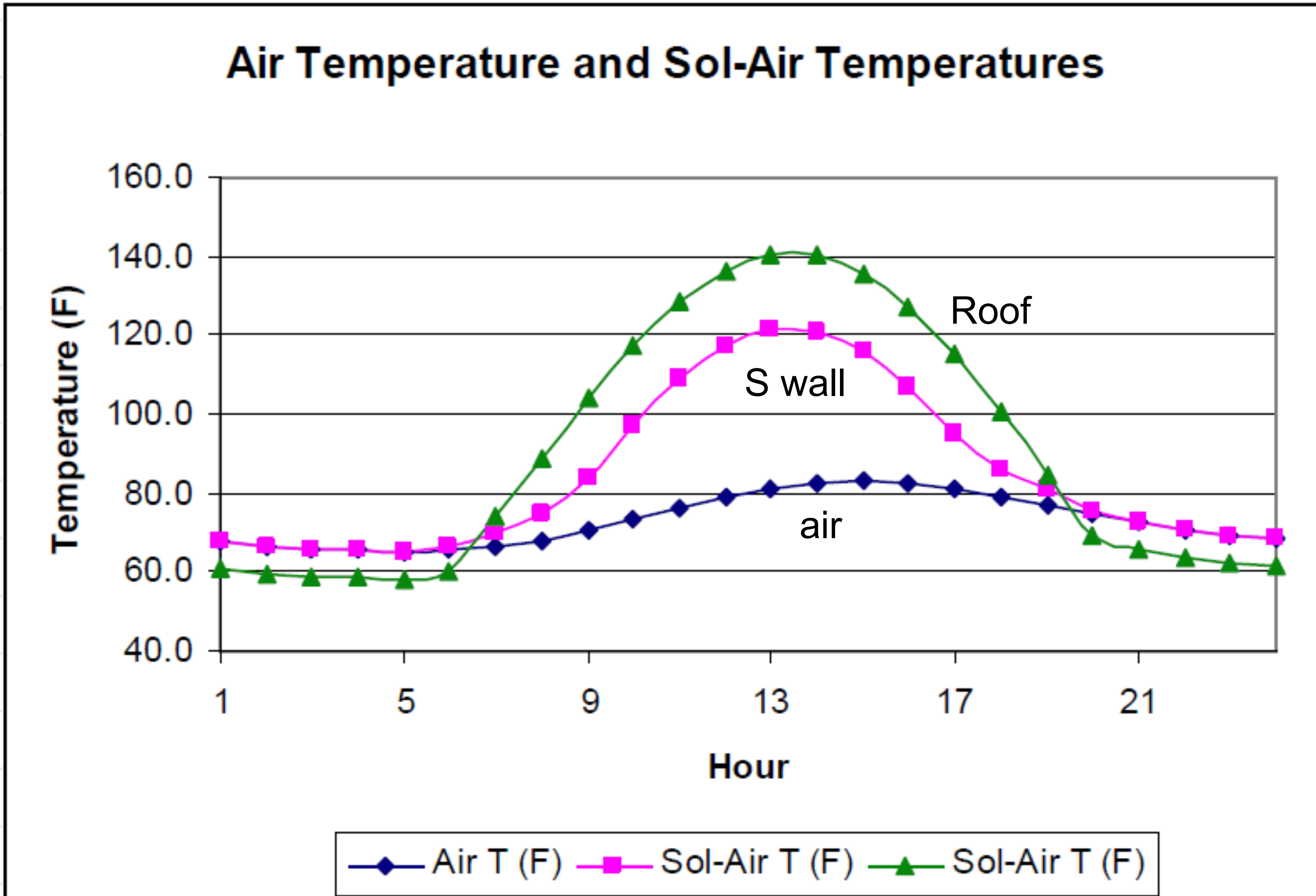
	A	B	C	D	E	F	G	H	I	J
1	This spreadsheet calculates cooling loads for a zone with the ASHRAE RTS Procedure.									
2	Data that is entered by the user is shown highlighted.									
3										
4										
5										
6										
7	Design Conditions							Intermediate Variables		
8										
9	Location	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



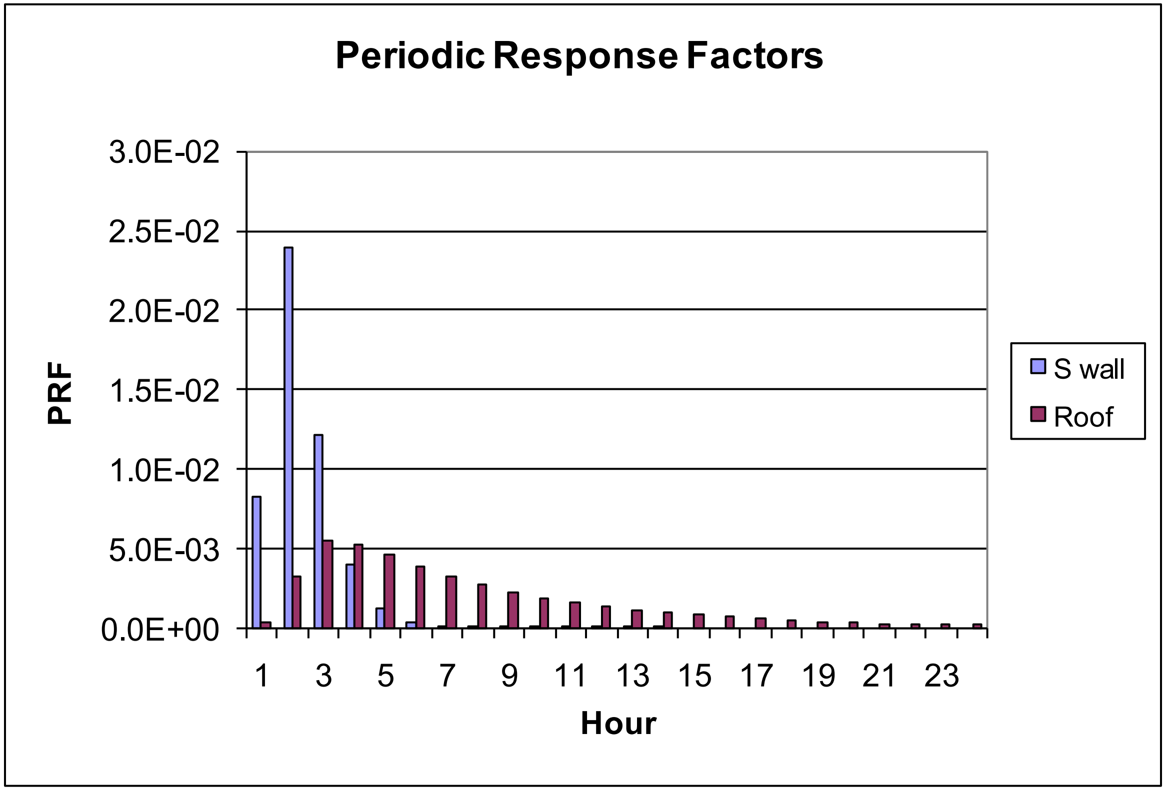
Find sol-air temperatures



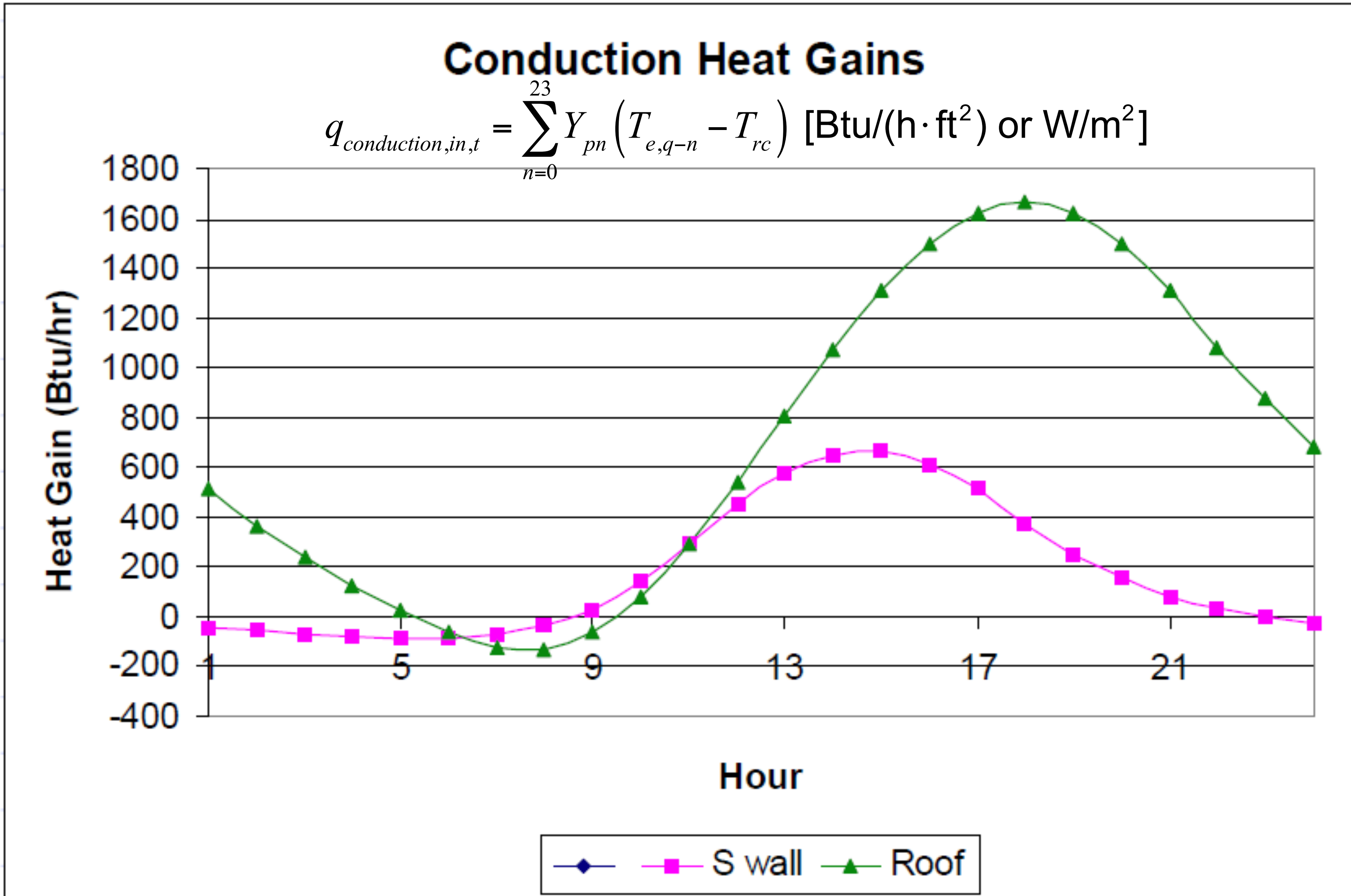
Find periodic response factors for conduction

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

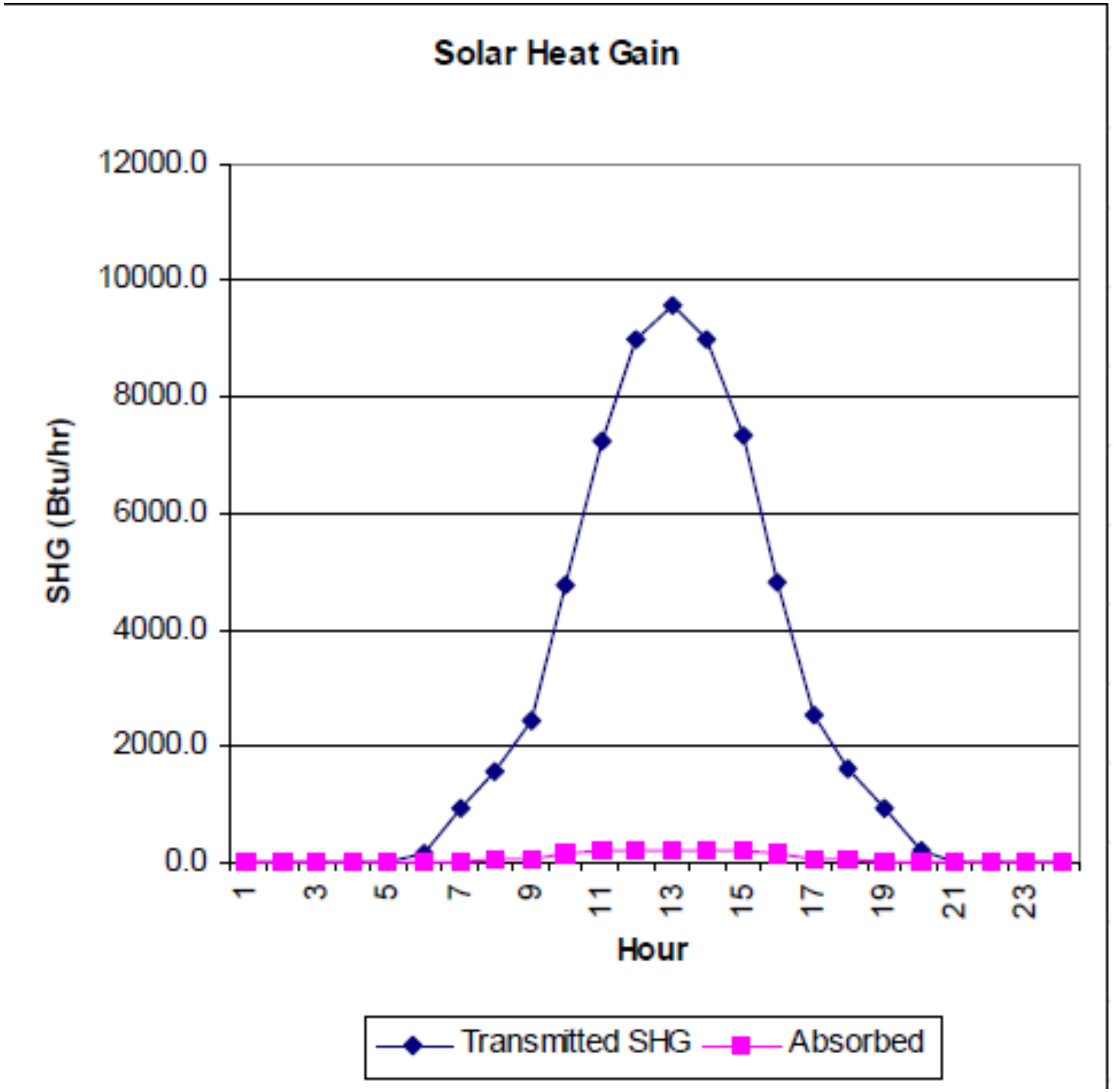
Y_{pn}



Estimate hourly conductive heat gains



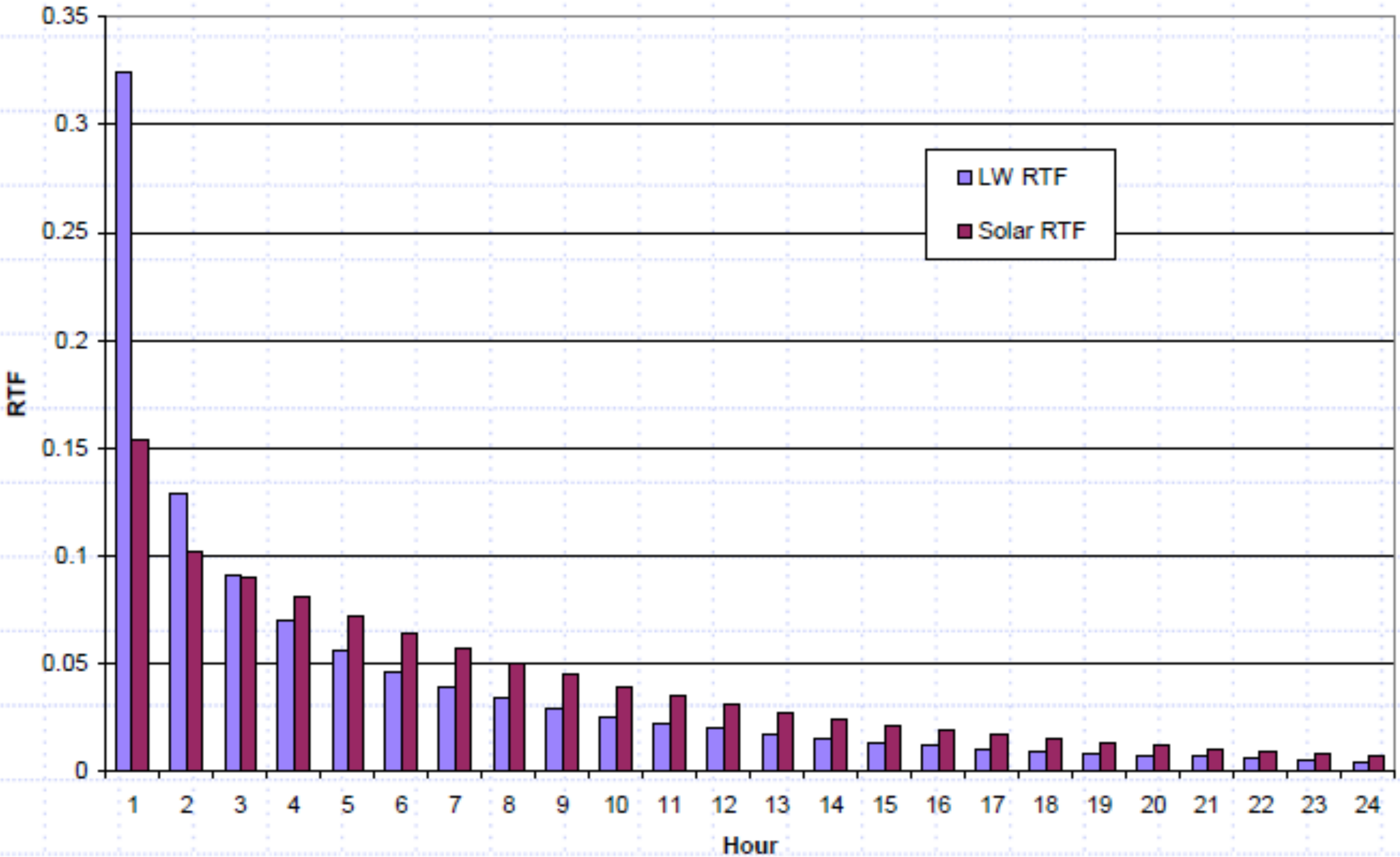
Find solar heat gains



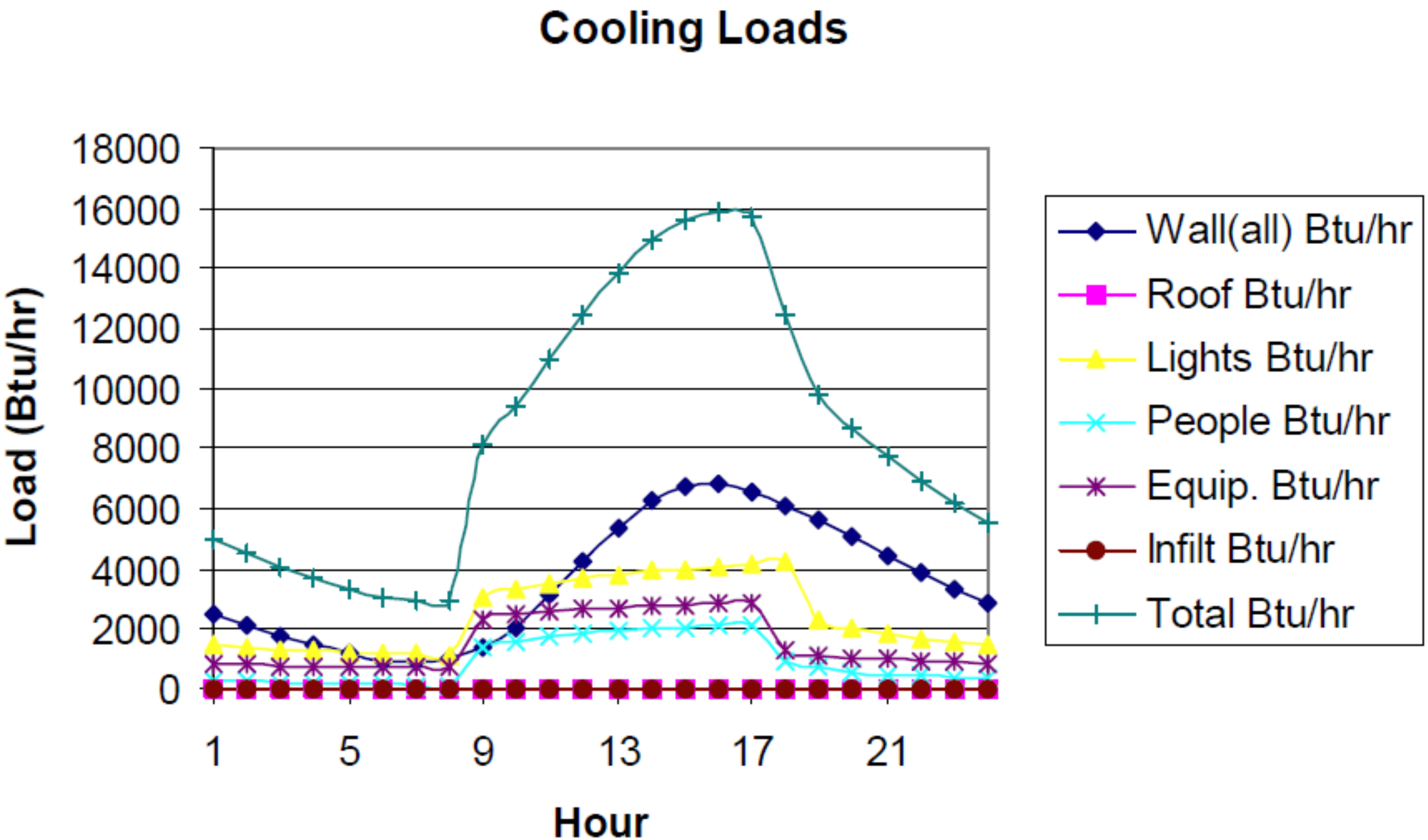
Radiative vs. convective split gains

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



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

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 if you'd like
  - Academic version is available on Alumni 218 Lab Computers

HW 6: Trane Trace 700

Getting Started

TRACE™ 700

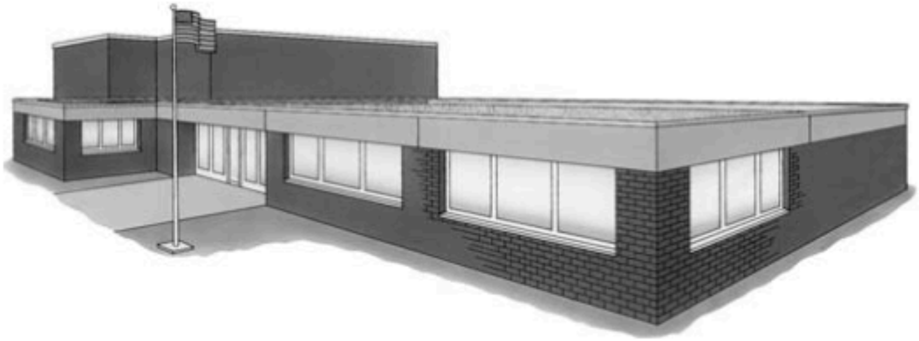
Comprehensive Building Analysis

version 6.2

Load Design Tutorial

Scenario

The architect provided a floor plan, descriptions of the construction materials, and other basic design criteria for the fictitious Washington Elementary School. You will finish creating a project file, define the rooms and HVAC systems, and print the results.



Washington Elementary School

Due Thursday December 1st