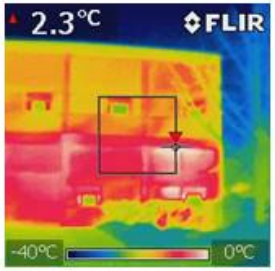
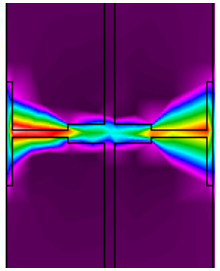
CAE 331/513 Building Science

Fall 2019





November 19, 2019

Load calculations and energy estimation part 2

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HW 6 QUESTIONS?

HW 6 Part 1 – Little boxes

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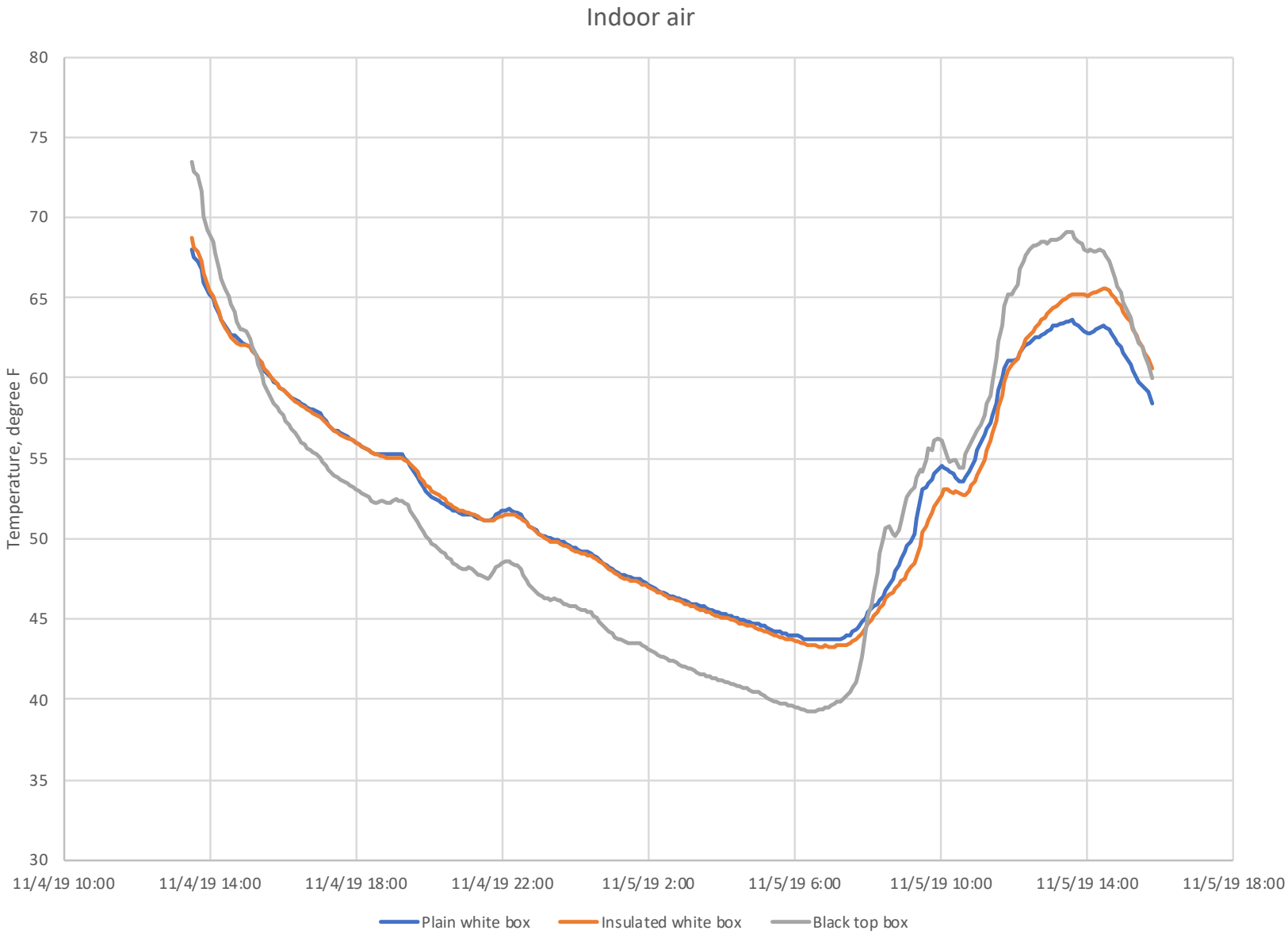
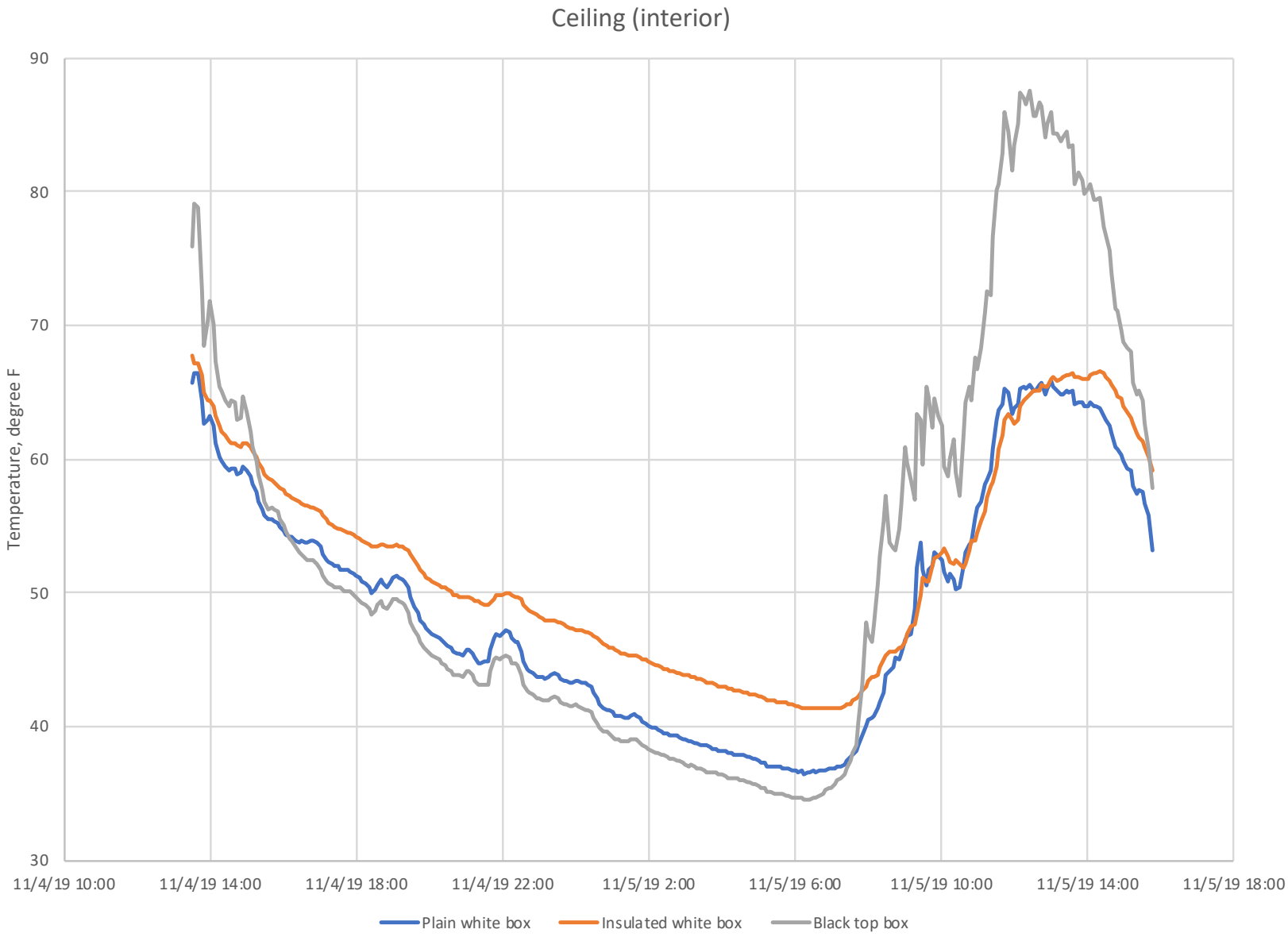
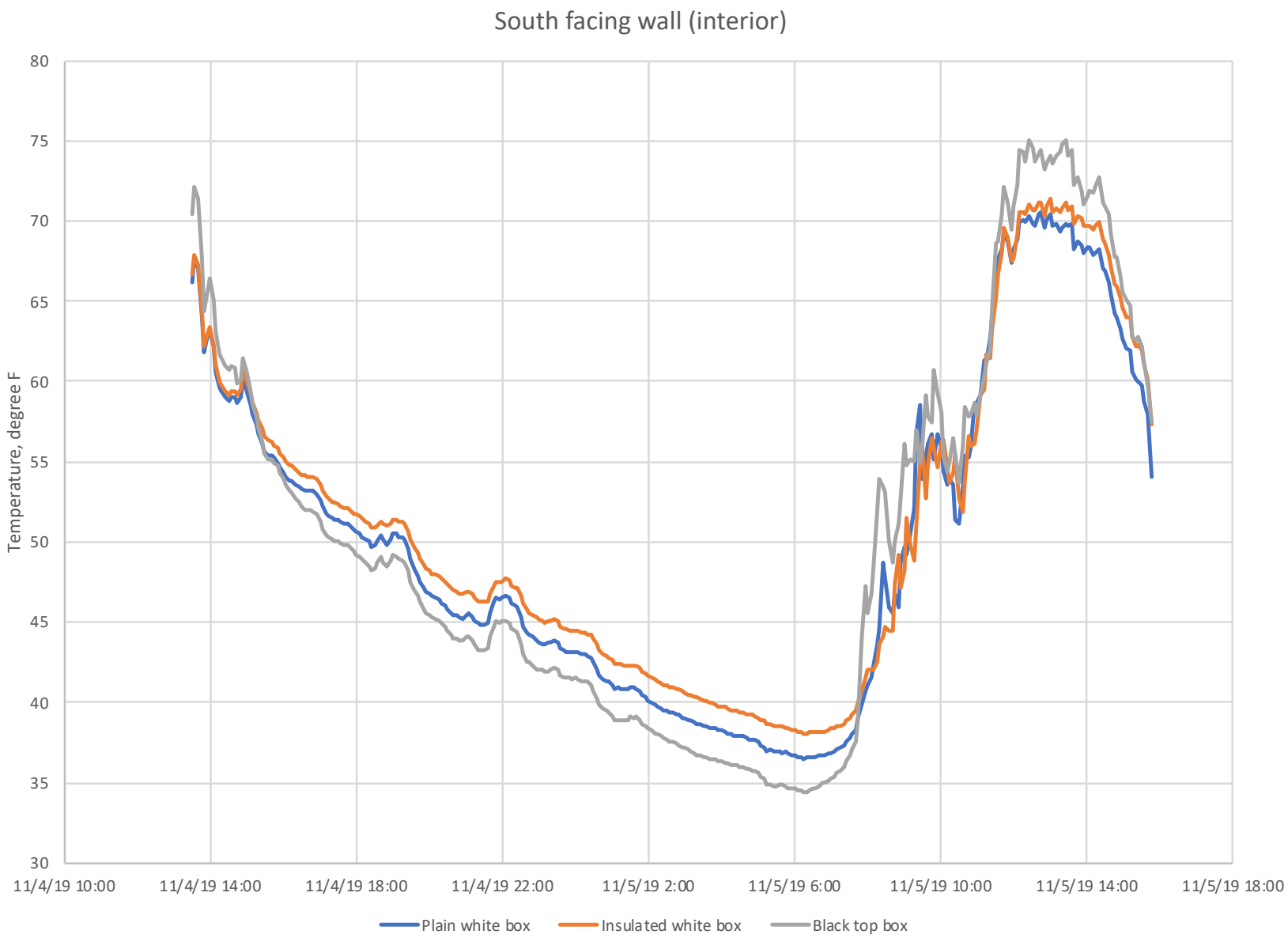


HW 6 Part 1 – Little boxes



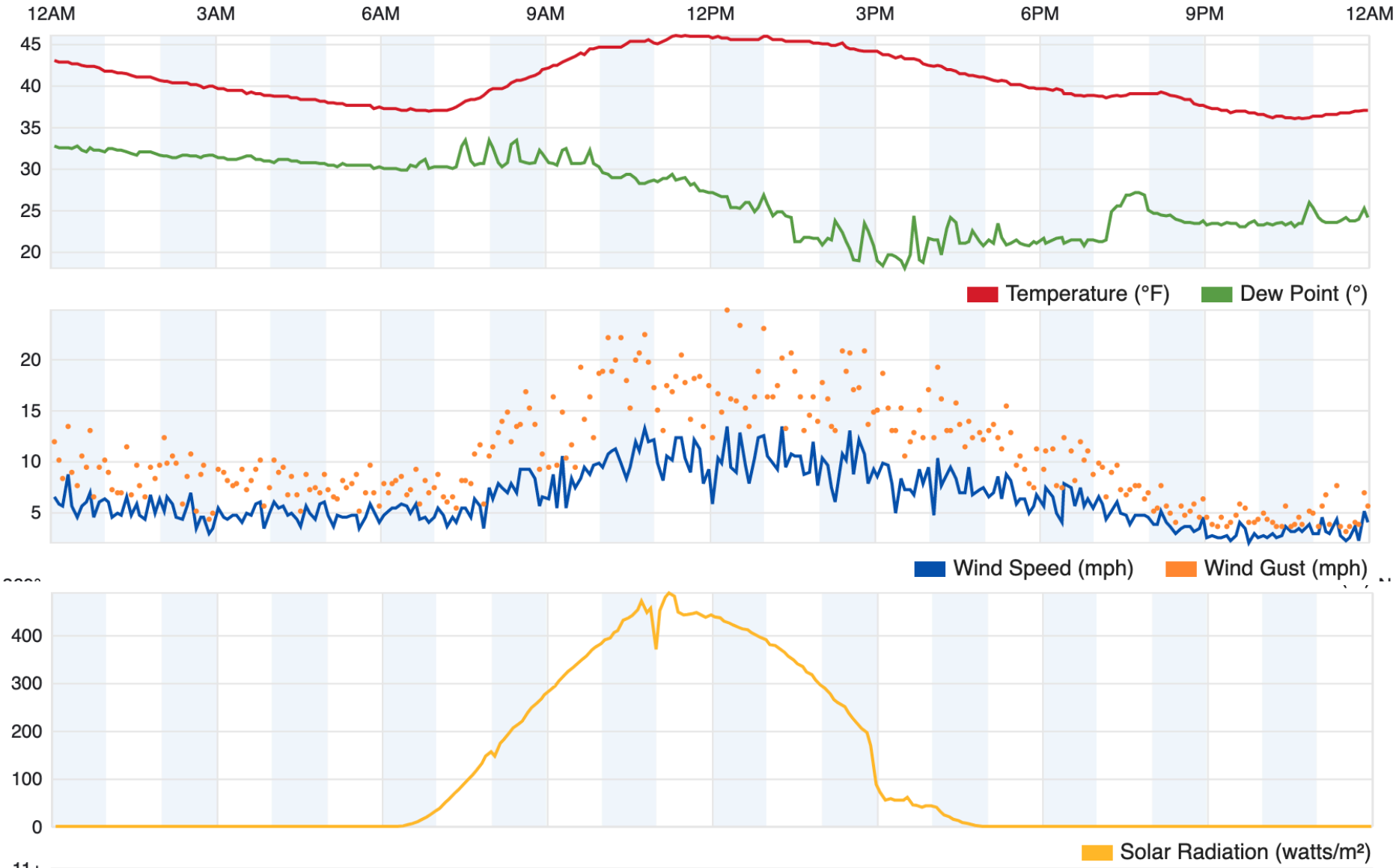
HW 6 Part 1 – Little boxes



HW 6 Part 1 – Little boxes

November 5, 2019

https://www.wunderground.com/dashboard/pws/KILCHICA692/graph/2019-11-5/2019-11-5/daily



What are energy balances useful for?

1. Heating and cooling load calculations
   - i.e., equipment sizing to meet peak heating/cooling loads

2. Annual energy estimation

Last time and today

Last time:

- Design conditions for heating/cooling load calculations
- Heating load calculations
- Heating energy estimation via Heating Degree Days (HDD)

Today:

- Cooling load calculations
- Energy estimation using whole building energy simulation

COOLING LOAD CALCULATIONS & ENERGY ESTIMATION

Cooling loads

- Cooling load calculations are more complicated than heating load calculations
- Peak cooling loads will occur during the day when solar radiation is present
  - People and equipment can also be highly variable
- Radiation varies throughout the day and the building's **thermal mass** affects the time release of this heat energy
  - Calculations must be ***dynamic*** to account for ***storage***

$$Q_{sensible\,load} =$$

$$Q_{envelope\,transmission} + Q_{air\,exchange} - Q_{solar} - Q_{people} - Q_{equipment} - Q_{lights} \pm Q_{storage}$$

Remember:
Q is typically positive (+) when there is a heating load (cold outside)
Q is typically negative (-) when there is a cooling load (hot outside)

Dynamic response for cooling loads

- Cooling load calculations differ because gains from **radiation** do not directly heat up the air in the space
  - Only **convection** from interior surfaces contributes to an immediate temperature rise in the air space

- Radiation through windows, from interior surfaces, and from internal sources (e.g., lights) will be absorbed by other interior surfaces, and then those surfaces will eventually transfer that heat energy to the air by convection
  - But the addition of radiative heat <u>does not occur immediately</u>

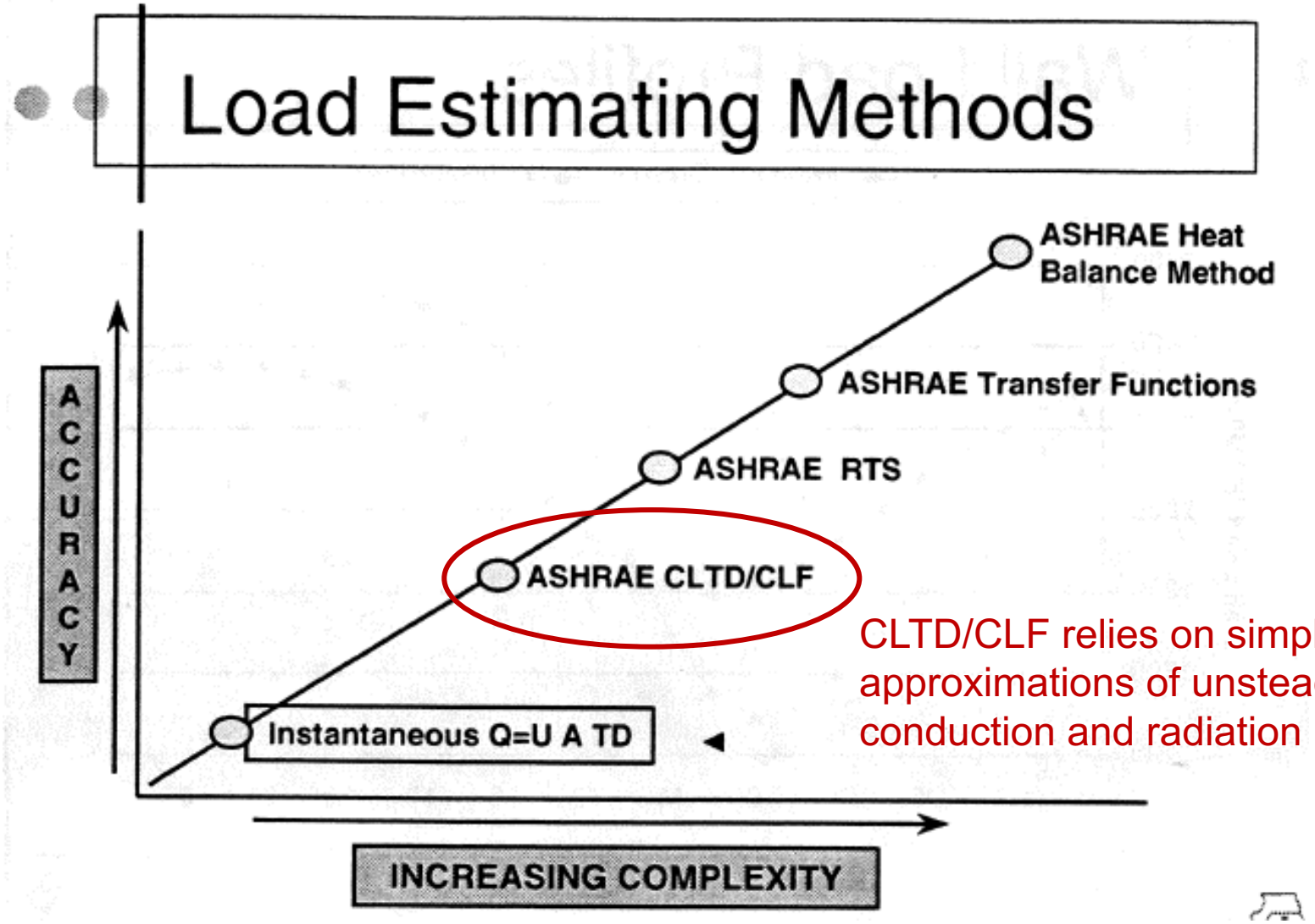
- Because radiative heating is not direct, **heat storage** through **thermal mass** can create a thermal lag, which can have a large effect on cooling loads

COOLING LOAD CALCULATION METHODS

Cooling load calculation methods

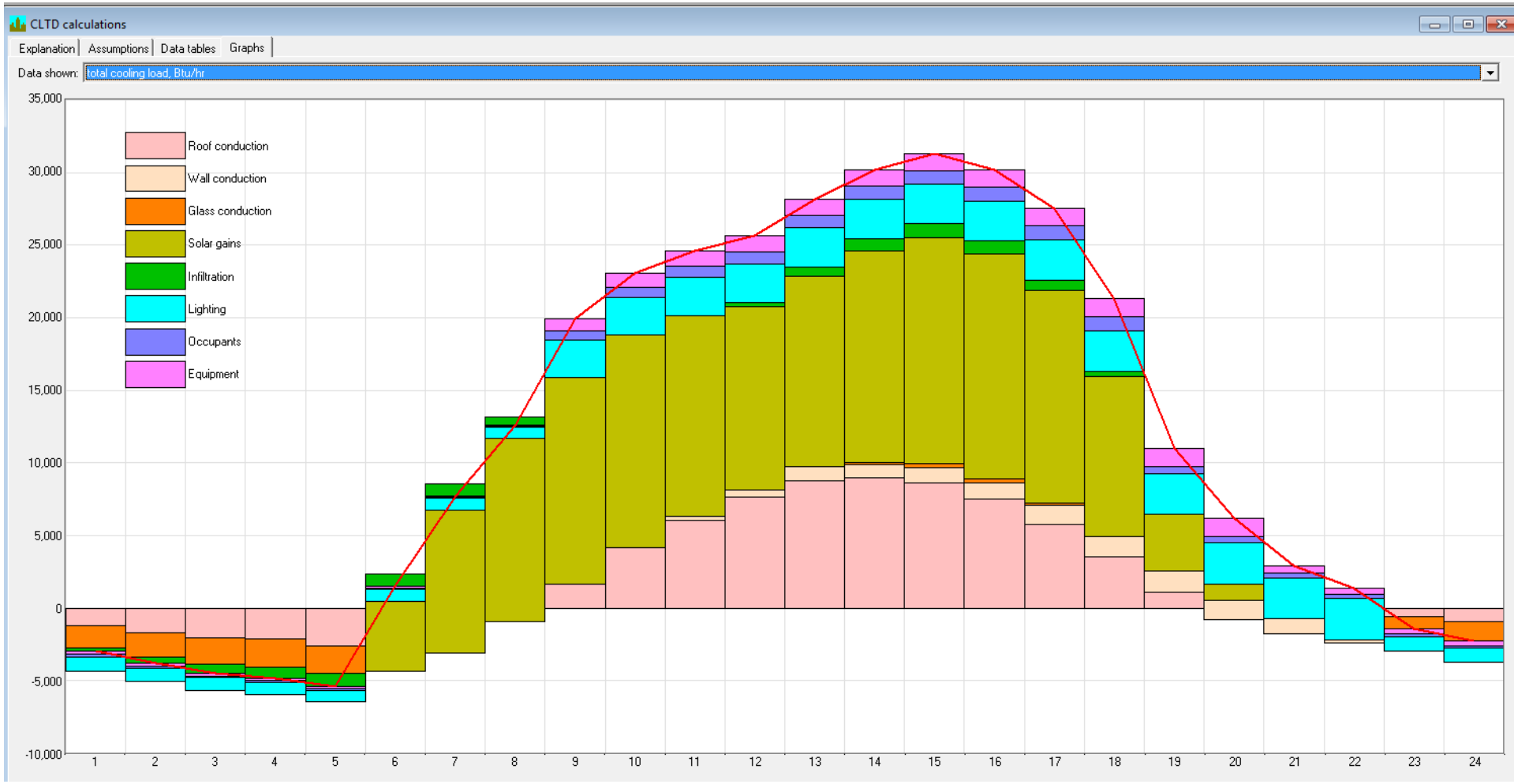
- Dynamic responses & thermal mass make cooling load calculations much more complex than heating loads
- There are <u>several methods</u> of estimating peak cooling loads
  - They vary in complexity, accuracy, computational time, and requirements for input details
- Common cooling load calculation methods:
  - Transfer Function (TF)
  - Total Equivalent Temperature Difference (TETD)
  - Cooling Load Temperature Difference/Cooling Load Factor (CLTD/CLF)
  - Radiant Time-Series (RTS)
  - Heat Balance Method (HBM)
- They all rely on spreadsheets and/or computer programs

Cooling load calculation methods

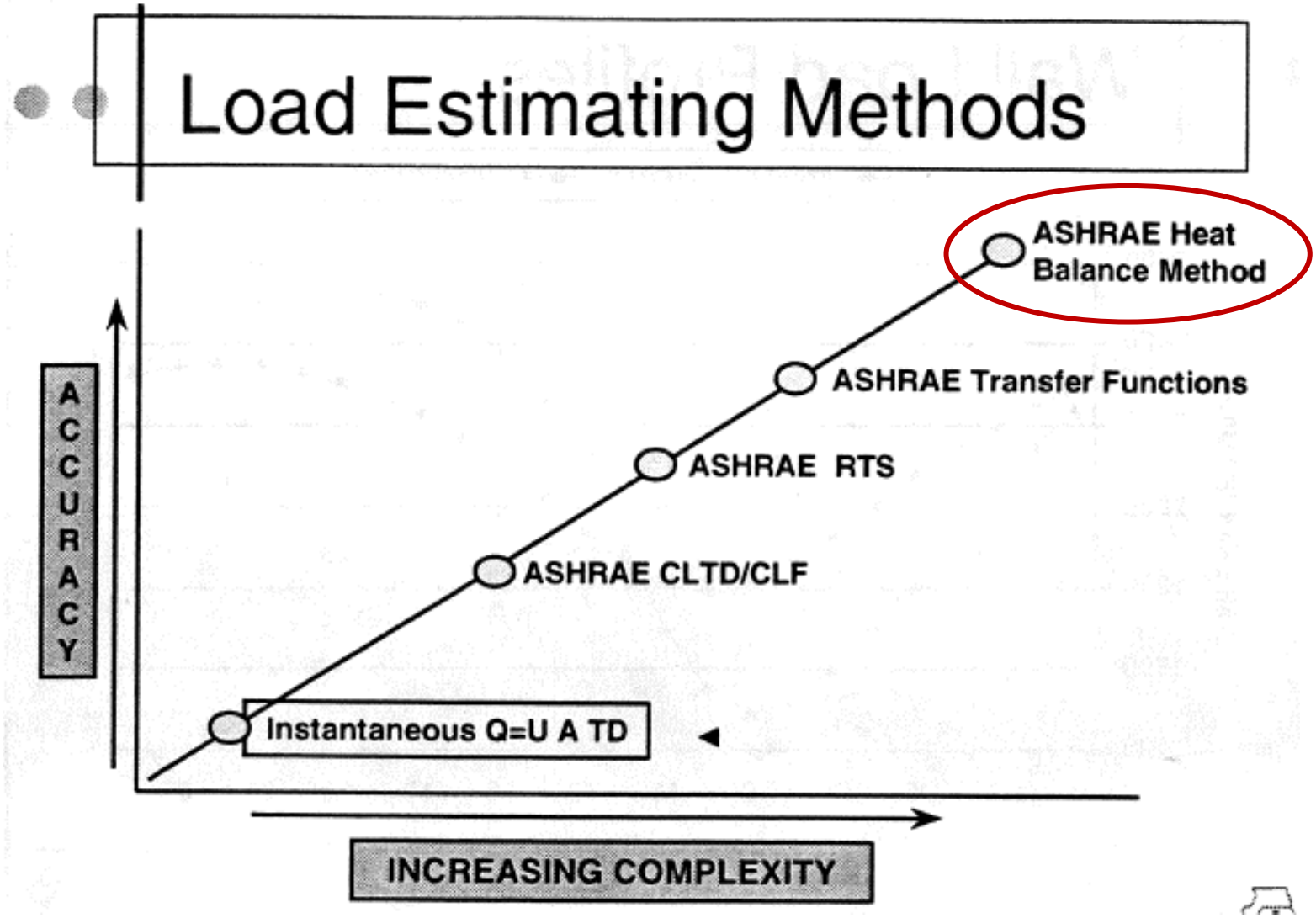


CLTD/CLF relies on simple table approximations of unsteady conduction and radiation

CLTD/CLF method demonstration



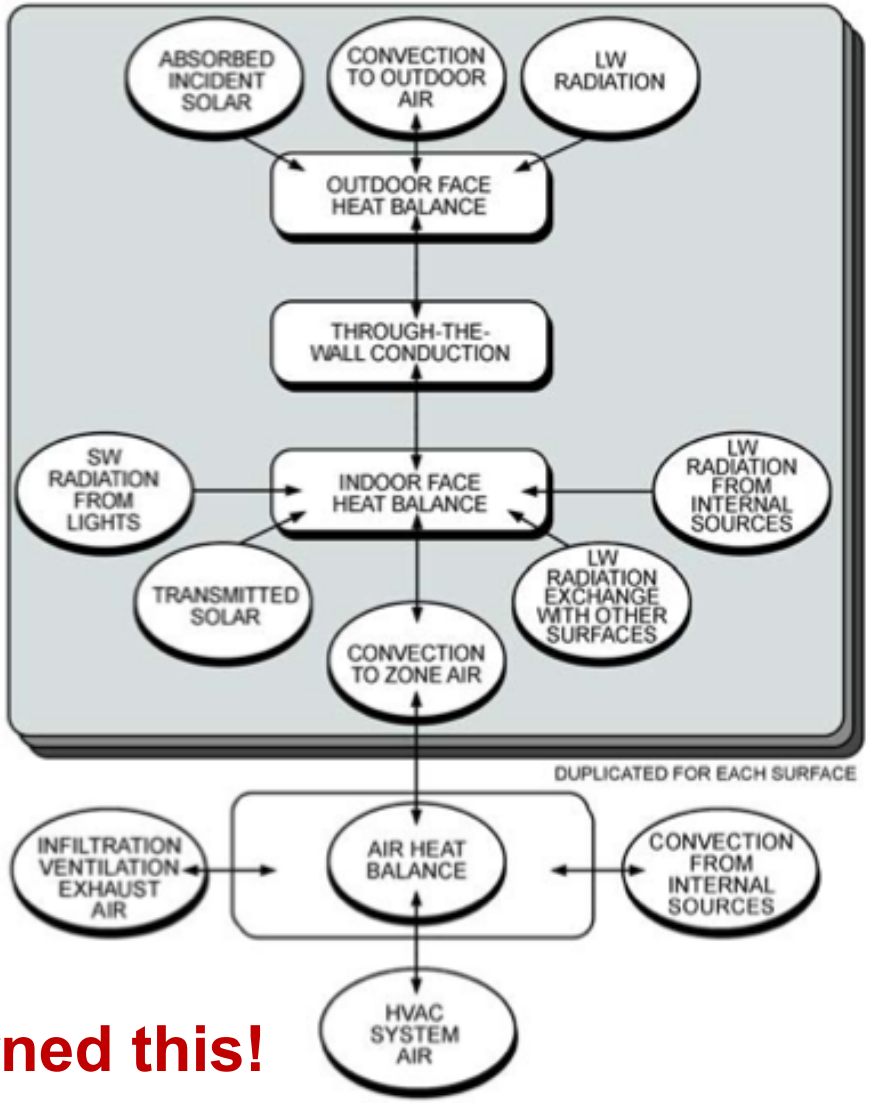
Cooling load calculation methods



Heat balance method (HBM)

- HBM is based on the law of conservation of energy
  - A set of energy balance equations for an enclosed space is solved simultaneously for unknown surface and air temperatures
- Consists of three important energy balance equations:
  - Heat balance on exterior surfaces
  - Heat balance on interior surfaces
  - Heat balance on indoor air
    - The energy balance is based on the fundamental heat transfer equations we already know
- Calculations are initiated by hourly outdoor weather data
  - Design day meteorological data (or full year, e.g., TMY3)
- It is more fundamentally linked than other approaches
  - Makes fewer assumptions than the other methods
    - But is more complex to solve
  - HBM provides the basis for modern energy simulation programs

Heat balance method (HBM)



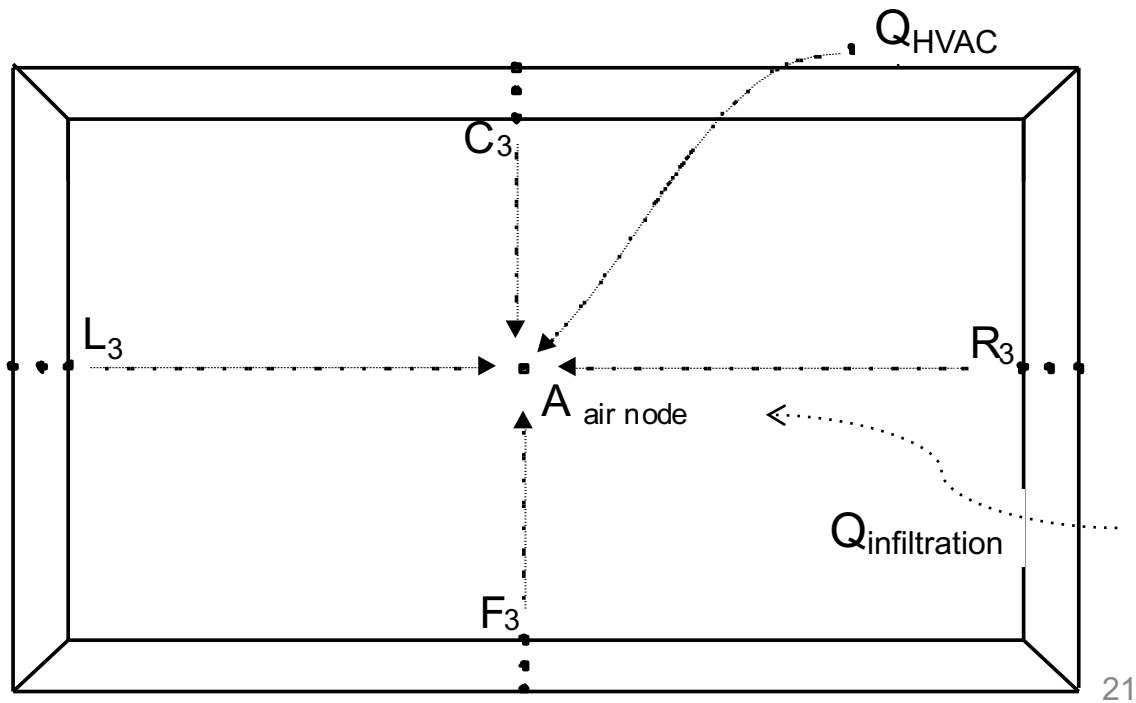
We already learned this!

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



HBM: Surface energy balances

- For an example 2-D room like this, you would setup a system of equations where the temperature at each node (either a surface or within a material) is unknown
  - 12 material nodes + 1 indoor air node

Heat Xfer @ external surfaces:
Radiation and convection

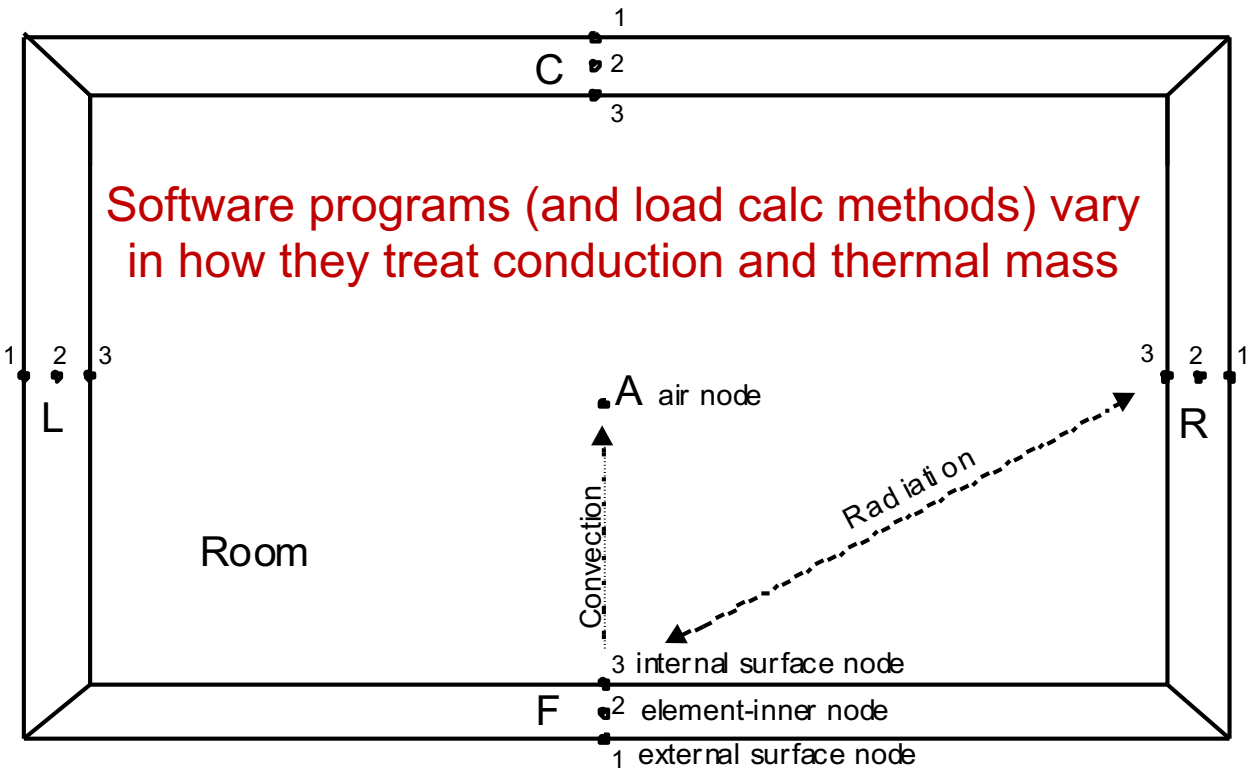
At surface nodes:

$$\sum q = 0$$

At nodes inside materials:

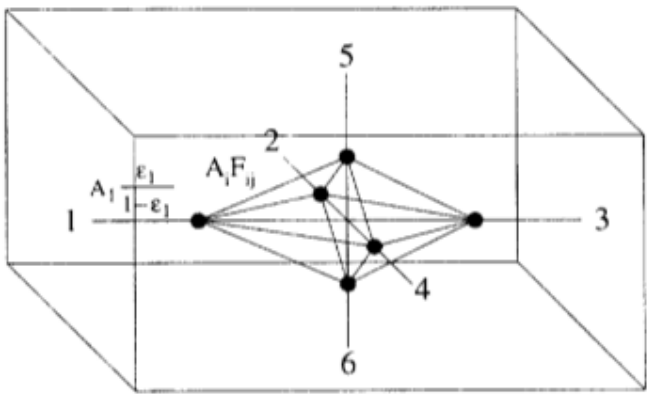
$$mc_p \frac{dT}{dt} = \sum q_{at\ boundaries}$$

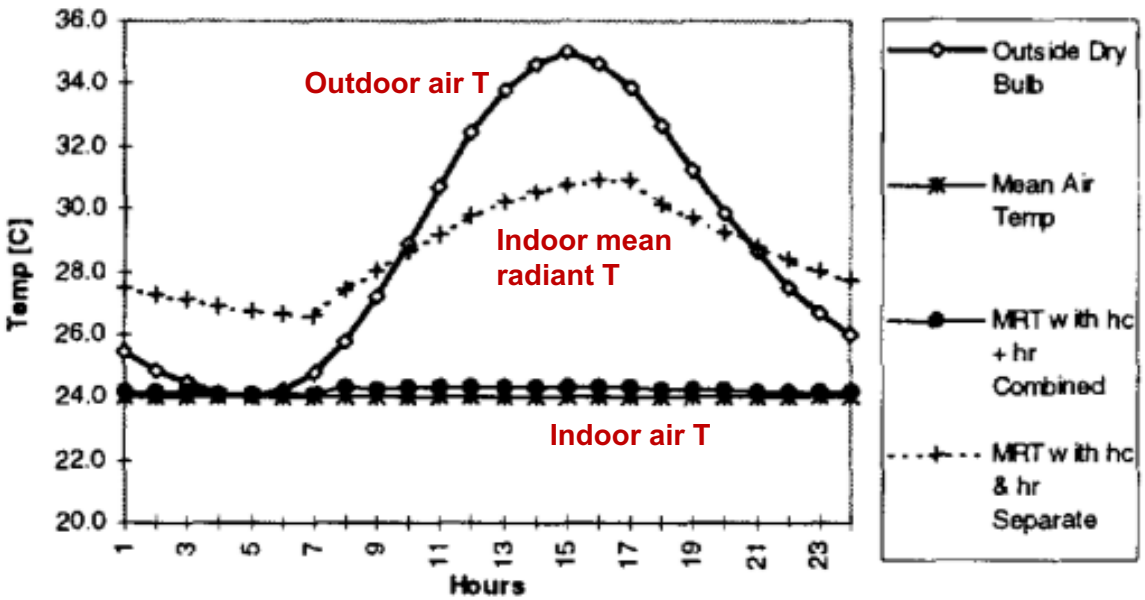
Unsteady conduction (storage) is based on density and heat capacity of material



Using HBM to calculate peak loads

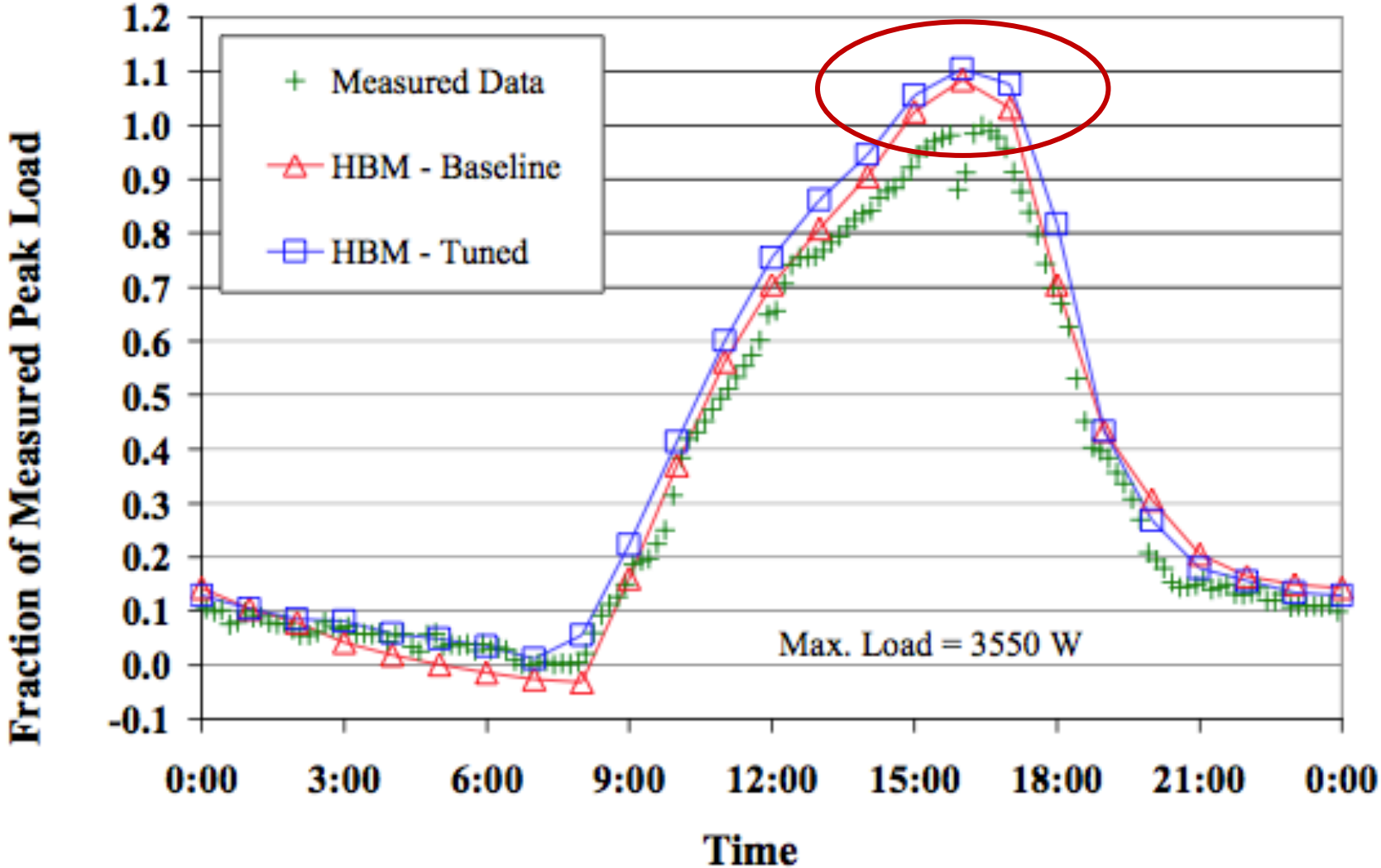
- Tracking indoor and outdoor temperatures for a simple space:





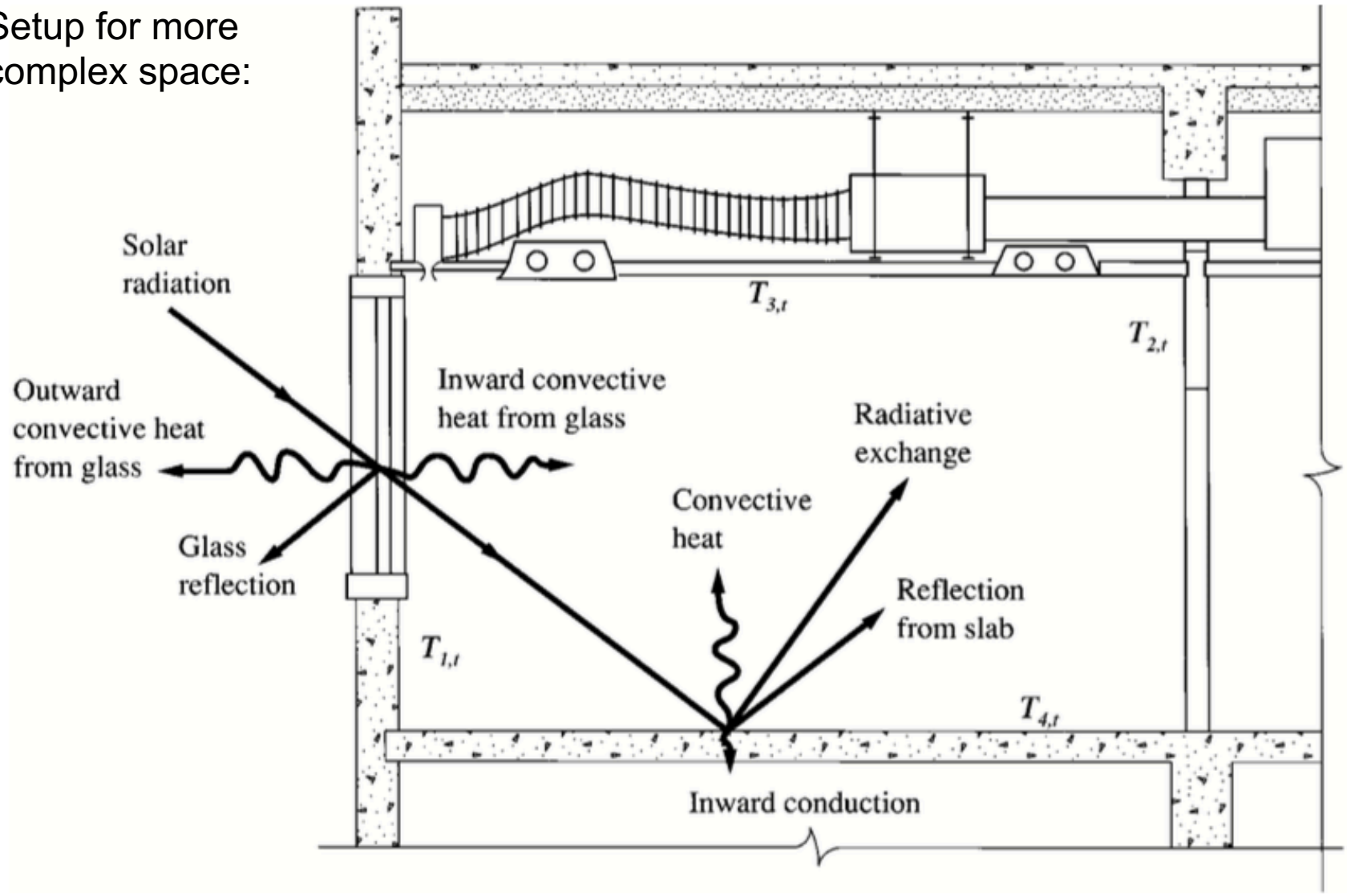
Using HBM to calculate peak loads

- Tracking the cooling load for a simple space:

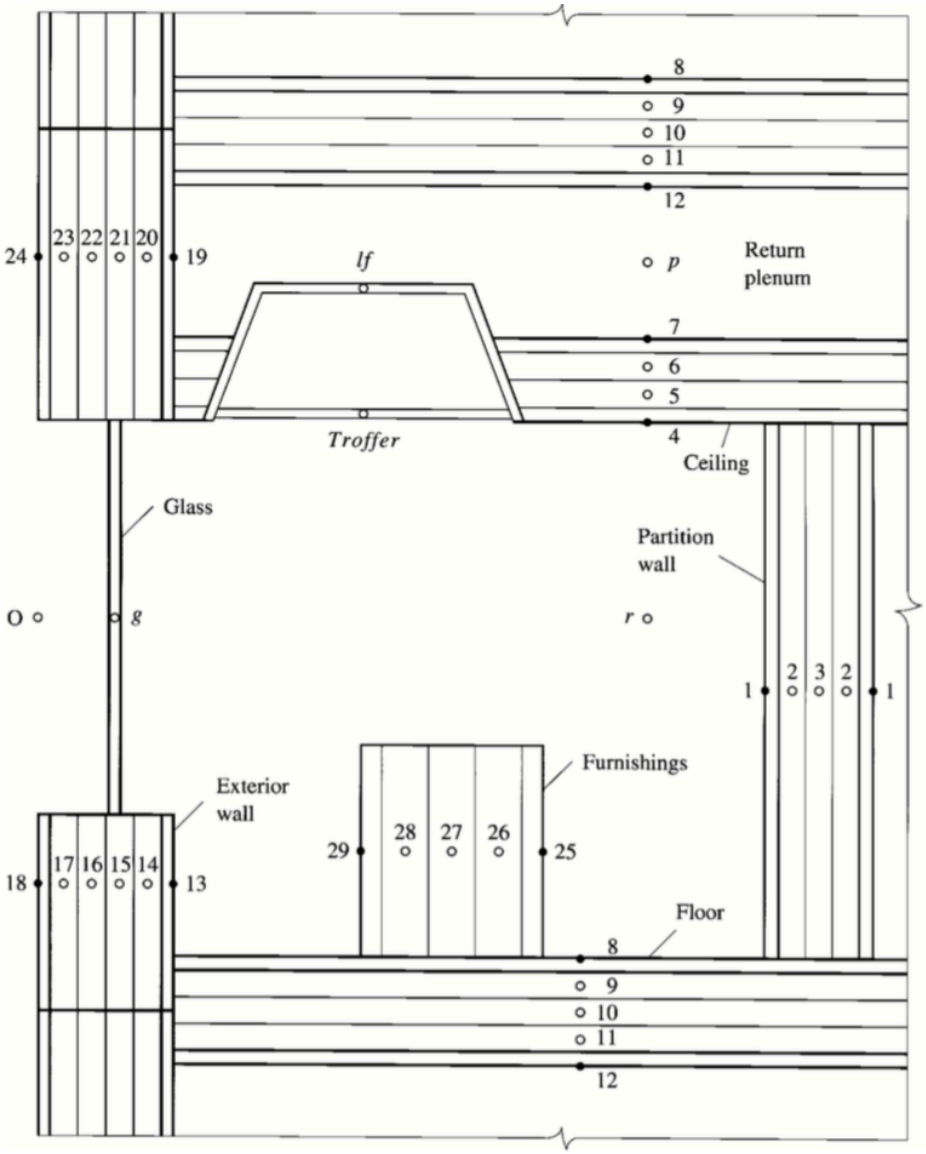


Using HBM to calculate peak loads

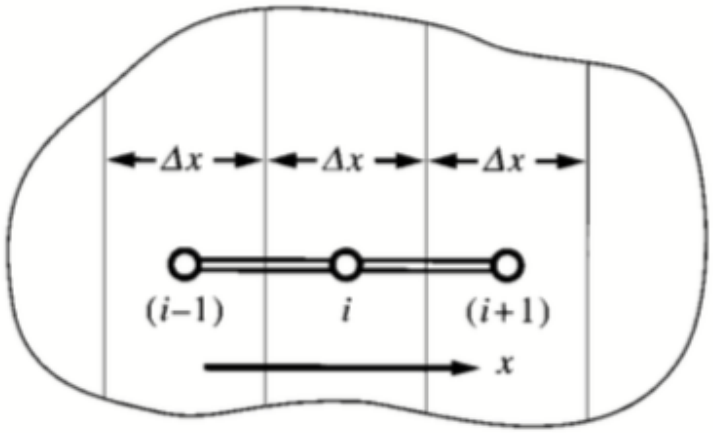
Setup for more complex space:



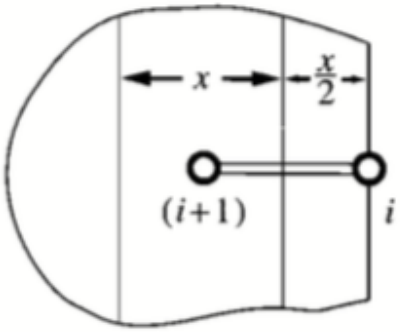
Using HBM to calculate peak loads: Complex



Setup for more complex space:



Interior node



Surface node

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

Software packages for heating/cooling load calcs

- Trane Trace 700
- Carrier HAP
- ASHRAE Radiant Time Series (RTS) spreadsheet

- Full-fledged energy simulation programs

BUILDING ENERGY SIMULATION

Building energy simulation

- The same methods for estimating peak heating and cooling loads (i.e. the **heat balance method**) can also be used to develop **whole building annual energy simulations**

- Annual energy simulations use software to solve systems of equations (dozens, hundreds, or thousands) to predict hourly (or sub-hourly) energy use over the course of a Typical Meteorological Year (TMY)
  - All based on energy balances at surface nodes, interior nodes for materials, and indoor air nodes

Whole building energy simulation

- We use the same equations for calculating peak cooling loads to write the total **building energy balance**
  - This forms the core of all building energy modeling programs
- We build a **system of equations** linking energy balances at a series of "nodes"
  - Each node has an equation accounting for all modes of heat transfer
  - Involves linking the nodes and predicting hourly indoor air temperatures (or HVAC loads) as the primary unknown
  - Also requires us to add interior heat gains
    - People, lights, equipment, etc.
    - Direct power draw + indirect heat gains
- Whole building energy simulation goes a few steps further:
  - Include HVAC system capacity & efficiency models to get HVAC energy
  - Gives us estimates of total energy use

Estimating energy use from load calculations

- Once we have estimated the hourly heating or cooling energy demand, we can fairly easily estimate energy use required for heating or cooling purposes

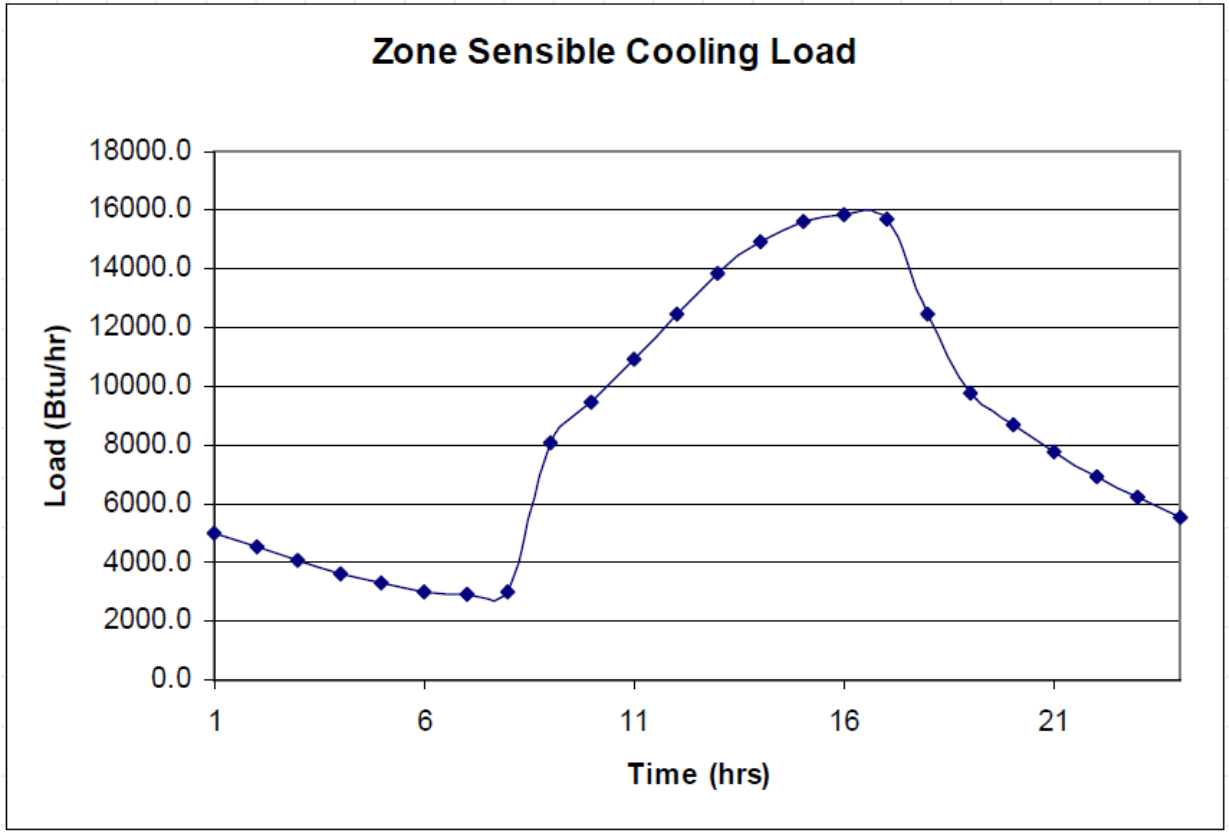
- If you know the hourly load (either for just a peak day or for the whole year), you can estimate the amount of energy required to meet that load by knowing the efficiency of the system (COP or EER)

$$\mathrm{P}_{elec} = \frac{Q_{cooling,load}}{COP} \quad [\mathrm{W\ or\ kW}]$$

$$E = \sum \mathrm{P}_{elec}\,\Delta t \quad [\mathrm{Wh\ or\ kWh}]$$

Estimating energy use from load calculations

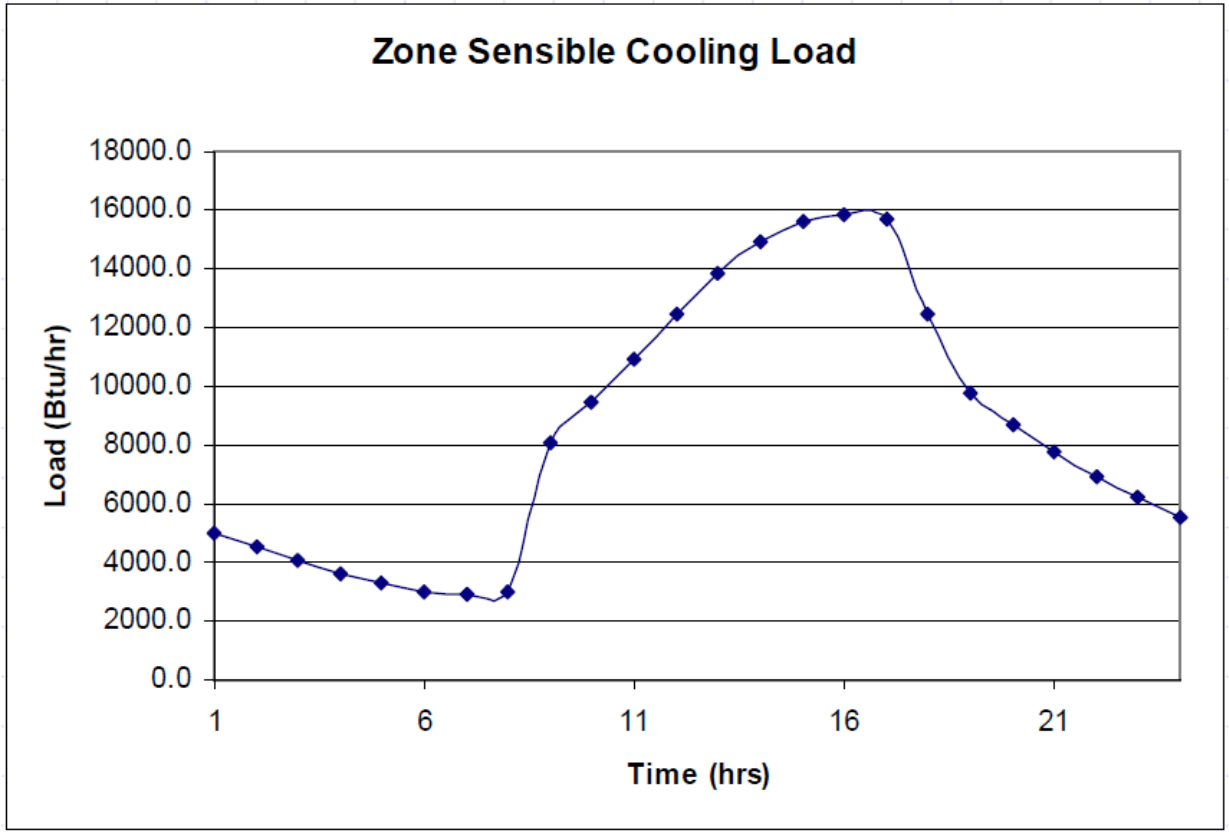
Example for cooling energy:



Total load Btu/hr
4418
3843
3352
2940
2623
2419
2465
2737
8190
9562
10883
12143
13275
14250
15007
15486
15701
10635
9550
8460
7477
6588
5777
5057

Estimating energy use from load calculations

Example for cooling energy:



Total load Btu/hr	Power draw W
4418	432
3843	375
3352	327
2940	287
2623	256
2419	236
2465	241
2737	267
8190	800
9562	934
10883	1063
12143	1186
13275	1297
14250	1392
15007	1466
15486	1513
15701	1534
10635	1039
9550	933
8460	827
7477	730
6588	644
5777	564
5057	494

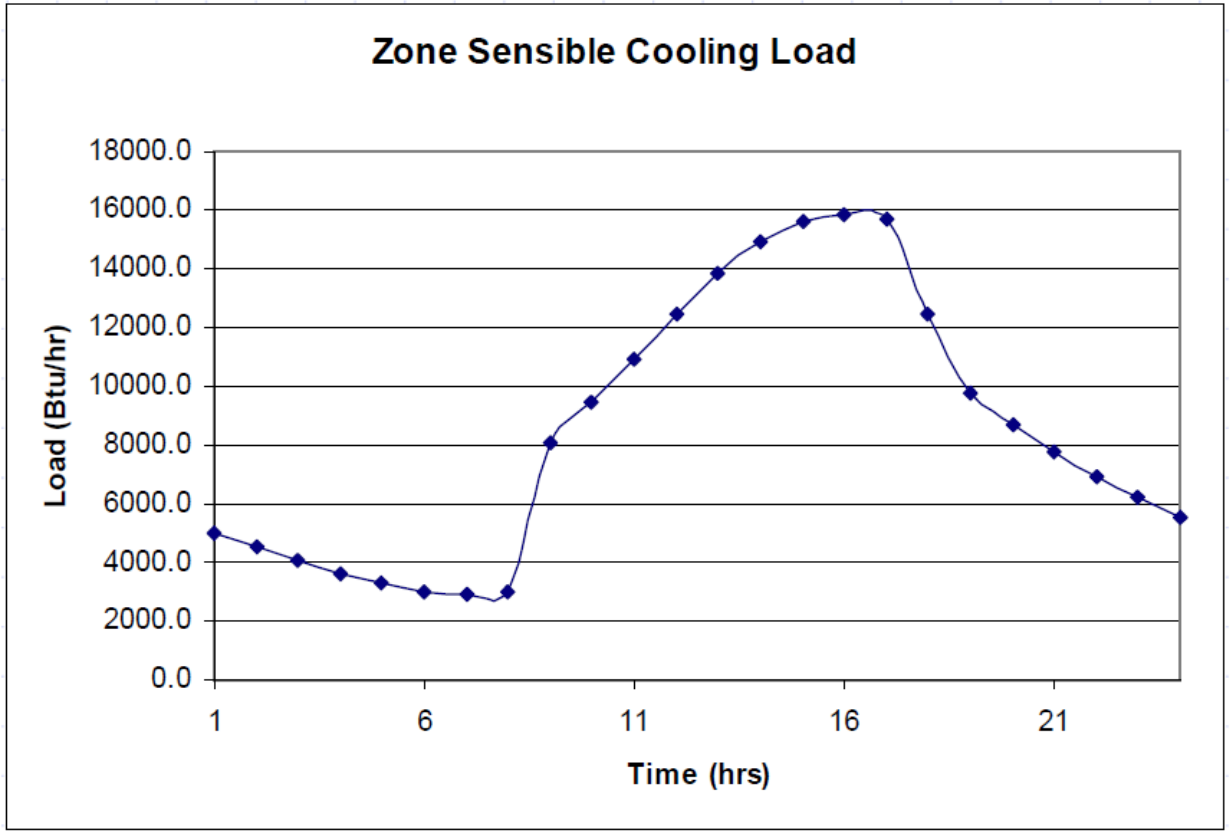
$$P_{elec}(t) = \frac{Q_{cooling,load}(t)}{EER}$$

COP 3.0

EER 10.24

Estimating energy use from load calculations

Example for cooling energy:



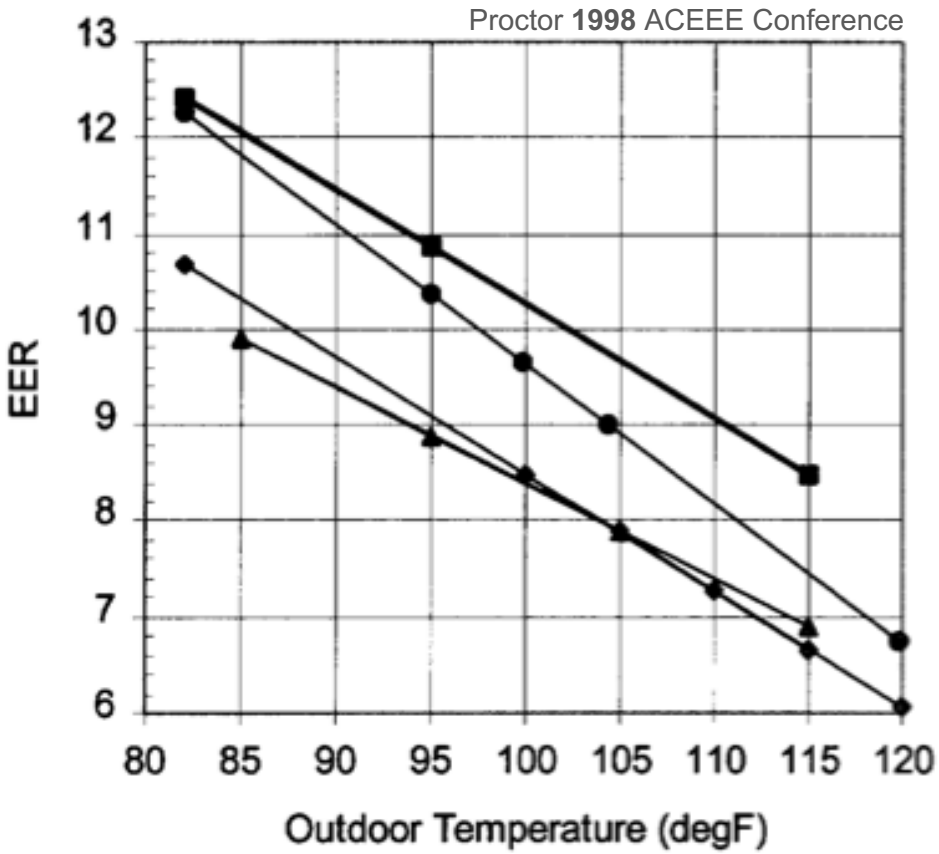
Total load Btu/hr	Power draw W	Energy kWh
4418	432	0.43
3843	375	0.38
3352	327	0.33
2940	287	0.29
2623	256	0.26
2419	236	0.24
2465	241	0.24
2737	267	0.27
8190	800	0.80
9562	934	0.93
10883	1063	1.06
12143	1186	1.19
13275	1297	1.30
14250	1392	1.39
15007	1466	1.47
15486	1513	1.51
15701	1534	1.53
10635	1039	1.04
9550	933	0.93
8460	827	0.83
7477	730	0.73
6588	644	0.64
5777	564	0.56
5057	494	0.49
	Energy used (kWh)	**18.8**
	Energy price ($/kWh)	**0.11**
	Energy cost ($)	**$2.07**

$$E = \sum P_{elec} \Delta t$$

*Note that COP will vary as a function of time and outdoor conditions

Estimating energy use from load calculations

- Accounting for varying COP/EER w/ T_{out}

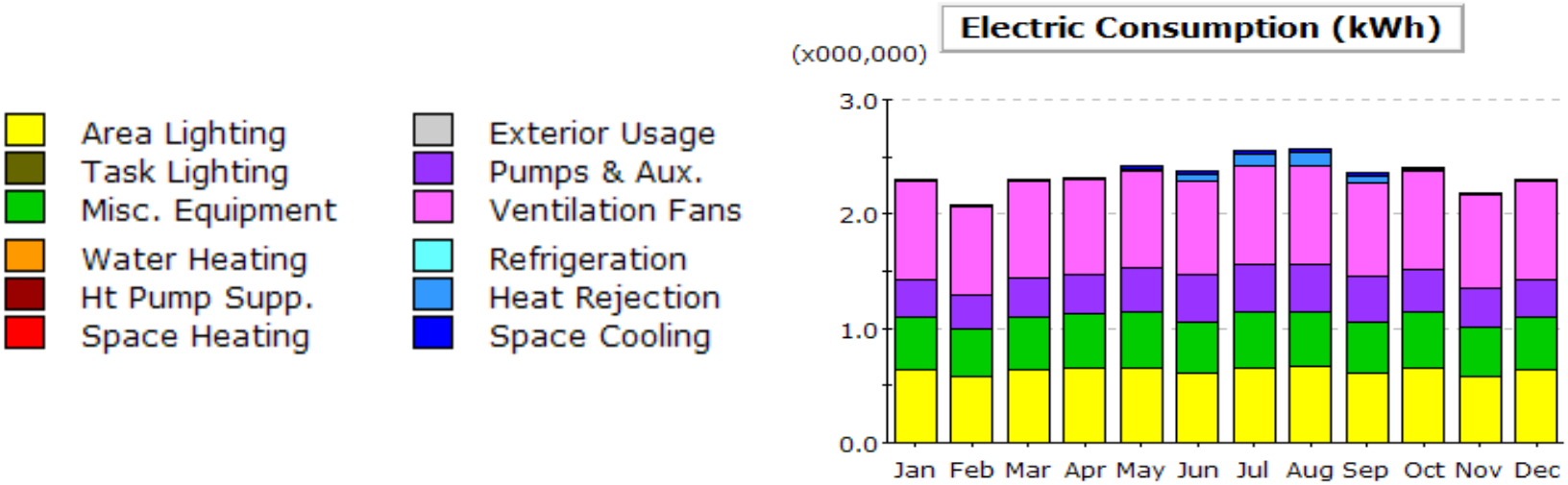


$$P_{elec}(t) = \frac{Q_{cooling,load}(t)}{\text{EER}} \qquad E = \sum P_{elec}\,\Delta t$$

Total load	Outdoor Temp	Varying EER	Power draw	Energy
Btu/hr	deg F	kBTU/hr /kW	W	kWh
4762	75.9	11.0	433	0.43
4324	75.0	11.1	390	0.39
3953	74.2	11.3	351	0.35
3641	73.7	11.4	319	0.32
3409	73.5	11.5	296	0.30
3274	73.9	11.4	287	0.29
3377	74.8	11.2	302	0.30
3694	76.5	11.0	336	0.34
9174	78.9	10.8	849	0.85
10538	81.6	10.5	1004	1.00
11805	84.8	10.2	1153	1.15
12962	87.7	10.0	1296	1.30
13950	90.0	9.7	1438	1.44
14753	91.4	9.5	1553	1.55
15325	92.0	9.3	1648	1.65
15625	91.4	9.5	1645	1.64
15682	90.2	9.7	1617	1.62
10495	88.1	10.0	1049	1.05
9335	85.7	10.3	906	0.91
8226	83.3	10.4	791	0.79
7283	81.3	10.5	694	0.69
6491	79.4	10.7	607	0.61
5816	77.9	10.9	534	0.53
5250	76.8	11.0	477	0.48
			Energy used (kWh)	**20.0**
			Energy price ($/kWh)	**0.11**
			Energy cost ($)	**$2.20**

Whole building energy simulation

- Takes into account:
  - External conditions (outdoor temperature, RH, W, solar radiation)
  - Building material properties (conductivity, U-values, R-values, SHGC, heat capacity, absorptivity, etc.)
  - HVAC system types, efficiencies, capacities, and controls
  - Building schedules (occupancy profiles, lighting profiles, thermostat settings, equipment profiles, etc.)
- Hourly (or sub-hourly) results are then used to sum over the entire year to estimate annual energy consumption



Whole building energy simulation

We can use software tools and knowledge of basic building physics and heat transfer equations to predict building energy use with ***reasonable*** accuracy

But be careful!!!

Never fool yourself into thinking your model will be <u>exact</u>

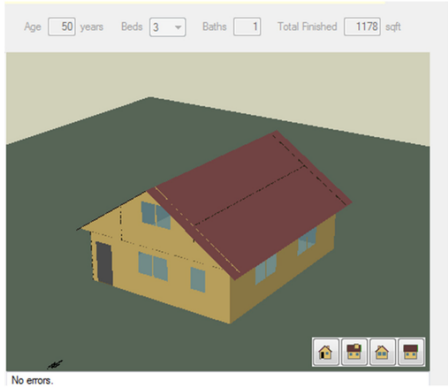
Building energy models are best used to understand design options and trade-offs (i.e., <u>relative comparisons</u>)

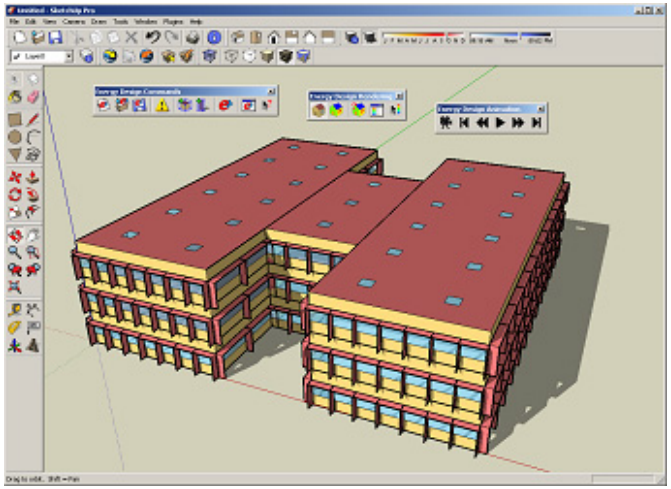
Building energy simulation (BES) tools

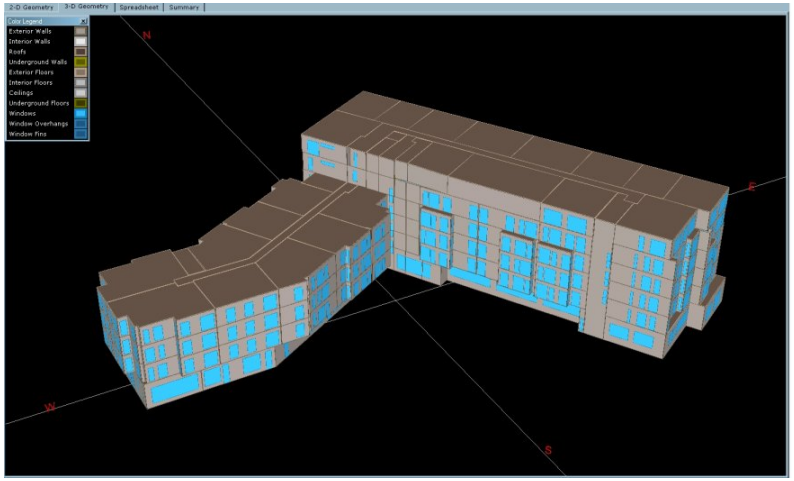
There are many software packages available (some are free)

Examples:

- EnergyPlus
  - OpenStudio
  - Simergy
  - BEopt
- eQUEST
- IES-VE
- TRNSYS
- Trane Trace
- Many others







http://apps1.eere.energy.gov/buildings/tools_directory/subjects.cfm/pagename=subjects/pagename_menu=whole_building_analysis/pagename_submenu=energy_simulation

Important input parameters for energy simulation

- Meteorological data (TMY, AMY)
  - Temperature, wind speed, solar radiation, cloud cover
- Envelope heat transfer properties
- Radiation and convection models
  - Internal and external
- Windows and shading
- Air infiltration models
- Conduction to the ground
- HVAC system and control models
- Conduction (and storage) solution method
  - Finite difference (explicit, implicit)
  - Response function techniques (simpler, less accurate)
- Time steps
  - Too short and calculations take forever
  - Too long and solutions diverge

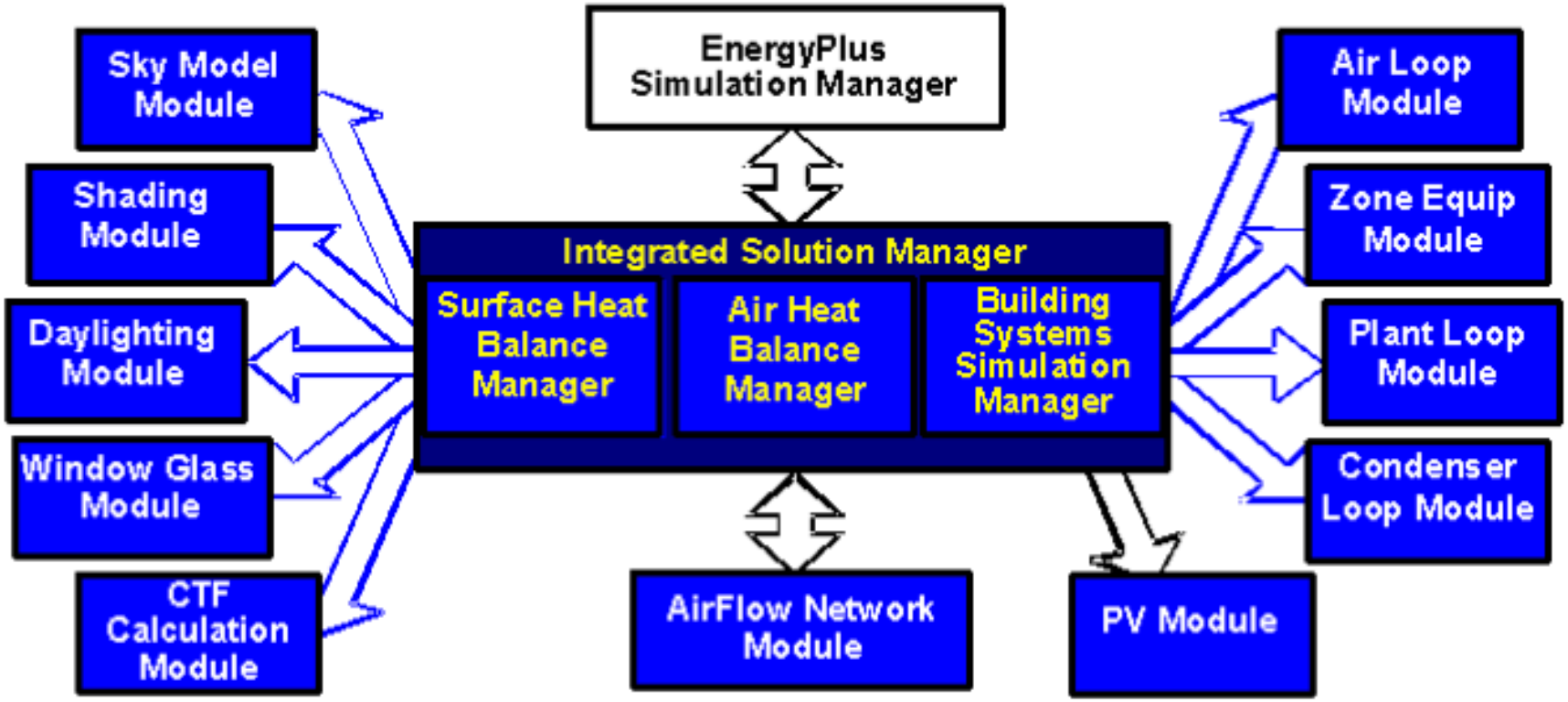
EnergyPlus

- EnergyPlus is an extremely powerful building energy simulation tool
  - Uses hourly or sub-hourly time steps
  - Models nearly all physical phenomena well
    - Including transient heat conduction (thermal mass)
  - Combined heat and mass (air) transfer modeling
  - Excellent system models
  - Thermal comfort modeling
  - Modular for future extensions

- http://apps1.eere.energy.gov/buildings/energyplus/energyplus_about.cfm

- Runs on Windows, Mac, and Linux

EnergyPlus program organization



One **huge** limitation: it does not have a graphical user interface (GUI)

EnergyPlus only has a text based input file editor

IDF Editor - C:\Documents and Settings\Administrator\Desktop\simple.idf

File Edit View Help

New Obj | Dup Obj | Del Obj

Class List

Location - Climate - Weather File Access
---
[004] RunPeriod
[------] SpecialDayPeriod
[------] DaylightSavingPeriod
[------] Location
[------] DesignDay
[------] GROUNDTEMPERATURES

Simulation Parameters
---
[001] BUILDING
[001] TIMESTEP IN HOUR
[001] INSIDE CONVECTION ALGORITHM
[001] OUTSIDE CONVECTION ALGORITHM
[001] SKY RADIANCE DISTRIBUTION

1

Comments from IDF

IFC to IDF file generated by Client (Beta 4) to BSPro COM-Server (Release 1.12b) for EnergyPlus (V1.0, or Beta 4 or 5)
Imported IFC Path Name: C:\Documents and Settings\Administrator\Desktop\simple.ifc
Generated IDF Path Name: C:\Documents and Settings\Administrator\Desktop\simple.idf
Generated on: April 26, 2001: 13:36

Explanation of Keyword

ID: N1
Default: 0
Range: 1 <= X <= 12 and integers only

Field	Units	Obj1	Obj2	Obj3	Obj4
Begin Month		1	4	6	9
Begin Day Of Month		1	1	1	1
End Month		1	4	6	9
End Day Of Month		7	7	7	7
Day Of Week For Start Day					
Use WeatherFile Holidays/Specia					

Example engineering calculations for BES program

ENERGYPLUS™

EnergyPlus Engineering Reference

The Reference to EnergyPlus Calculations

(in case you want or need to know)

EnergyPlus Engineering Reference, 2012

Example engineering calculations for BES program

Outside Surface Heat Balance

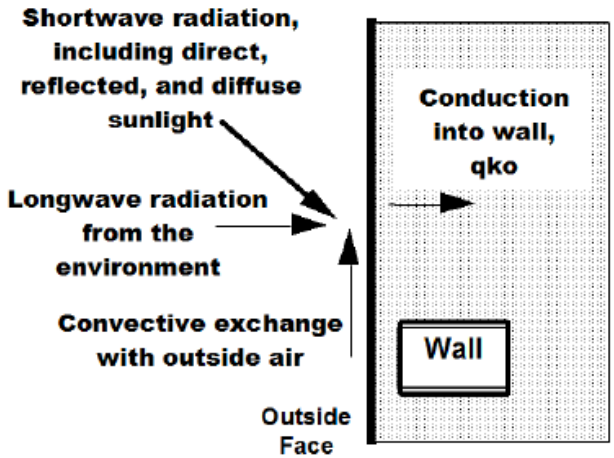


Figure 17. Outside Heat Balance Control Volume Diagram

The heat balance on the outside face is:

$$q''_{\alpha sol} + q''_{LWR} + q''_{conv} - q''_{ko} = 0 \qquad (64)$$

where:

$q''_{\alpha sol}$ = Absorbed direct and diffuse solar (short wavelength) radiation heat flux.

q''_{LWR} = Net long wavelength (thermal) radiation flux exchange with the air and surroundings.

q''_{conv} = Convective flux exchange with outside air.

q''_{ko} = Conduction heat flux (q/A) into the wall.

- We know how to model all of these elements now
- Programs differ in how they select inputs, particularly heat transfer coefficients…

EnergyPlus Engineering Reference, 2012

Example engineering calculations for BES program

Simple Combined

The simple algorithm uses surface roughness and local surface windspeed to calculate the exterior heat transfer coefficient (key:SimpleCombined). The basic equation used is:

$$h = D + EV_z + FV_z^2 \qquad (82)$$

where

h = heat transfer coefficient

V_z = local wind speed calculated at the height above ground of the surface centroid

D, E, F = material roughness coefficients

The roughness correlation is taken from Figure 1, Page 22.4, ASHRAE Handbook of Fundamentals (ASHRAE 1989). The roughness coefficients are shown in the following table:

Table 6. Roughness Coefficients D, E, and F.

Roughness Index	D	E	F	Example Material
1 (Very Rough)	11.58	5.894	0.0	Stucco
2 (Rough)	12.49	4.065	0.028	Brick
3 (Medium Rough)	10.79	4.192	0.0	Concrete
4 (Medium Smooth)	8.23	4.0	-0.057	Clear pine
5 (Smooth)	10.22	3.1	0.0	Smooth Plaster
6 (Very Smooth)	8.23	3.33	-0.036	Glass

EnergyPlus Engineering Reference, 2012

Example engineering calculations for BES program

Inside Heat Balance

The heart of the heat balance method is the internal heat balance involving the inside faces of the zone surfaces. This heat balance is generally modeled with four coupled heat transfer components: 1) conduction through the building element, 2) convection to the air, 3) short wave radiation absorption and reflectance and 4) longwave radiant interchange. The incident short wave radiation is from the solar radiation entering the zone through windows and emittance from internal sources such as lights. The longwave radiation interchange includes the absorption and emittance of low temperature radiation sources, such as all other zone surfaces, equipment, and people.

The heat balance on the inside face can be written as follows:

$$q''_{LWX} + q''_{SW} + q''_{LWS} + q''_{ki} + q''_{sol} + q''_{conv} = 0 \qquad (92)$$

where:

q''_{LWX} = Net longwave radiant exchange flux between zone surfaces.

q''_{SW} = Net short wave radiation flux to surface from lights.

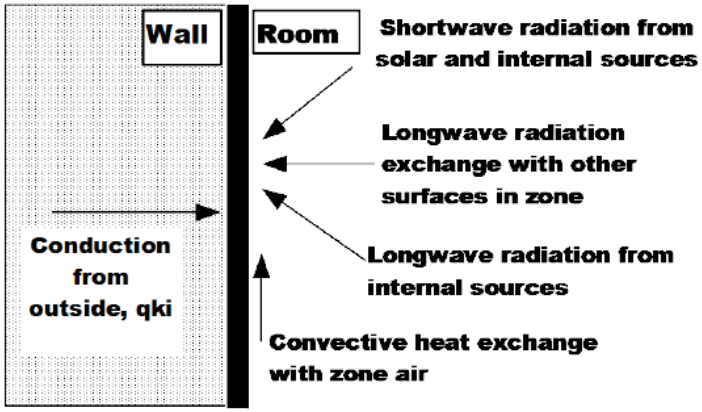
q''_{LWS} = Longwave radiation flux from equipment in zone.

q''_{ki} = Conduction flux through the wall.

q''_{sol} = Transmitted solar radiation flux absorbed at surface.

q''_{conv} = Convective heat flux to zone air.

Each of these heat balance components is introduced briefly below.



EnergyPlus Engineering Reference, 2012

Example engineering calculations for BES program

- Relies on the same equations we've been using:

$$C_z \frac{dT_z}{dt} = \sum_{i=1}^{N_{sl}} \dot{Q}_i + \sum_{i=1}^{N_{surfaces}} h_i A_i \left(T_{si} - T_z\right) + \sum_{i=1}^{N_{zones}} \dot{m}_i C_p \left(T_{zi} - T_z\right) + \dot{m}_{\inf} C_p \left(T_\infty - T_z\right) + \dot{Q}_{sys}$$

where:

$\sum_{i=1}^{N_{sl}} \dot{Q}_i$ = sum of the convective internal loads

$\sum_{i=1}^{N_{surfaces}} h_i A_i \left(T_{si} - T_z\right)$ = convective heat transfer from the zone surfaces

$\dot{m}_{\inf} C_p \left(T_\infty - T_z\right)$ = heat transfer due to infiltration of outside air

$\sum_{i=1}^{N_{zones}} \dot{m}_i C_p \left(T_{zi} - T_z\right)$ = heat transfer due to interzone air mixing

$\dot{Q}_{sys}$ = air systems output

$C_z \frac{dT_z}{dt}$ = energy stored in zone air

$C_z = \rho_{air} C_p C_T$

ρ_{air} = zone air density

C_p = zone air specific heat

EnergyPlus Engineering Reference, 2012

Example engineering calculations for BES program

- Discretizing for time t versus time $t - \delta t$:

$$C_z \frac{T_z^t - T_z^{t-\delta t}}{dt} + T_z^t \left(\sum_{i=1}^{N_{surfaces}} h_i A_i + \sum_{i=1}^{N_{zones}} \dot{m}_i C_p + \dot{m}_{\inf} C_p + \dot{m}_{sys} C_p \right) =$$

$$\sum_{i=1}^{N_{sl}} \dot{Q}_i^t + \dot{m}_{sys} C_p T_{\text{supply}}^t + \left(\sum_{i=1}^{N_{surfaces}} h_i A_i T_{si} + \sum_{i=1}^{N_{zones}} \dot{m}_i C_p T_{zi} + \dot{m}_{\inf} C_p T_\infty \right)^{t-\delta t}$$

- If there is any thermal mass at any element, link to surface T:

$$C_p \rho \Delta x \frac{T_i^{j+1} - T_i^j}{\Delta t} = \frac{1}{2} \left[\left(k_W \frac{\left(T_{i+1}^{j+1} - T_i^{j+1}\right)}{\Delta x} + k_E \frac{\left(T_{i-1}^{j+1} - T_i^{j+1}\right)}{\Delta x} \right) + \left(k_W \frac{\left(T_{i+1}^{j} - T_i^{j}\right)}{\Delta x} + k_E \frac{\left(T_{i-1}^{j} - T_i^{j}\right)}{\Delta x} \right) \right]$$

<u>Discretized conduction</u>

BES programs vary in how they treat conduction and thermal mass

EnergyPlus Engineering Reference, 2012

Example engineering calculations for BES program

- Or use a lumped capacitance model for thermal mass:

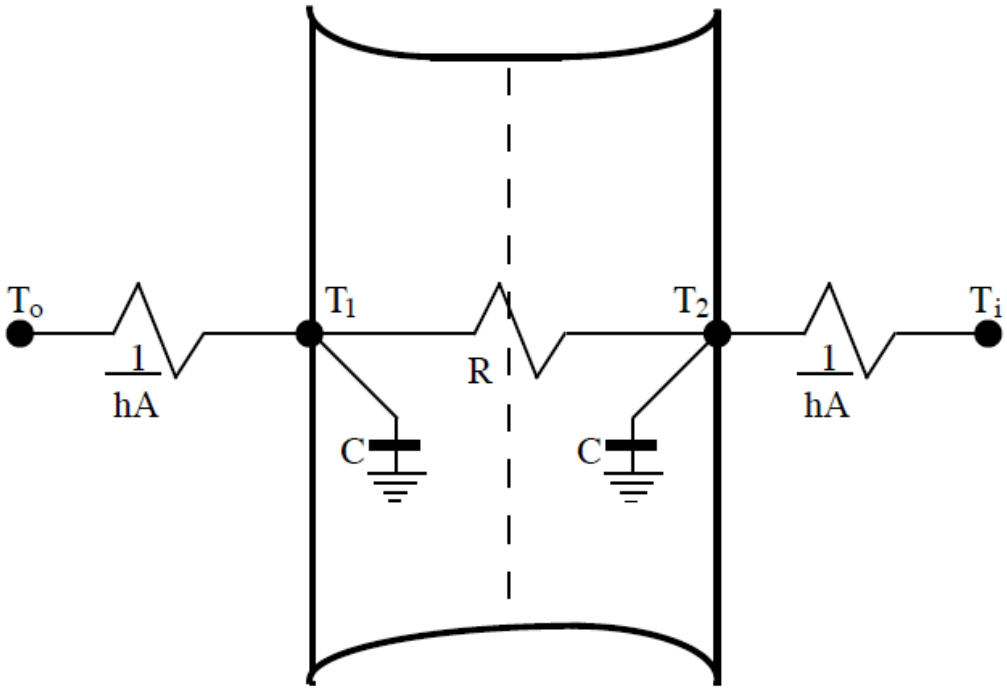


Figure 9. Two Node State Space Example.

$$C\frac{dT_1}{dt} = hA(T_o - T_1) + \frac{T_2 - T_1}{R}$$

$$C\frac{dT_2}{dt} = hA(T_i - T_2) + \frac{T_1 - T_2}{R}$$

where:

$$R = \frac{\ell}{kA},$$

$$C = \frac{\rho c_p \ell A}{2}$$

BES programs vary in how they treat conduction and thermal mass

EnergyPlus Engineering Reference, 2012

Example engineering calculations for BES program

- Rearrange to solve for instantaneous HVAC system capacity:

$$-\dot{Q}_{sys} = \sum_{i=1}^{N_{sl}} \dot{Q}_i + \sum_{i=1}^{N_{surfaces}} h_i A_i \left(T_{si} - T_z\right) + \sum_{i=1}^{N_{zones}} \dot{m}_i C_p \left(T_{zi} - T_z\right) + \dot{m}_{\inf} C_p \left(T_\infty - T_z\right)$$

- Instantaneous HVAC sensible capacity also equals:

$$\dot{Q}_{sys} = \dot{m}_{sys} C_p \left(T_{\sup} - T_z\right)$$

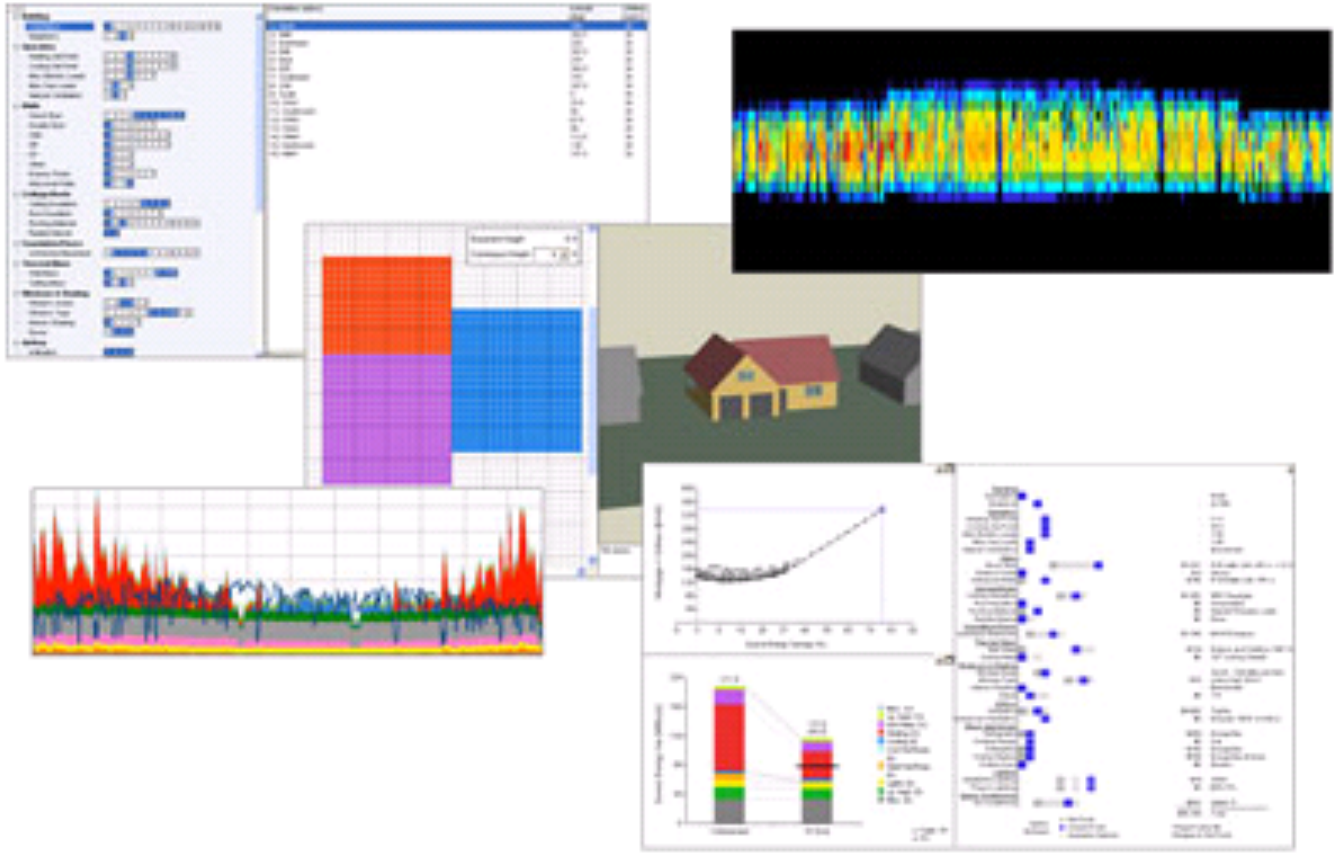
- Once you have Q_{sys} at each time step, you can calculate the **<u>energy required</u>** to deliver that rate of bulk heat transfer by knowing the efficiency/COP of your equipment

$$COP = \frac{Q_{sys}}{P_{sys}} \longrightarrow P_{sys} = \frac{Q_{sys}}{COP}$$

EnergyPlus Engineering Reference, 2012

We need front-end GUIs for EnergyPlus

- *OpenStudio*
- DesignBuilder
- EFEN
- AECOsim
- Hevacomp
- N++
- gEnergy
- *Simergy*
- *Sefaira*
- *BEopt*



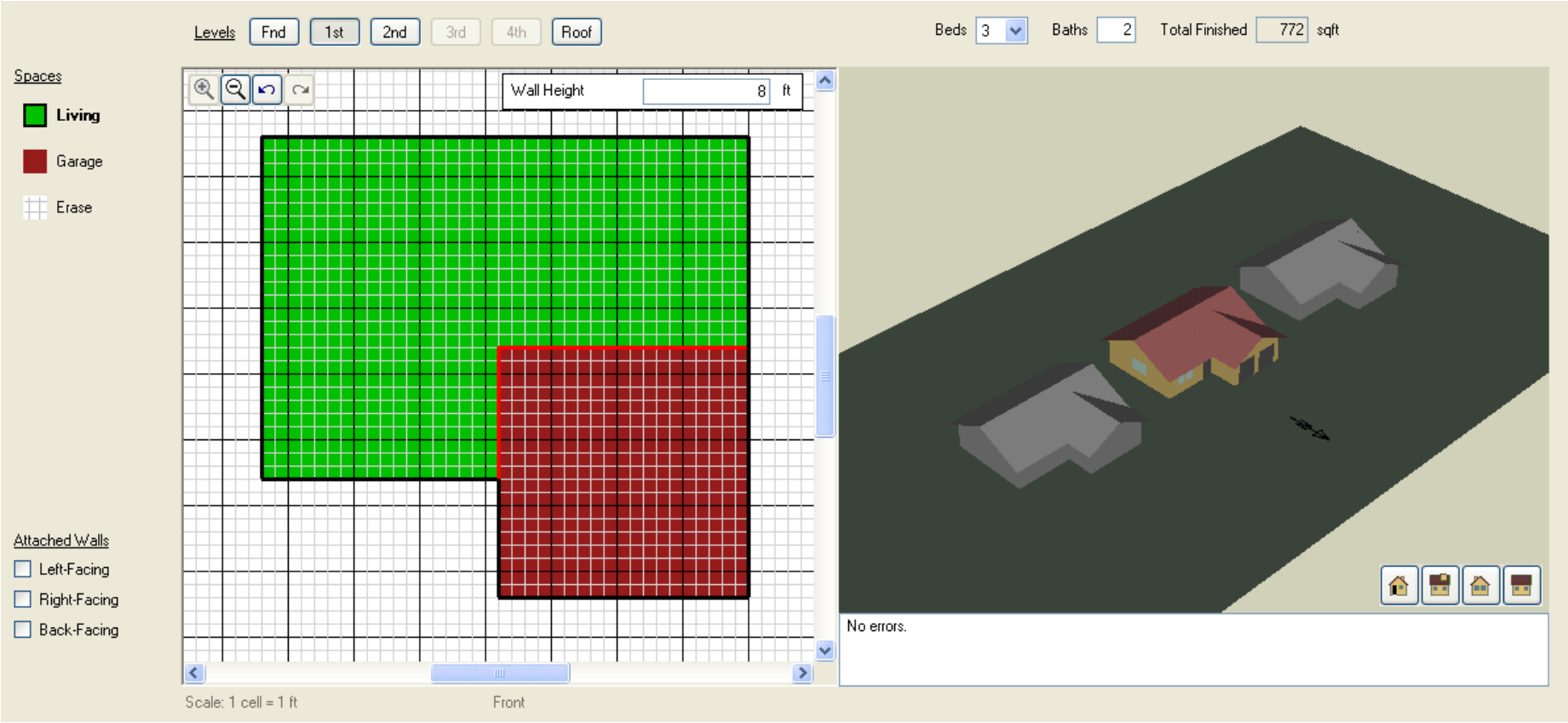
BEOPT AND ENERGYPLUS

BEopt

- BEopt (Building Energy Optimization) combines a user-friendly GUI for building model geometry and specifying enclosure details, systems, etc. with both parametric analysis and an optimization engine for identifying cost-optimal efficiency packages
  - Includes annual energy costs/savings, construction costs, and material/equipment costs
  - https://beopt.nrel.gov

- Strictly limited to residential buildings
- Only runs on Windows
- Uses either EnergyPlus or DOE-2.2 as the simulation engine
  - eQUEST uses DOE-2.2
  - We will use EnergyPlus (more robust)

BEopt: Start with building geometry



BEopt: Then pick basic characteristics

Building

EPW Location	USA_GA_Atlanta-Hartsfield-Jackson.	
Terrain	Suburban	

Economics

Project Analysis Period	30	years
Inflation Rate	3.0	%
Discount Rate (Real)	3.0	%
Material Cost Multiplier	1.00	
Labor Cost Multiplier	1.00	

Mortgage

Down Payment	0.0	%
Mortgage Interest Rate	7.0	%
Mortgage Period	30	years
Marginal Income Tax Rate, Federal	28.0	%
Marginal Income Tax Rate, State	0.0	%

Incentives

Tax Credits & Rebates: Whole-House Efficiency | ☑ PV

Electricty | Natural Gas | Oil | Propane

Utility Rates

◉ User Specified	Marginal	0.0800	$/kWh
○ State Average	Fixed	8.00	$/month
○ National Average	Average	0.0870	$/kWh
○ OpenEI Utility Rate			
Fuel Escalation (Real)		0.00	%/year

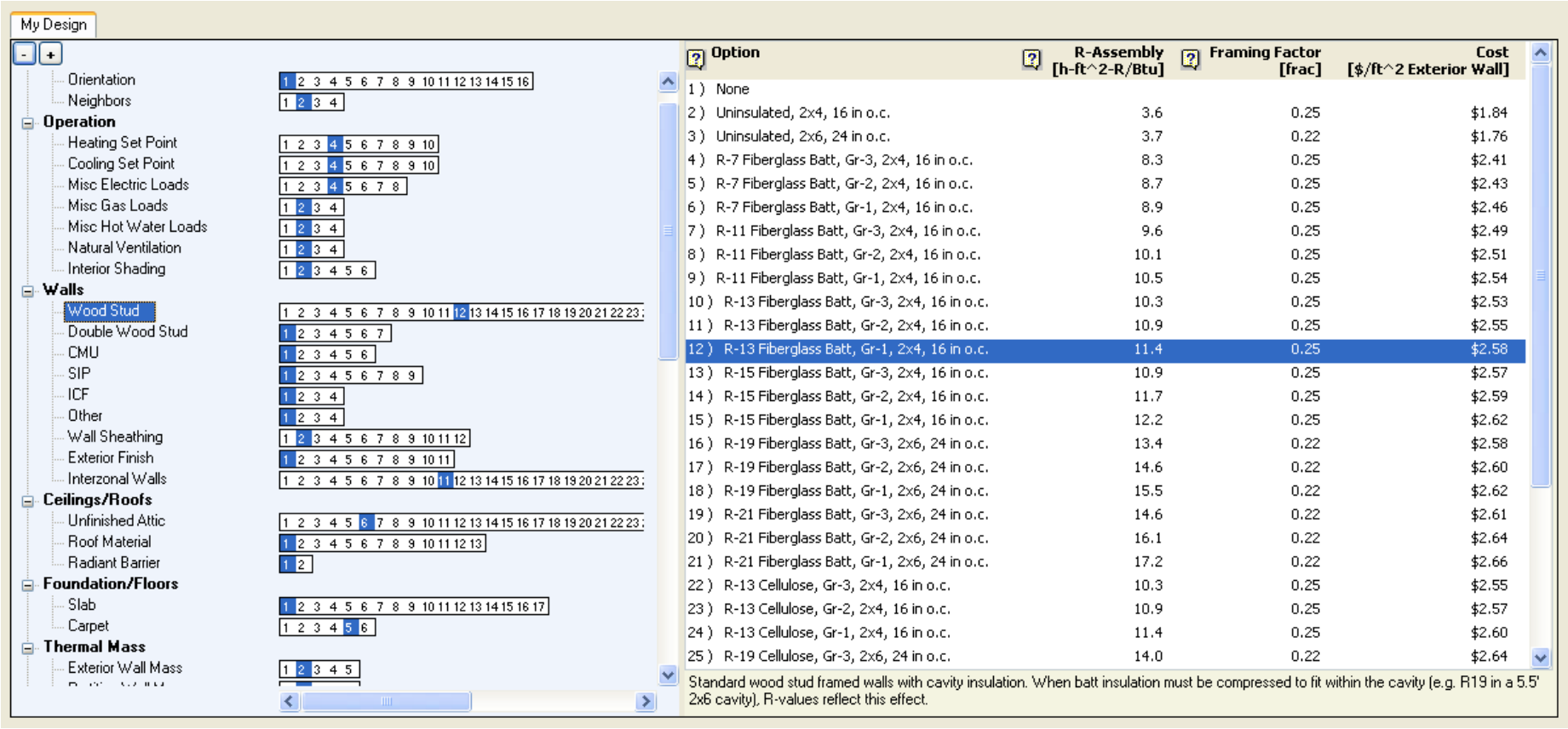
Net-Metered Annual Excess Sellback Rate

◉ Retail Electricity Cost	0.08000	$/kWh
○ User Specified		

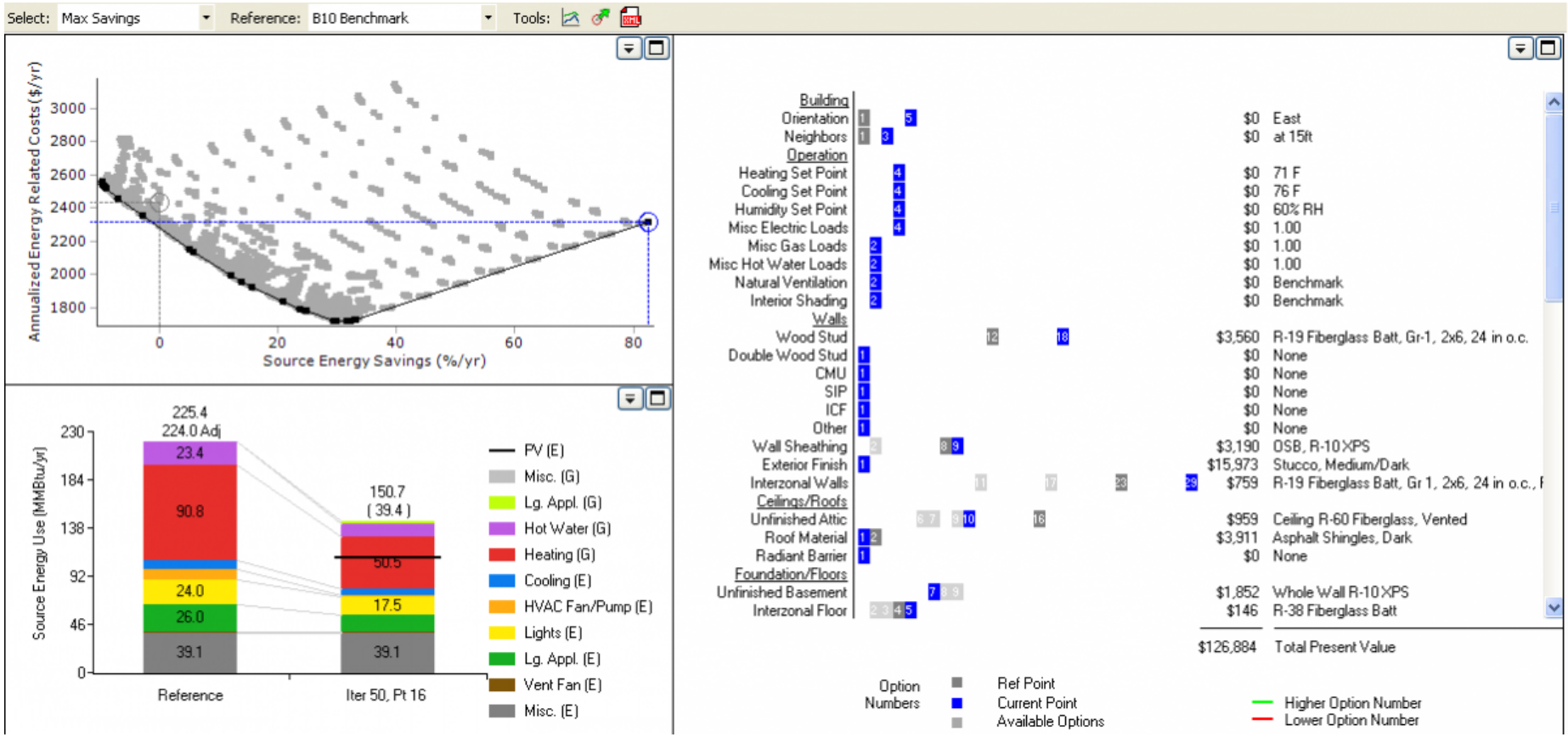
Energy Factors

Source/Site Ratio	3.365	
Carbon Factor	1.670	lb/kWh

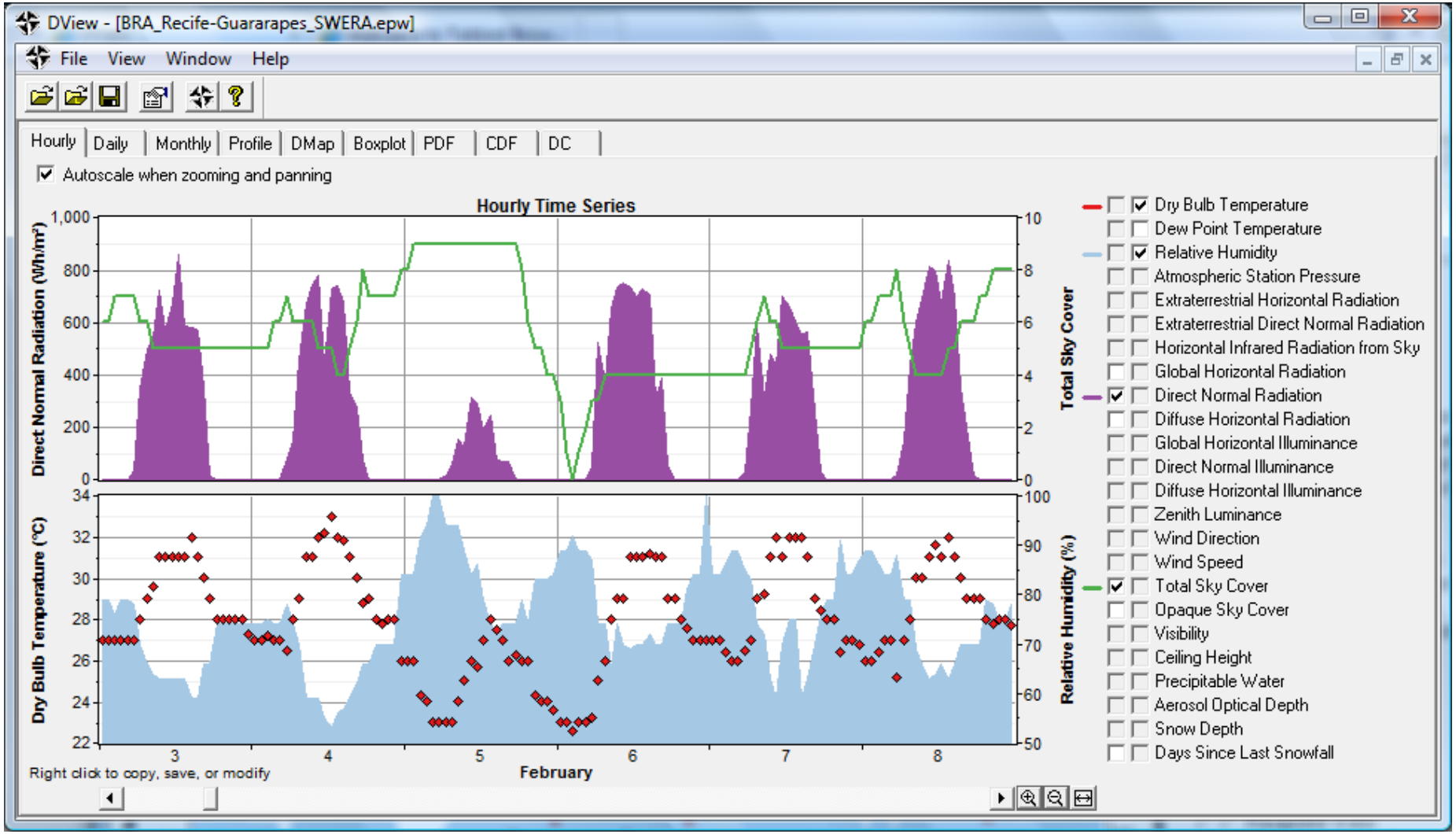
BEopt: Then pick basic characteristics



BEopt: Simulate and compare results

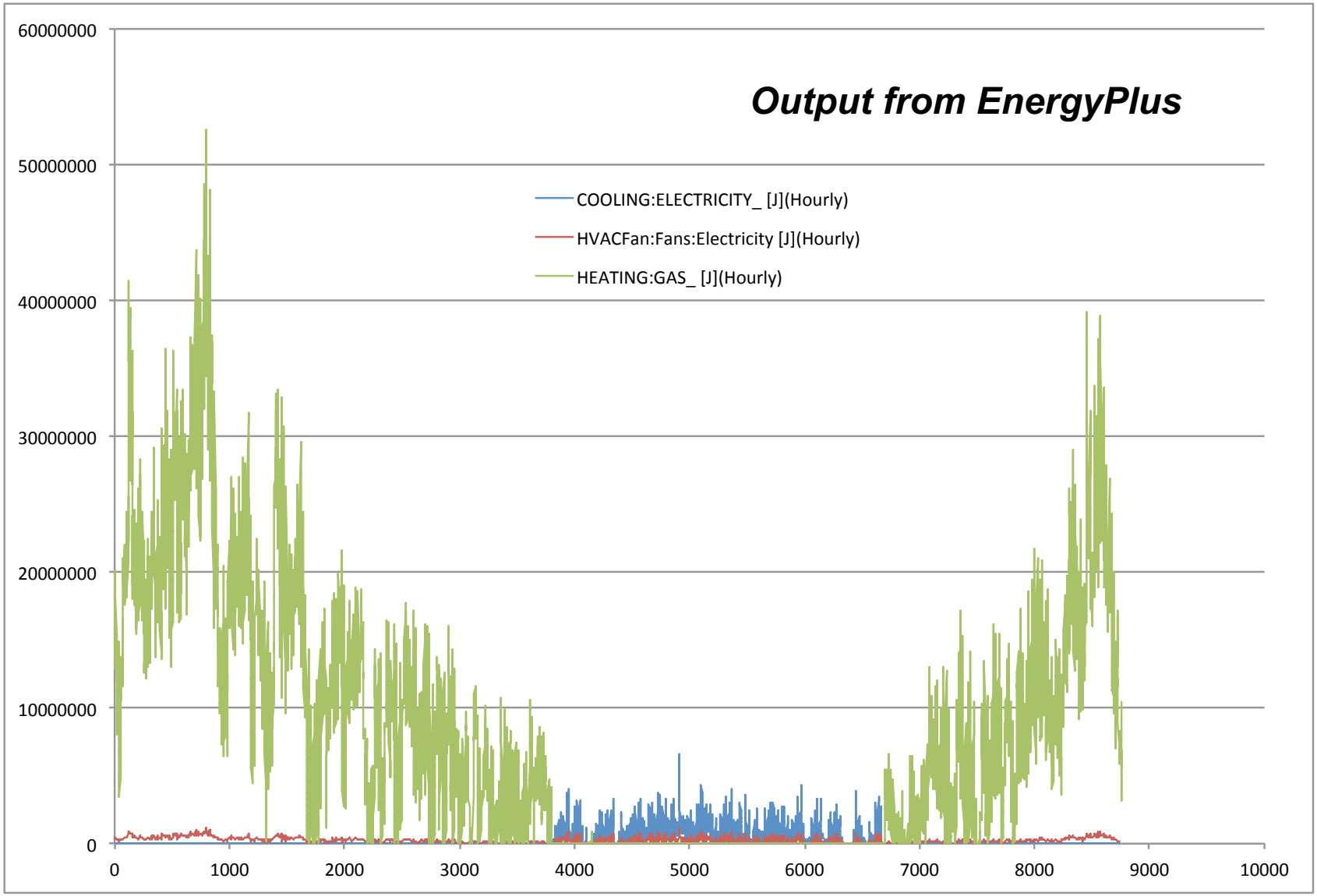


BEopt: Can also download DView for detailed results



BEopt + EnergyPlus demonstration

Building energy simulation results: Example home in Chicago



Building energy simulation results: Example home in Chicago

- Annual summary

	Electric	Gas
Total J	29270600548	90956293121
Total kWh	8131	
Total MMBTU		86.2
$/unit	$0.10	$8.00
Annual energy cost	$813	$690

~$1500 in annual energy costs in this home

- Once we've established a baseline, we can make design and system changes to predict the impacts on energy, costs, and environmental pollution

Output from EnergyPlus