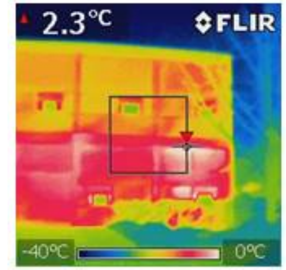
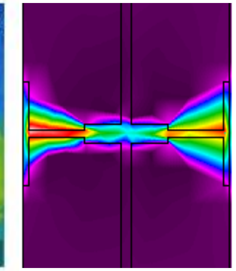
CAE 331/513
Building Science
Fall 2015



Week 15: December 1, 2015
Energy estimation methods and design for efficiency

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Dr. Brent Stephens, Ph.D.
Civil, Architectural and Environmental Engineering
Illinois Institute of Technology
brent@iit.edu

Updates

- Problems with HW 6
  - Revised instructions emailed to you
  - Still due this Thursday
  - Will grade by Friday morning
- Final exam policy
  - Email me if you prefer NOT to take the final exam (brent@iit.edu)
  - See your updated grade on Blackboard
- Complete your course evaluations in myIIT

Just a few topics left

- Building energy use estimation methods
- Building design standards and guidelines
- Building performance diagnostics, and course wrap-up

BUILDING ENERGY USE

Energy end uses from actual data

Energy use profiles: Actual data

Research highlights from a large scale residential monitoring study in a hot climate

Danny S. Parker*

Florida Solar Energy Center, 1679 Clearlake Road, Cocoa, FL 32922, USA

ENERGY and BUILDINGS

- 204 residences in Florida measured electricity use at 15 minute intervals

Total = 17,130 kWh

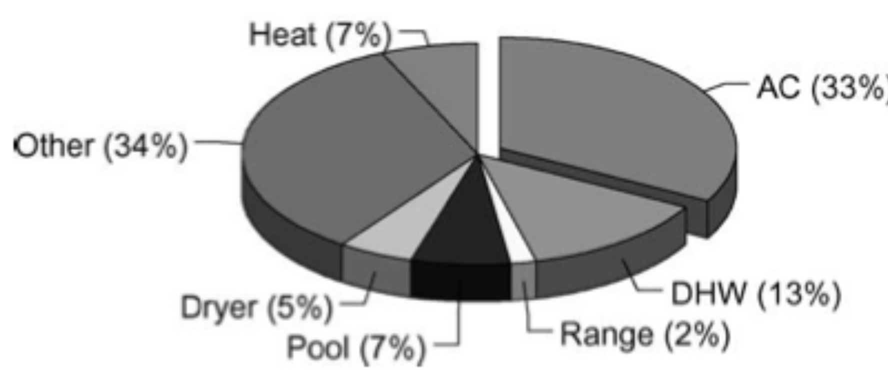
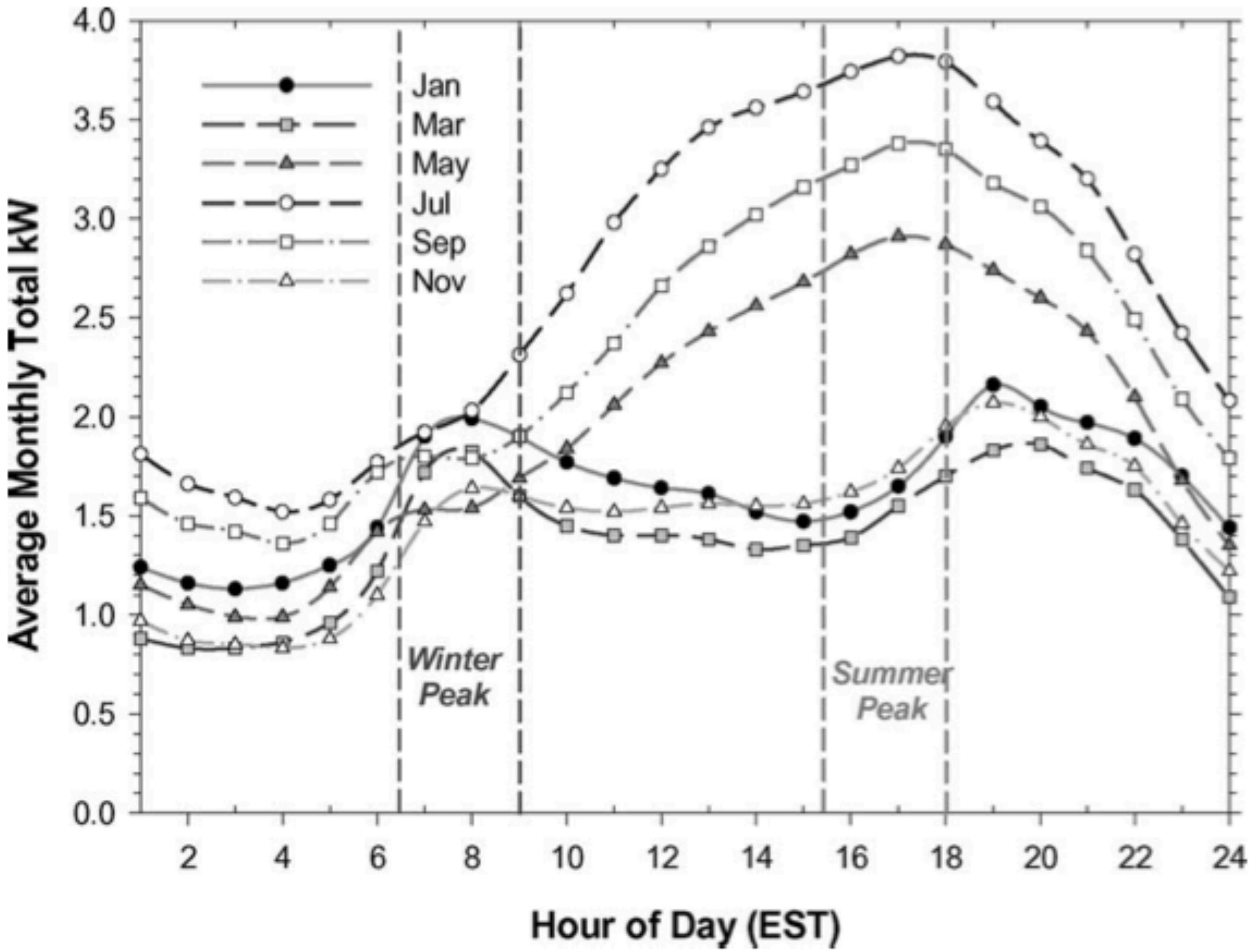


Fig. 1. Percentage of measured electricity consumption by end-use in pure sample ($n = 171$).

Parker **2003** *Energy and Buildings* 35:863-876

Large scale residential energy monitoring: FL homes



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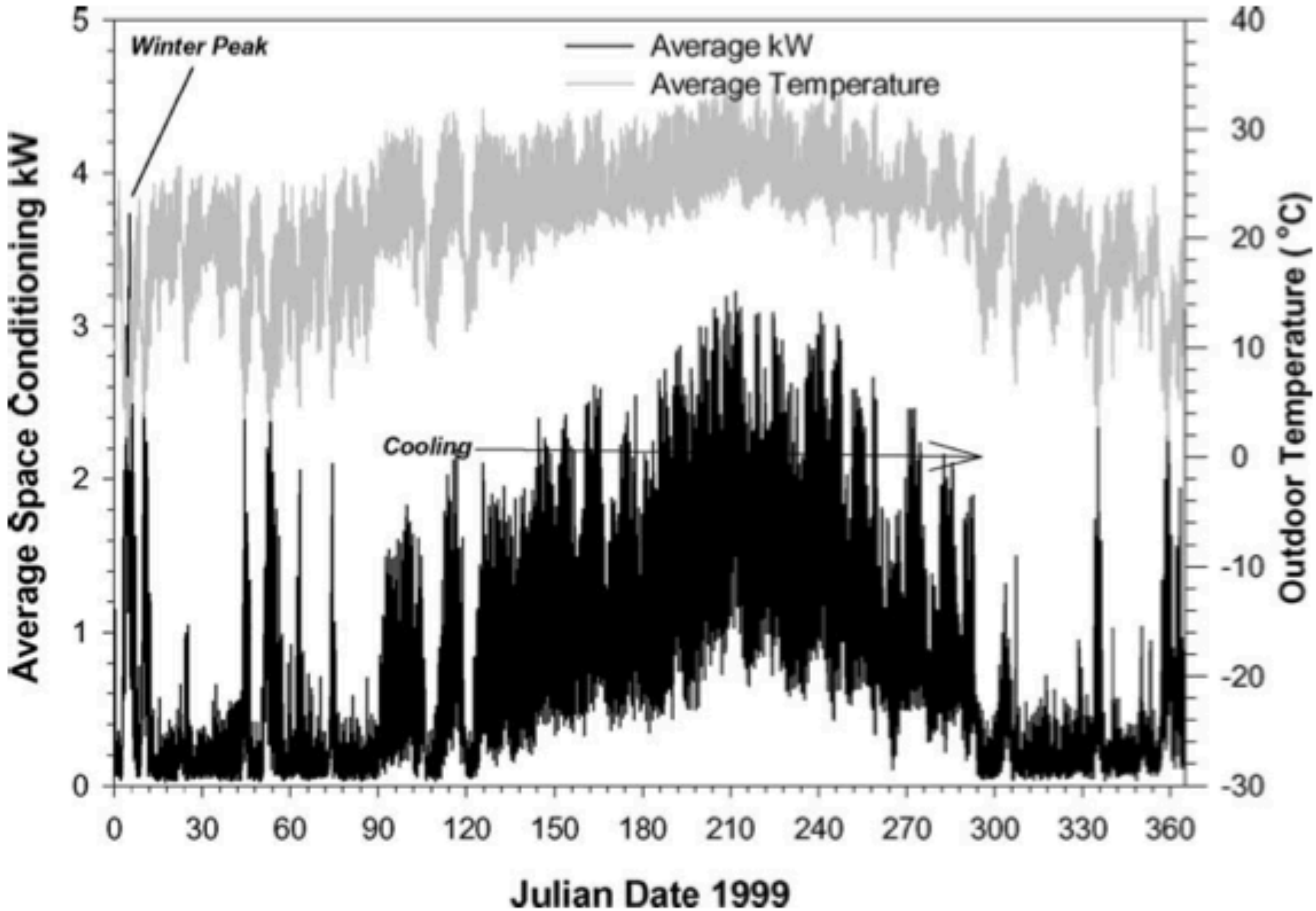
Large scale residential energy monitoring: FL homes



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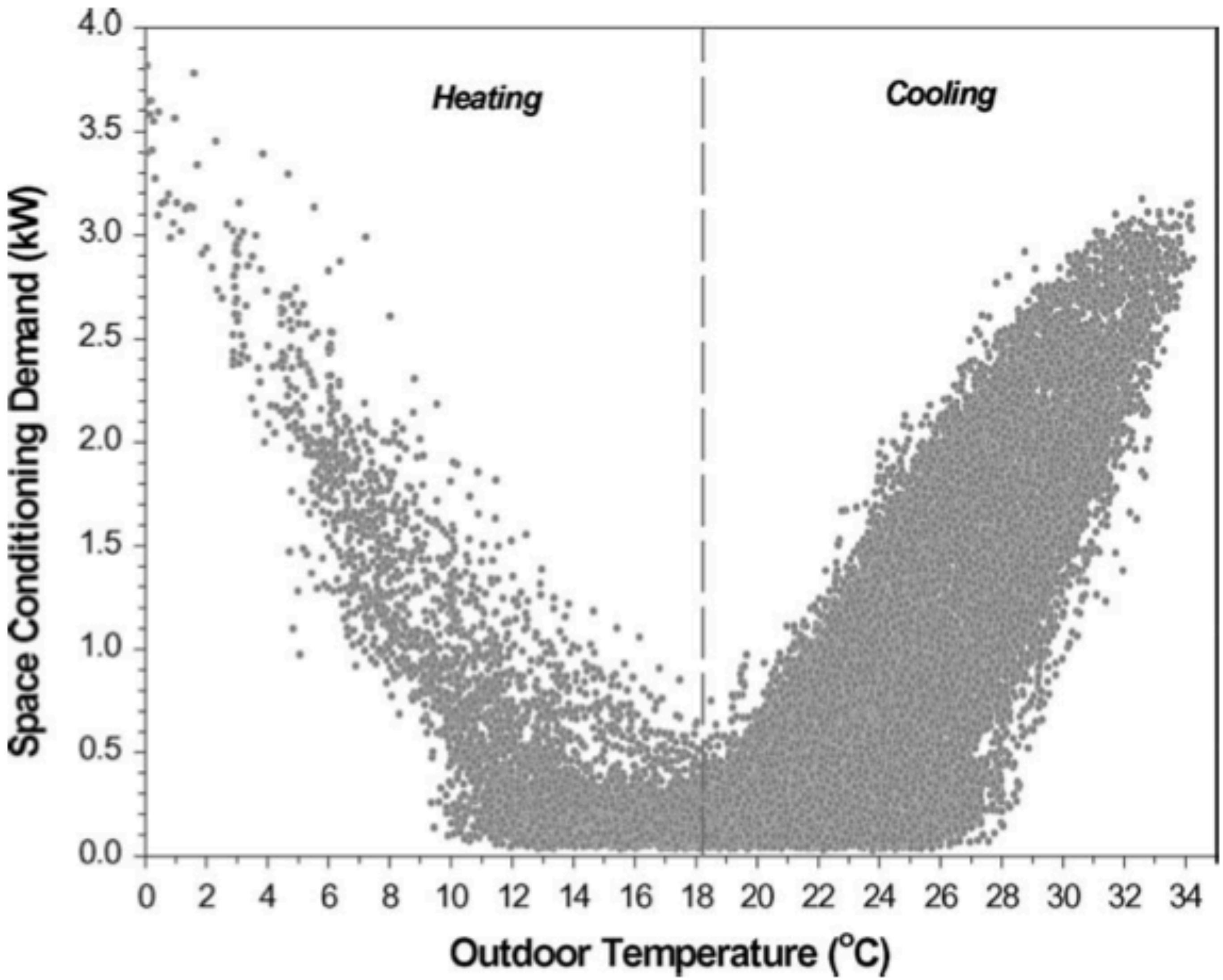
Large scale residential energy monitoring: FL homes



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Large scale residential energy monitoring: FL homes

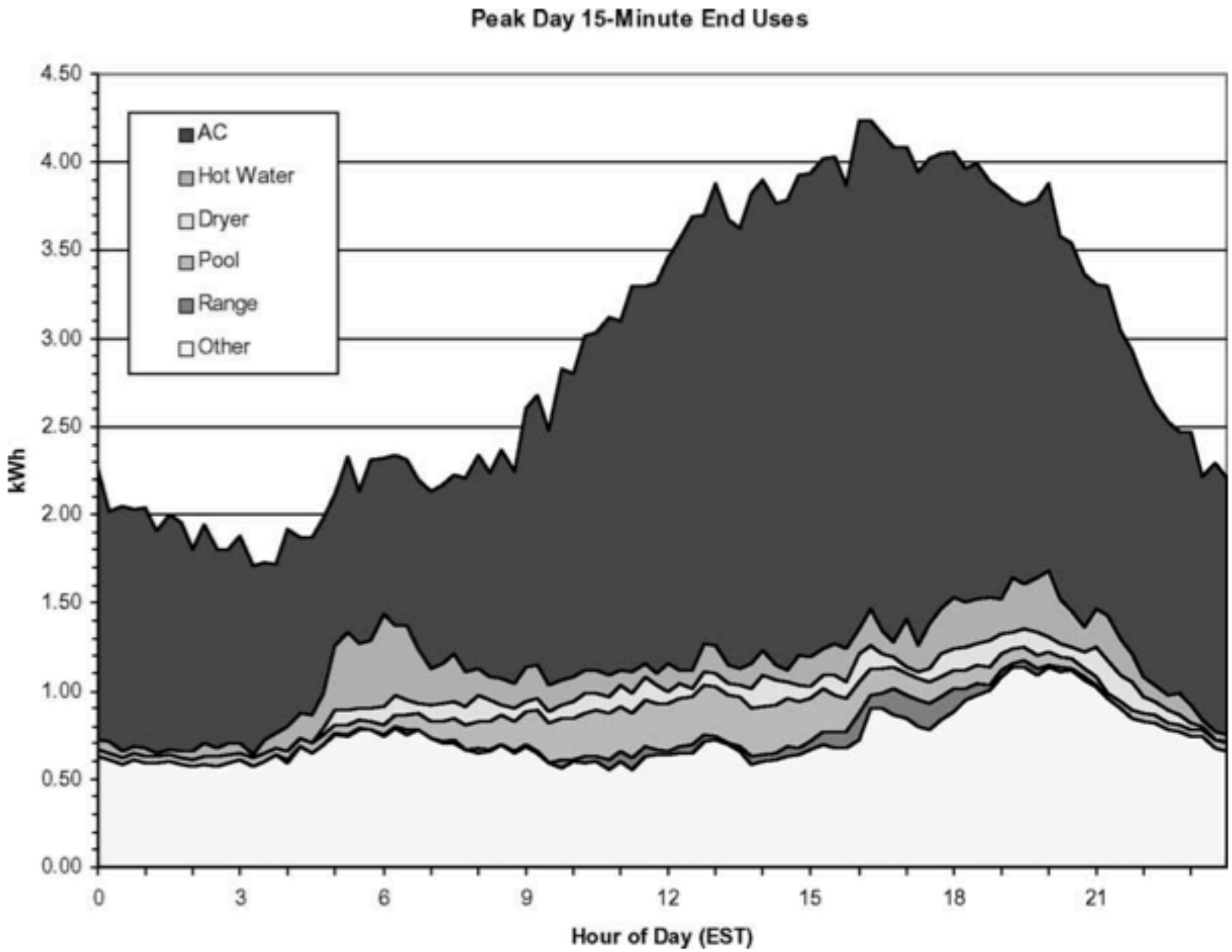


Fig. 8. End-use demand components on summer peak day (30 August 1999).

Parker **2003** *Energy and Buildings* 35:863-876

ENERGY ESTIMATION METHODS

Annual energy estimation

- The same methods for estimating peak heating and cooling loads (particularly the heat balance method) are 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)

Annual energy estimation

- Takes into account:
  - External conditions (outdoor temperature, RH, W, solar radiation)
  - Building material properties (conductivity, U-values, R-values, SHGC, heat capacity, absorptivity, etc.)
  - 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 of a building
  - Absolute accuracy is difficult to achieve
  - Relative accuracy is good – allows for making decisions about design trade-offs

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

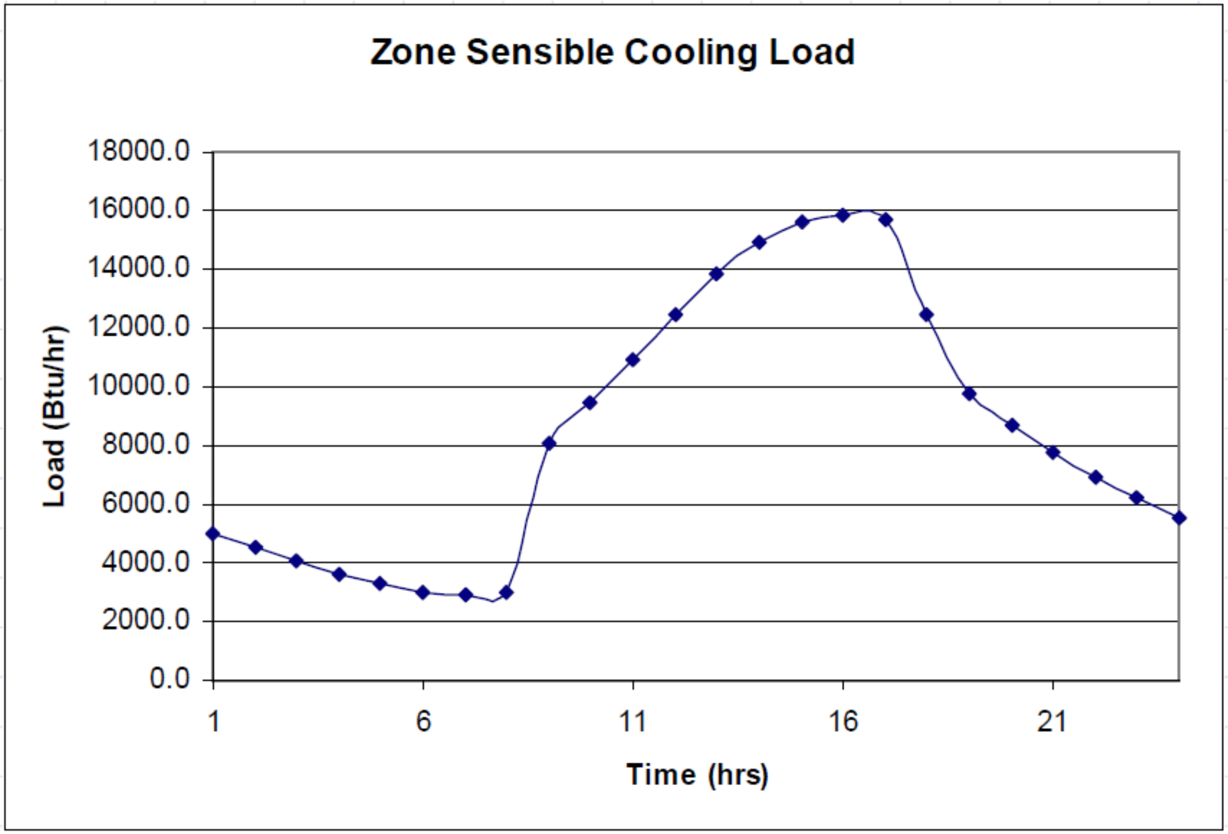
- If you know the hourly load (either for just a peak day or for the whole year), you can estimate the amount of energy required to meet that load by knowing the efficiency of the system (COP or EER)

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

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

Estimating energy use from load calculations

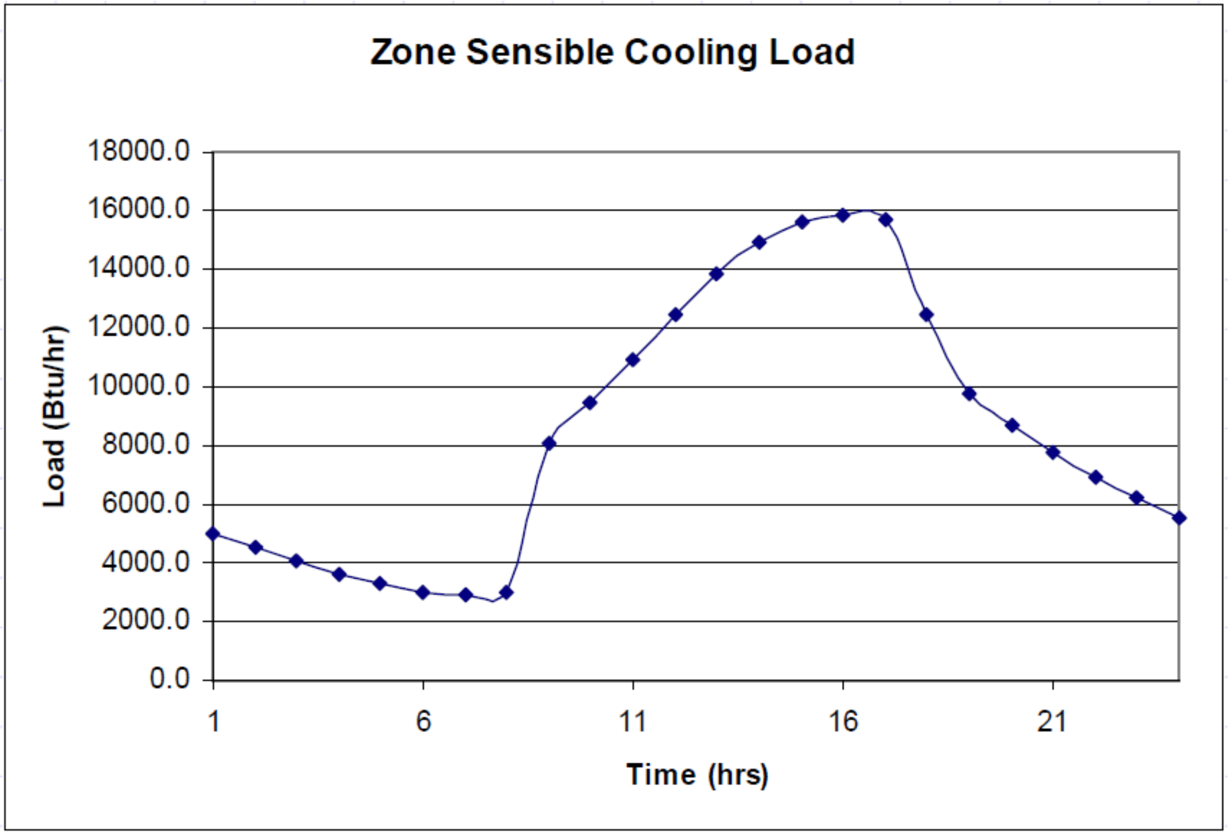
Example for cooling energy:



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:



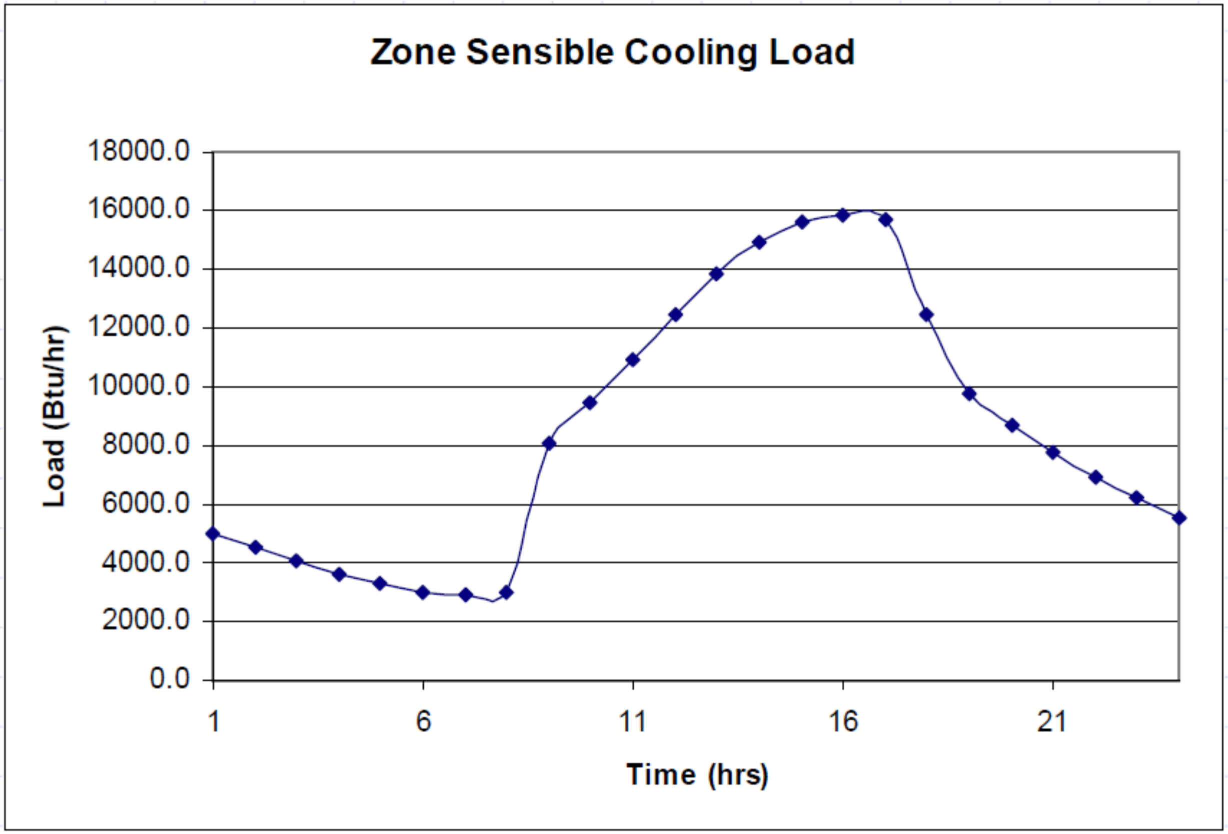
Total load Btu/hr	Power draw W
4418	432
3843	375
3352	327
2940	287
2623	256
2419	236
2465	241
2737	267
8190	800
9562	934
10883	1063
12143	1186
13275	1297
14250	1392
15007	1466
15486	1513
15701	1534
10635	1039
9550	933
8460	827
7477	730
6588	644
5777	564
5057	494

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

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**

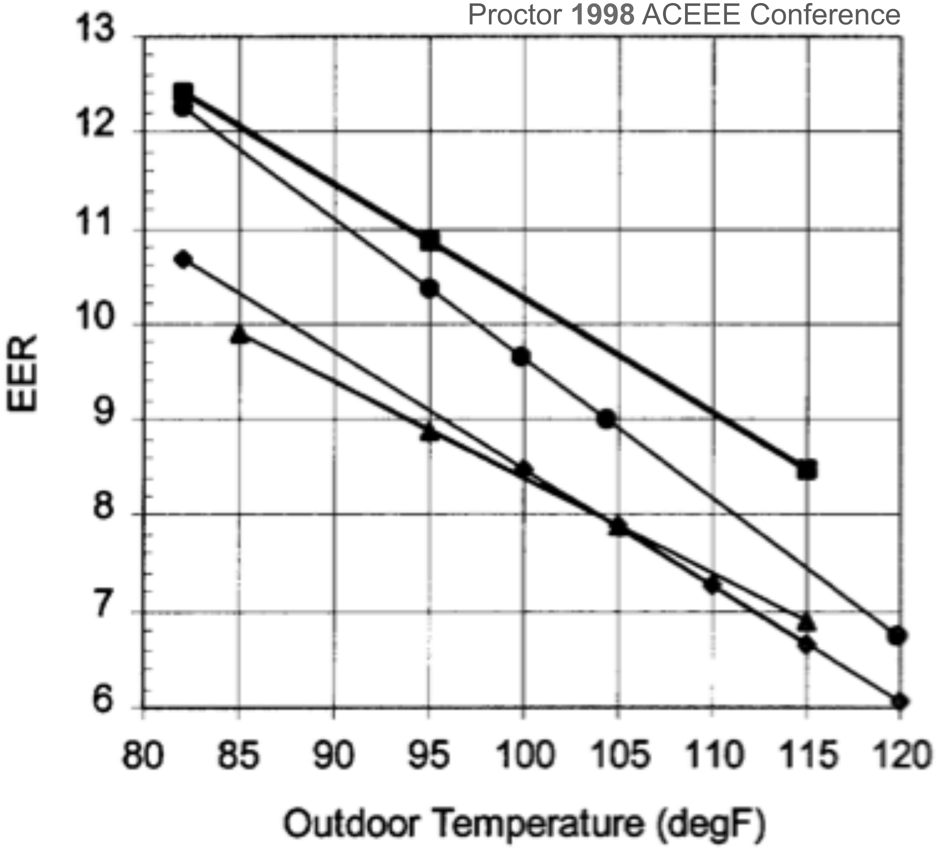
$$E = \sum \mathrm{P}_{elec}\, \Delta t$$

*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}

Proctor **1998** ACEEE Conference



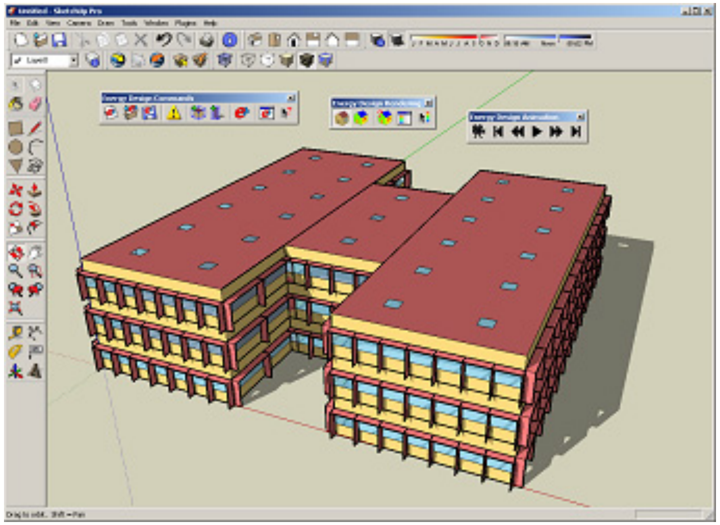
$$P_{elec}(t) = \frac{Q_{cooling,load}(t)}{\text{EER}} \qquad E = \sum P_{elec}\,\Delta t$$

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**

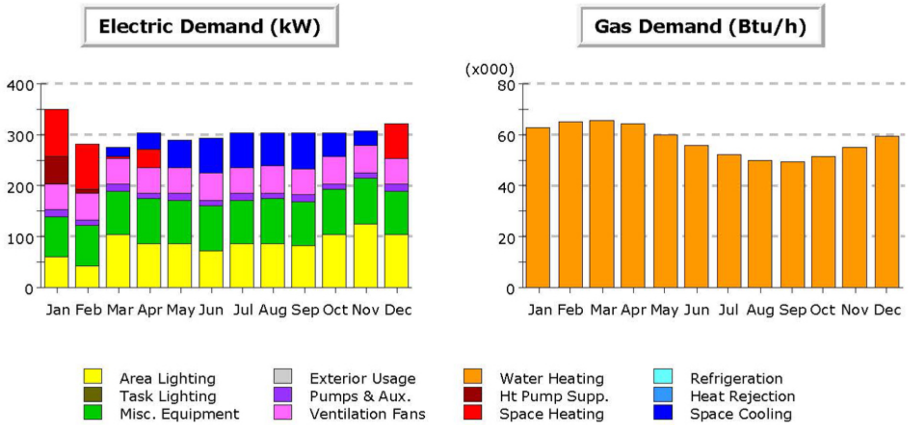
Annual energy estimation

- There are many software packages available (some are free)

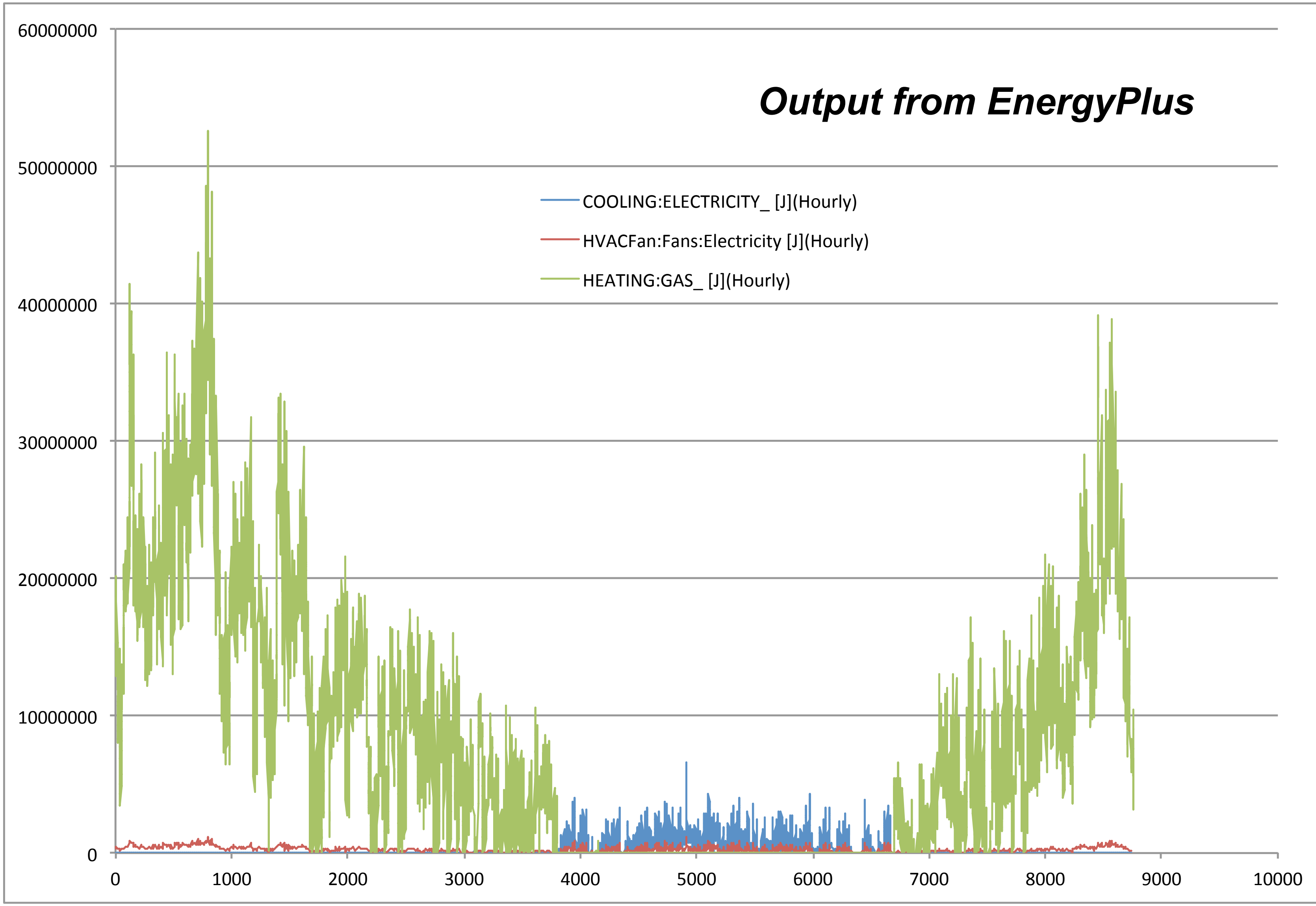
- EnergyPlus
- eQUEST
- IES-VE
- TRNSYS
- Many others



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



Annual energy simulation: Example home in Chicago



Annual energy simulation: Example home in Chicago

- Annual summary

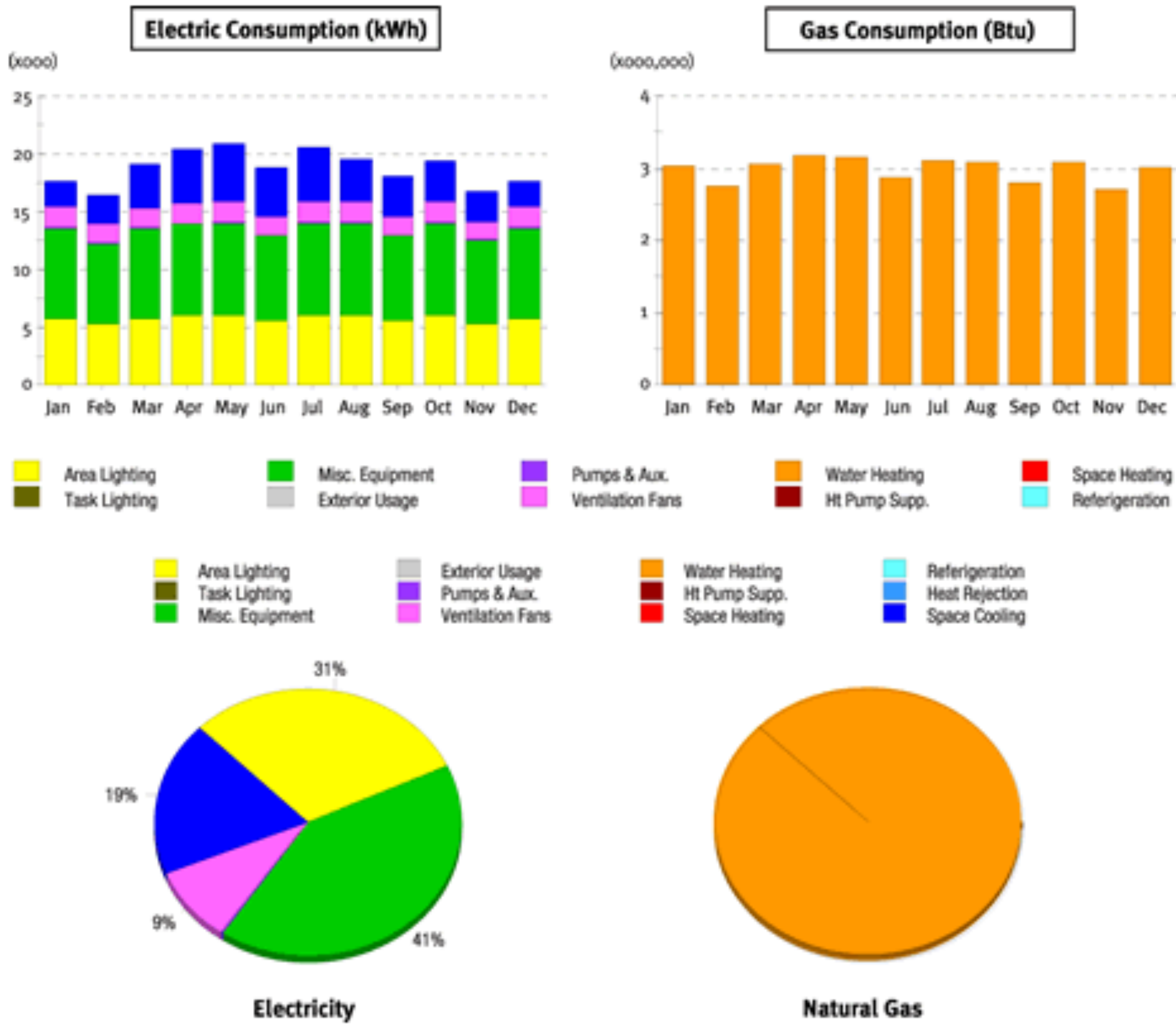
	Electric	**Gas**
Total J	29270600548	90956293121
Total kWh	8131	
Total MMBTU		86.2
$/unit	$0.10	$8.00
Annual energy cost	$813	$690

~$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

Annual energy simulation results (eQuest)



SIMPLER ENERGY ESTIMATION METHODS

Heating Degree Day and Cooling Degree Day Methods

Degree-day method

- There is also a simpler method of estimating annual energy use: **The Degree-Day Method (DDM)**
  - Less accurate but much faster/easier
- The DDM makes uses the concept of the **degree-day (DD)** to estimate energy used for heating or cooling
- The method is better for estimating heating requirements than cooling requirements because solar gain is ignored
- Works best where the efficiency of the HVAC equipment is constant

Degree-day method

- The basic idea is that the energy use of a building is directly related to the **temperature difference between outdoor and indoor air**
- Heating equipment is assumed to run when the outdoor temperature drops below the "balance temperature"
  - The **balance temperature** is the outdoor air temperature at which the internal heat gains balance the heat loss to the outside
  - This is **less than** the interior temperature set point
  - These are **Heating Degree Days**
- Cooling equipment is assumed to run when the outdoor temperature is above the balance temperature
  - The balance temperature might not be the same for heating and cooling because the interior temperature, interior heat gain, and building heat loss usually differ in summer and winter
  - These are **Cooling Degree Days**

Selecting a base temperature

- HDD_{65F} and CDD_{65F} are common HDD/CDD levels that are used regularly in industry (both with a base of 65°F)
- You can also calculate a different base or reference temperature based on your building
  - The base temperature is the balance point temperature where internal gains balance the heat loss to outside:

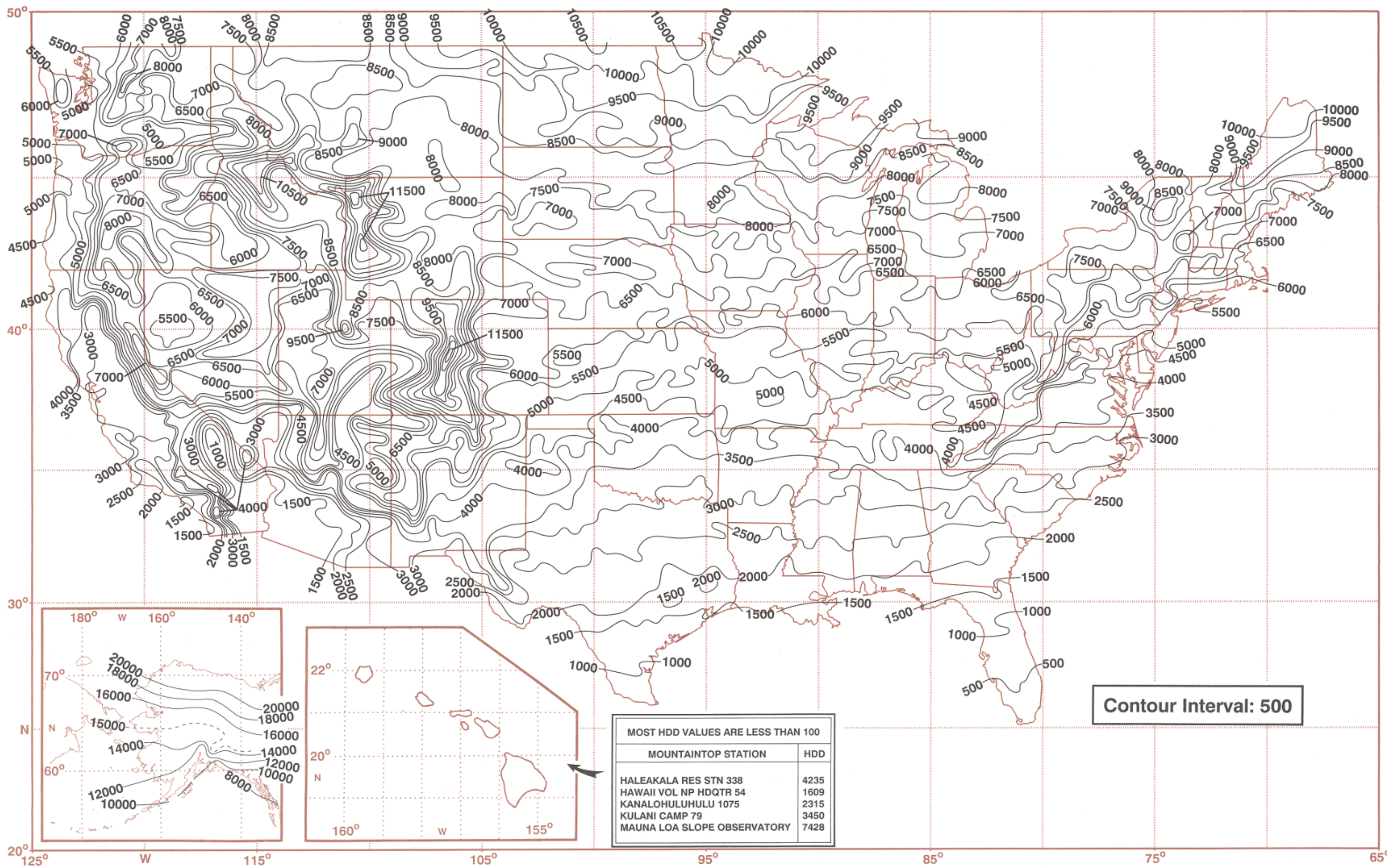
$$T_{bal} = T_{in} - \frac{Q_{gains}}{\left(UA\right)_{total} + \dot{V}_{\mathrm{inf}} \rho C_p}$$

  - As the insulation increases, T_{bal} decreases
  - As infiltration decreases, T_{bal} decreases
  - As internal gains increase, T_{bal} decreases

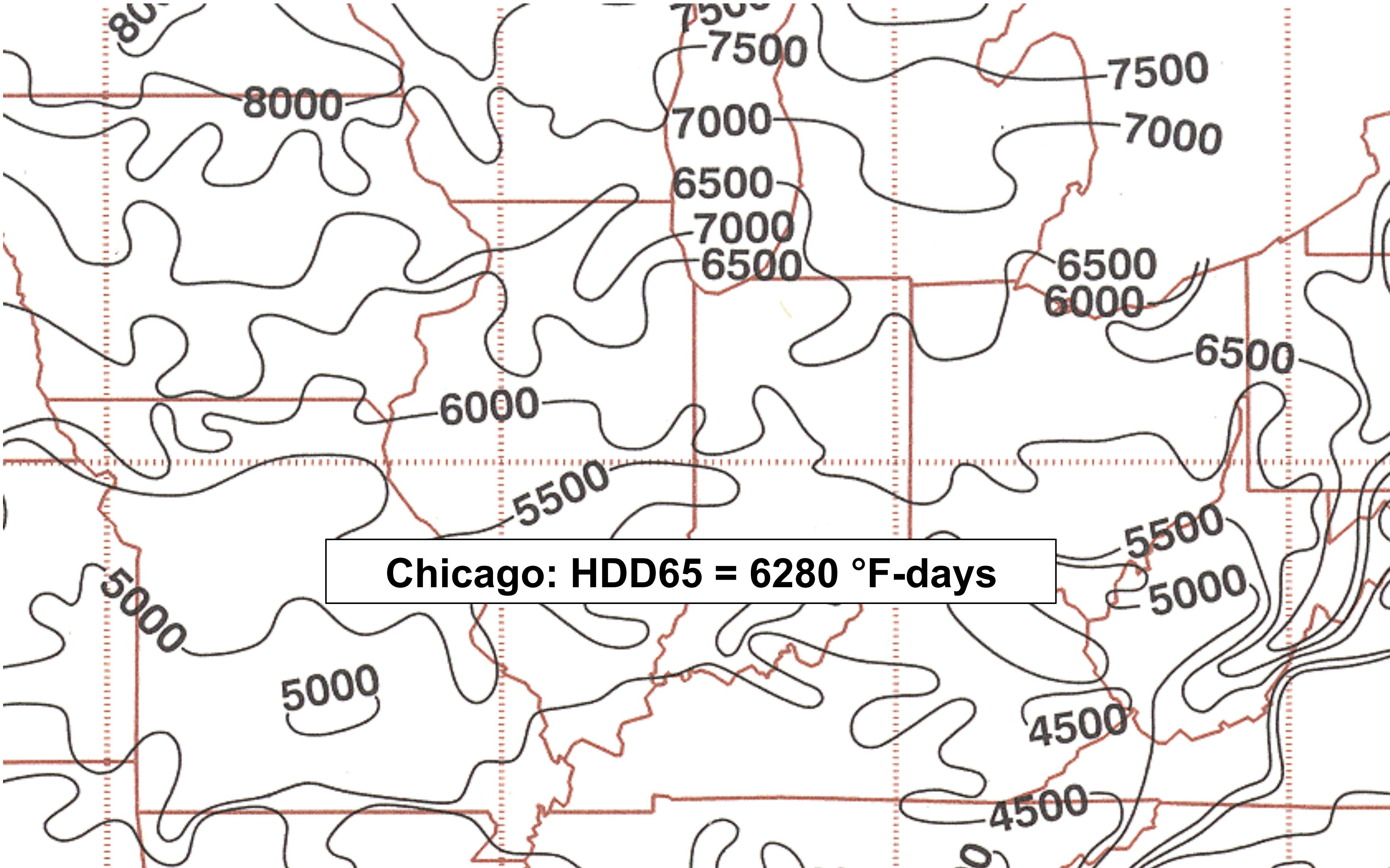
HDD_{65F} maps

ANNUAL HEATING DEGREE DAYS

BASED ON NORMAL PERIOD 1961-1990

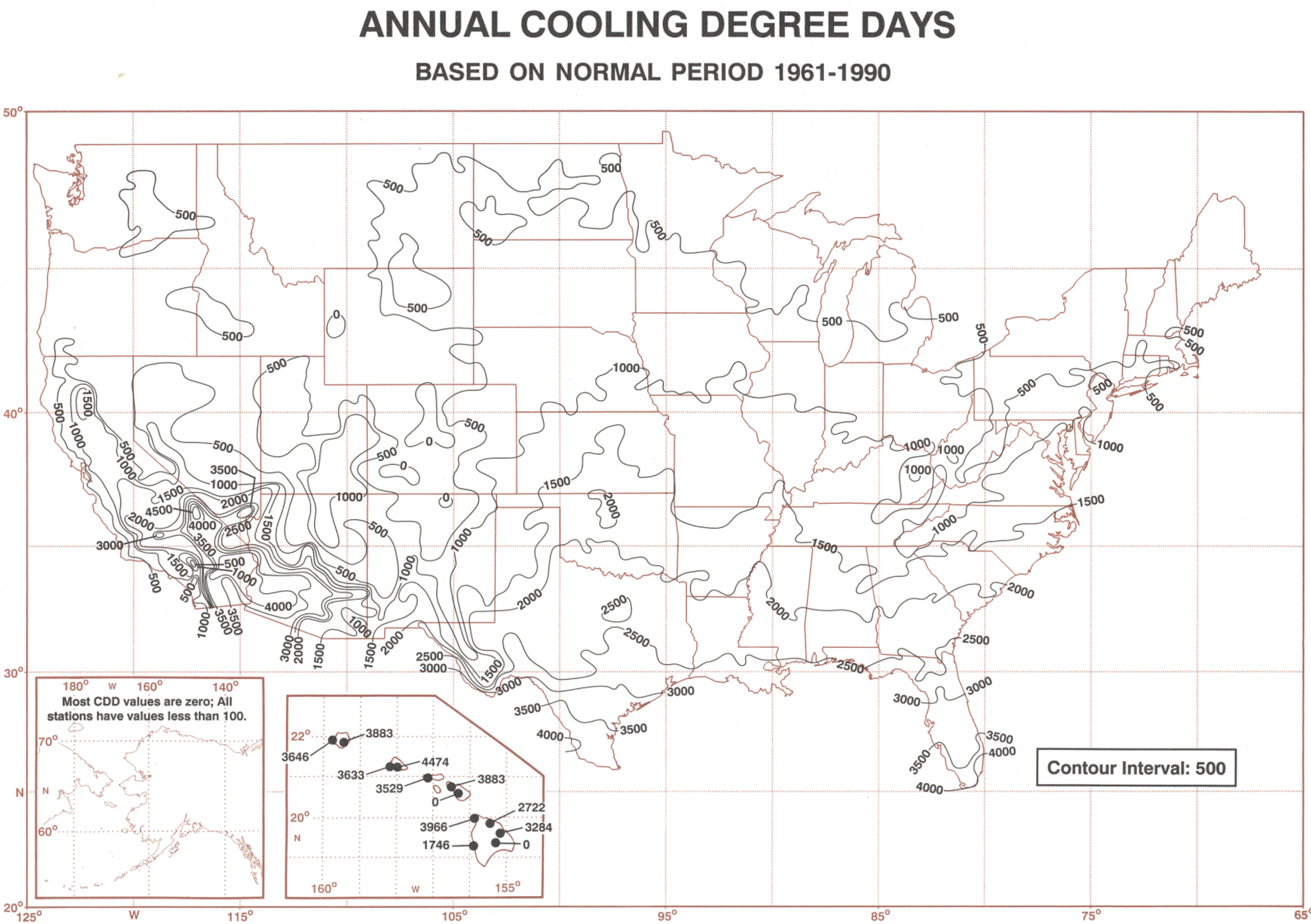


HDD$_{65F}$ maps

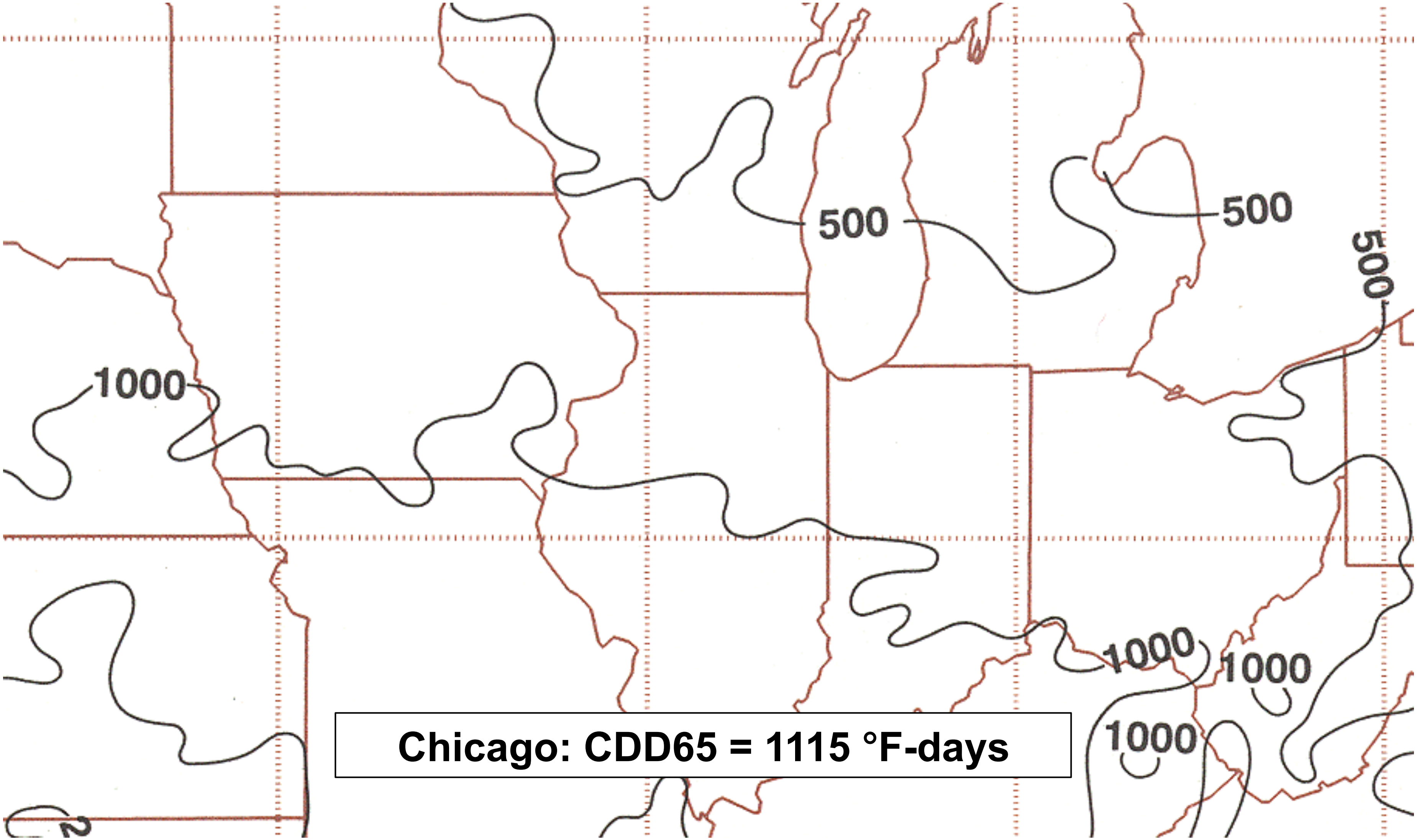


Chicago: HDD65 = 6280 °F-days

CDD_{65F} maps


ANNUAL COOLING DEGREE DAYS
BASED ON NORMAL PERIOD 1961-1990
Most CDD values are zero; All stations have values less than 100.
Contour Interval: 500

CDD_{65F} maps



Chicago: CDD65 = 1115 °F-days

Estimating energy use with HDD

- Now that we know how to get HDD, we can calculate the heating energy, E, required to keep the building heated

- Using hourly values:

$$E_{heating} = \frac{(UA)_{total}}{\eta} \int [T_{bal} - T_{out}(t)]\,dt \quad \text{when} \quad T_{out} < T_{bal}$$

Where η = heating system efficiency (-)

- Using HDD:

$$E_{heating} = \frac{(UA)_{total}}{\eta} HDD$$

*Convert HDD to proper units (degree-seconds or degree-hours)

Estimating energy use with HDD

- Find the annual heating bill for a house in Chicago under the following conditions:
  - UA_{total} = 400 BTU/(hr °F)
  - T_{bal} = 65°F
  - Natural gas heating system is 75% efficient
  - Natural gas fuel price is \$8/MMBTU
  - HDD_{65F} = 6280 °F-days

$$E_{heating} = \frac{400\,\frac{\text{BTU}}{\text{hr°F}}}{0.75}(6280\ \text{°F-days})\left(\frac{24\ \text{hours}}{1\ \text{day}}\right) = 6.03\times10^{7}\ \text{BTU} = 60.3\ \text{MMBTU}$$

$$Costs_{heating} = 60.3\ \text{MMBTU} \times \frac{\$8}{\text{MMBTU}} = \$482$$

ENERGY EFFICIENCY IN BUILDINGS

Designing for efficiency

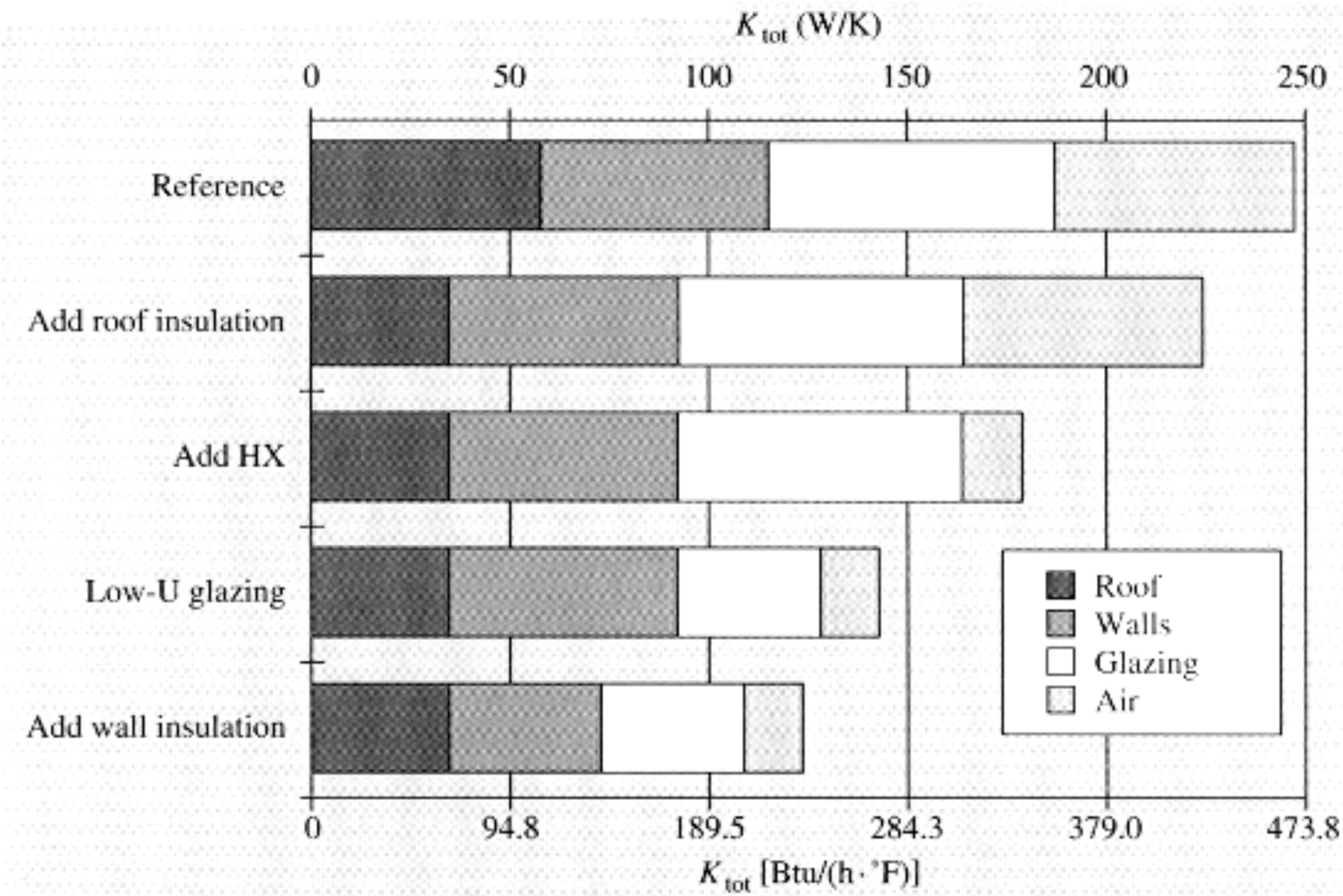
- We can't change outdoor conditions (e.g., temperature, solar radiation, or HDD and CDD)
  - So what can we do to reduce energy consumption?

- Reduce UA (including infiltration contribution, $\rho C_p \dot{V}$)
- Increase COP/efficiency of equipment
- Reduce internal loads and electrical power draws
- Change thermostat settings (affects thermal comfort)
- Utilize passive solar and thermal mass to shift loads

- The earlier in the design phase that we do this, the better

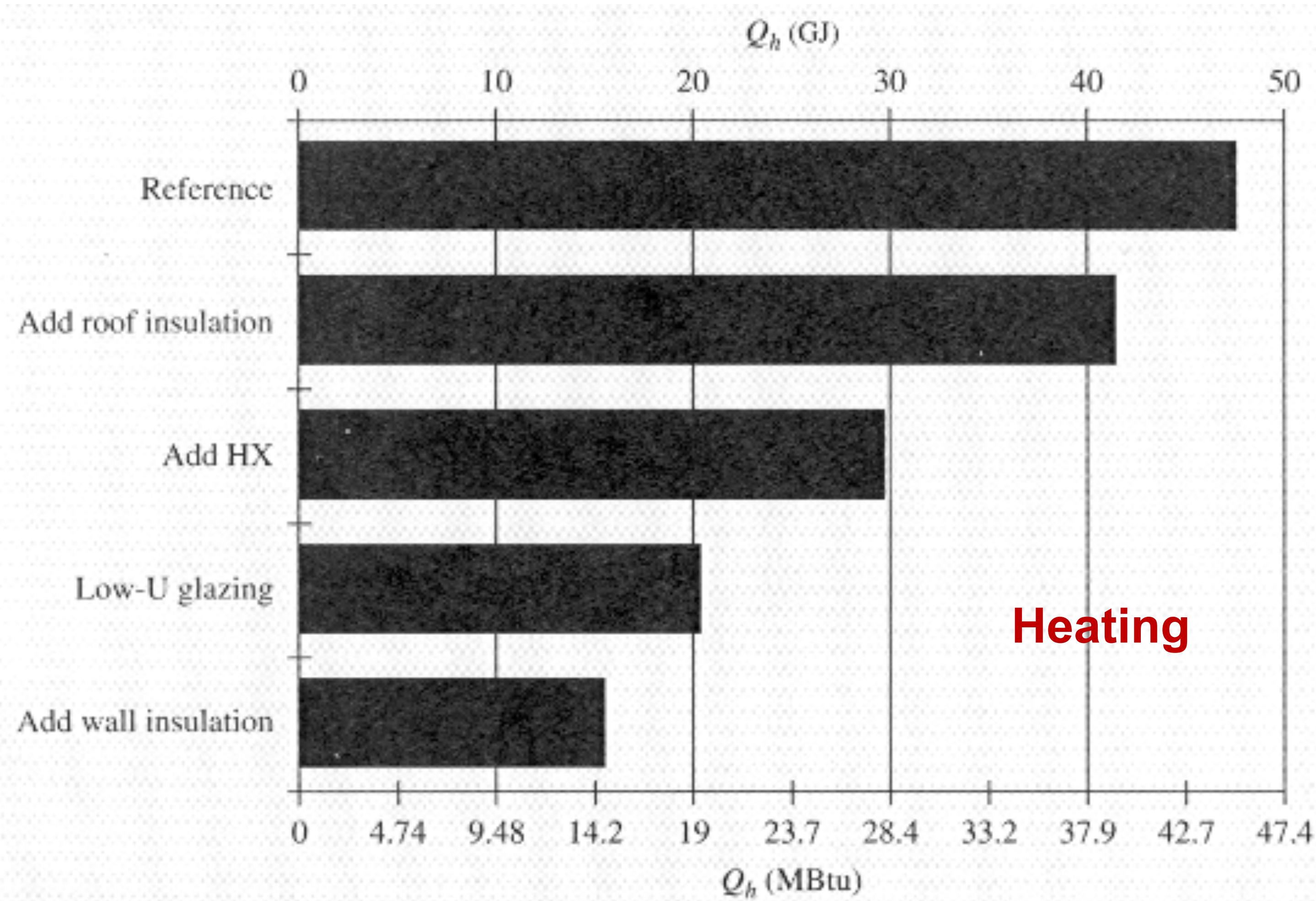
Design for efficiency: Parametric changes early in design phase

- We can make changes to the envelope $(UA)_{total}$



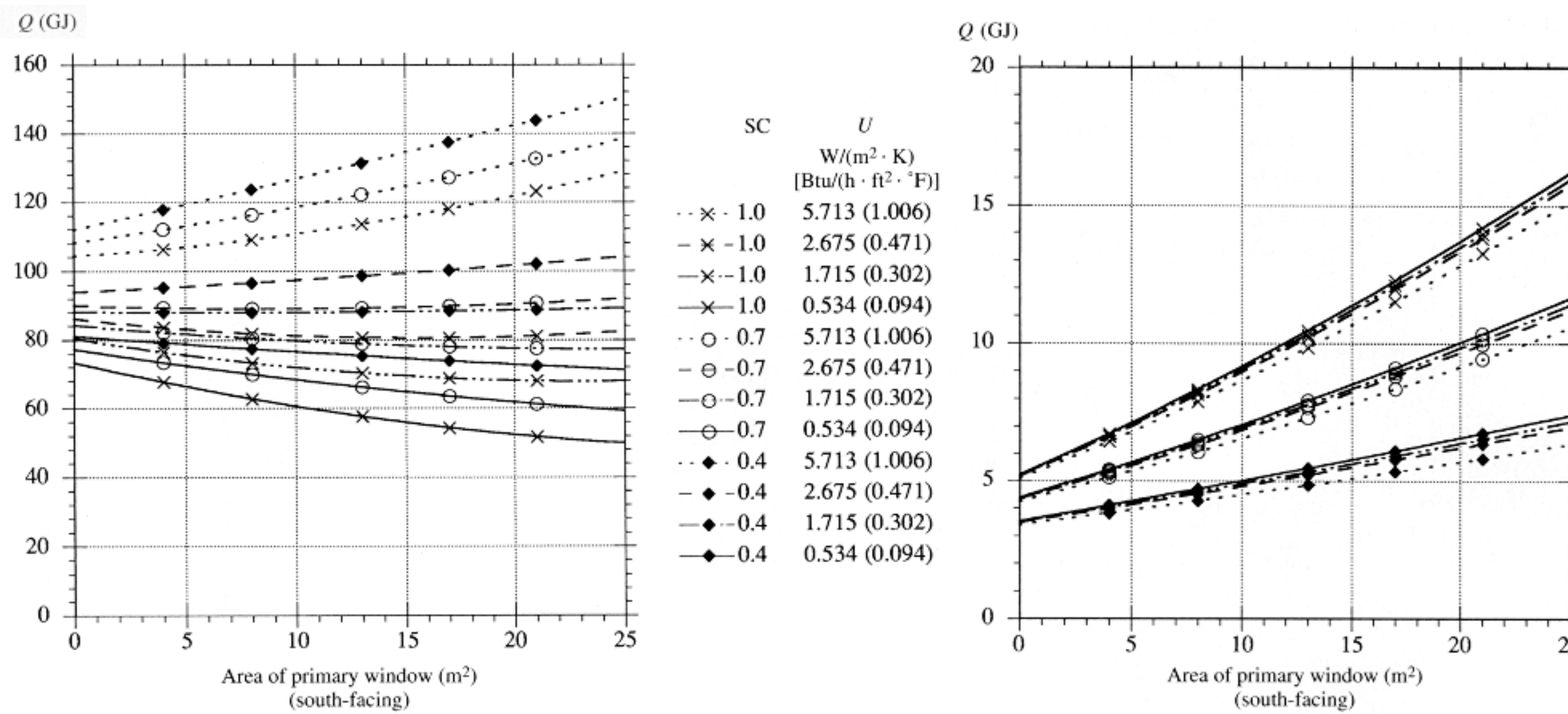
Design for efficiency: Parametric changes early in design phase

- We can estimate impact of changes to the envelope $(UA)_{total}$



Design for efficiency: Parametric changes early in design phase

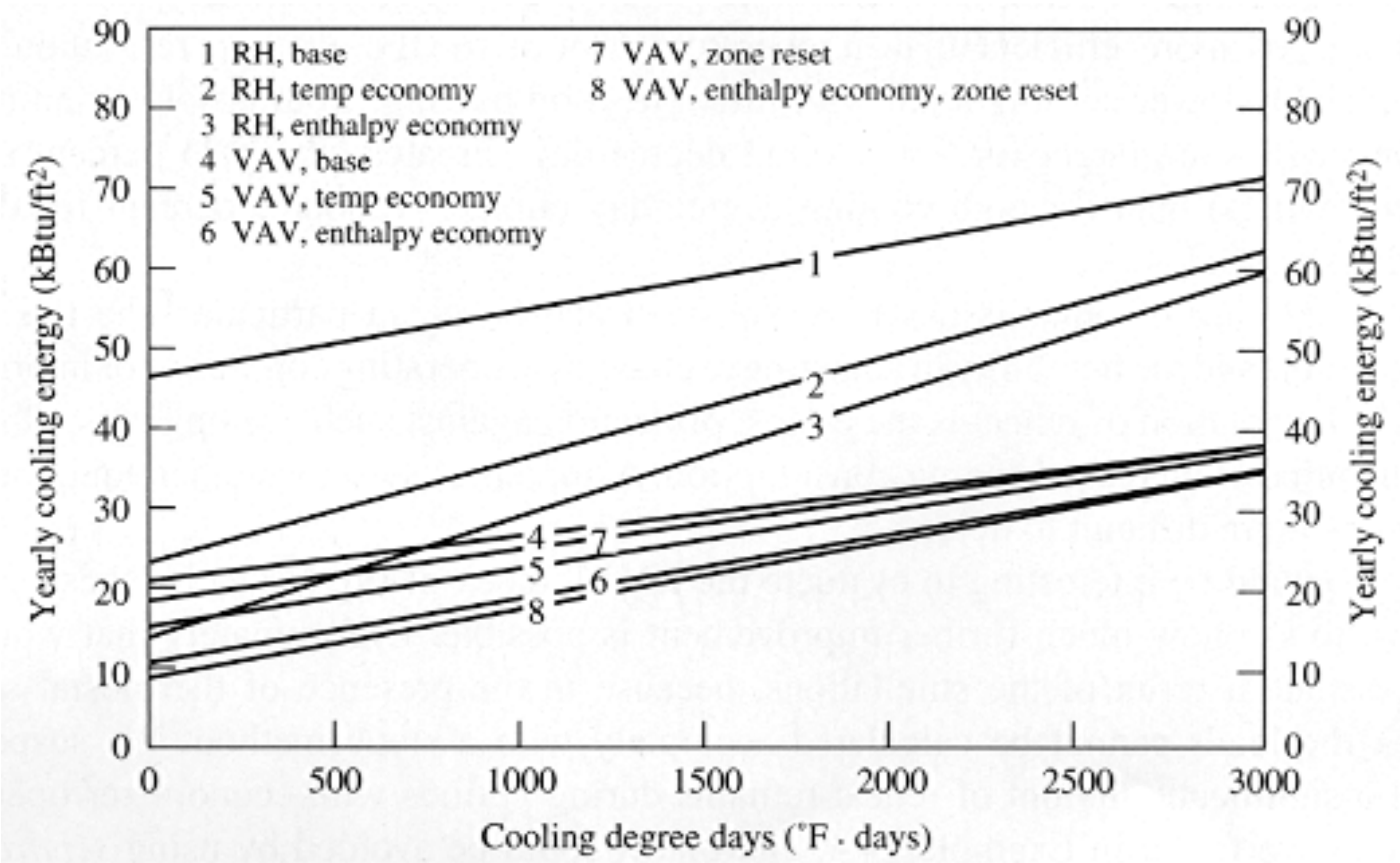
- Window area, shading, and U-values

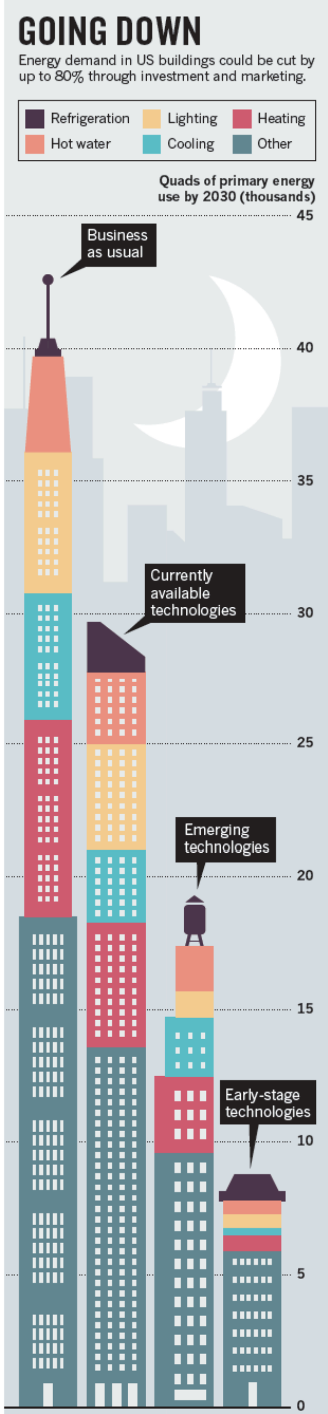


Heating **Cooling**

Design for efficiency: Parametric changes early in design phase

- Changing HVAC type in an office





Paths toward *lower energy* buildings

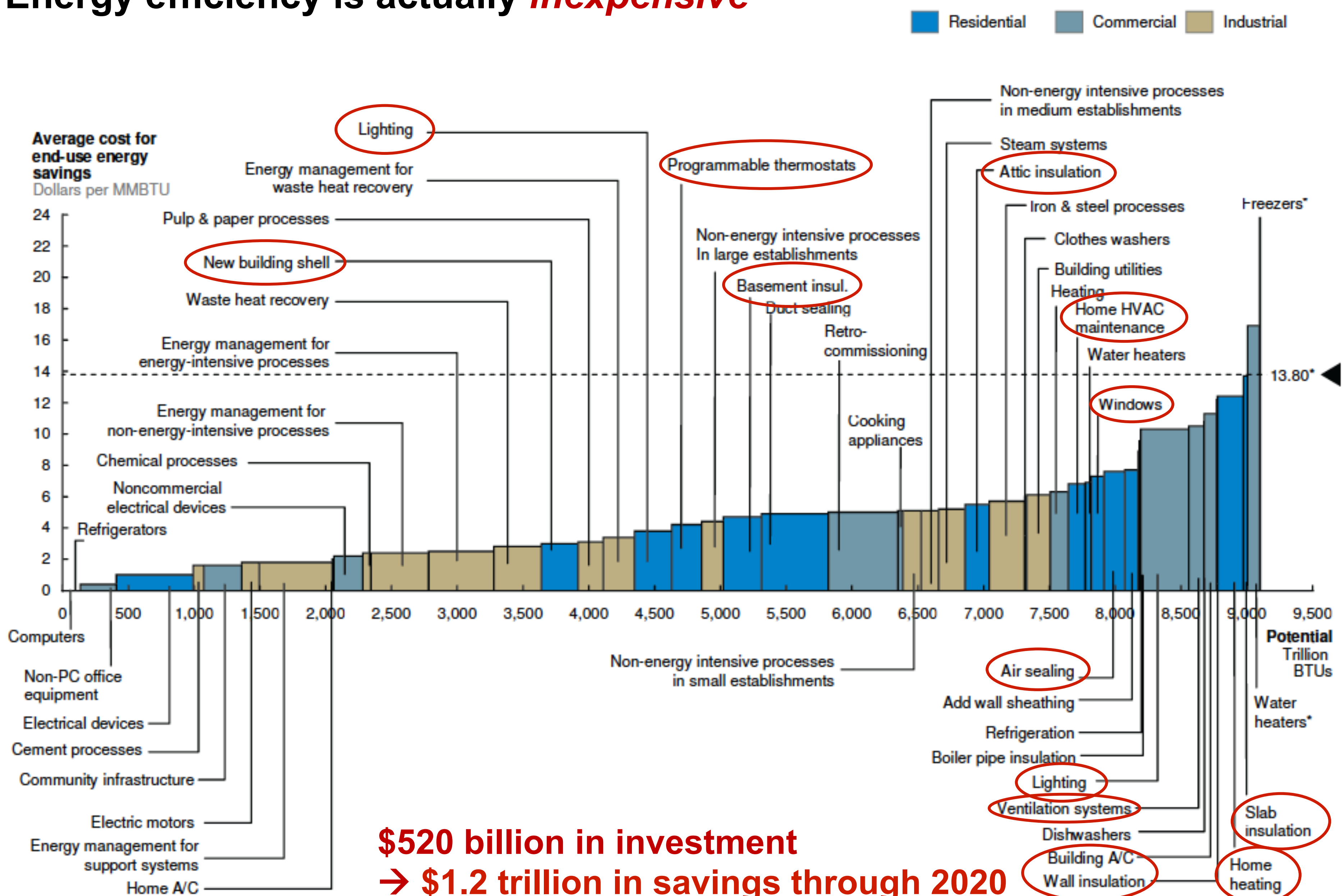
- Efficient building ***systems***
  - Mechanical systems
  - Mechanical driving forces
  - Controls and equipment

- ***Passive*** building design
  - Natural systems
  - Natural driving forces
  - Form and materials

"Energy demand in U.S. buildings could be cut by up to 80% through investment and marketing"

Farese, 2012, How to build a low-energy future. *Nature* 488:275-277

Energy efficiency is actually *inexpensive*

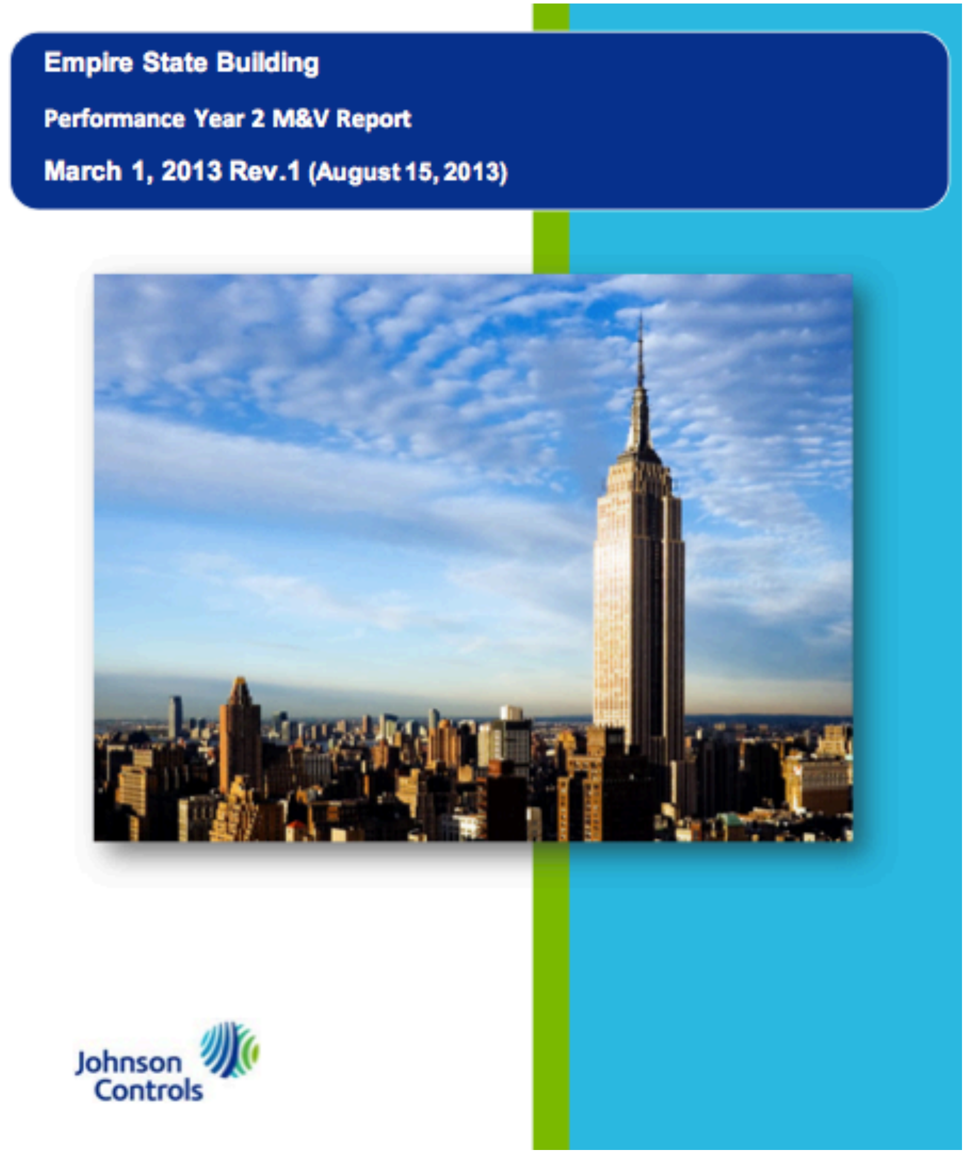


$520 billion in investment
→ $1.2 trillion in savings through 2020

McKinsey & Company, 2009 *Unlocking energy efficiency in the US economy*

Energy savings in commercial buildings

- Empire State Building
  - New York, NY
- Implemented 5 energy conservation measures (ECMs) in 2011
  - Window retrofit
  - Radiator insulation and steam traps
  - Building automation system
  - Chiller retrofit
  - Tenant energy management
- Collected data and compared modeled savings versus measured

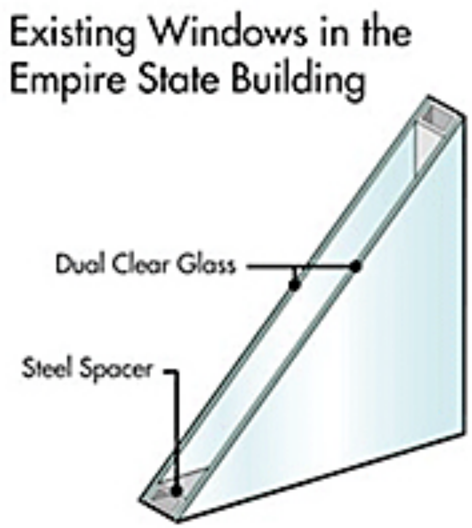


ECMs in the Empire State Building

Window retrofits

- Upgraded over 6500 double-hung insulated glazing units

ECMs in the Empire State Building



Original windows:

- U-value = 0.58 Btu/hr-ft^2-°F
- SHGC = 0.65

New windows (krypton + argon):

- U-value = 0.37 Btu/hr-ft^2-°F on north wall and 0.38 on S-E-W walls
- SHGC = 0.45 on north wall and 0.33 on S-E-W walls

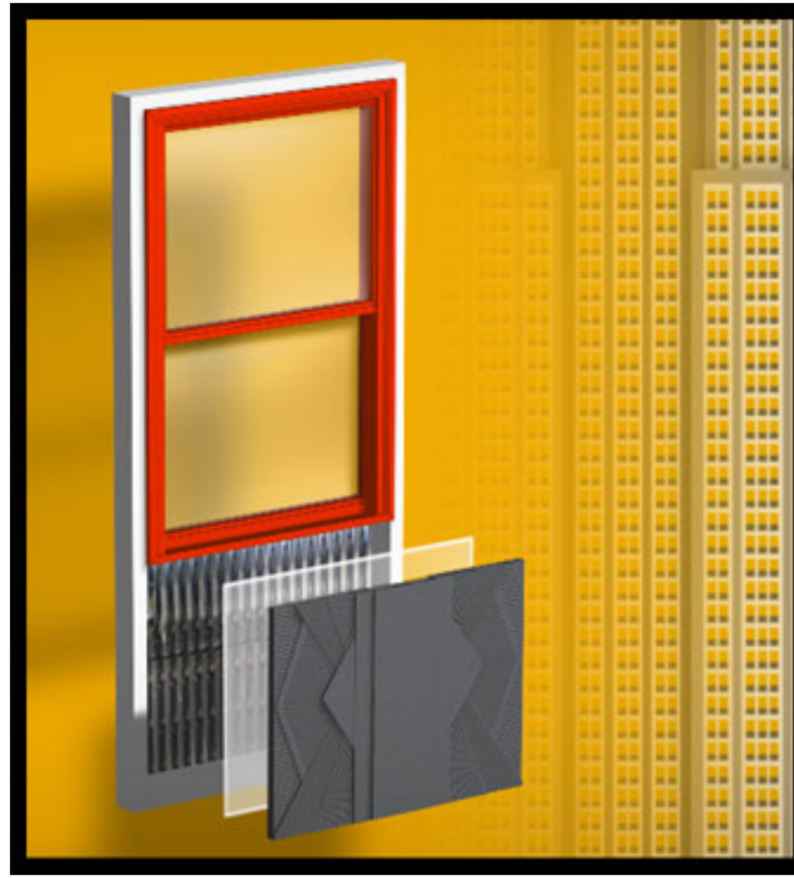
ECMs in the Empire State Building

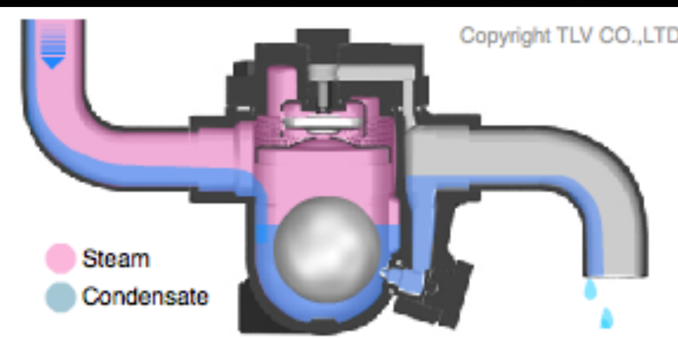
Radiator system

- Added insulated reflective barriers *behind* radiator units and in front of walls on the perimeter of the building

- Original insulation:
  – U-value = 0.21 Btu/hr-ft^2-°F
- New insulation:
  – U-value = 0.12 Btu/hr-ft^2-°F

- Also upgraded control system and added “steam traps”



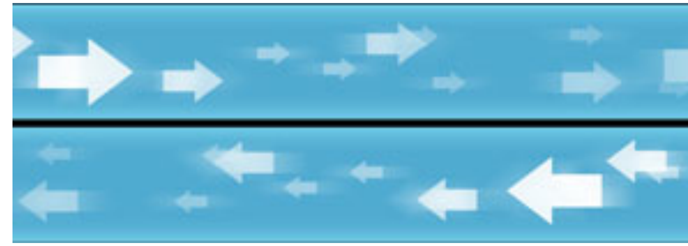


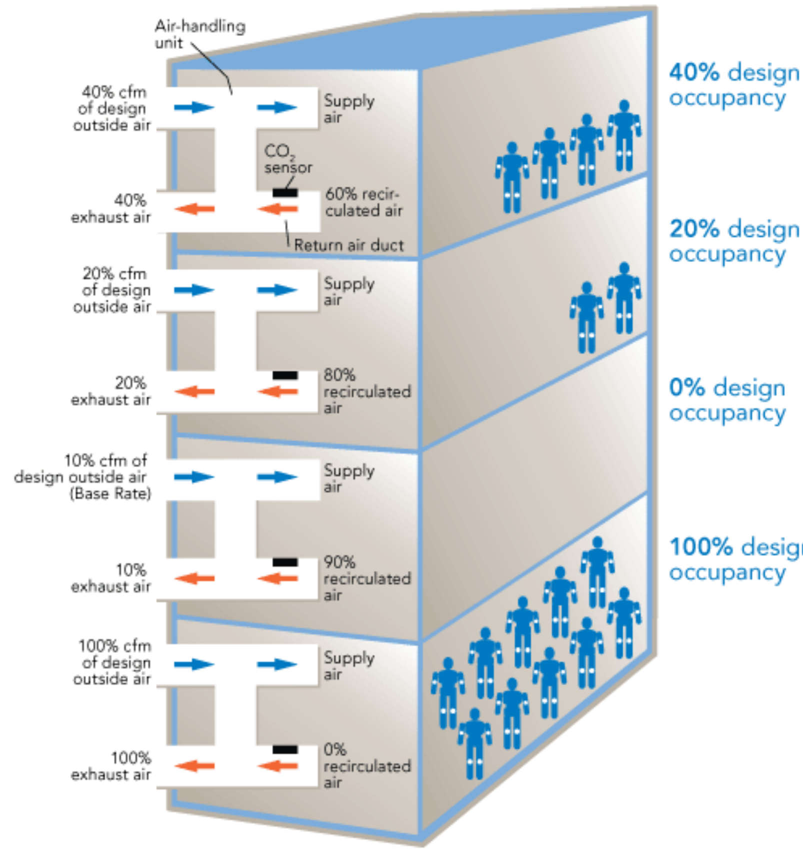
ECMs in the Empire State Building

Building automation system (BAS)

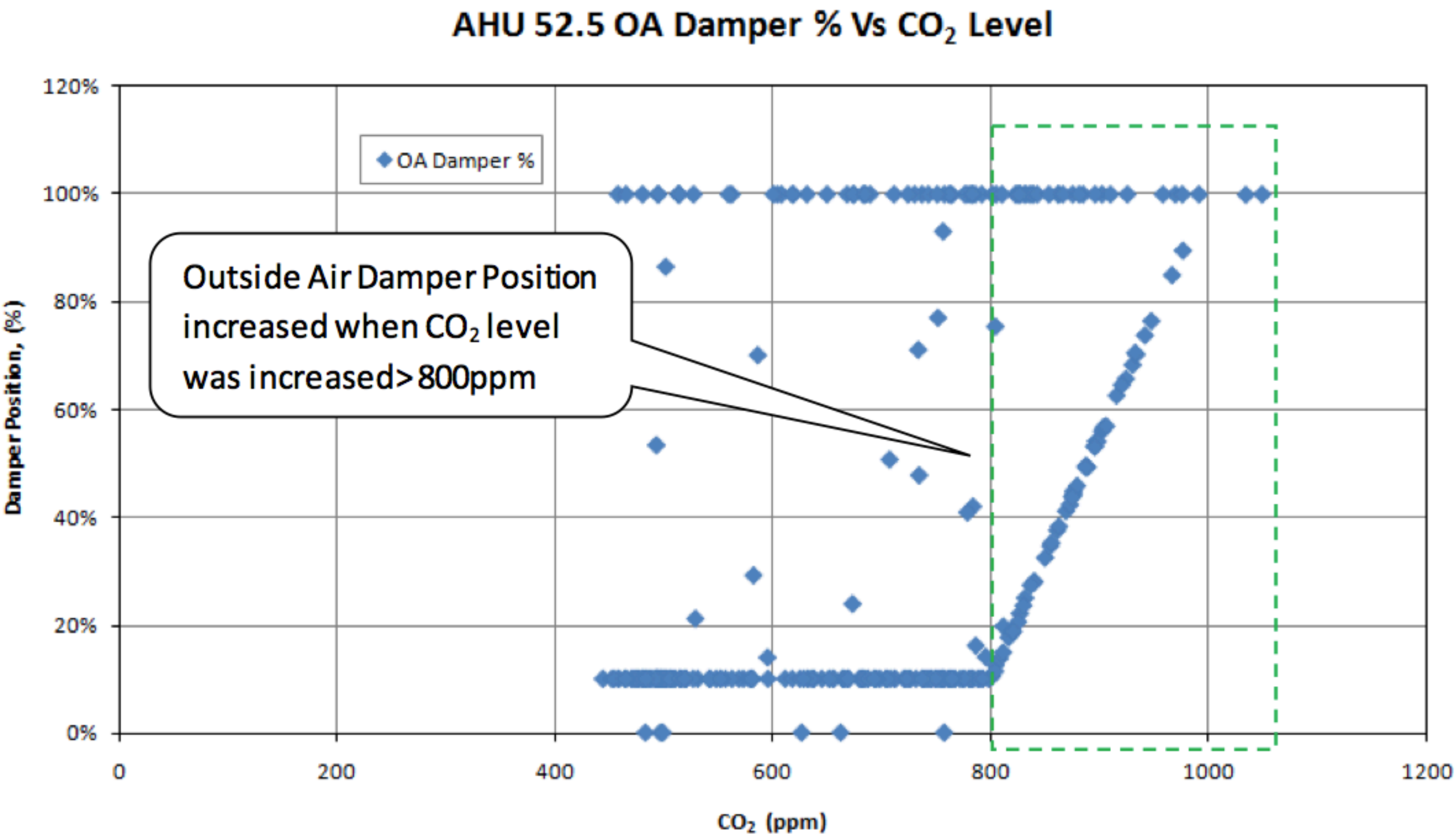
- Reduced overall outdoor air intake by using "demand controlled ventilation" (DCV) and modulating dampers
  - Uses CO_2 to measure occupancy

- Original BAS:
  - No controls, OA = from 0.25 cm/ft^2
- New BAS:
  - Keep OA low until CO_2 in return air = 800 ppm and better controls for OA economizer
  - New OA = from 0.12 cm/ft^2





ECMs in the Empire State Building



ECMs in the Empire State Building

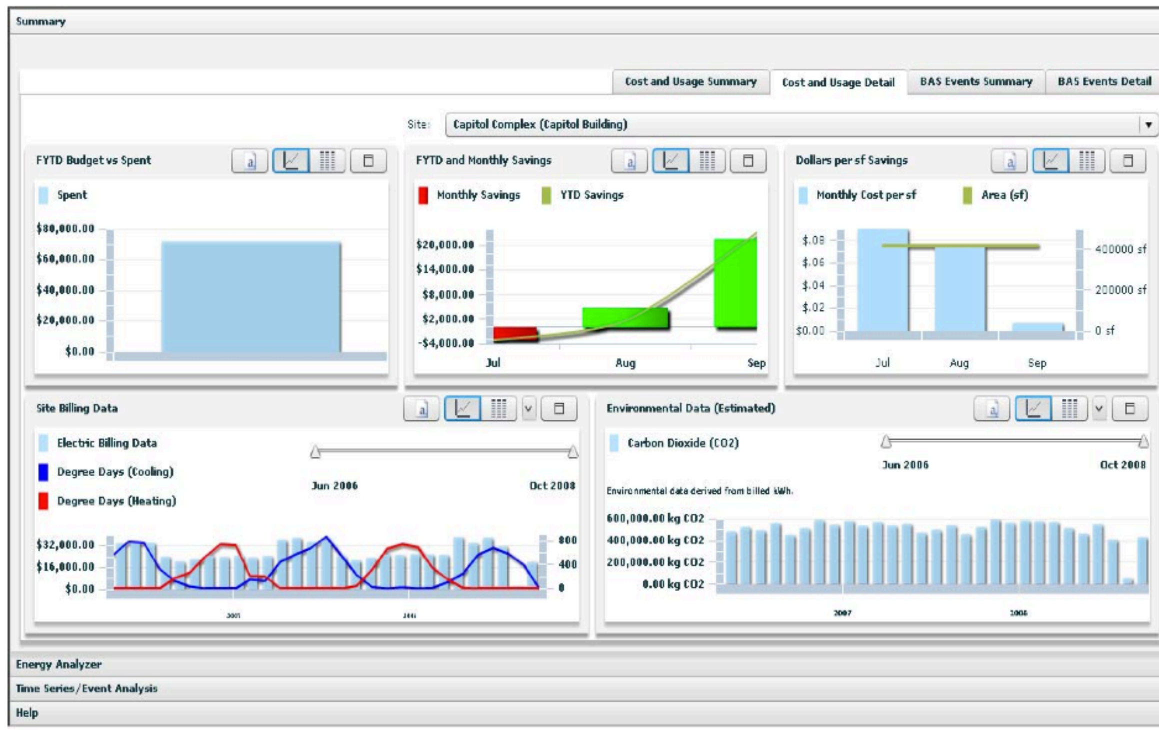
Chiller plant retrofit

- Replaced compressors with variable speed drives (VSDs)
  - Better part load efficiency
- Replaced evaporator and condenser tubes
  - Increase UA of heat exchangers
- Increased chilled water supply T and added “reset”
  - Decreases only when T_{out} is high
- Valve changes and VSD automation
- Cooling tower fan switched to automated VSD

ECMs in the Empire State Building

Tenant energy management portal

- Gave tenants a digital dashboard displaying energy use and endorsing energy efficient practices
  - Lighting, thermostat settings, etc.



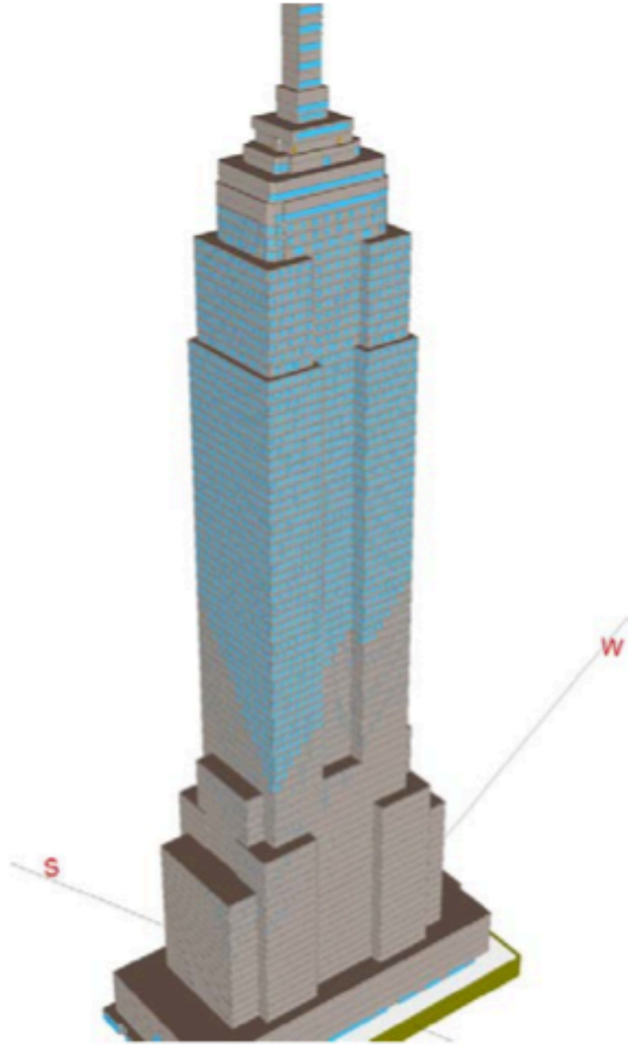
Energy simulation to predict cost savings

eQUEST Model Setup Overview

Modeling Software	eQUEST v3.64, build 7130
Model Author	Quest Energy Group, LLC 1620 W Fountainhead Pkwy #303 Tempe, AZ 85282 +1 480 467 2480

Model Build

- A detailed architectural model of the building was created based on archive drawings, photos taken at the site, and site inspections. Site inspections included verifying wall and roof constructions, external shading, and glass types.
- Schedules based on building operation were used in the model.
- Lighting demand and energy (schedules) were put into the model based on the lighting information provided by JLL.
- Representative internal equipment loads by space type (office, corridor, etc.) were incorporated into the model.

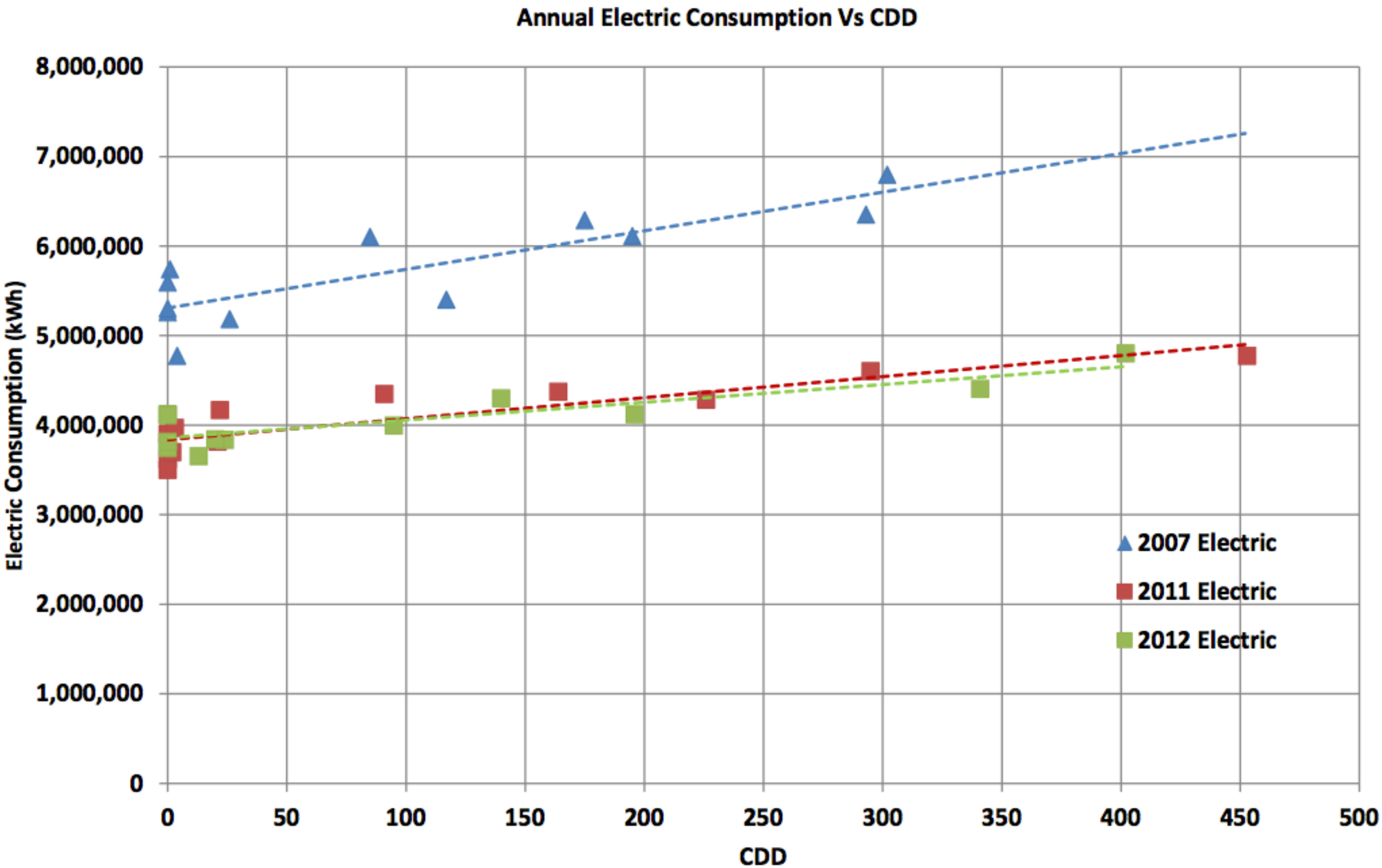


Predicted cost and savings in the Empire State Building

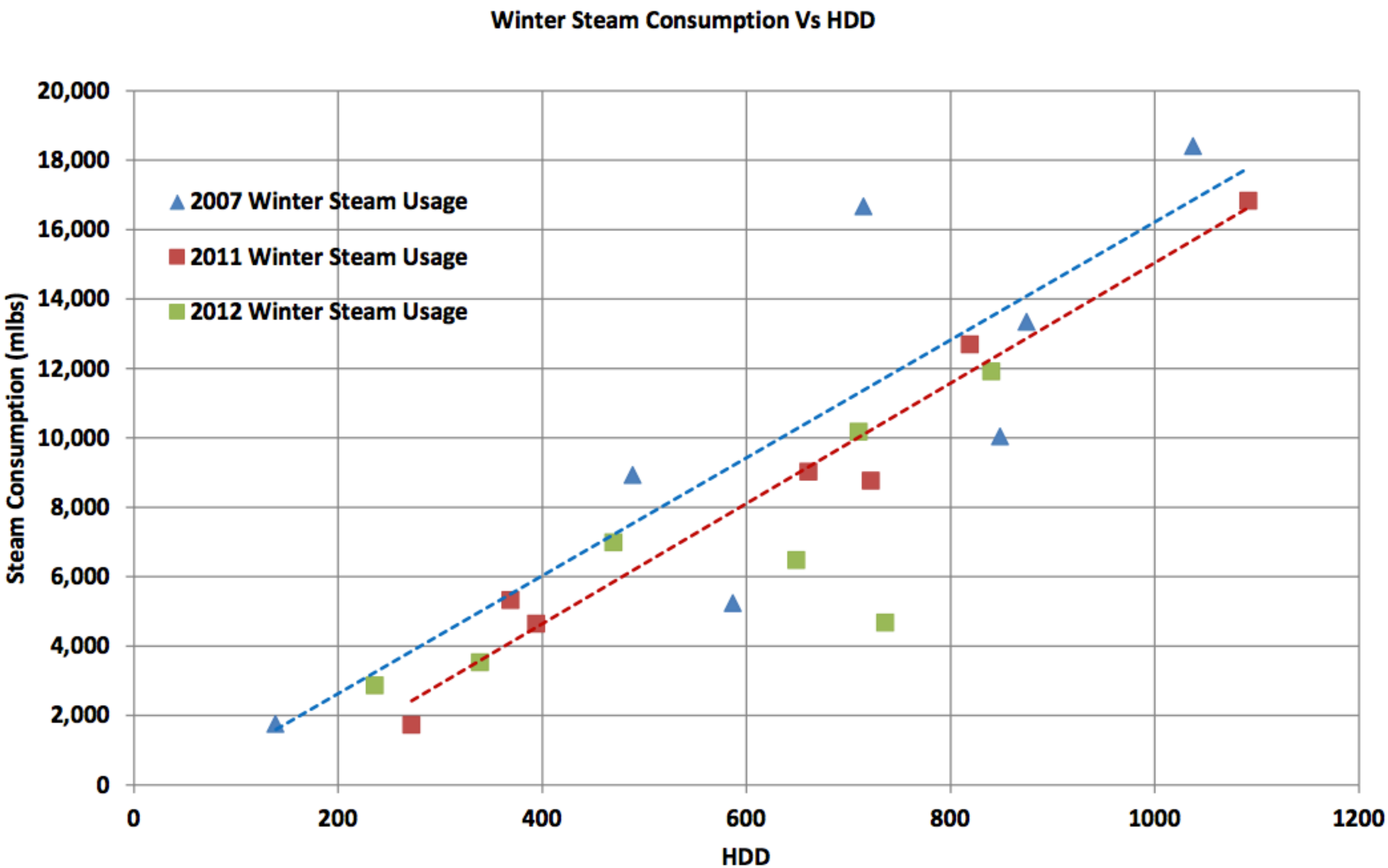
Project Description	*Projected Capital Cost*	*2008 Capital Budget*	*Incremental Cost*	*EstimatedAnnual Energy Savings**
Windows	$4.5m	$455k	$4m	$410k
Radiative Barrier	$2.7m	$0	$2.7m	$190k
DDC Controls	$7.6m	$2m	$5.6m	$741k
Demand Control Vent	Inc. above	$0	Inc. above	$117k
Chiller Plant Retrofit	$5.1m	$22.4m	-$17.3m	$675k
VAV AHUs	$47.2m	$44.8m	$2.4m	$702k
Tenant Day/Lighting/Plugs	$24.5m	$16.1m	$8.4m	$941k
Tenant Energy Mgmt.	$365k	$0	$365k	$396k
Power Generation (optional)	$15m	$7.8m	$7m	$320k
TOTAL (ex. Power Gen)	$106.9m	$93.7m	$13.2m	$4.4m

Invested a total of ~$13 million in energy retrofits while undergoing a $107 million planned retrofit

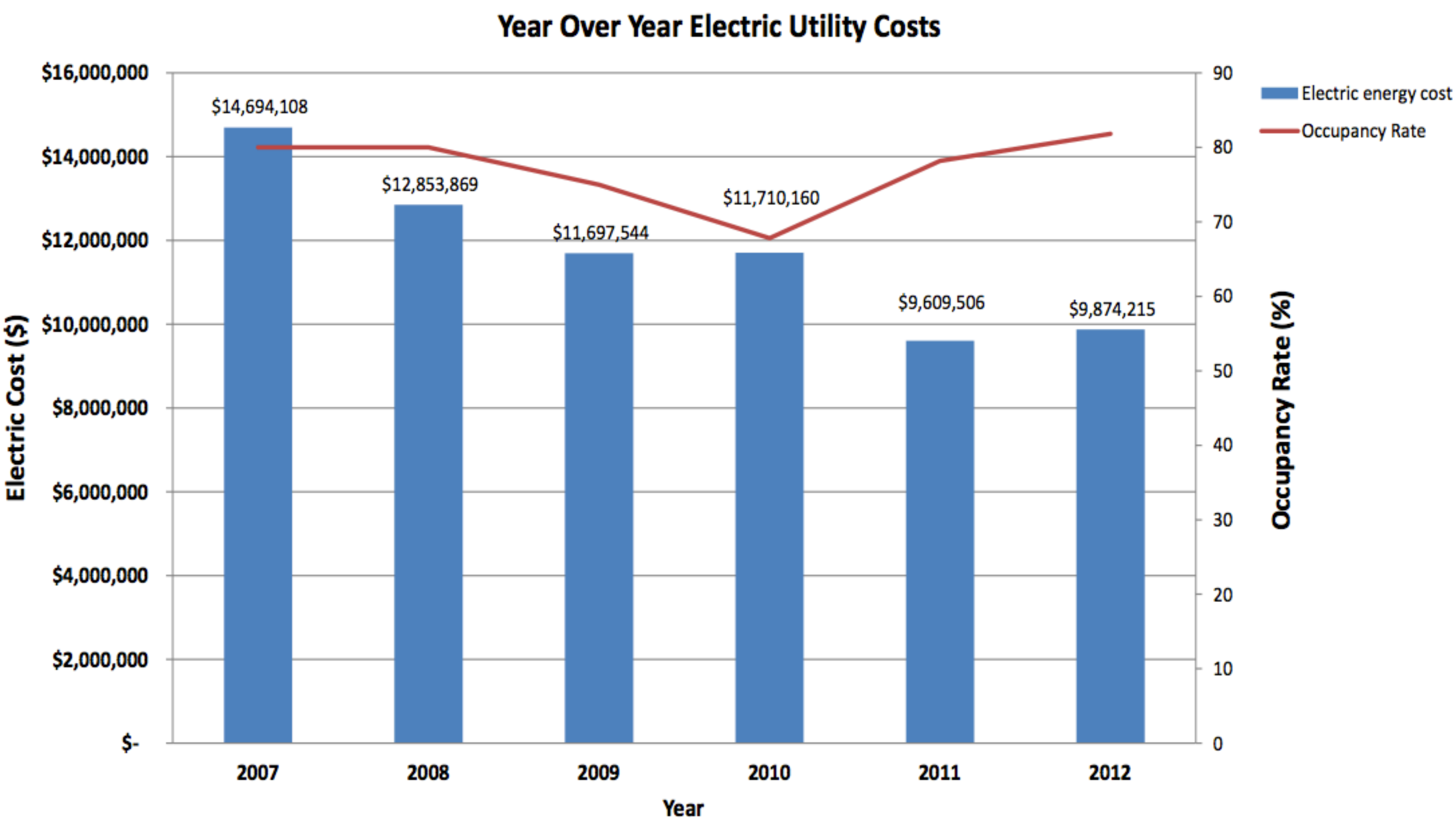
Measured performance in the Empire State Building



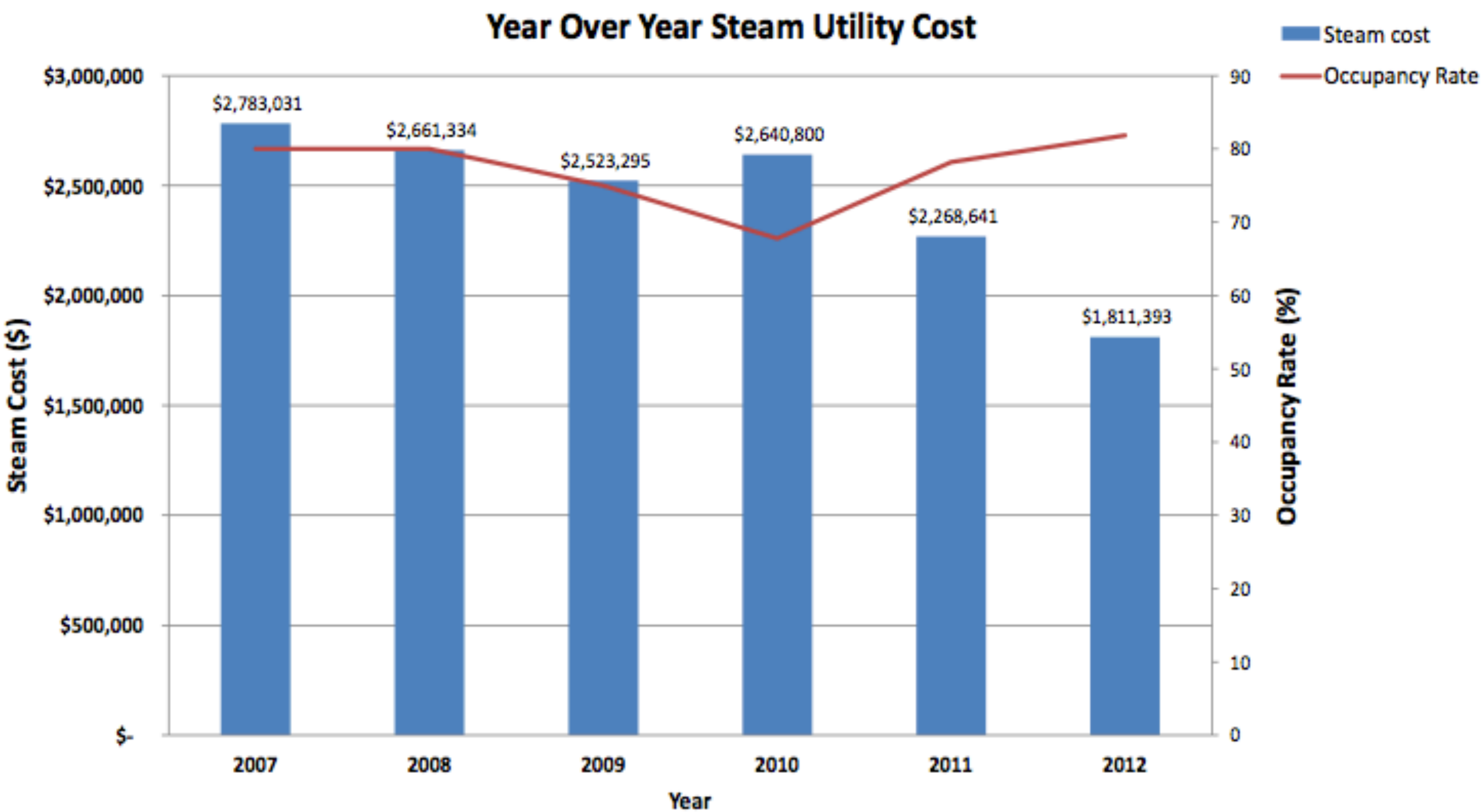
Measured performance in the Empire State Building



Measured performance in the Empire State Building



Measured performance in the Empire State Building



Measured performance in the Empire State Building

- Investments of a total of **~$13 million** is saving **~$2.5 million per year**
  - Predicted to save more than this
  - Still a 20% rate of return with payback period around only 5 years
- Lessons: **Energy efficiency pays!**
- For building science, we now understand enough fundamental concepts to drive lower-energy buildings
  - Basic building physics
  - HVAC loads
  - Internal gains
  - HVAC equipment efficiency

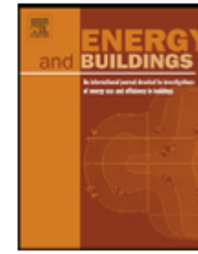
INTEGRATING RENEWABLES AND ENERGY EFFICIENCY

Very low-energy homes: Real data

Very low energy homes in the United States: Perspectives on performance from measured data

Danny S. Parker *

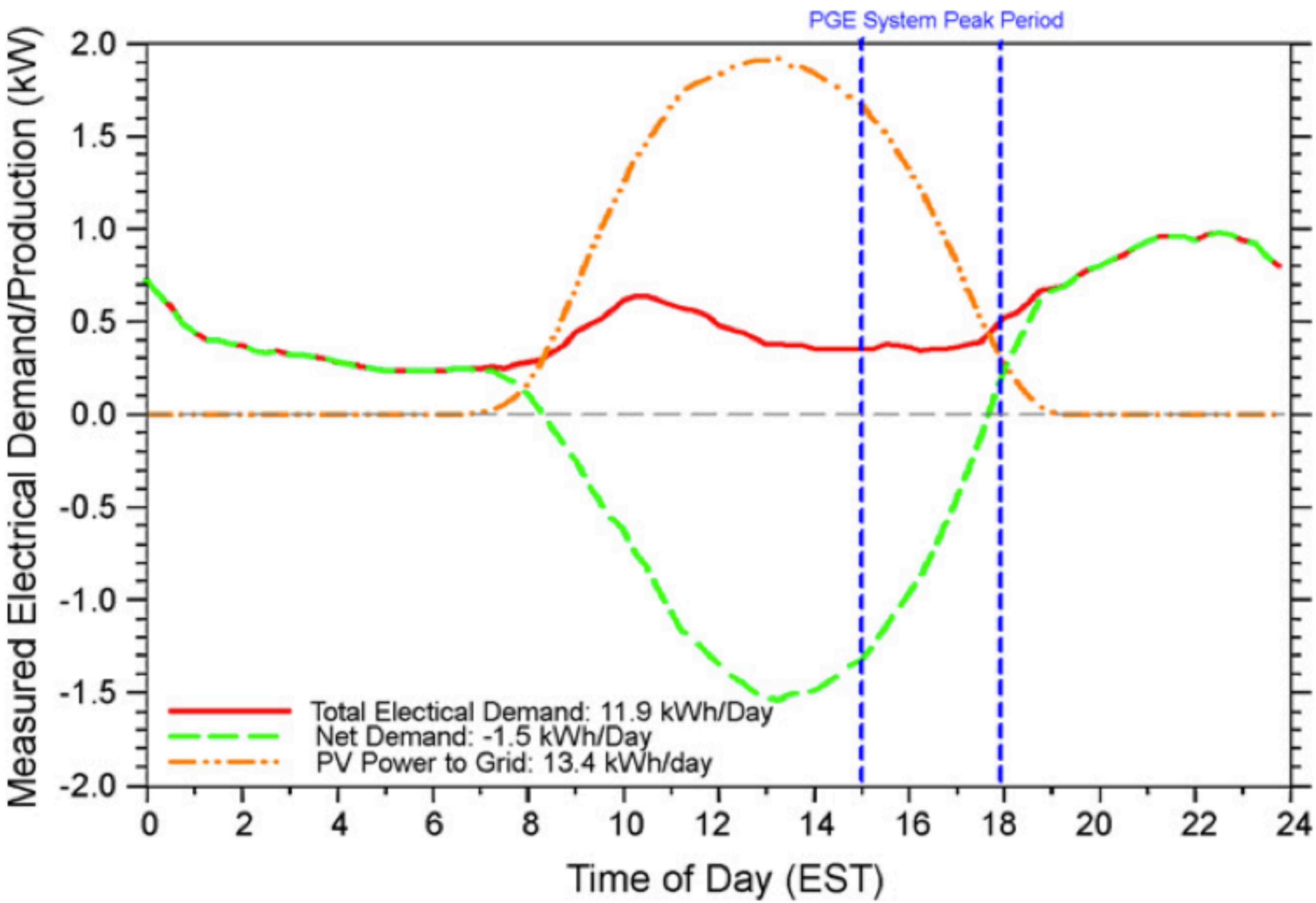
Florida Solar Energy Center, 1679 Clearlake Rd., Cocoa, FL 32922, USA



- Recent survey of very low energy homes
  - Low UA, low infiltration, highly efficient equipment
- Also net-zero-energy homes or (near) net-zero-energy homes
  - With solar PV providing electricity in addition to large savings from efficiency
- Homes from all over the US

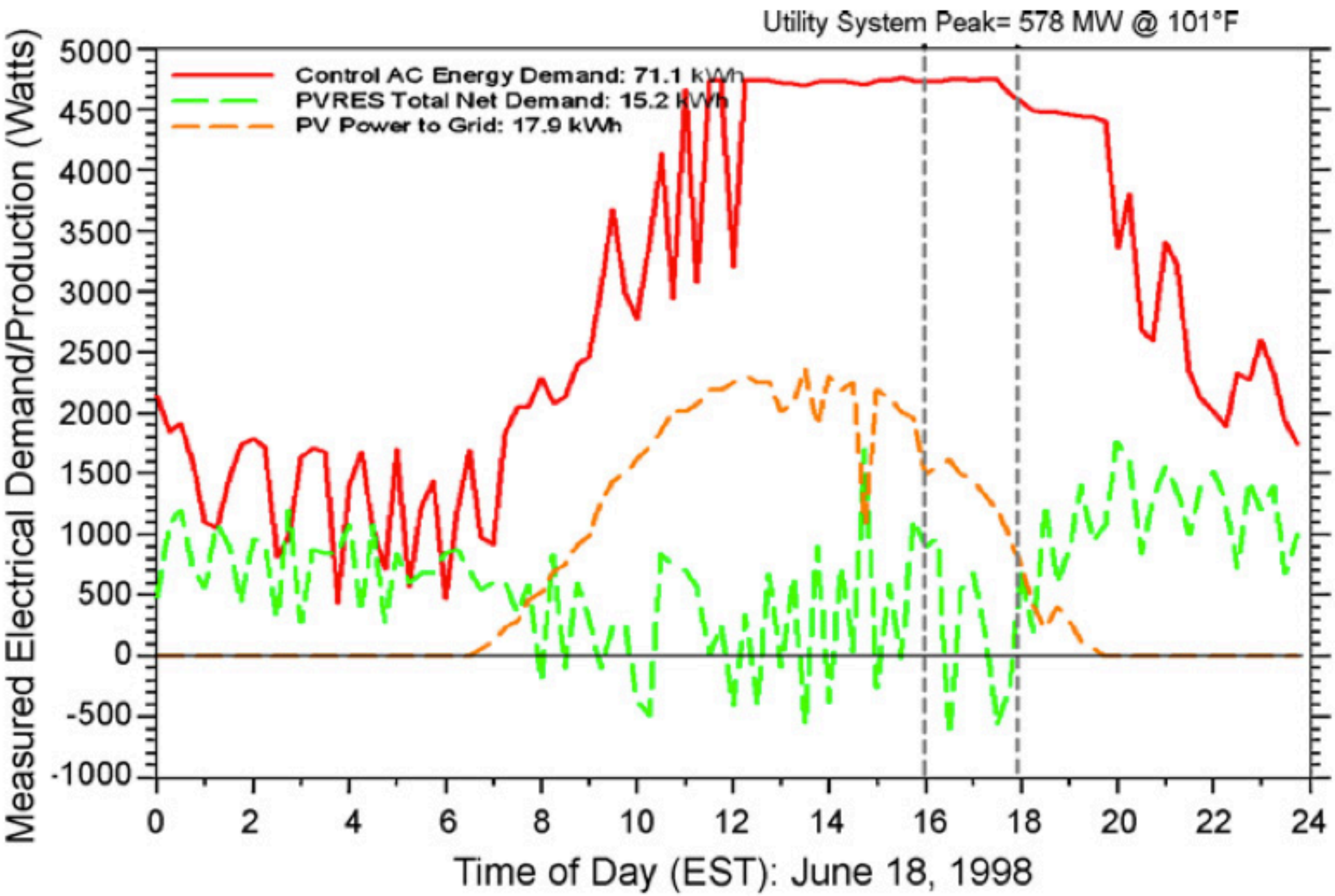
Parker **2009** *Energy and Buildings* 41:512-520

Large-scale monitoring of very low-energy homes



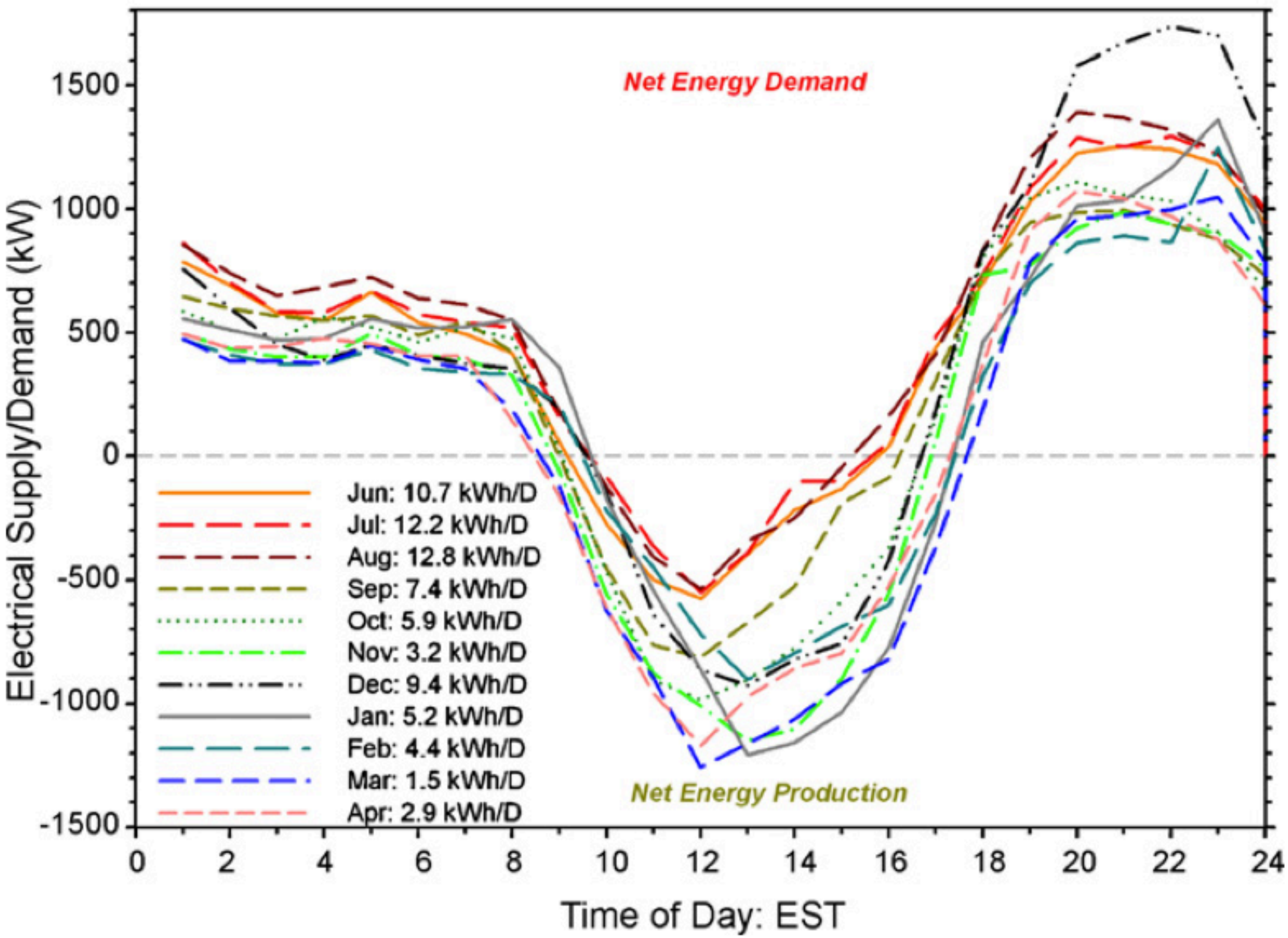
Parker **2009** *Energy and Buildings* 41:512-520

Large-scale monitoring of very low-energy homes



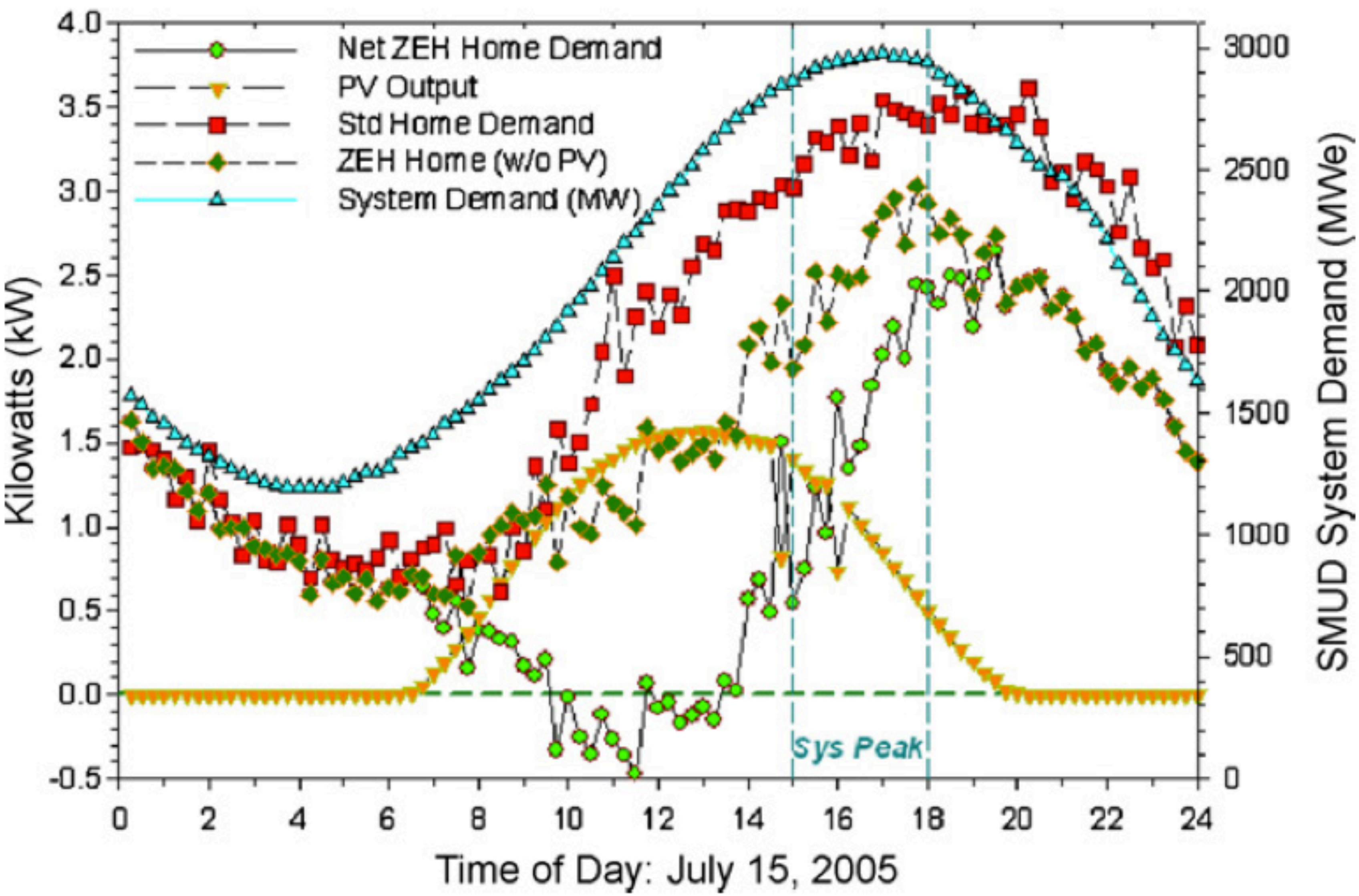
Parker **2009** *Energy and Buildings* 41:512-520

Large-scale monitoring of very low-energy homes



Parker **2009** *Energy and Buildings* 41:512-520

Large-scale monitoring of very low-energy homes



Parker **2009** *Energy and Buildings* 41:512-520

Large-scale monitoring of very low-energy homes

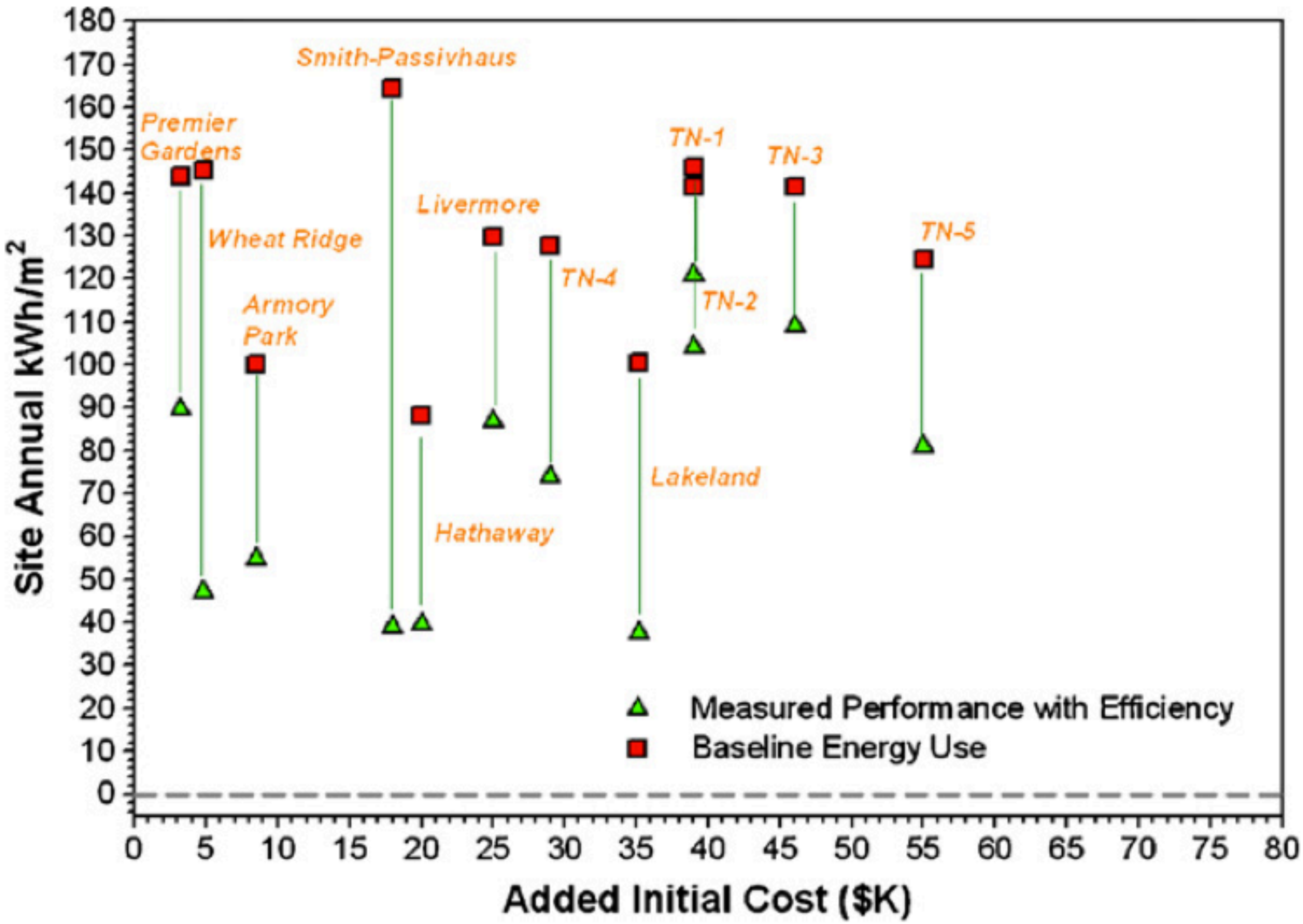


Fig. 10. Performance of efficiency measures in low energy homes.

Parker **2009** *Energy and Buildings* 41:512-520

Large-scale monitoring of very low-energy homes

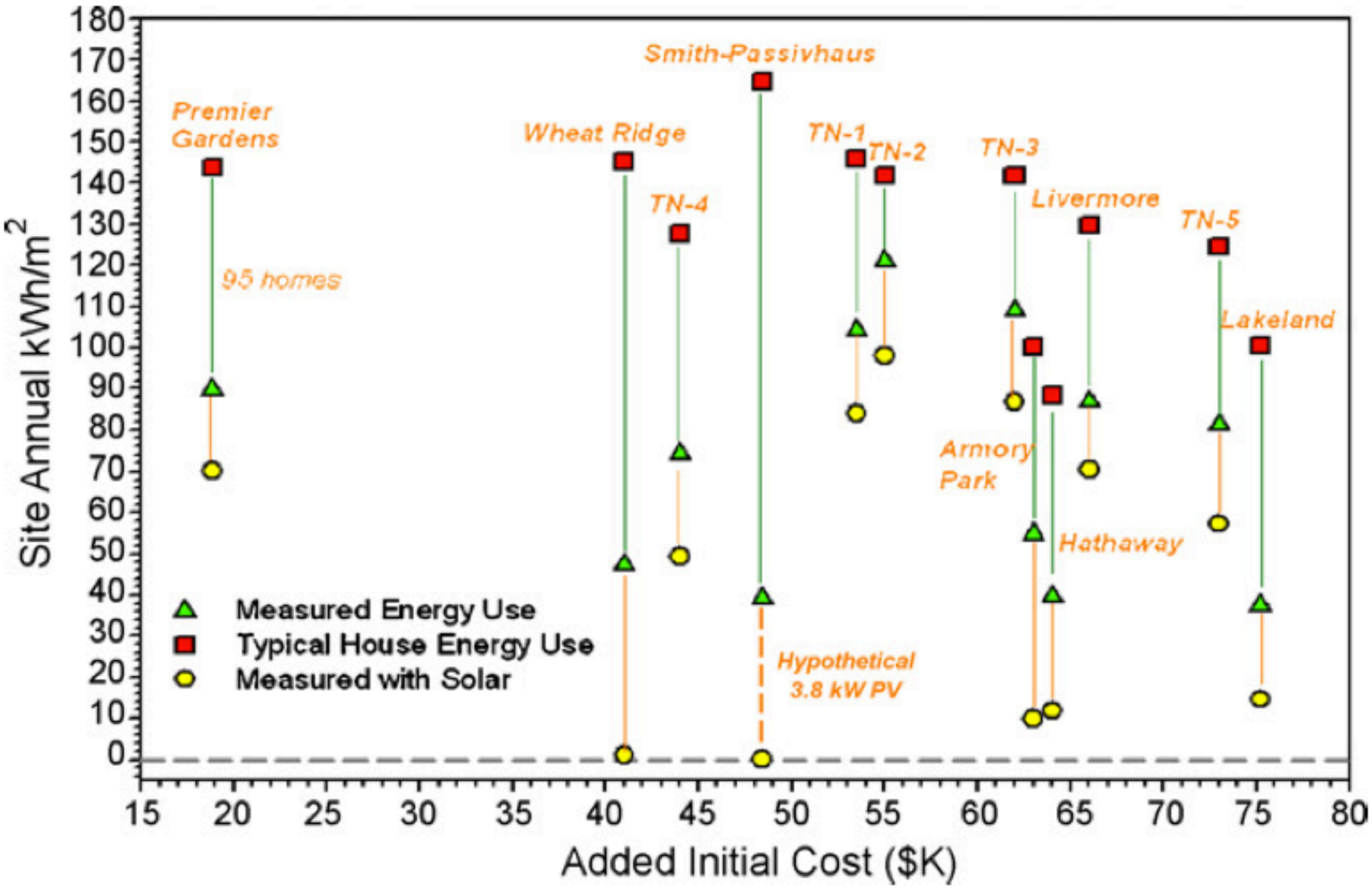


Fig. 11. Summary of energy performance of twelve advanced Zero Energy Homes around the United States.

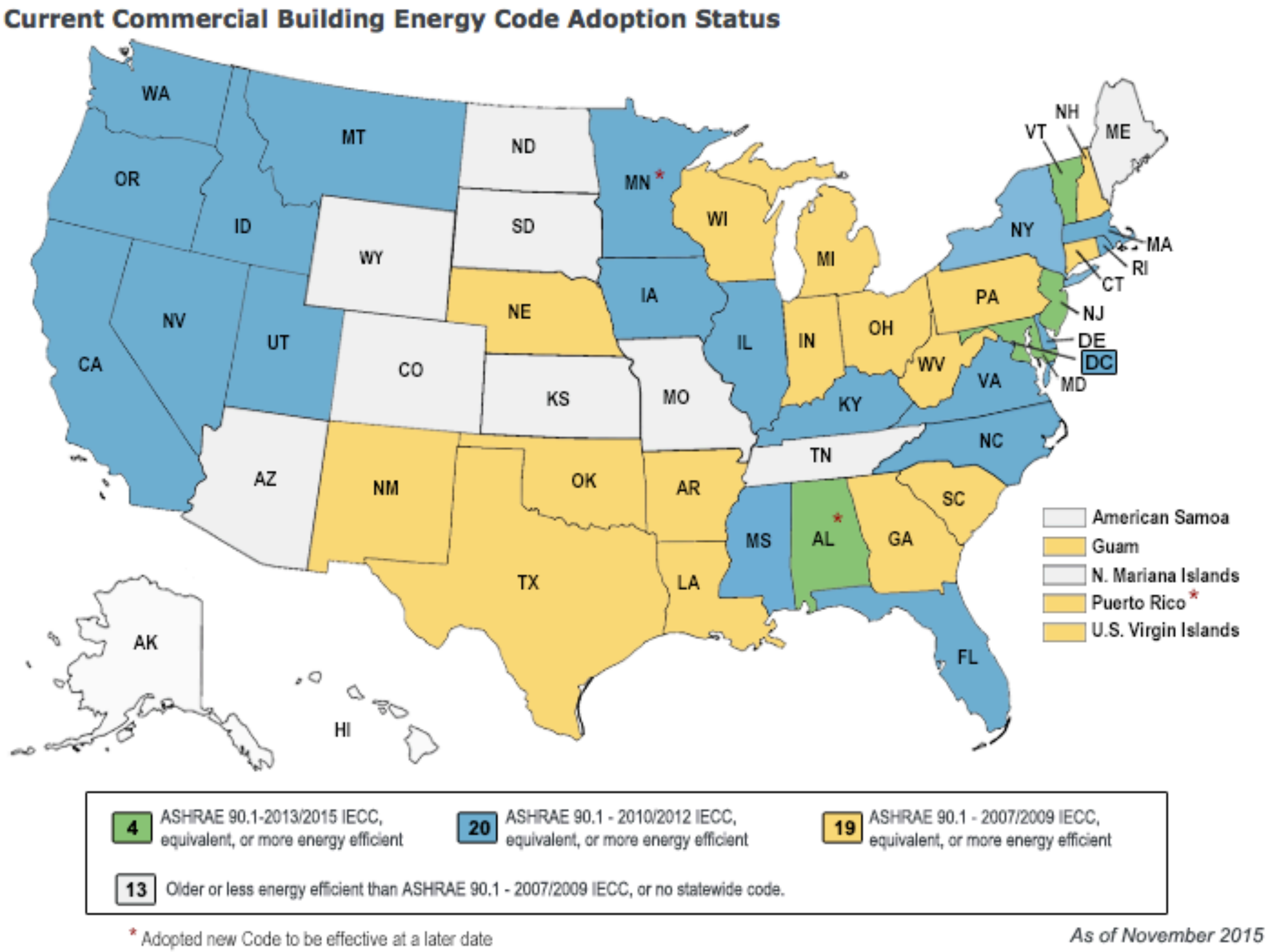
Parker **2009** *Energy and Buildings* 41:512-520

BUILDING DESIGN GUIDELINES AND STANDARDS

Designing for efficiency

- Whether designing a new building or retrofitting an old building…
- There are a number of building codes and standards that help design for energy efficiency and sustainability
- Codes generally provide minimum criteria
  - Your building can’t be worse than this
  - City codes, state codes, national codes, etc.
- Standards often go above and beyond code
  - Or can become cited in code
- Green building standards
  - Several green building standards exist with varying levels of building energy efficiency criteria

State energy codes: Commercial buildings



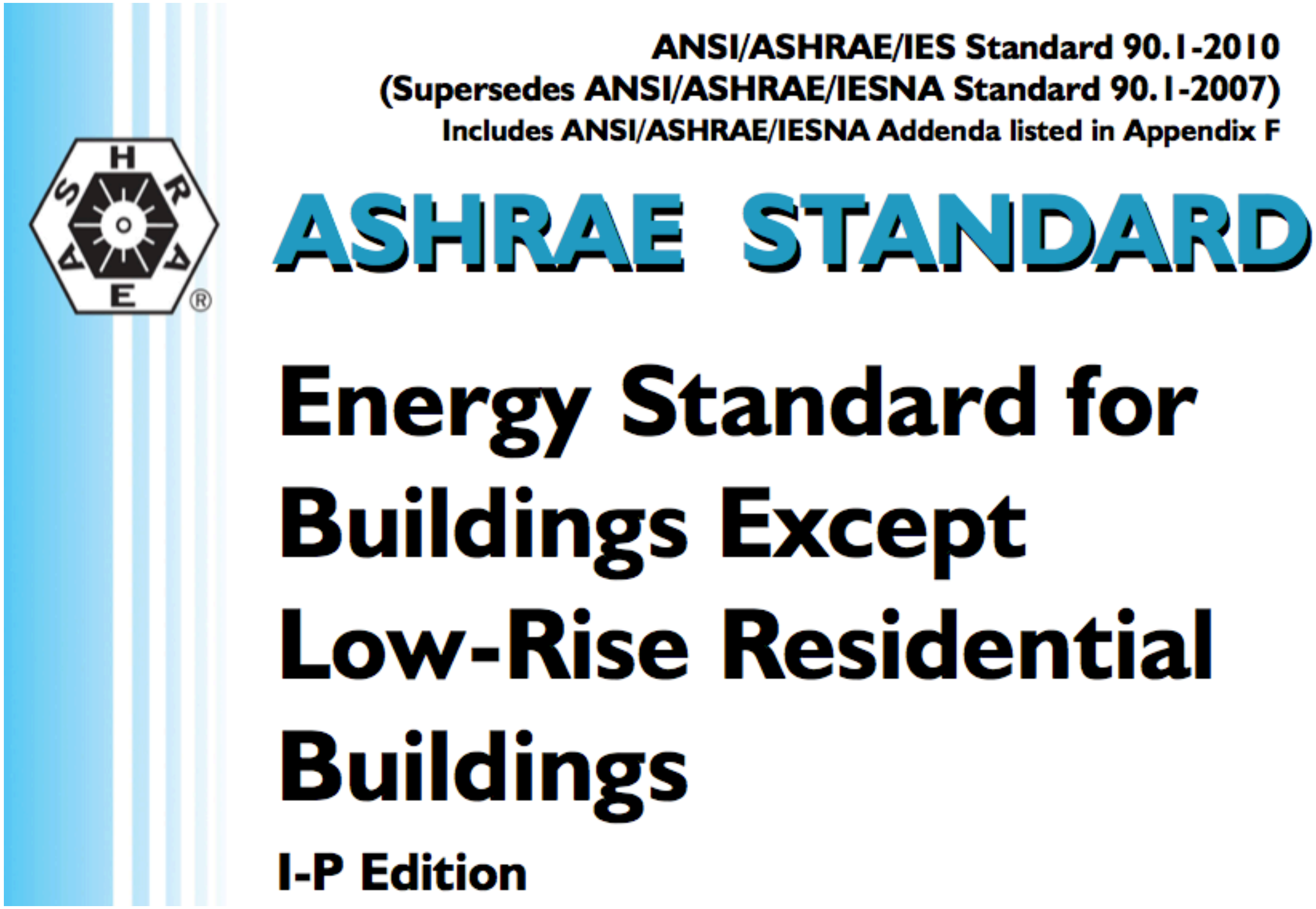
http://www.energycodes.gov/status-state-energy-code-adoption

Designing for efficiency: Codes, standards, and guidelines

- ASHRAE Standards and Guidelines
  - Standard 90.1: Energy standard for buildings except low-rise residential buildings
  - Standard 90.2: Energy Efficient Design of Low-Rise Residential Buildings
  - Standard 189.1: Standard for the design of high-performance, green buildings
  - Advanced Energy Guidelines for 30% and 50% savings

- IECC: International Energy Conservation Code
  - From the International Code Council (ICC)

- IRC: International Residential Code



- ASHRAE 90.1-2007, 2010, & now 2013, *Energy Standard for Buildings Except Low-Rise Residential Buildings*
- Look for Addenda to the standard
  - Corrections and changes
  - http://www.ashrae.org/standards-research--technology/standards-addenda

ASHRAE Standards 90.1 and 90.2

- ASHRAE/ANSI/IESNA 90.1
  - Energy Standard for Buildings Except Low-Rise Residential Buildings
  - Will continue to be reference for commercial buildings
  - First appeared in 1975 with major updates in 80,89,99,04,07,10
    - Major changes include a change in climatic categories and lighting power density

- ASHRAE Standard 90.1 is the basis of energy efficiency for nearly all Building Codes and Green Building Ratings
  - ICC codes, DOE/Federal Government Codes, State and City Codes, LEED, Green Globes

What is in ASHRAE Standard 90.1?

- 90.1 has energy performance requirements for:
  - Building enclosure
  - Lighting
  - HVAC equipment
  - Water heating
  - Power delivery systems, and more

- Purpose and scope

1. PURPOSE

To establish the minimum *energy efficiency* requirements of buildings, other than low rise *residential* buildings, for:

1. design, *construction*, and a plan for operation and maintenance, and
2. utilization of on-site, renewable *energy* resources.

2. SCOPE

2.1 This standard provides:

a. minimum *energy*-efficient requirements for the design, *construction*, and a plan for operation and maintenance of:

   1. new buildings and their *systems*
   2. new portions of buildings and their *systems*
   3. new *systems* and *equipment* in existing buildings
   4. new *equipment* or building *systems* specifically identified in the standard that are part of industrial or manufacturing processes

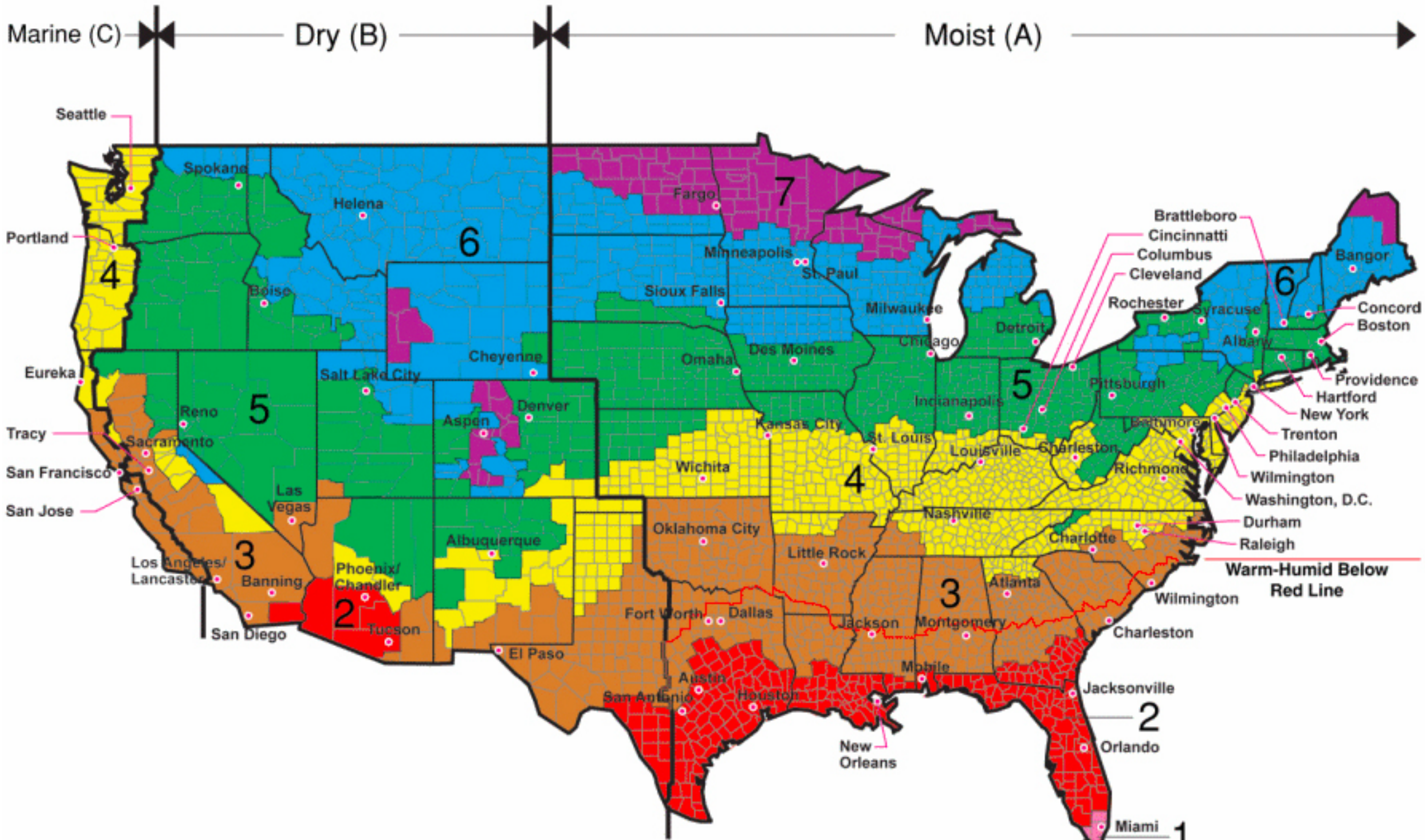
ASHRAE 90.1: Table of contents

CONTENTS

ANSI/ASHRAE/IESNA Standard 90.1-2007
Energy Standard for Buildings Except Low-Rise Residential Buildings

ASHRAE 90.1: Climate zone specific

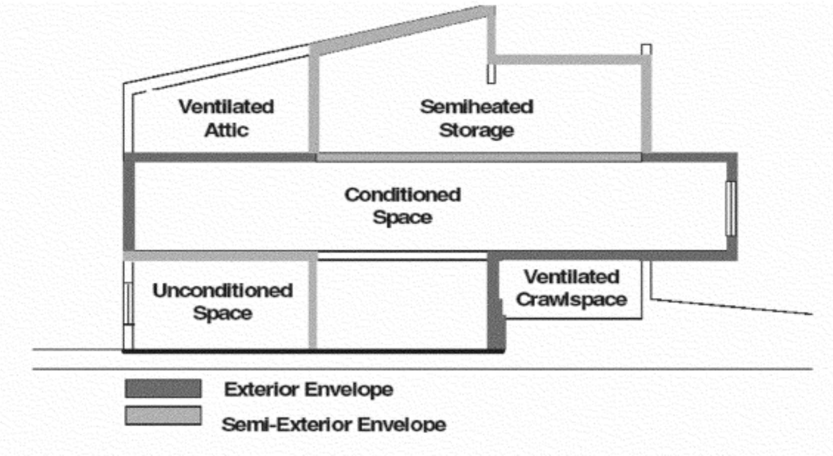
Select your climate zone



All of Alaska in Zone 7 except for the following Boroughs in Zone 8: Bethel, Dellingham, Fairbanks, N. Star, Nome North Slope, Northwest Arctic, Southeast Fairbanks, Wade Hampton, and Yukon-Koyukuk

Zone 1 includes: Hawaii, Guam, Puerto Rico, and the Virgin Islands

ASHRAE 90.1: Building envelope



Satisfy mandatory provisions

Sealant requirements

- Locations where joints must have sealants applied

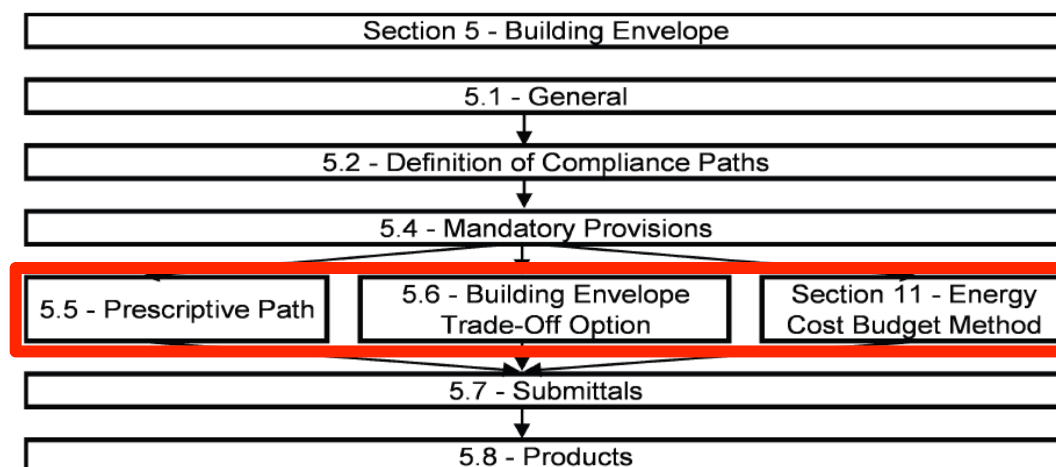
Air leakage

- Maximum air leakage of doors and windows

Vestibule entrances

- Requirements for the use of vestibules or revolving-doors at an entrance

Select your path for compliance



ASHRAE 90.1: Building envelope (IP)

Prescriptive path: Requirements for U, R, and SHGC for enclosure elements

TABLE 5.5-6 Building Envelope Requirements for Climate Zone 6 (A, B)*

Opaque Elements	Nonresidential		Residential		Semiheated	
	Assembly Maximum	Insulation Min. R-Value	Assembly Maximum	Insulation Min. R-Value	Assembly Maximum	Insulation Min. R-Value
Roofs						
Insulation Entirely above Deck	U-0.048	R-20.0 c.i.	U-0.048	R-20.0 c.i.	U-0.093	R-10.0 c.i.
Metal Building[a]	U-0.049	R-13.0 + R-19.0	U-0.049	R-13.0 + R-19.0	U-0.072	R-16.0
Attic and Other	U-0.027	R-38.0	U-0.027	R-38.0	U-0.034	R-30.0
Walls, Above-Grade						
Mass	U-0.080	R-13.3 c.i.	U-0.071	R-15.2 c.i.	U-0.151[b]	R-5.7 c.i.[b]
Metal Building	U-0.069	R-13.0 + R-5.6 c.i.	U-0.069	R-13.0 + R-5.6 c.i.	U-0.113	R-13.0
Steel-Framed	U-0.064	R-13.0 + R-7.5 c.i.	U-0.064	R-13.0 + R-7.5 c.i.	U-0.124	R-13.0
Wood-Framed and Other	U-0.051	R-13.0 + R-7.5 c.i.	U-0.051	R-13.0 + R-7.5 c.i.	U-0.089	R-13.0
Walls, Below-Grade						
Below-Grade Wall	C-0.119	R-7.5 c.i.	C-0.119	R-7.5 c.i.	C-1.140	NR
Floors						
Mass	U-0.064	R-12.5 c.i.	U-0.057	R-14.6 c.i.	U-0.137	R-4.2 c.i.
Steel-Joist	U-0.038	R-30.0	U-0.032	R-38.0	U-0.052	R-19.0
Wood-Framed and Other	U-0.033	R-30.0	U-0.033	R-30.0	U-0.051	R-19.0
Slab-On-Grade Floors						
Unheated	F-0.540	R-10 for 24 in.	F-0.520	R-15 for 24 in.	F-0.730	NR
Heated	F-0.860	R-15 for 24 in.	F-0.688	R-20 for 48 in.	F-1.020	R-7.5 for 12 in.

ASHRAE 90.1: Building envelope (IP)

Prescriptive path: Requirements for U, R, and SHGC for enclosure elements

Fenestration	Assembly Max. U	Assembly Max. SHGC	Assembly Max. U	Assembly Max. SHGC	Assembly Max. U	Assembly Max. SHGC
Vertical Glazing, 0%–40% of Wall						
Nonmetal framing (all)[c]	U-0.35		U-0.35		U-0.65	
Metal framing (curtainwall/storefront)[d]	U-0.45	SHGC-0.40 all	U-0.45	SHGC-0.40 all	U-0.60	SHGC-NR all
Metal framing (entrance door)[d]	U-0.80		U-0.80		U-0.90	
Metal framing (all other)[d]	U-0.55		U-0.55		U-0.65	
Skylight with Curb, Glass, % of Roof						
0%–2.0%	U_{all}–1.17	$SHGC_{all}$–0.49	U_{all}–0.98	$SHGC_{all}$–0.46	U_{all}–1.98	$SHGC_{all}$–NR
2.1%–5.0%	U_{all}–1.17	$SHGC_{all}$–0.49	U_{all}–0.98	$SHGC_{all}$–0.36	U_{all}–1.98	$SHGC_{all}$–NR
Skylight with Curb, Plastic, % of Roof						
0%–2.0%	U_{all}–0.87	$SHGC_{all}$–0.71	U_{all}–0.74	$SHGC_{all}$–0.65	U_{all}–1.90	$SHGC_{all}$–NR
2.1%–5.0%	U_{all}–0.87	$SHGC_{all}$–0.58	U_{all}–0.74	$SHGC_{all}$–0.55	U_{all}–1.90	$SHGC_{all}$–NR
Skylight without Curb, All, % of Roof						
0%–2.0%	U_{all}–0.69	$SHGC_{all}$–0.49	U_{all}–0.58	$SHGC_{all}$–0.49	U_{all}–1.36	$SHGC_{all}$–NR
2.1%–5.0%	U_{all}–0.69	$SHGC_{all}$–0.49	U_{all}–0.58	$SHGC_{all}$–0.39	U_{all}–1.36	$SHGC_{all}$–NR

*The following definitions apply: c.i. = *continuous insulation* (see Section 3.2), NR = no (insulation) requirement.
[a]When using R-value compliance method, a thermal spacer block is required; otherwise use the *U-factor* compliance method. See Table A2.3.
[b]Exception to Section A3.1.3.1 applies.
[c]Nonmetal framing includes framing materials other than metal with or without metal reinforcing or cladding.
[d]Metal framing includes metal framing with or without thermal break. The "all other" subcategory includes operable windows, fixed windows, and non-entrance *doors*.

ASHRAE 90.1: HVAC

Satisfy mandatory provisions

Must perform load calculations
- ASHRAE Standard 183
- Radiant time series or heat balance method

Other items
- Thermostat controls
- Fan speed controls
- Minimum damper leakage
- Duct insulation
- Fan power limits (efficiency req)
- Pipe sizing requirements
- Energy recovery requirements
- Testing and balancing requirements

Select your path for compliance

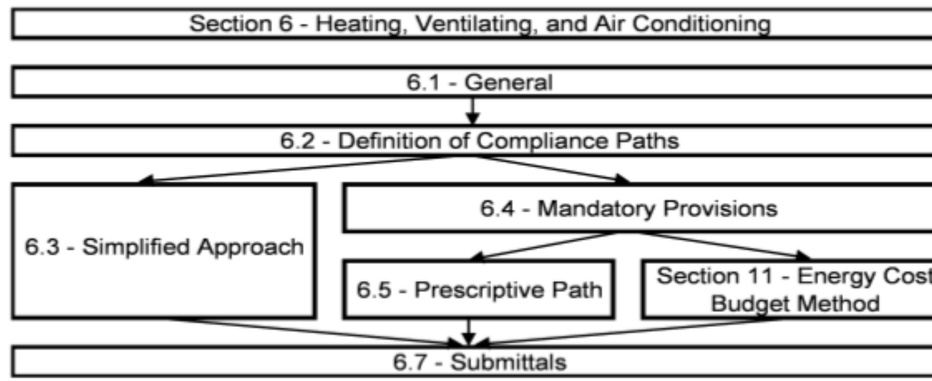


TABLE 6.8.1A Electronically Operated Unitary Air Conditioners and Condensing Units—Minimum Efficiency Requirements

Equipment Type	Size Category	Heating Section Type	Subcategory or Rating Condition	Minimum Efficiency[a]	Test Procedure[b]
Air conditioners, air cooled	<65,000 Btu/h[c]	All	Split system	13.0 SEER	AHRI 210/240
			Single package	13.0 SEER	
Through-the-wall (air cooled)	≤30,000 Btu/h[c]	All	Split system	12.0 SEER	
			Single package	12.0 SEER	
Small-duct high-velocity (air cooled)	<65,000 Btu/h[c]	All	Split system	10.0 SEER	
	≥65,000 Btu/h and <135,000 Btu/h	Electric resistance (or none)	Split system and single package	11.2 EER 11.4 IEER	
		All other	Split system and single package	11.0 EER 11.2 IEER	

ASHRAE 90.1: Service hot water heating

Satisfy mandatory provisions

Must perform load calculations

- ASHRAE Handbook

Other items

- Minimum efficiency
- Temperature controls
- Pump controls
- Heat traps

Select your path for compliance

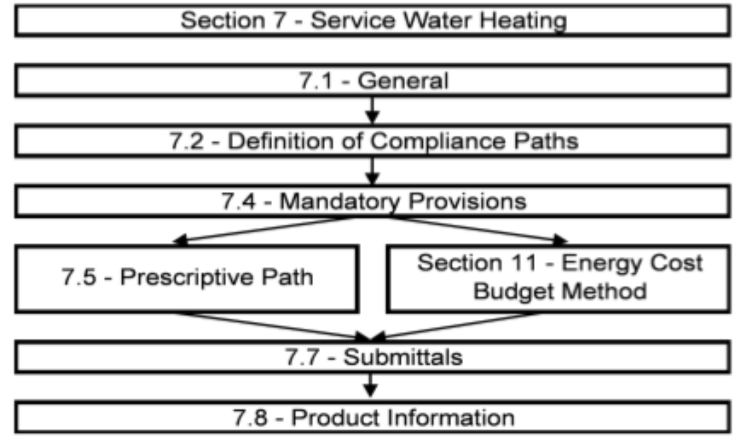


TABLE 7.8 Performance Requirements for Water Heating Equipment

Equipment Type	Size Category (Input)	Subcategory or Rating Condition	Performance Required [a]	Test Procedure[b,c]
Electric table top water heaters	≤12 kW	Resistance ≥20 gal	0.93–0.00132V EF	DOE 10 CFR Part 430
Electric water heaters	≤12 kW	Resistance ≥20 gal	0.97–0.00132V EF	DOE 10 CFR Part 430
	>12 kW	Resistance ≥20 gal	$20 + 35\sqrt{V}$ SL, Btu/h	Section G.2 of ANSI Z21.10.3
	≤24 Amps and ≤250 Volts	Heat Pump	0.93–0.00132V EF	DOE 10 CFR Part 430

[a] *Energy factor* (EF) and thermal *efficiency* (E_t) are minimum requirements, while standby loss (SL) is maximum Btu/h based on a 70°F temperature difference between stored water and ambient requirements. In the EF equation, V is the rated volume in gallons. In the SL equation, V is the rated volume in gallons and Q is the nameplate input rate in Btu/h.

ASHRAE 90.1: Power

Satisfy mandatory provisions

- Efficiency for transformers
- Automatic control requirements

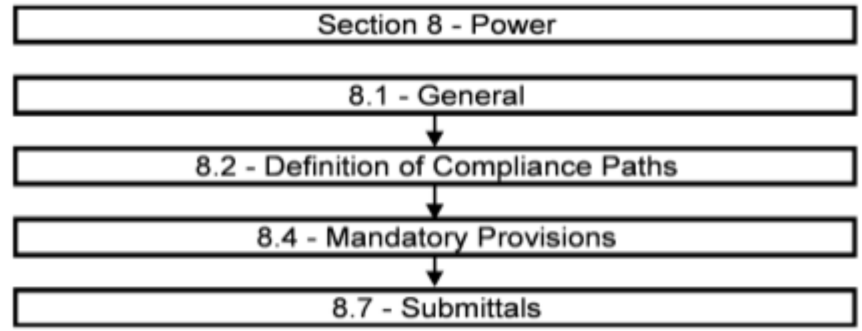
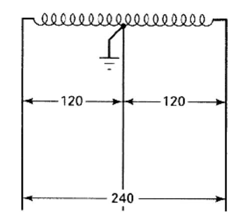


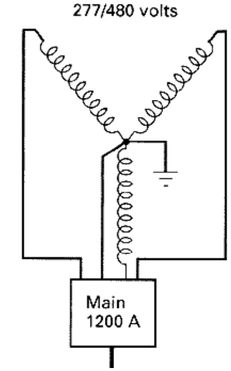
TABLE 8.1 Minimum Nominal Efficiency Levels for NEMA Class I Low-Voltage Dry-Type Distribution Transformers[a]

Single Phase Transformers		Three Phase Transformers	
kVA[b]	Efficiency,%[c]	kVA[b]	Efficiency,%[c]
15	97.7	15	97.0
25	98.0	30	97.5
37.5	98.2	45	97.7
50	98.3	75	98.0
75	98.5	112.5	98.2
100	98.6	150	98.3
167	98.7	225	98.5
250	98.8	300	98.6
333	98.9	500	98.7
		750	98.8
		1000	98.9

A typical 120/240 volt, single-phase, three-wire system



1000-kVA transformer 277/480 volts



ASHRAE 90.1: Lighting

Satisfy mandatory provisions

- Automatic control requirements
- Power density requirements

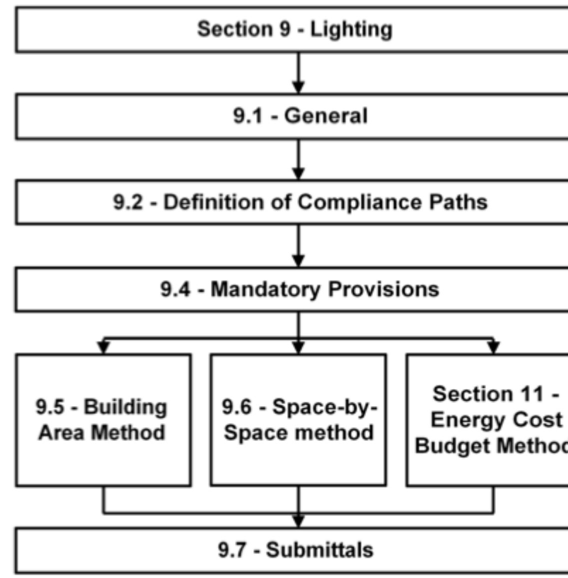
TABLE 9.5.1 Lighting Power Densities Using the Building Area Method

Building Area Type[a]	*LPD* (W/ft^2)
Automotive facility	0.82
Convention center	1.08
Courthouse	1.05
Dining: bar lounge/leisure	0.99
Dining: cafeteria/fast food	0.90

TABLE 9.6.1 Lighting Power Densities Using the Space-by-Space Method *(continued)*

Building-Specific Space Types	*LPD*, W/ft^2	RCR Threshold
Audience Seating	0.82	4
Exhibit Space	1.45	4
Courthouse/Police Station/Penitentiary		
Courtroom	1.72	6
Confinement Cells	1.10	6
Judges' Chambers	1.17	8
Penitentiary Audience Seating	0.43	4
Penitentiary Classroom	1.34	4
Penitentiary Dining	1.07	6
Dormitory		
Living Quarters	0.38	8

Select your path for compliance



Building entrances and exits

Main entries	No allowance	20 W/linear foot of door width	20 W/linear foot of door width	30 W/linear foot of door width	30 W/linear foot of door width
Other doors	No allowance	20 W/linear foot of door width	20 W/linear foot of door width	20 W/linear foot of door width	20 W/linear foot of door width
Entry canopies	No allowance	0.25 W/ft^2	0.25 W/ft^2	0.4 W/ft^2	0.4 W/ft^2

Moving beyond baseline performance …

GREEN BUILDING STANDARDS AND RATING SYSTEMS

LEED: Leadership in Energy and Environmental Design

LEED 2009 FOR NEW CONSTRUCTION AND MAJOR RENOVATIONS

System of 110 possible points;

- Site (26)
- Water (10)
- Energy and atmosphere (35)
- Materials and resources (14)
- Indoor environmental quality (15)
- Innovation in design (6)
- Regional priorities (4)

LEED® for Homes Rating System

System of 136 possible points;

- Innovation and design (11)
- Location and linkages (10)
- Sustainable sites (22)
- Water efficiency (15)
- Energy and atmosphere (38)
- Materials and resources (16)
- Indoor environmental quality (21)
- Awareness and education (3)

LEED v4

LEED and energy use

- USGBC LEED-NC 2009
  - "NC" = new construction

Energy and Atmosphere			35 Possible Points
☑	Prerequisite 1	Fundamental Commissioning of Building Energy Systems	Required
☑	Prerequisite 2	Minimum Energy Performance	Required
☑	Prerequisite 3	Fundamental Refrigerant Management	Required
☐	Credit 1	Optimize Energy Performance	1–19
☐	Credit 2	On-site Renewable Energy	1–7
☐	Credit 3	Enhanced Commissioning	2
☐	Credit 4	Enhanced Refrigerant Management	2
☐	Credit 5	Measurement and Verification	3
☐	Credit 6	Green Power	2

LEED and energy use

EA Prerequisite 2: Minimum Energy Performance

Requirements

OPTION 1. Whole Building Energy Simulation

Demonstrate a 10% improvement in the proposed building performance rating for new buildings, or a 5% improvement in the proposed building performance rating for major renovations to existing buildings, compared with the baseline building performance rating.

Calculate the baseline building performance rating according to the building performance rating method in Appendix G of ANSI/ASHRAE/IESNA Standard 90.1-2007 (with errata but without addenda[1]) using a computer simulation model for the whole building project. Projects outside the U.S. may use a USGBC approved equivalent standard[2].

OPTION 2. Prescriptive Compliance Path: ASHRAE Advanced Energy Design Guide

Comply with the prescriptive measures of the ASHRAE Advanced Energy Design Guide appropriate to the project scope, outlined below. Project teams must comply with all applicable criteria as established in the Advanced Energy Design Guide for the climate zone in which the building is located. Projects outside the U.S. may use ASHRAE/ASHRAE/IESNA Standard 90.1-2007 Appendices B and D to determine the appropriate climate zone.

PATH 1. ASHRAE Advanced Energy Design Guide for Small Office Buildings 2004

The building must meet the following requirements:

- Less than 20,000 square feet (1,800 square meters).
- Office occupancy.

PATH 2. ASHRAE Advanced Energy Design Guide for Small Retail Buildings 2006

The building must meet the following requirements:

- Less than 20,000 square feet (1,800 square meters).
- Retail occupancy.

PATH 3. ASHRAE Advanced Energy Design Guide for Small Warehouses and Self Storage Buildings 2008

LEED and energy use

EA Credit 1: Optimize Energy Performance

1–19 Points

OPTION 1. Whole Building Energy Simulation (1–19 points)

Demonstrate a percentage improvement in the proposed building performance rating compared with the baseline building performance rating. Calculate the baseline building performance according to Appendix G of ANSI/ASHRAE/IESNA Standard 90.1-2007 (with errata but without addenda[1]) using a computer simulation model for the whole building project. Projects outside the U.S. may use a USGBC approved equivalent standard[2]. The minimum energy cost savings percentage for each point threshold is as follows:

New Buildings	Existing Building Renovations	Points
12%	8%	1
14%	10%	2
16%	12%	3
18%	14%	4
20%	16%	5
22%	18%	6
24%	20%	7
26%	22%	8
28%	24%	9
30%	26%	10
32%	28%	11
34%	30%	12
36%	32%	13
38%	34%	14
40%	36%	15
42%	38%	16
44%	40%	17
46%	42%	18
48%	44%	19

ASHRAE Advanced Energy Design Guides

- Targets of 30% energy savings or 50% energy savings
  - Over ASHRAE 90.1-1999

- Guidelines for many types of buildings:
  - Medium to big box retail buildings
  - Small to medium office buildings
  - K-12 school buildings
  - Large hospitals
  - Small office buildings
  - Highway lodging
  - Small warehouses
  - etc.

- You can download most of these for free
  - http://aedg.ashrae.org/GetSubscription.aspx

ASHRAE AEDG: 30% savings in small offices

- Office buildings smaller than 20,000 ft^2
- Only a recommendation document
  - Not a code or standard (unless a standard implements this)
- Represents “a way” to build energy efficient small offices
- Recommendations for energy-efficiency in:
  - Building envelope
  - Lighting
  - HVAC equipment and systems
  - Service water heating
- Focus on integrated process

ASHRAE AEDG: 30% savings in small offices

Climate Zone 6 Recommendation Table

	Item	Component	Recommendation	How-To's in Chapter 4
Envelope	Roof	Insulation entirely above deck	R-20 c.i.	EN2, 17, 20-21
		Metal building	R-13 + R-19	EN3, 17, 20-21
		Attic and other	R-38	EN4, 17-18, 20-21
		Single rafter	R-38 + R-5 c.i.	EN5, 17, 20-21
		Surface reflectance/emittance	No recommendation	
	Walls	Mass (HC > 7 Btu/ft^2)	R-11.4 c.i.	EN6, 17, 20-21
		Metal building	R-13 + R-13	EN7, 17, 20-21
		Steel framed	R-13 + R-7.5 c.i.	EN8, 17, 20-21
		Wood framed and other	R-13 + R-3.8 c.i.	EN9, 17, 20-21
		Below grade walls	R-7.5 c.i.	EN10, 17, 20-21
	Floors	Mass	R-10.4 c.i.	EN11, 17, 20-21
		Steel framed	R-30	EN12, 17, 20-21
		Wood framed and other	R-30	EN12, 17, 20-21
	Slabs	Unheated	R-10 for 24 in	EN13, 17, 19-21
		Heated	R-10 for 36 in.	EN14, 17, 19-21
	Doors	Swinging	U-0.70	EN15, 20-21
		Non-swinging	U-0.50	EN16, 20-21
	Vertical Glazing	Window to wall ratio (WWR)	20% to 40% maximum	EN23, 36-37
		Thermal transmittance	U-0.42	EN25, 31
		Solar heat gain coefficient (SHGC)	N, S, E, W - 0.46 | N only - 0.46	EN27-28
		Window orientation	$(A_N * SHGC_N + A_S * SHGC_S) > (A_E * SHGC_E + A_W * SHGC_W)$	A_x–Window area for orientation x EN26-32
		Exterior sun control (S, E, W only)	No recommendation	EN24, 28, 30, 36, 40, 42 DL5-6
	Skylights	Maximum percent of roof area	3%	DL5-7, DL8, DL13
		Thermal transmittance	U-0.69	DL7, DL8, DL13
		Solar heat gain coefficient (SHGC)	0.49	DL8, DL13

ASHRAE AEDG: 50% savings in small offices

- Similar to the 2004 30% guide but more stringent
  - Target: 50% lower energy than ASHRAE 90.1-2004

ASHRAE AEDG: 50% savings in small offices

Climate Zone 6 Recommendation Table for Small to Medium Office Buildings

	Item	Component	Recommendation	How-To Tips	✓
Envelope	Roofs	Insulation entirely above deck	R-30.0 c.i.	EN2, 17, 19, 21–22	
		Attic and other	R-49.0	EN3, 17, 19, 20–21	
		Metal building	R-25.0 + R-11.0 Ls	EN4, 17, 19, 21	
		SRI	No recommendation	None	
	Walls	Mass (HC > 7 Btu/ft^2)	R-19.0 c.i.	EN5, 17, 19, 21	
		Steel framed	R-13.0 + R-18.8 c.i.	EN6, 17, 19, 21	
		Wood framed and other	R-13.0 + R-12.5 c.i.	EN7, 17, 19, 21	
		Metal building	R-0.0 + R-19.0 c.i.	EN8, 17, 19, 21	
		Below-grade walls	R-10.0 c.i.	EN9, 17, 19, 21–22	
	Floors	Mass	R-16.7 c.i.	EN10, 17, 19, 21	
		Steel joint	R-38.0	EN11, 17, 19, 21	
		Wood framed and other	R-38.0	EN11, 17, 19, 21	
	Slabs	Unheated	R-20.0 for 24 in.	EN12, 14, 17, 19, 21–22	
		Heated	R-20.0 for 48 in.	EN13–14, 17, 19, 21–22	
	Doors	Swinging	U-0.50	EN15, 17–18	
		Nonswinging	U-0.50	EN16–17	
	Vestibules	At building entrance	Yes	EN18	
	Continuous Air Barriers	Continuous air barrier	Entire building envelope	EN17	
	Vertical Fenestration	WWR	20% to 40%	EN25; DL6	
		Window orientation	Area of W and E windows each less than area of S windows (N in southern hemisphere)	EN30–31	
		Exterior sun control (S, E, and W only)	No recommendation	None	
		Thermal transmittance	Nonmetal framing windows = U-0.35 Metal framing windows = U-0.39	EN23–24	
		SHGC	Nonmetal framing windows = 0.35 Metal framing windows = 0.38	EN24, 32–33; DL12	
	Daylighting	Light-to-solar-gain ratio	Minimum VT/SHGC = 1.10	EN34–40	
		Vertical fenestration EA	0.12	DL7–11	

Finally: ASHRAE 189.1

1. PURPOSE

The purpose of this standard is to provide minimum requirements for the siting, design, construction, and plan for operation of high-performance green buildings to:

a. balance environmental responsibility, resource efficiency, occupant comfort and well being, and community sensitivity, and
b. support the goal of development that meets the needs of the present without compromising the ability of future generations to meet their own needs.

ANSI/ASHRAE/USGBC/IES
Standard 189.1-2011

Standard for the Design of High-Performance Green Buildings

Except Low-Rise Residential Buildings

ASHRAE 189.1

- Mandatory provisions
- Prescriptive options
- Performance options

ANSI/ASHRAE/USGBC/IES Standard 189.1-2011
Standard for the Design of High-Performance Green Buildings
Except Low-Rise Residential Buildings

ASHRAE 189.1: Energy efficiency provisions

Mandatory

- Must comply with ASHRAE 90.1
- Must have space for future on-site renewables
- Must collect energy use data

Prescriptive

- Requirements in 189.1 supersede 90.1
- Must have on-site renewables (20 kWh/m^2)

ASHRAE 189.1: Envelope requirements

TABLE A-6 (Supersedes Table 5.5-6 in ANSI/ASHRAE/IES Standard 90.1)
Building Envelope Requirements for Climate Zone 6 (A, B) (I-P)

	Nonresidential		Residential		Semiheated	
	Assembly	Insulation	Assembly	Insulation	Assembly	Insulation
Opaque Elements	Max.	Min. R-Value	Max.	Min. R-Value	Max.	Min.R-Value
Roofs						
Insulation Entirely above Deck	U-0.032	R-30.0 ci	U-0.032	R-30.0 ci	U-0.063	R-15.0 ci
Metal Building	U-0.031	R-25.0 + R-11.0 Ls	U-0.031	R-25.0 + R-11.0 Ls	U-0.068	R-13.0 +R- 19.0
Attic and Other	U-0.021	R-49.0	U-0.021	R-49.0	U-0.027	R-38.0
Walls, Above Grade						
Mass	U-0.071	R-15.2 ci	U-0.060	R-20.0 ci	U-0.104	R-9.5 ci
Metal Building	U-0.052	R-13.0 + R-13.0 ci	U-0.052	R-13.0 + R-13.0 ci	U-0.079	R-13.0 + R-6.5 ci
Steel Framed	U-0.055	R-13.0 + R-10.0 ci	U-0.055	R-13.0 + R-10.0 ci	U-0.084	R-13.0 + R-3.8 ci
Wood Framed and Other	U-0.045	R-13.0 + R-10.0 ci	U-0.045	R-13.0 + R-10.0 ci	U-0.064	R-13.0 + R-3.8 ci
Wall, Below Grade						
Below Grade Wall	C-0.092	R-10.0 ci	C-0.092	R-10.0 ci	C-0.119	R-7.5 ci
Floors						
Mass	U-0.057	R-14.6 ci	U-0.051	R-16.7 ci	U-0.107	R-6.3 ci
Steel Joist	U-0.032	R-38.0	U-0.023	R-38.0 + R-12.5 ci	U-0.038	R-30.0
Wood Framed and Other	U-0.026	R-30.0 + R-7.5 ci	U-0.026	R-30.0 + R-7.5 ci	U-0.033	R-30.0
Slab-On-Grade Floors						
Unheated	F-0.520	R-15 for 24 in.	F-0.510	R-20 for 24 in.	F-0.540	R-10 for 24 in.
Heated	F-0.440	R-15.0 for 36 in. + R-5 ci below	F-0.440	R-15.0 for 36 in. + R-5 ci below	F-0.900	R-10 for 24 in.

ASHRAE 189.1: Envelope requirements

Opaque Doors						
Swinging	U-0.400		U-0.400		U-0.600	
Non-Swinging	U-0.400		U-0.400		U-0.500	
Fenestration	**Assembly Max. U**	**Assembly Max. SHGC**	**Assembly Max. U**	**Assembly Max. SHGC**	**Assembly Max. U**	**Assembly Max. SHGC**
Vertical Fenestration, 0%–40% of Wall						
Nonmetal framing: all[b]	U-0.25	SHGC-0.40 all	U-0.25	SHGC-0.40 all	U-0.45	SHGC-NR all
Metal fr: curtainwall/storefront[c]	U-0.35		U-0.35		U-0.50	
Metal framing: entrance door[c]	U-0.70		U-0.70		U-0.80	
Metal framing: all other[c]	U-0.45		U-0.45		U-0.55	
Skylight with Curb, Glass, % of Roof						
0%–2.0%	U_{all}-0.67	$SHGC_{all}$-0.46	U_{all}-0.67	$SHGC_{all}$-0.46	U_{all}-1.98	$SHGC_{all}$-NR
2.1%–5.0%	U_{all}-0.67	$SHGC_{all}$-0.46	U_{all}-0.67	$SHGC_{all}$-0.46	U_{all}-1.98	$SHGC_{all}$-NR
Skylight with Curb, Plastic, % of Roof						
0%–2.0%	U_{all}-0.69	$SHGC_{all}$-0.49	U_{all}-0.69	$SHGC_{all}$-0.49	U_{all}-1.90	$SHGC_{all}$-NR
2.1%–5.0%	U_{all}-0.69	$SHGC_{all}$-0.49	U_{all}-0.69	$SHGC_{all}$-0.49	U_{all}-1.90	$SHGC_{all}$-NR
Skylight without Curb, All, % of Roof						
0%–2.0%	U_{all}-0.45	$SHGC_{all}$-0.46	U_{all}-0.45	$SHGC_{all}$-0.39	U_{all}-1.36	$SHGC_{all}$-NR
2.1%–5.0%	U_{all}-0.45	$SHGC_{all}$-0.46	U_{all}-0.45	$SHGC_{all}$-0.39	U_{all}-1.36	$SHGC_{all}$-NR

The following definitions apply: ci = continuous insulation, Ls = *liner system*, NR = no (insulation) requirement.
[a] Mass *walls* with a heat capacity greater than 12 Btu/ft^2·°F which are unfinished or finished only on the interior do not need to be insulated.
[b] Nonmetal framing includes framing materials other than metal with or without metal reinforcing or cladding.
[c] Metal framing includes metal framing with or without thermal break. The all other subcategory includes operable windows, fixed windows, and non-entrance doors.

Passive House

- A Passive House is a very well-insulated, virtually air-tight building that is primarily heated by passive solar gain and by internal gains from people and equipment
- Performance characteristics:
  - Annual heat requirement less than 15 kWh/m^2 (4.75 kBTU/ft^2)
  - Primary energy less than 120 kWh/m^2 (38.1 kBTU/ft^2)
  - Window U-value less than 0.8 W/m^{2}K (0.15 Btu/hrft^{2}F)
  - Ventilation system with heat recovery greater than 75%
  - Airtight shell: 0.6 ACH @ 50 Pa
  - Thermal bridge free construction

PHIUS
Passive House Institute US