Overview of the Radiant Time Series Method

Prof. Jeffrey D. Spitler

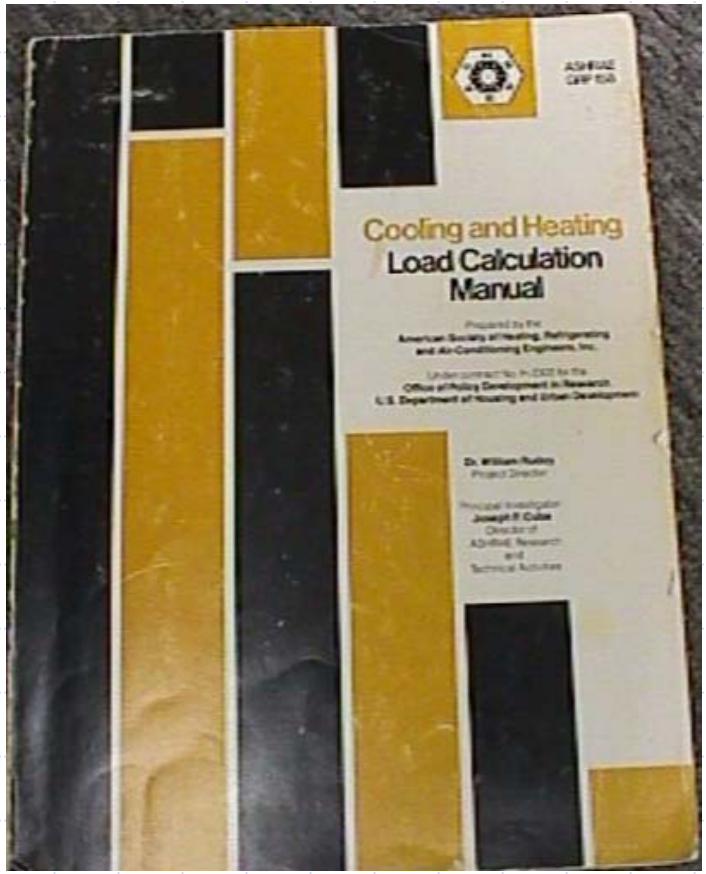
School of Mechanical and Aerospace Engineering, Oklahoma State University

Outline

- Motivations – a brief history
- Overview of the procedure
- Example

A brief history (1)

- 1975 – Rudoy and Duran develop CLTD/CLF procedure, using TFM as basis for CLTDs and CLFs
- 1980 – ASHRAE publishes Cooling and Heating Load Calculation Manual by Rudoy and Cuba

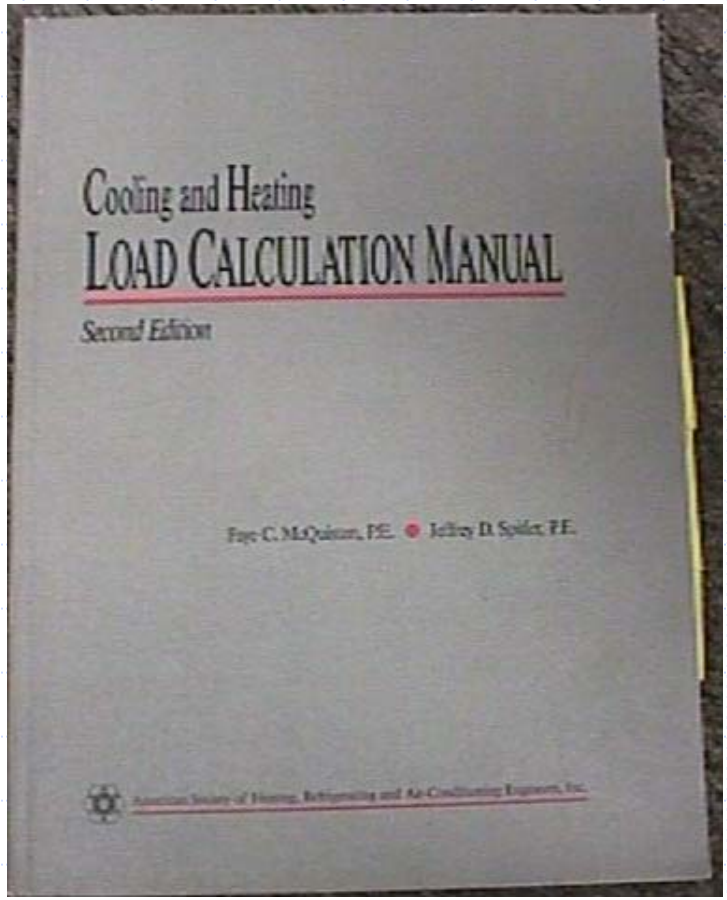


A brief history (2)

- 1985 – Sowell and Chiles publish work showing deficiencies in CLTD/CLF procedure.
- 1988 – Sowell publishes results of 200,000+ DOE-2 calculations of custom weighting factors; McQuiston and Harris publish 83 sets of CTF coefficients for walls and roofs. (ASHRAE RP-472)

A brief history (3)

- 1992 – ASHRAE publishes 2nd Edition of Cooling and Heating Load Calculation Manual by McQuiston and Spitler; CLTD/SCL/CLF procedure is developed; all methods (TFM, TETD/ TA, CLTD/SCL/CLF) are presented and all use data from ASHRAE RP-472.



A brief history (4)

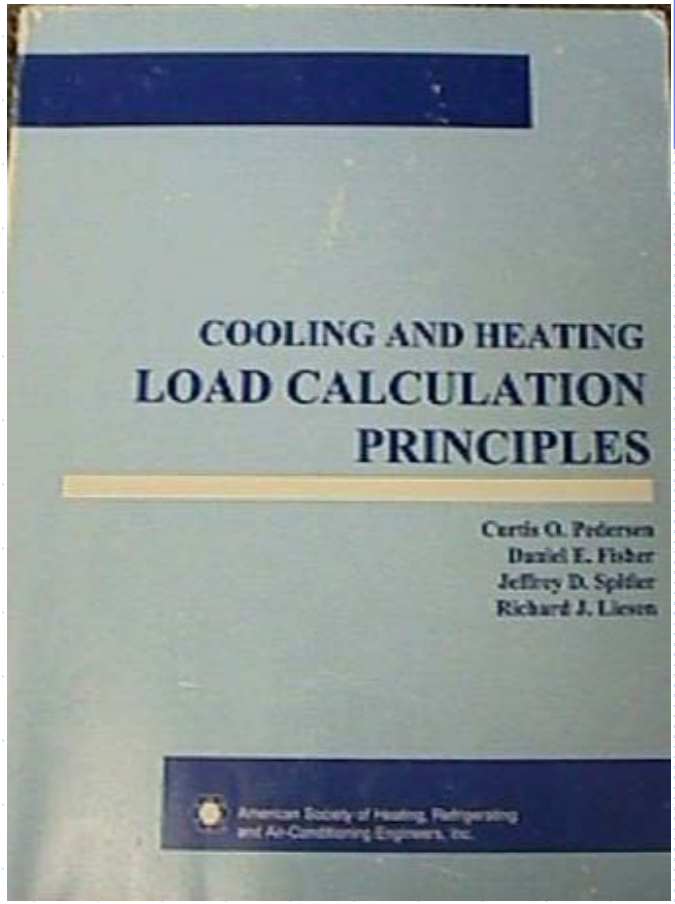
- Mid 1990's – Despite revisions to all of the methods, ASHRAE Load Calculations TC remains "dissatisfied" with existing methods.
  - TFM is difficult to use or understand; an approximation to the heat balance method.
  - CLTD/SCL/CLF and TETD/TA are 2nd generation approximations
  - TETD/TA requires substantial user judgment.

A brief history (5)

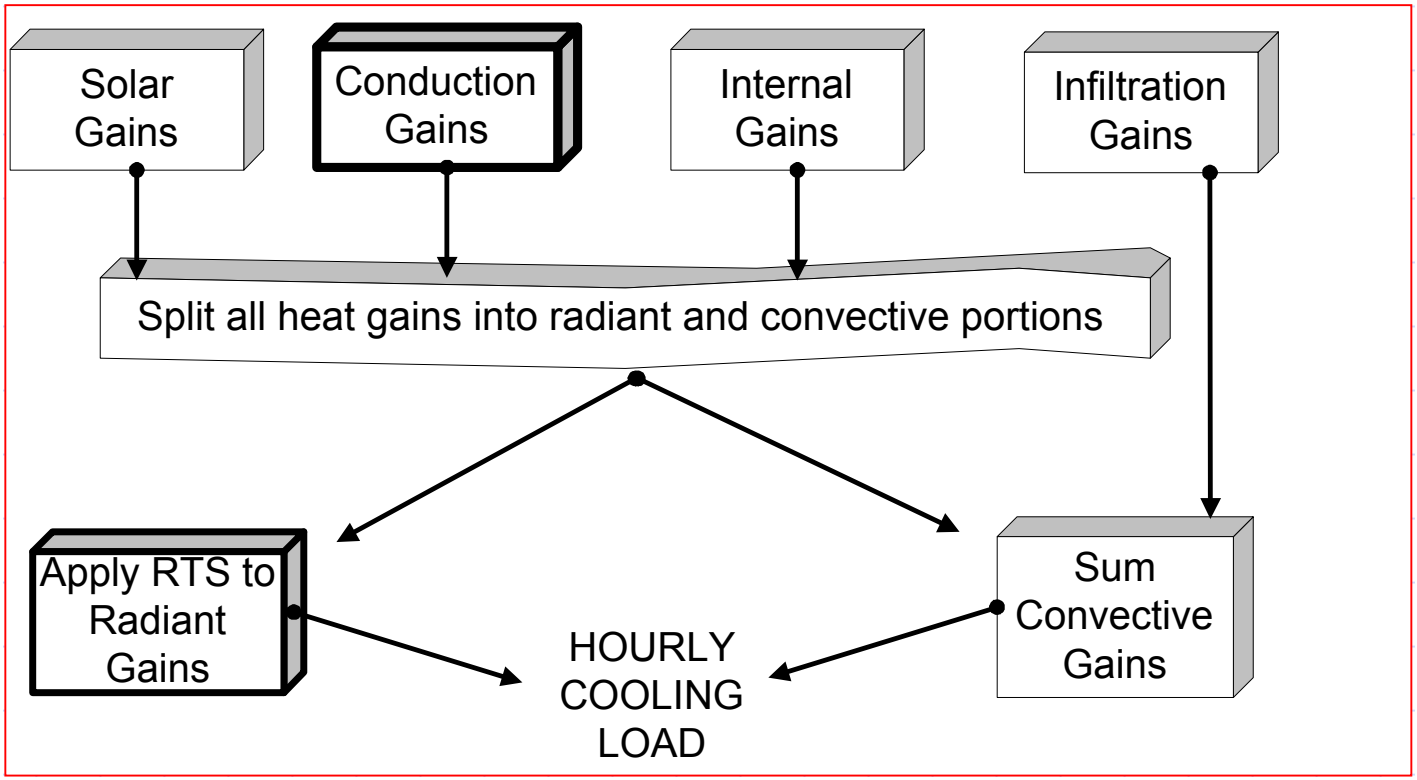
- 1996 – ASHRAE Load Calculations Technical Committee funds RP-875; goal is to replace existing methods with:
  - Heat Balance Method (most fundamental method)
  - Radiant Time Series Method (simplified method, intended to be derived directly from HBM, but be much easier to use; a “spreadsheet method”)

A brief history (6)

- 1998 – ASHRAE publishes Cooling and Heating Load Calculation Principles with HBM and RTSM
- 2001 – HBM and RTSM are published in ASHRAE Handbook of Fundamentals



RTSM Algorithm



RTSM Solution Technique

- Takes Advantage of Steady Periodic Nature of the Cooling Load Calculation
- Based on:
  - Radiant Time Series: Steady Periodic Zone Response Factors
  - Steady Periodic Response Factors for Conduction

Advantage of Steady Periodic Response Factors

- Reduce Computation Time
- Provide a Simplified (Spreadsheet Friendly) Method for Estimating Cooling Loads
- Provide Some Physical Insight Into the Nature of the Calculation

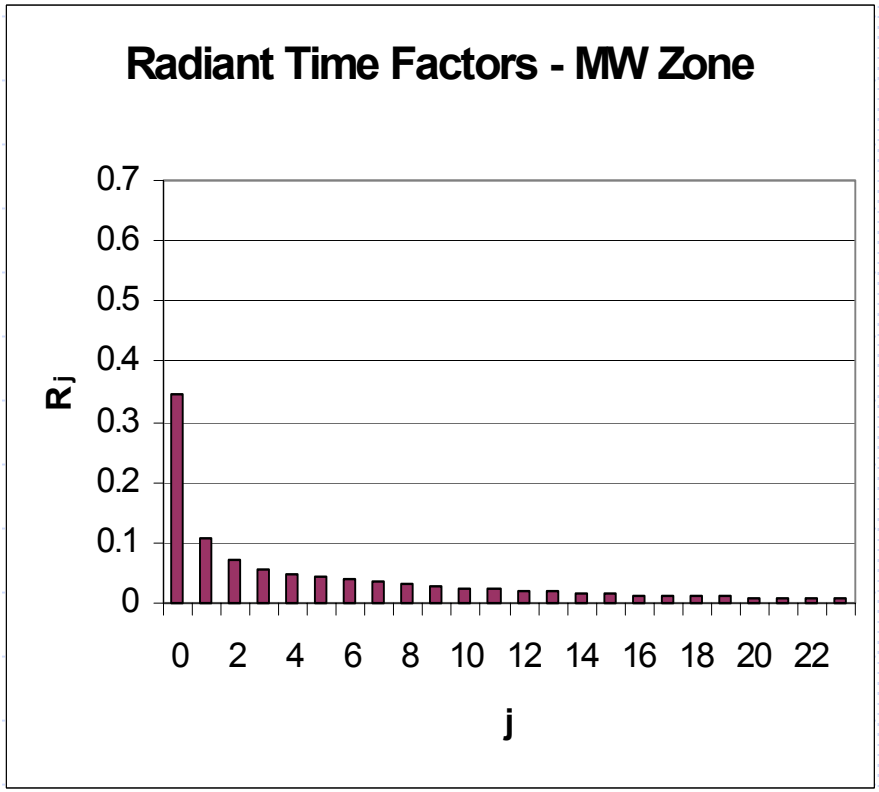
The Radiant Time Series

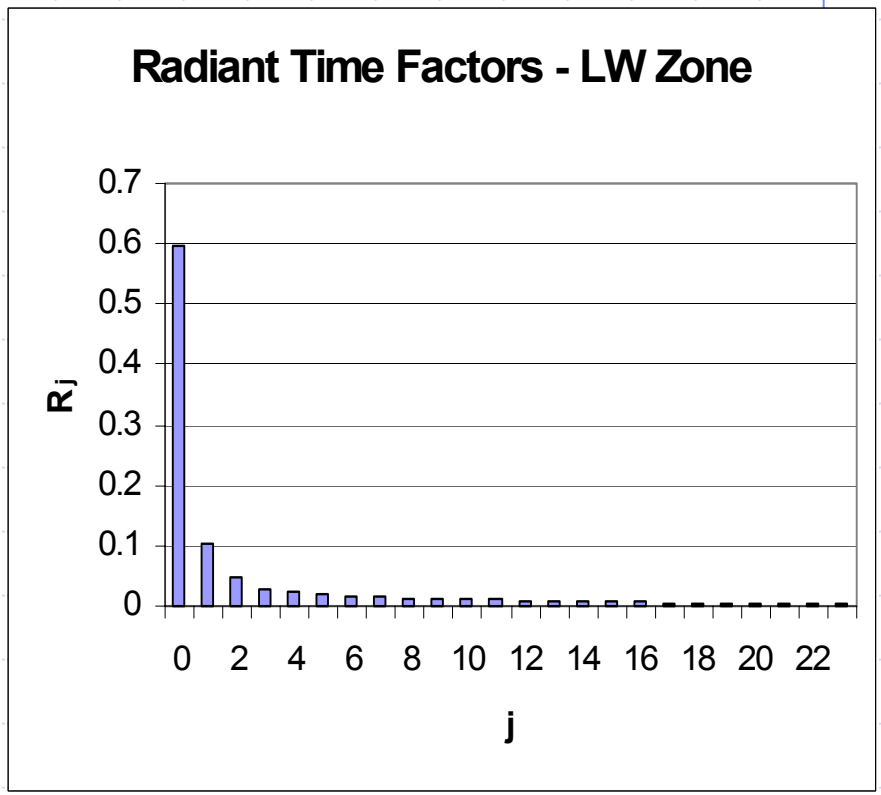
- Steady Periodic Zone Response Factors ("Radiant Time Factors")

$$Q_\theta = r_0 q_\theta + r_1 q_{\theta-\delta} + r_2 q_{\theta-2\delta} + r_3 q_{\theta-3\delta} + \ldots + r_{23} q_{\theta-23\delta}$$

- Calculate the Contribution of Radiant Heat Gains to Hourly Cooling Load

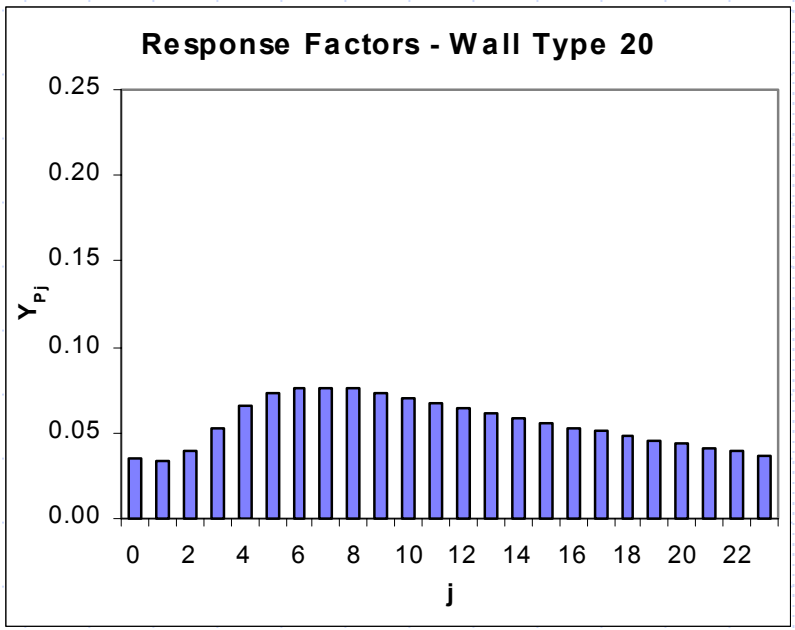
Steady Periodic Zone Response Factors

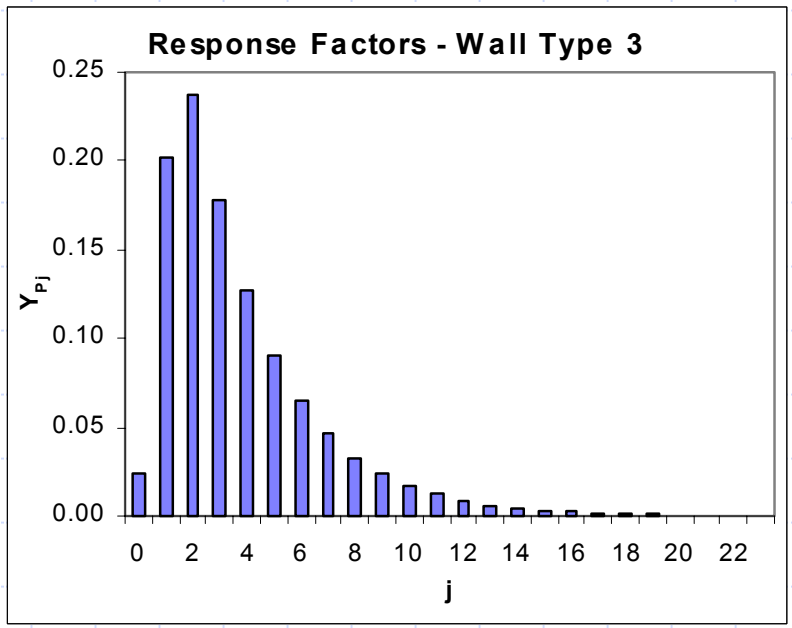




Steady Periodic Response Factors for Conduction

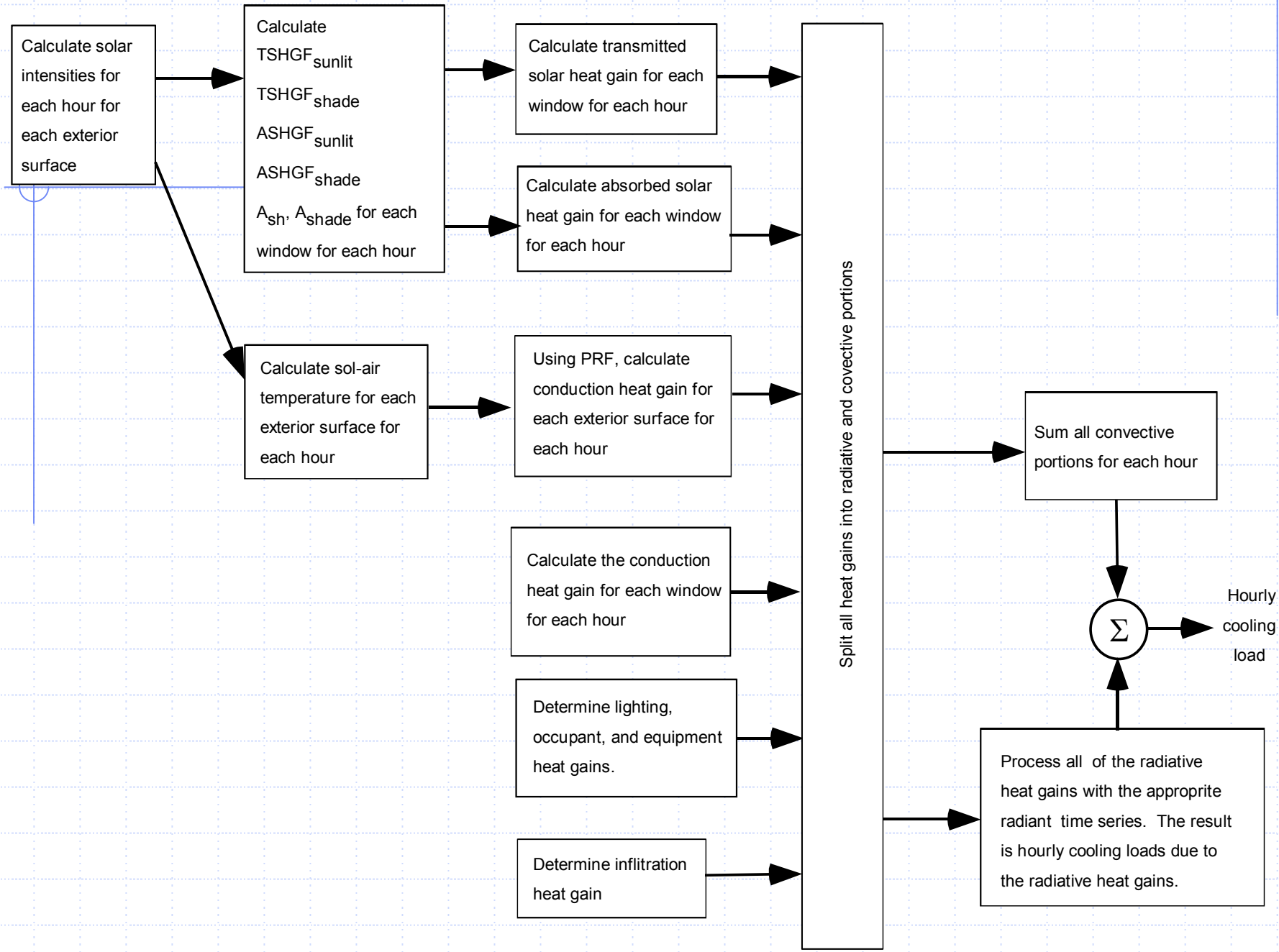
$$q''_\theta = \sum_{j=0}^{23} Y_{Pj} T_{e,\theta - j\delta} - T_{rc} \sum_{j=0}^{23} Y_{Pj}$$



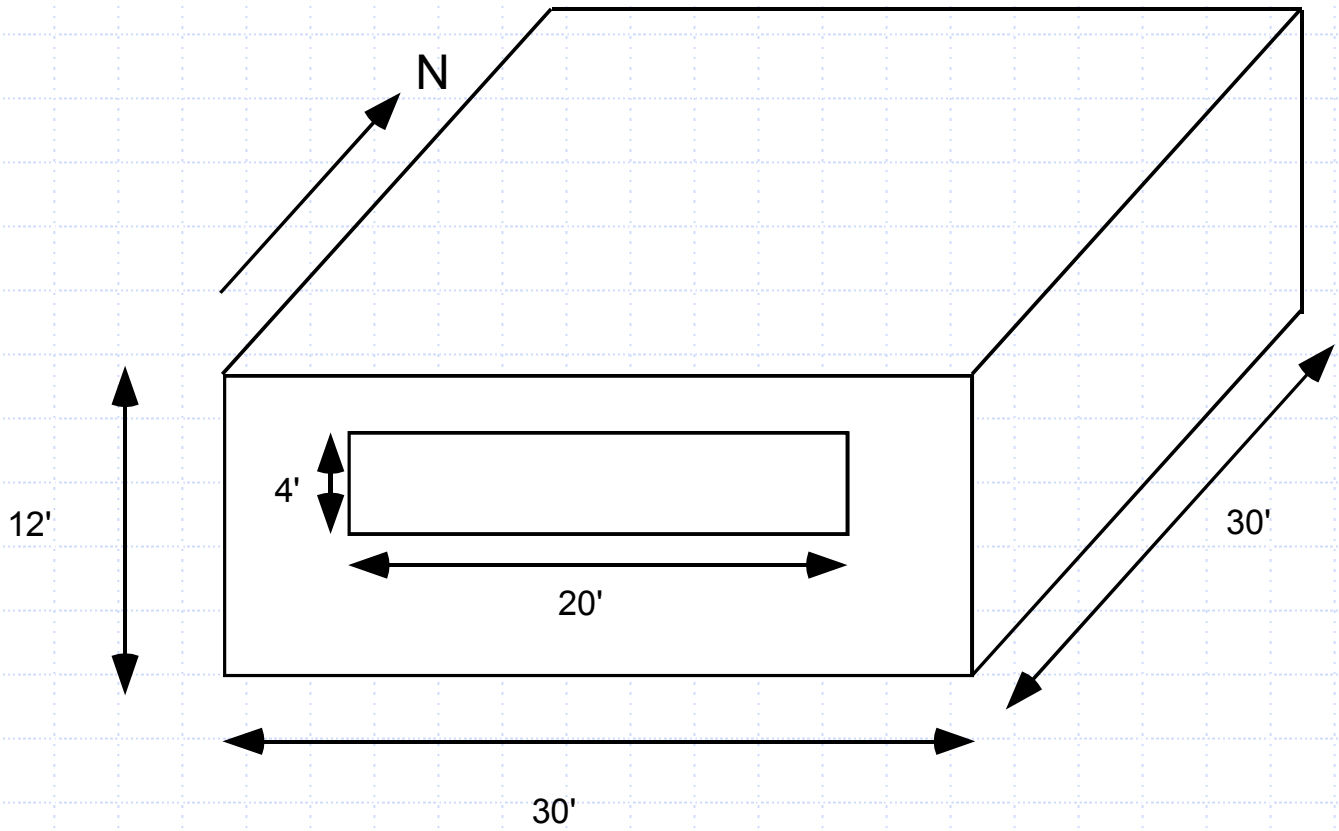


Characteristics of Steady Periodic Response Factors

- Operate on temperatures only (no flux history terms)
- Sum to the overall u-value of the wall
- Provide a qualitative measure of the time-lag associated with the surface
- Can be determined from Conduction Transfer Function Coefficients


Calculate solar intensities for each hour for each exterior surface
Calculate $TSHGF_{sunlit}$ $TSHGF_{shade}$ $ASHGF_{sunlit}$ $ASHGF_{shade}$ A_{sh}, A_{shade} for each window for each hour
Calculate transmitted solar heat gain for each window for each hour
Calculate absorbed solar heat gain for each window for each hour
Calculate sol-air temperature for each exterior surface for each hour
Using PRF, calculate conduction heat gain for each exterior surface for each hour
Calculate the conduction heat gain for each window for each hour
Determine lighting, occupant, and equipment heat gains.
Determine inflitration heat gain
Split all heat gains into radiative and covective portions
Sum all convective portions for each hour
Σ
Hourly cooling load
Process all of the radiative heat gains with the approprite radiant time series. The result is hourly cooling loads due to the radiative heat gains.

Example



Only South wall and roof are exposed to the outside.

Example

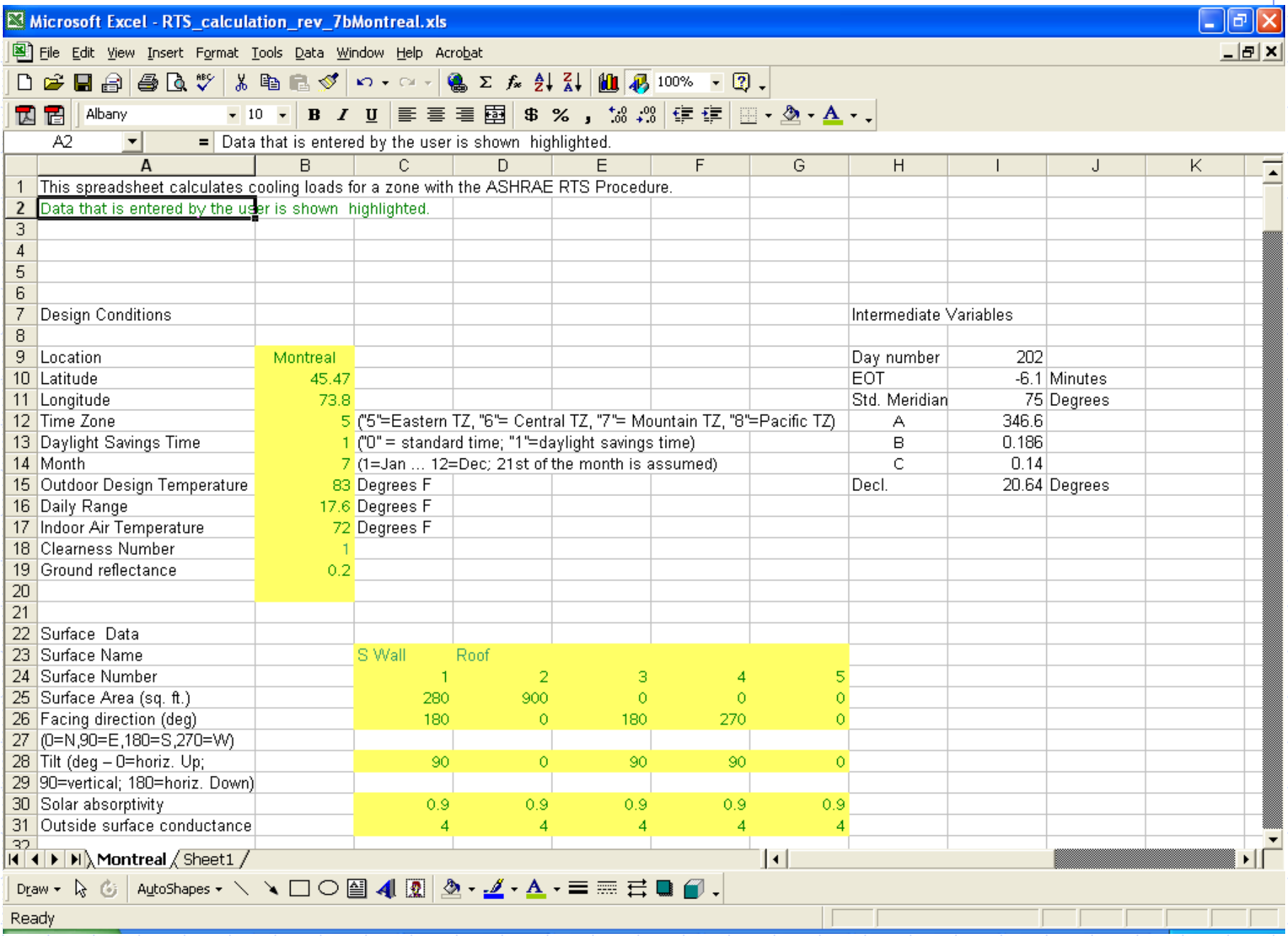
- Walls:
  - Outside Surface Resistance
  - 1 in. Stucco
  - 5 in. Insulation
  - ¾ in. Plaster or gypsum
  - Inside surface resistance
- 4” slab-on-grade floor
- Double pane window, SC=0.88
- Roof
  - Outside Surface Resistance
  - ½ in. Slag or stone
  - 3/8 in. Felt and membrane
  - 2 in. Heavyweight concrete
  - Ceiling air space
  - 6 in. Insulation
  - Acoustic tile
  - Inside surface resistance

Example

- Outside
  - Montreal
  - July 21
  - 83 F DB, 17.6 Daily Range
  - Ground Reflectivity = 0.2
- Inside
  - Air temp. = 72 F
- Other heat gains
  - 10 occupants, 8-5
  - 1 W/ft^2 equipment heat gain from 8-5
  - 1.5 W/ft^2 lighting heat gain, 8-5
  - 0.2 W/ft^2 equipment, 0.3 W/ft^2 lights, 5-8
  - Suspended fluorescent lights.

Example – Solar Calculations

- Calculate solar intensity on each surface, using solar angles and ASHRAE ABC sky model.
- Calculate sol-air temperatures on each surface.
- Calculate solar heat gain for windows.
- Could be done with a program or a spreadsheet.



Microsoft Excel - RTS_calculation_rev_7bMontreal.xls

File Edit View Insert Format Tools Data Window Help Acrobat

Albany 10

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

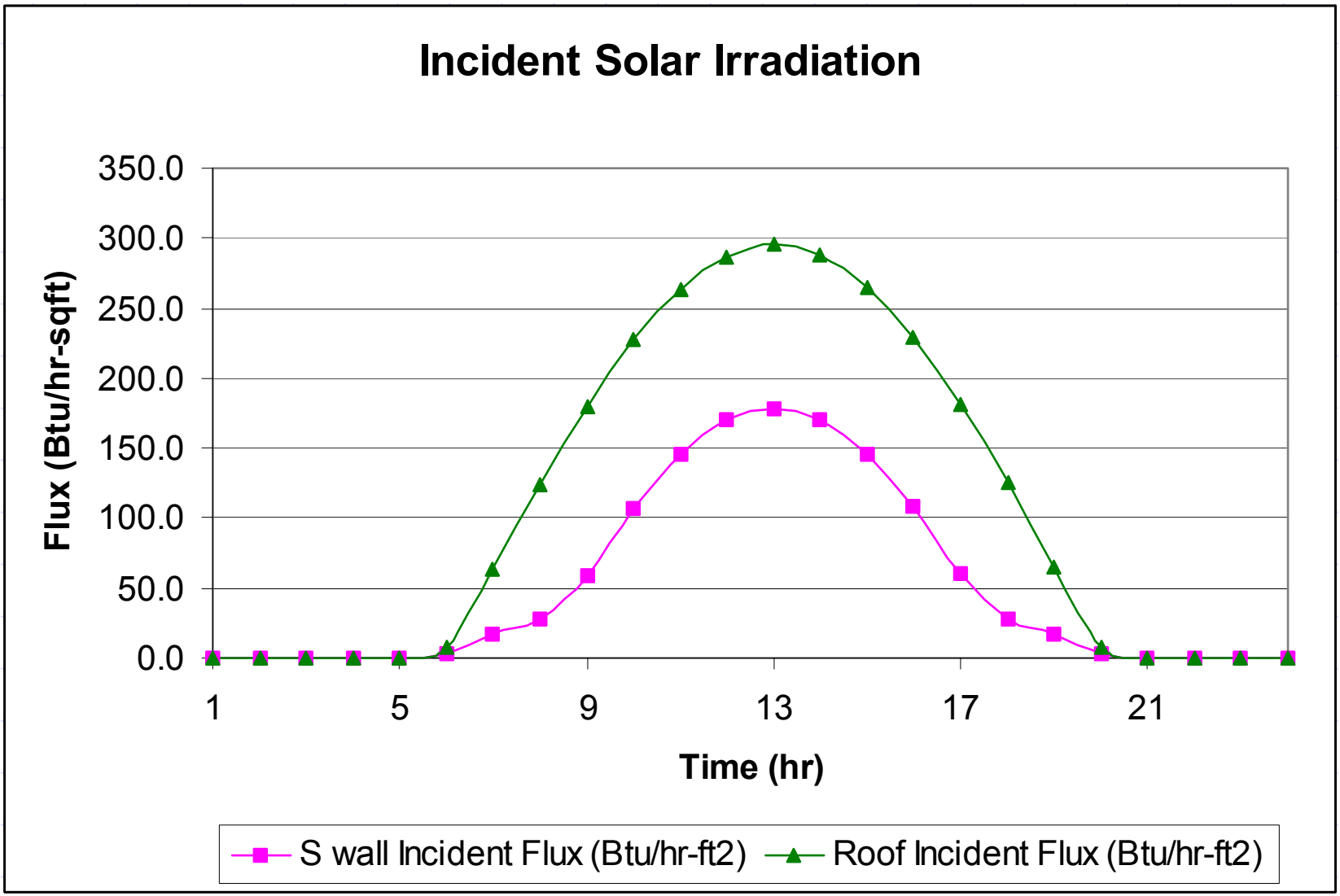
	A	B	C	D	E	F	G	H	I	J	K
1	This spreadsheet calculates cooling loads for a zone with the ASHRAE RTS Procedure.										
2	Data that is entered by the user is shown highlighted.										
3											
4											
5											
6											
7	Design Conditions							Intermediate Variables			
8											
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											
22	Surface Data										
23	Surface Name		S Wall	Roof							
24	Surface Number		1	2	3	4	5				
25	Surface Area (sq. ft.)		280	900	0	0	0				
26	Facing direction (deg)		180	0	180	270	0				
27	(0=N,90=E,180=S,270=W)										
28	Tilt (deg – 0=horiz. Up;		90	0	90	90	0				
29	90=vertical; 180=horiz. Down)										
30	Solar absorptivity		0.9	0.9	0.9	0.9	0.9				
31	Outside surface conductance		4	4	4	4	4				
32											

Montreal Sheet1

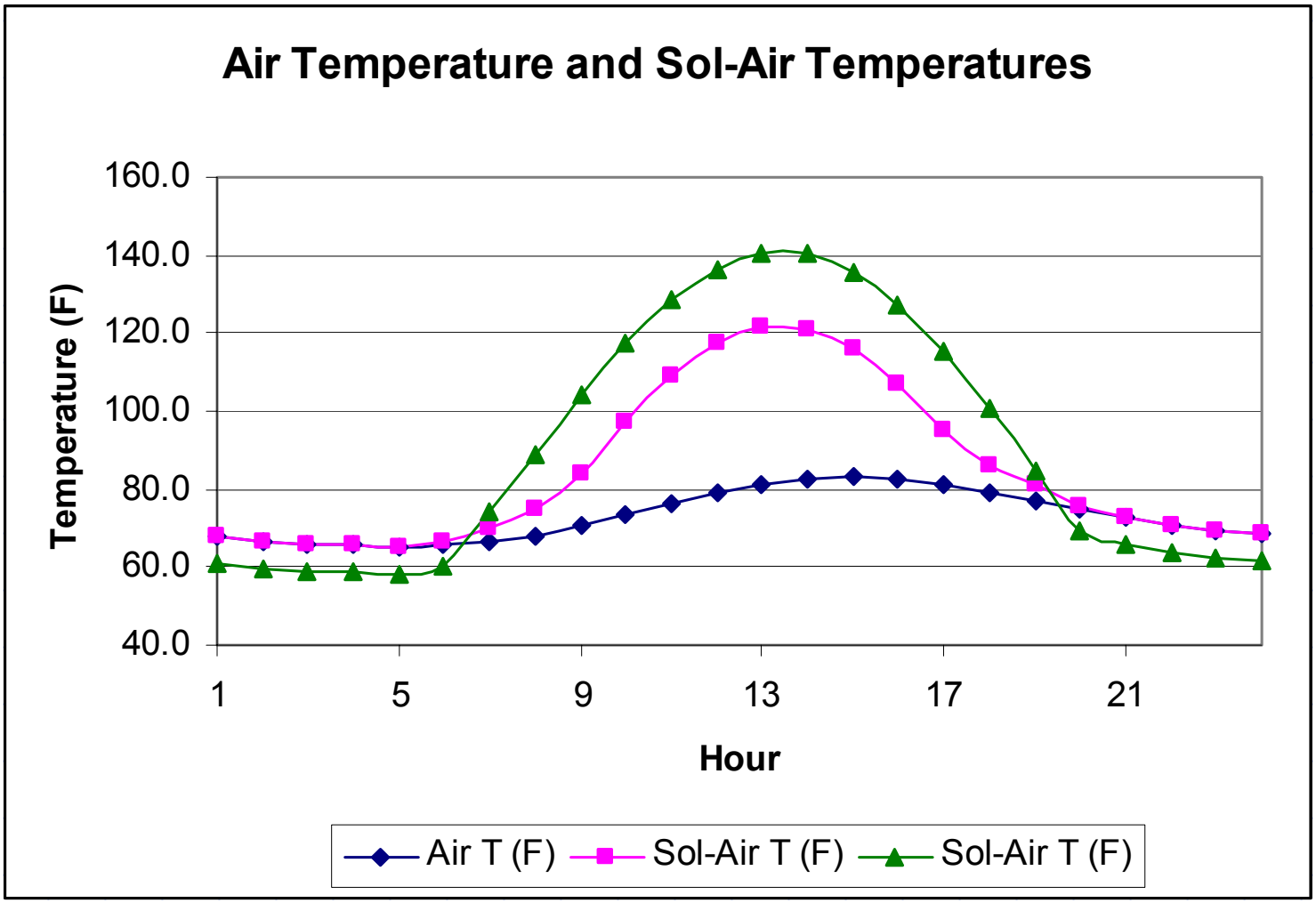
Draw AutoShapes

Ready

Total Incident Solar Radiation



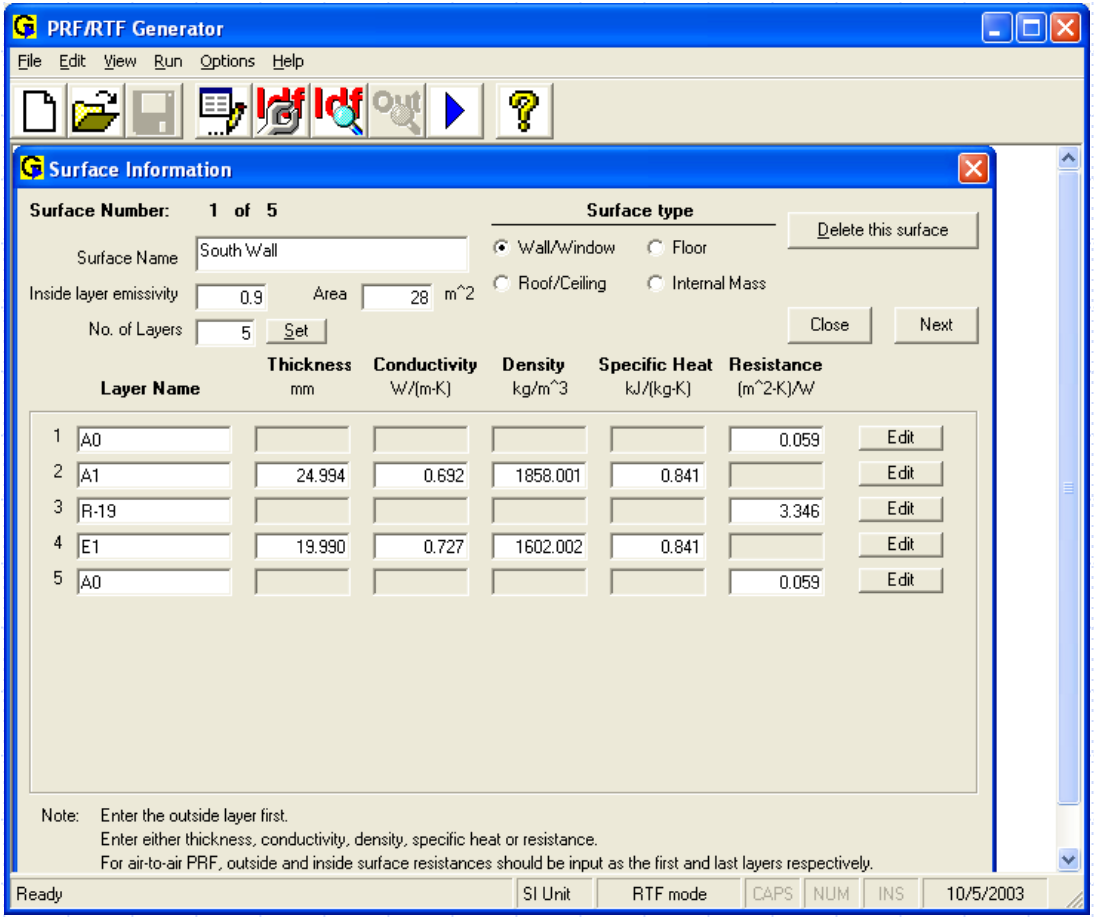
Sol-Air Temperatures



Generate Periodic Response Factors

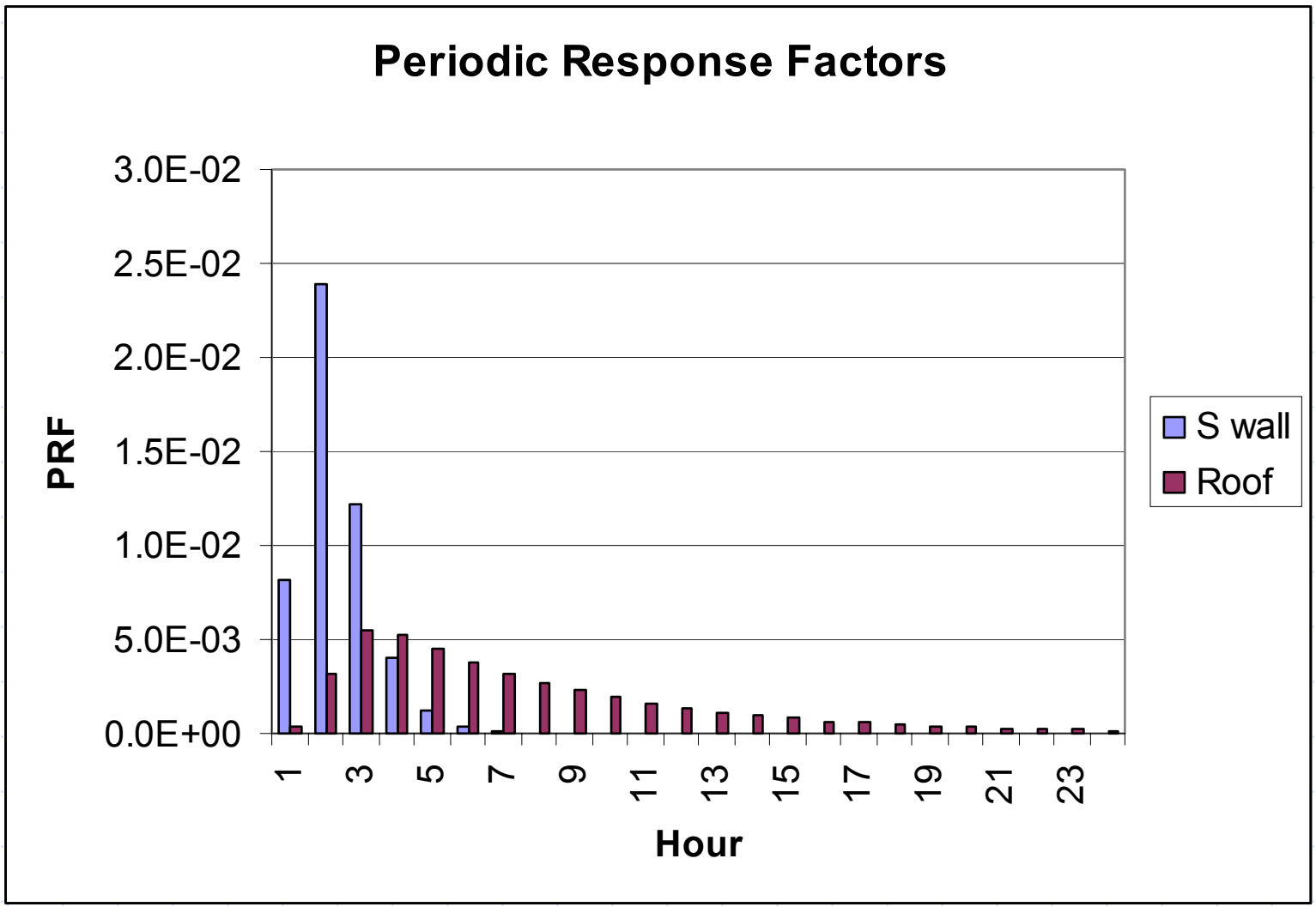
- Options
  - ASHRAE Load Calculation Principles Book
  - Software that comes with textbook
  - PRF/RTF Generator Software can be downloaded from www.hvac.okstate.edu
  - Tabulated in paper

PRF/RTF Generator



Free from www.hvac.okstate.edu

PRFs


Periodic Response Factors
PRF
3.0E-02
2.5E-02
2.0E-02
1.5E-02
1.0E-02
5.0E-03
0.0E+00
1
3
5
7
9
11
13
15
17
19
21
23
Hour
S wall
Roof

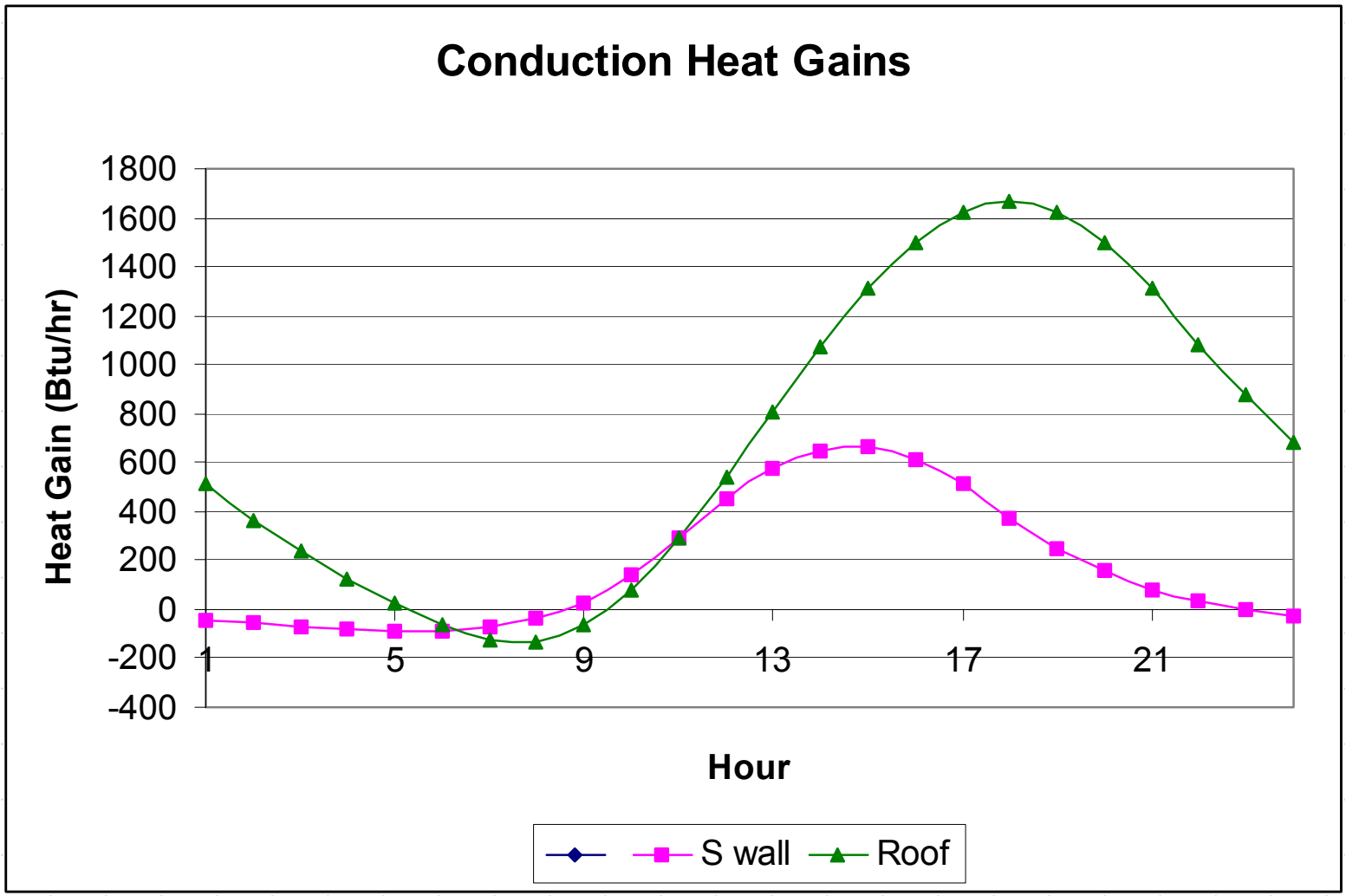
Calculate conduction heat gain

- Once PRFs and sol-air temperatures, are known, conduction heat gains can be directly calculated with a spreadsheet.

$$q''_{\theta} = \sum_{j=0}^{23} Y_{Pj} T_{e,\theta - j\delta} - T_{rc} \sum_{j=0}^{23} Y_{Pj}$$

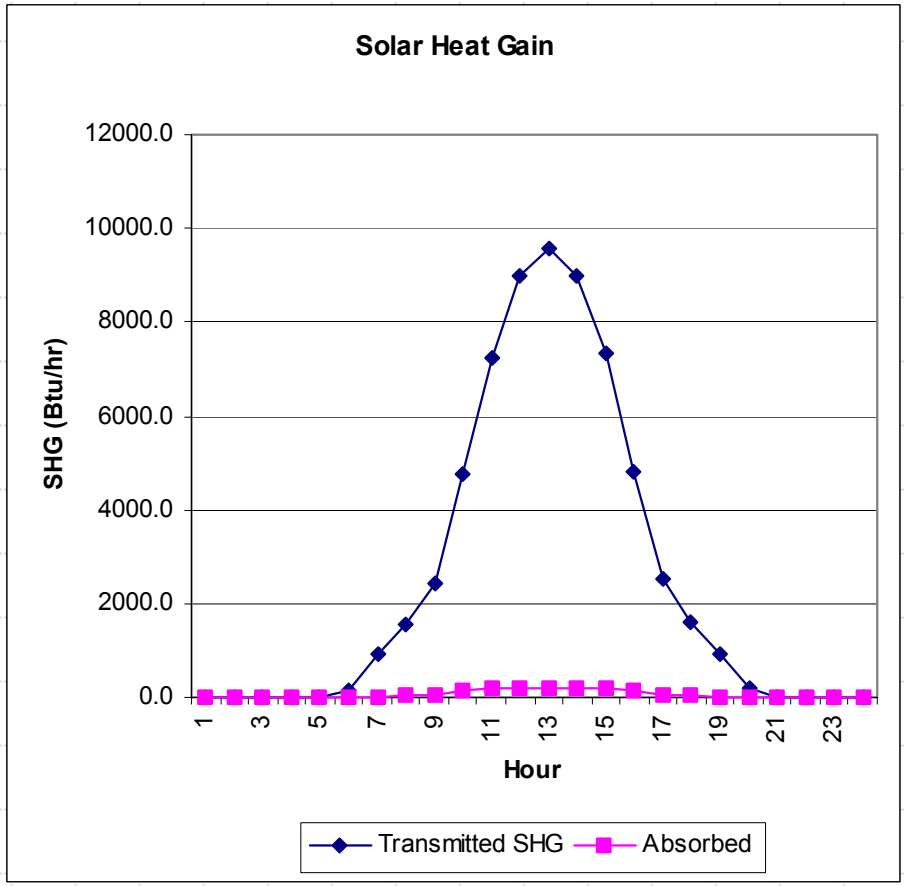
Conduction heat flux = YP0*current hour sol-air temperature + YP1* previous hour's sol-air temperature…

Conduction Heat Gains



Solar heat gains from window

- In this spreadsheet, done with shading coefficients.
- Current ASHRAE method uses SHGC.



Split heat gains

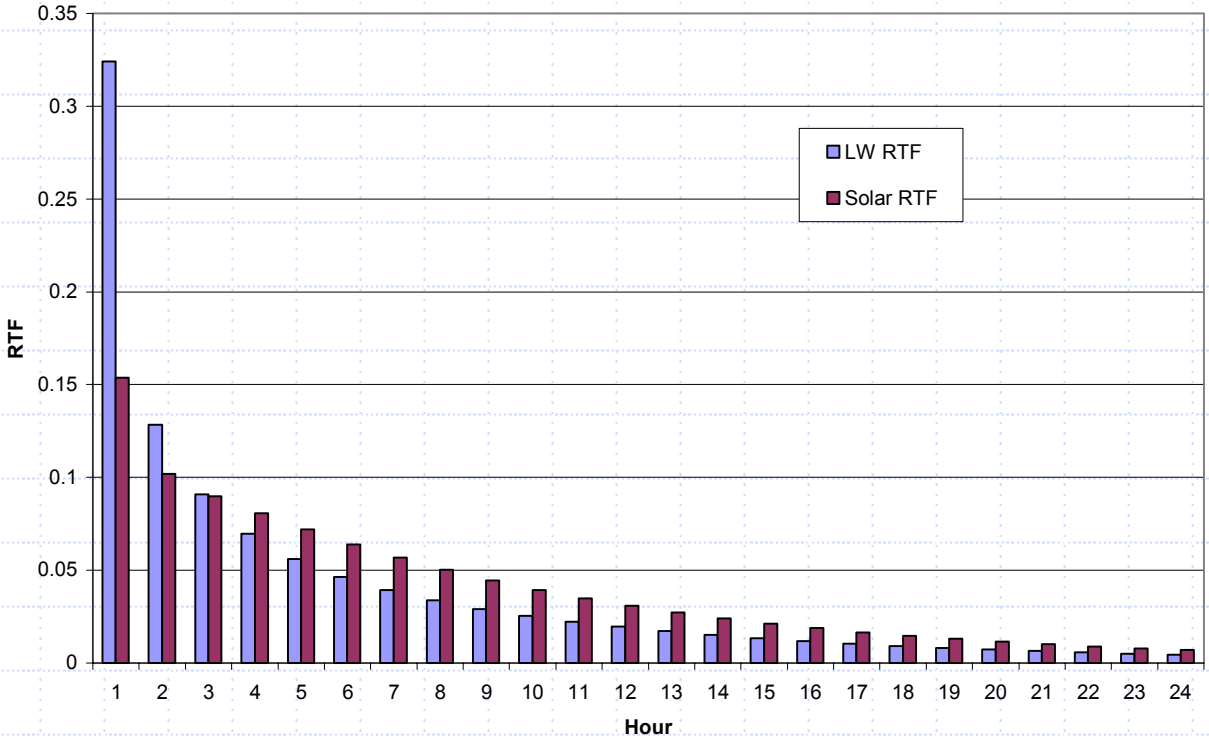
- Once all heat gains have been determined, they can be split into radiative and convective portions:

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

Determine RTS coefficients

- It is now necessary to determine the coefficients of the Radiant Time Series, also known as Radiant Time Factors
- Can be done with:
  - Software that comes with ASHRAE Load Calculation Principles Book
  - Software that comes with a text book.
  - PRF/RTF Generator Software

Calculated RTF



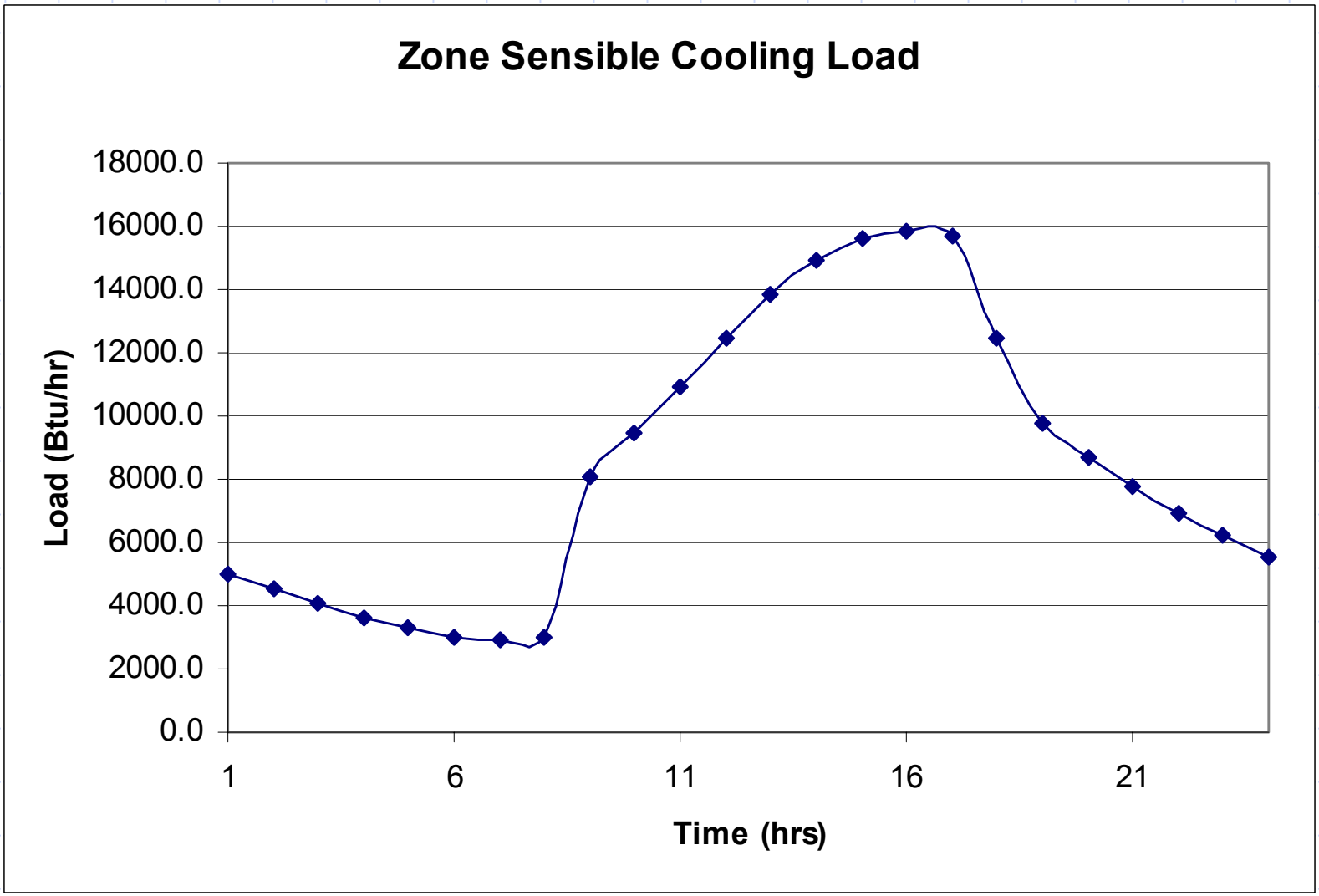
Apply using periodic response factor equation:

$$Q_\theta = r_0 q_\theta + r_1 q_{\theta-\delta} + r_2 q_{\theta-2\delta} + r_3 q_{\theta-3\delta} + \ldots + r_{23} q_{\theta-23\delta}$$

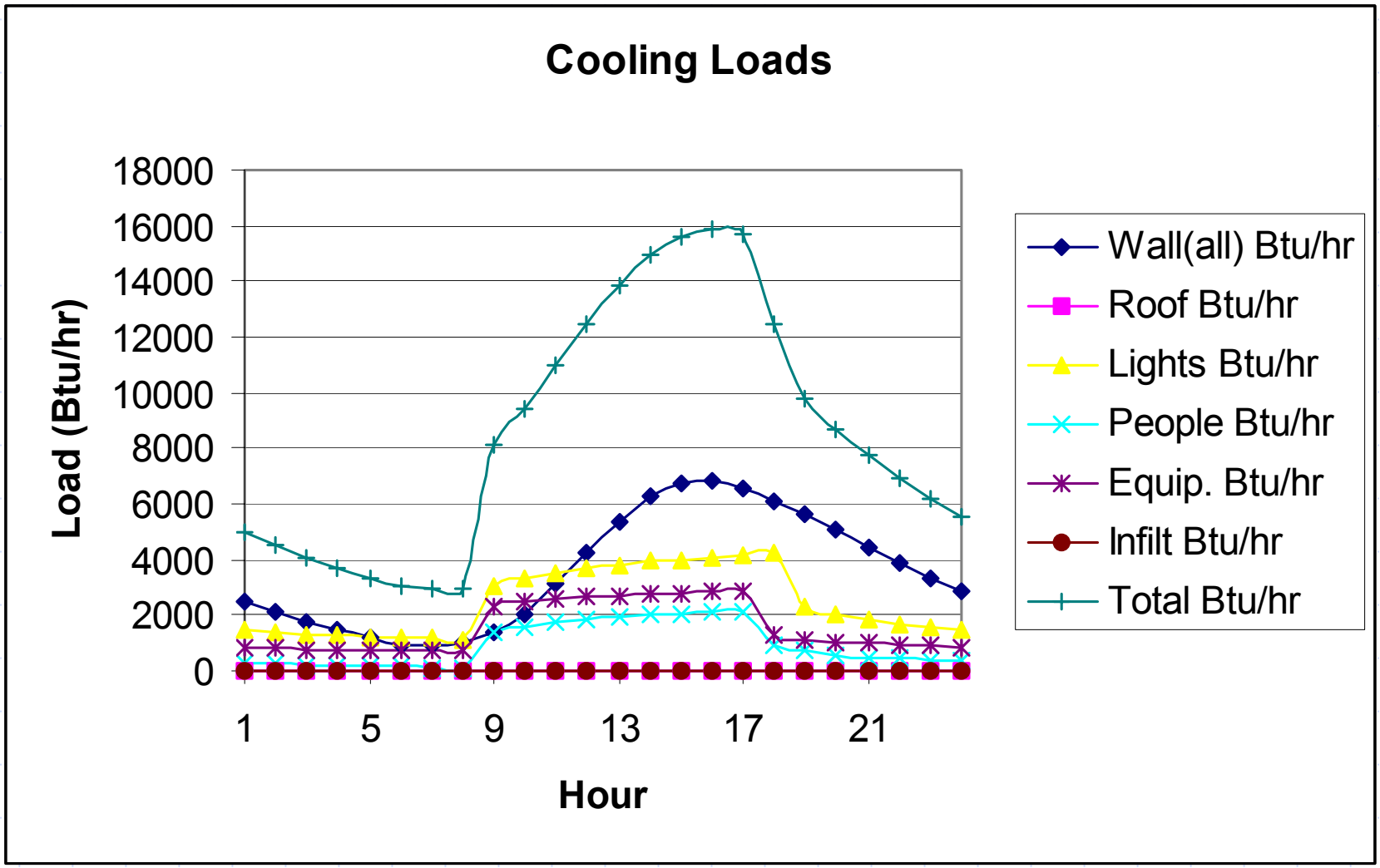
Calculate Loads

- Sum radiative loads (calculated from radiative heat gains and RTFs) and convective loads.

Total Cooling Loads



Component Loads



Conclusions

- The RTS method replaces other simplified methods. It has the following features:
  - Accuracy similar to the Transfer Function Method, with greatly simplified calculation procedure.
  - Spreadsheet-friendly.
  - Intermediate results can be inspected and understood.

Future Work

- Incorporation of SHGC for Fenestration.
- This spreadsheet and presentations will be available at www.hvac.okstate.edu.
- Commercial programs.

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