ENERGY MODELING
BEST PRACTICES AND APPLICATIONS

Sam Mason, , P.E., BEMP
Erik Kolderup, P.E., BEMP

Orlando
February 4, 2020

1

COPYRIGHT

2

2

AIA/CES Registered Provider

- ASHRAE is a Registered Provider with The American Institute of Architects Continuing Education Systems. Credit earned on completion of this program will be reported to CES Records for AIA members. Certificates of Completion for non-AIA members are available on request.
- This program is registered with the AIA/CES for continuing professional education. As such, it does not include content that may be deemed or construed to be an approval or endorsement by the AIA of any material of construction or any method or manner of handling, using, distributing, or dealing in any material or product. Questions related to specific materials, methods, and services will be addressed at the conclusion of this presentation.

3

3

EDUCATION PARTNER

Energy Modeling Best Practices and Applications

By ASHRAE

GBCI cannot guarantee that course sessions will be delivered to you as submitted to GBCI. However, any course found to be in violation of the standards of the program, or otherwise contrary to the mission of GBCI, shall be removed. Your course evaluations will help us uphold these standards.

Course ID: 90004961

Approved for:

6

General CE hours

0

LEED-specific hours

LEED GREEN ASSOCIATE ☐

LEED AP BD+C ☐

LEED AP HOMES ☐

LEED AP ID+C ☐

LEED AP ND ☐

LEED AP O+M ☐

4

4

Introduction
Training Team

Sam Mason, P.E., BEMP, LEED BD+C, Member ASHRAE
Principal, Encompass Energy LLC
Expertise: Energy modeling and analysis

Erik Kolderup, P.E., BEMP, LEED BD+C
Principal, Kolderup Consulting
Expertise: Energy Modeling and Analysis

5

5

Introduction
Training Objectives

- ❑ Improve modeling quality
- ❑ Clarify modeling procedures
- ❑ Effective use of modeling during the building life cycle

Indoor snow dome in Dubai…
Model that!

6

6

INTRODUCTION
LEARNING OBJECTIVES

- Identify best practices for providing high-quality and consistent modeling services
- Inform building design through energy modeling
- Develop an effective business case for energy efficiency
- Implement measurement and verification procedures that use calibrated building energy simulation models to calculate savings

7

7

INTRODUCTION
TRAINING OVERVIEW—SYLLABUS

Schedule	Topic	Presenter
Apr 24	Introduction	Mason/Kolderup
	Modeling to Inform Design	Mason
	Modeling Fundamentals—Part 1	Kolderup
	Break	
	Modeling Fundamentals—Part 2	Kolderup
	Q&A, Adjourn	
	Best Practices	Mason
	Performance Rating Method (PRM)	Mason
	Break	
	Calibration and M&V	Kolderup
	Q&A, Adjourn	

8

8

Modeling to Inform Design

Integrated Design Process

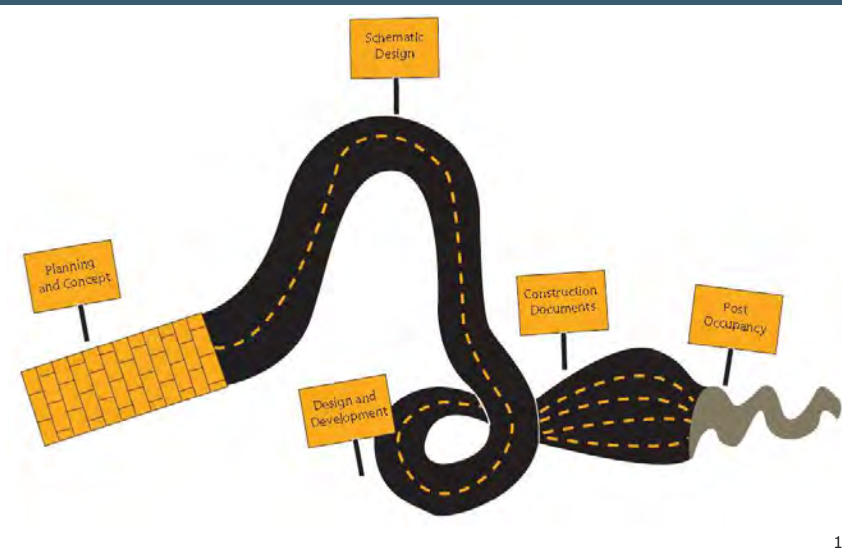
Modeling Procedures

ASHRAE Standard 209

9

9

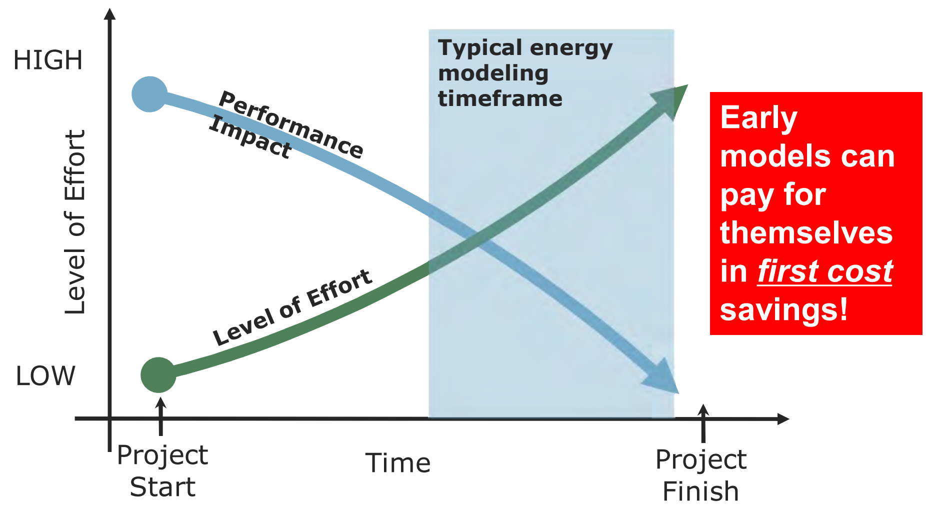
Modeling and The Building Life Cycle



10

10

Early Decisions Are the Most Important



11

11

Integrated Design Process

Role of the Energy Modeler

- To analyze the energy use in the building
- To make sure the design works in terms of minimizing the amount of energy used and maximizing the comfort in the space and ensuring that necessary code compliance is met
- To audit the design and point out any areas of concern to the design team

12

12

INTEGRATED DESIGN PROCESS
OVERVIEW

Activities

Goal Setting | Technical Potential | "Right Steps" Energy Modeling

Modeling Objectives

- Align team around energy-related goals
- Make design recommendations **early** to increase potential for impact
- Identify where efforts should be focused to maximize energy savings and equipment downsizing
- Maximize opportunity for energy efficiency

13

13

INTEGRATED DESIGN PROCESS
GOAL SETTING

Quantify the Energy Targets with the Design Team

- kBtu/ft²·yr
- % Reduction below ANSI/ASHRAE/ IES Standard 90.1
- What Certification?
- End-Use Specific

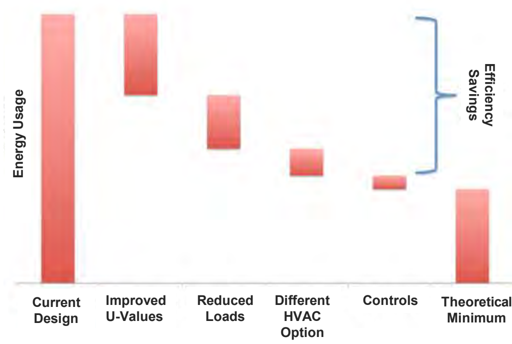
Types of Goals

Overall Target Values	Comparative	Certifications	End-Use Specific
•EISA 2007 •EUI <35 kBtu/ft²·yr •Net zero operating carbon •Demand <3 W/ft²	•55% better than ANSI/ASHRAE/ IES Standard 90.1 •Lowest EUI of any U.S. museum •80% water reduction from current use	•LEED Platinum •ENERGY STAR® score •ASHRAE Building Energy Quotient •Living Building Challenge	•80% reduction in lighting energy from natural daylight •100% of heating from waste heat and solar thermal

14

14

INTEGRATED DESIGN PROCESS
TECHNICAL POTENTIAL



What is Technical Potential?

The minimum level of energy consumption possible for a building, given today's technology (excluding renewables)

Why is this Important?

- Challenges conventional ways of thinking
- Not limited by industry benchmarks/norms
- Can lead to more aggressive design targets
- Explicitly states where ground has been lost

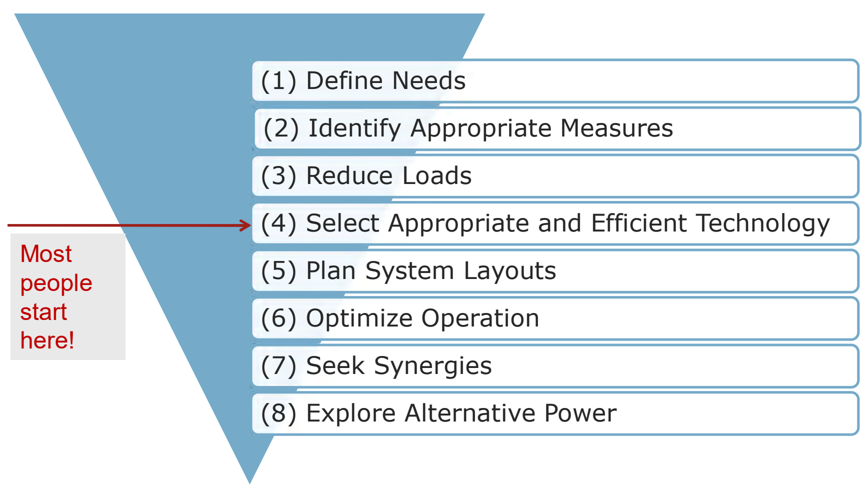
How Do We Determine Technical Potential?

- Start with a baseline or current design
- Removes the losses and inefficiencies with best available technology

15

15

INTEGRATED DESIGN PROCESS
THE RIGHT STEPS IN THE RIGHT ORDER

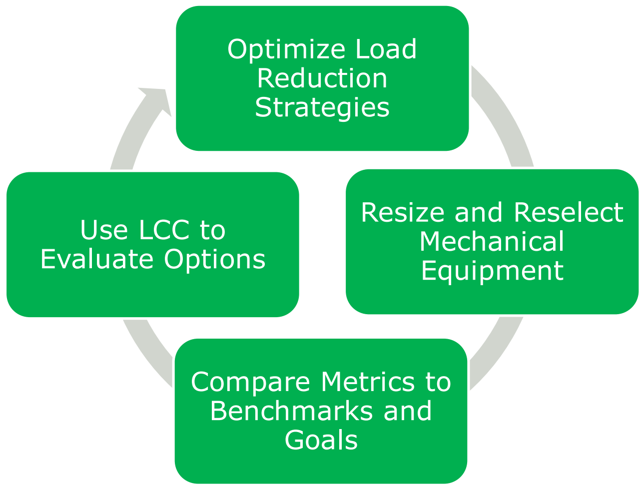


16

16

Integrated Design Process

Iterative Analysis Procedure



17

17

Technical Potential Case Study

Empire State Building

An Existing Building

18

18

Empire State Building (ESB)

Application of Technical Potential

www.esbsustainability.com

19

19

ESB Pre-Retrofit

Prior to 2008, the Empire State Building's performance was average compared to most U.S. office buildings.

Annual Utility Costs:
$11 million ($4/ft^2)

Annual CO_2 Emissions:
25,000 metric tons (22 lbs/ft^2)

Annual Energy Use:
88 kBtu/ft^2

Peak Electric Demand:
9.5 MW (3.8 W/ft^2 inc. HVAC)

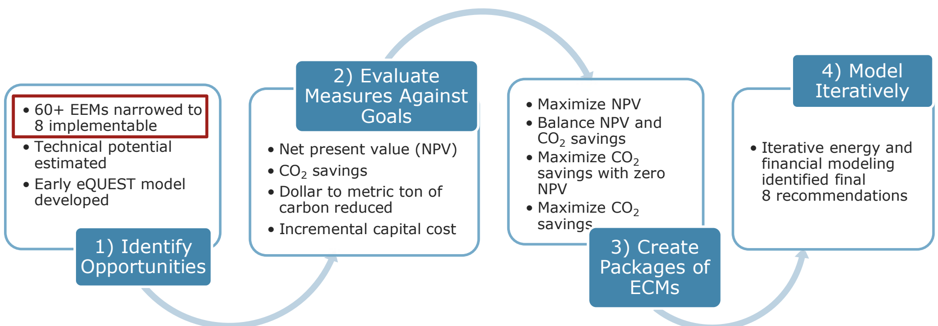
20

20

ESB Process

Motivation of Empire State Building Ownership

To demonstrate how to cost-effectively retrofit a large multi-tenant office building to inspire others to embark on whole-building retrofits

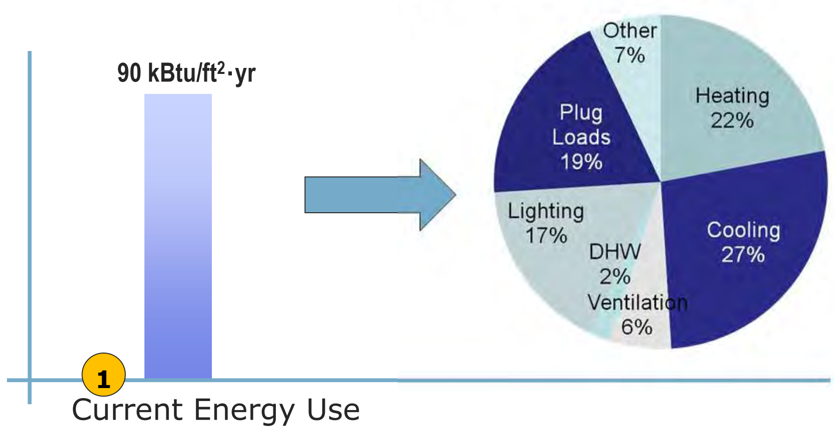


21

21

ESB: Technical Potential—Exercise

What is the maximum level of energy savings for this building given today's technology?

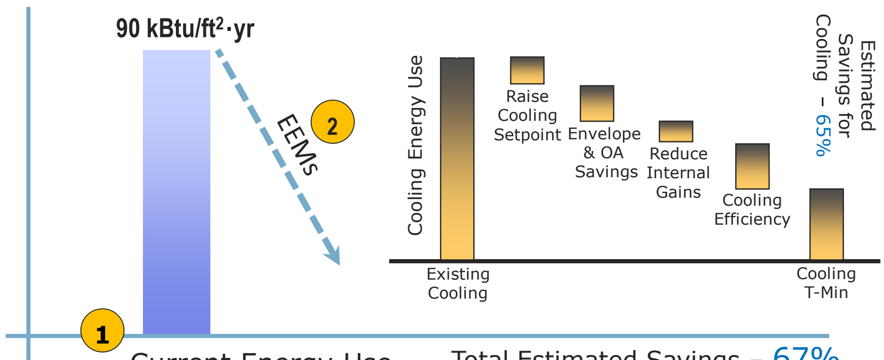


22

22

ESB: Technical Potential—Exercise

What is the maximum level of energy savings for this building given today's technology?



Current Energy Use

Total Estimated Savings – 67%

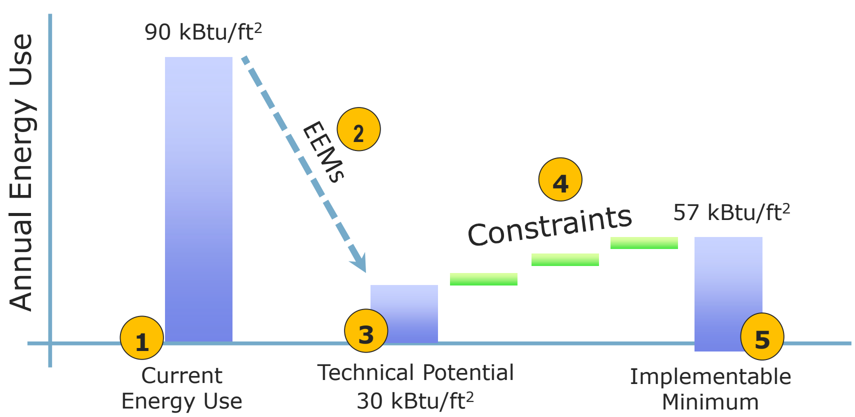
Technical Potential – 30 kBtu/ft²

23

23

ESB: Technical Potential—Exercise

What is the maximum level of energy savings for this building given today's technology?

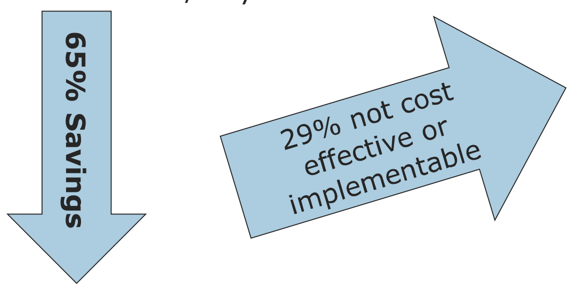


24

24

ESB: Technical Potential—Exercise

Baseline: 90 kBtu/ft²·yr



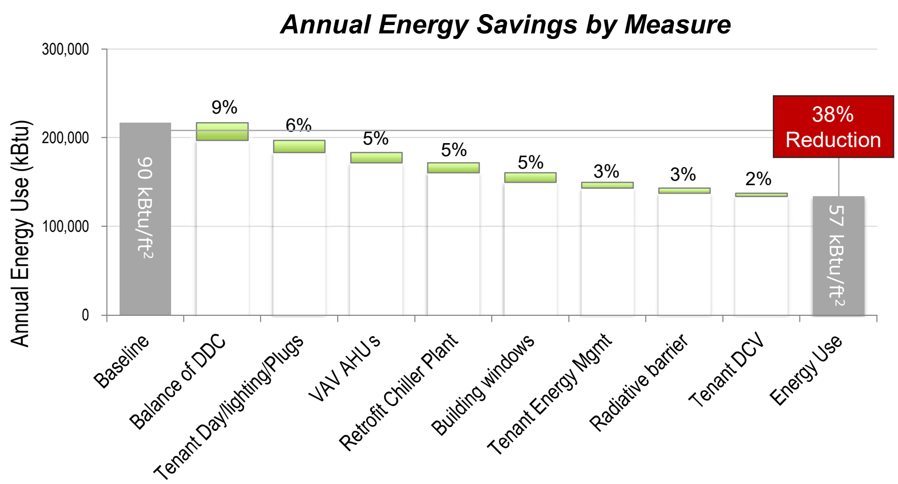
Implementable Minimum: 57 kBtu/ft²·yr

Technical Potential: 30 kBtu/ft²·yr

25

25

ESB: Implementable Minimum



26

26

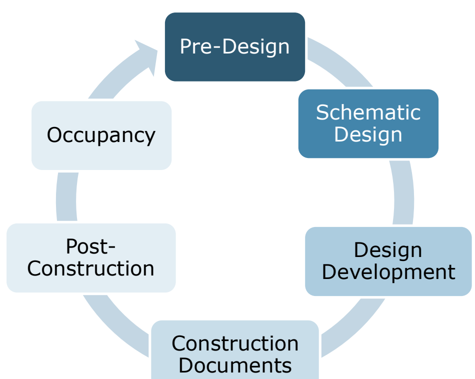
Modeling to Inform Design

Modeling Procedures

27

27

Modeling Procedures



How is energy modeling best utilized during the building life cycle?

What are the key steps to be followed during each phase?

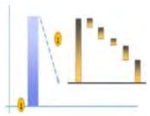
28

28

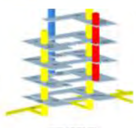
Modeling Procedures
Pre-Design

Pre-Design—design team establishes the building program and owners' project requirements

Establish and align team around energy savings goals



Use energy modeling technical potential analysis to understand potential of building



Perform modeling to inform early design decisions

Help team understand if the design will work

29

29

Modeling Procedures
Pre-Design

Confirm critical assumptions and big picture analysis:

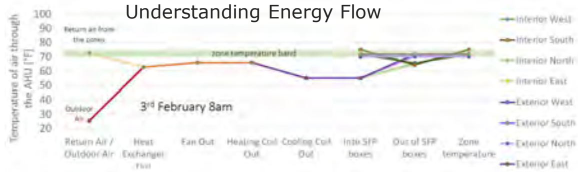
1. Take what you know (footprint, building type, etc.) and construct a baseline standard model (ANSI/ASHRAE/IES Standard 90.1)
2. Document all assumptions, note values to be validated
3. Evaluate the end-use breakdown to identify areas where there are major savings opportunities
4. Evaluate peak heating and cooling load contributions to identify ways to downsize mechanical systems
5. Analyze how energy moves through the building and identify areas where there could be heating and cooling conflicts
6. Analyze certain measures that are early design decisions and will be difficult to change later
7. Determine the "technical potential" for reduced energy consumption to challenge the actual design

30

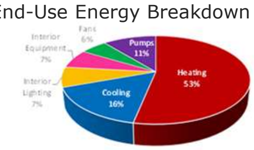
30

Modeling Procedures
Pre-Design

Understanding Energy Flow

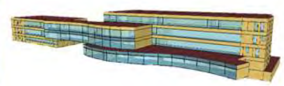


End-Use Energy Breakdown

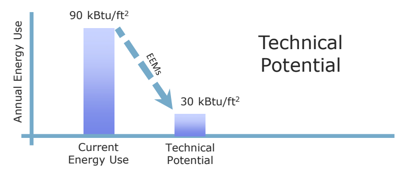


Document Assumptions

Simplified Model Pre-Design



Complex Model Design Development



Technical Potential

31

31

Modeling Procedures
Schematic Design

Be timely

Decision making can happen quickly. If modeling is time constrained, consider simplifying schedules, spaces/HVAC zones, and window geometry. Recommendations made based on a targeted, simplified analysis are better than no recommendations.

Address design components that are laid out and decided upon in schematic designs

- Low pressure-drop system design with energy recovery
- Floor-to-floor height and space layout to maximize daylight-use potential
- Integrated systems: UFAD, natural ventilation, mixed-mode ventilation

Respond to and leverage the project specifics

- Client motivations
- Design team need for information
- The project story

32

32

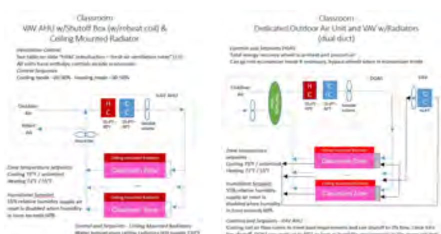
Modeling Procedures
Schematic Design

1. Review all available documents (owner's requirements, narratives, drawings). Extract known data, document assumptions.
2. Compile schedules, lighting power density (LPD), and equipment power density (EPD) design data for team to review, get info for ASHRAE fan power calculation (filters, sound attenuation, etc.)
3. Evaluate those things that can't be modeled with alternative methods (e.g., thermodynamic equivalent, spreadsheet, 8760 schedule, etc.)
4. Evaluate impact of change from "reference" to "technical potential"
5. Define several HVAC alternatives
6. Expand EEMs to include synergistic elements
7. Make series of runs that include one EEM at a time to facilitate quality control
8. Define packages to cover range of targets
9. Check results against metrics (site, plant, end-use) and targets

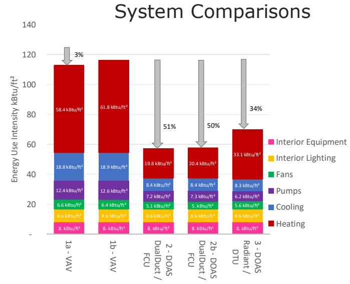
33

33

Modeling Procedures
Schematic Design

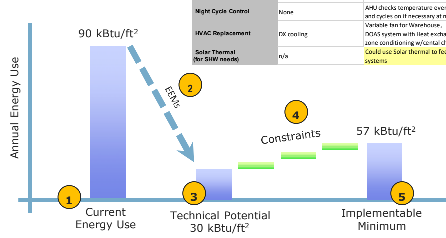


System Comparisons



EEM Details

Items Considered	Building	
	Original	EEM
Thermostat (efficiency class B)	Schedule: 2am - 7pm (class C) DIN EN 15232 Warehouse: 20°C (24hrs) Office: 20°C /15.6°C (heating) 24°C / 26.7°C (Cooling)	Schedule: 3am - 5pm (class B) DIN EN 15232 Warehouse: 13°C (24hrs) Office: 26°C / 30°C (cooling)
Lighting Control	Schedule: 4am - 5pm 30% night office Warehouse lights run 24hr	Schedule: follow occupancy, 5% at night ASHRAE (warehouse remain the same)
Tightening and sealing the building envelop	Storage: 3 ach Office: 0.001133 m³/s . m² exterior surface	Storage: 0.4 ach Office: 0.4 ach Leakage test protocol for buidling envelops v3 2012
Additional insulation where we can (roof/walls)	Wall: Double brick air gap gypsum Roof: Metal Decking	Wall: Insulation in the gap or interior insulation (addition of 4in) Roof: addition of 12in
Window Replacement / improvement	Single glazed 3.5 W/m².K	addition of double glazed low E unit on the inside 2 W/m².K
Lower Lighitng Levels (Design Guide)	Warehouse 3.34 W/m² Office 11.8 W/m²	Office 7.5W/m² Corridors 5.4W/m² Server Rooms 7.5W/m² Warehouse: 5.4W/m²
Lighting Controls (Daylight / Occupancy)	none	Daylight sensors added where possible
Improved fan efficiencies and control	Constant Volume eff 0.55	Variable volume 0.65
Improved Pump Efficiencies	none for cooling	Variable high efficiency
Reset controls on the Chiller	None	As ASHRAE 90.1 2007
Night Cycle Control	None	AHU checks temperature every 30 minutes and cycles on if necessary at night
HVAC Replacement	DX cooling	Variable fan for Warehouse, DOAS system with Heat exchanger - individual zone conditioning w/cental chiller
Solar Thermal (for SHW needs)	n/a	Could use Solar thermal to feed into radiant systems



Technical Potential Constraints

34

34

Modeling Procedures
Design Development

Rightsizing of systems

Size most systems to just meet design loads

Oversizing (typically systems with VFDs): allow room for expansion and benefit from improved efficiencies at part load

Inform value engineering decisions

Convey the cumulative impact of efficiency measures

Analyze the impact of value engineering options

Inform the design relative to fine-tuning of efficiency strategies

Controls: Staging/delta T/resets/VAV minimums/etc.

Shading characteristics—width of overhangs/fins, etc.

35

35

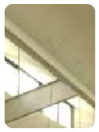
Modeling Procedures
Design Development

1. Update model input with latest design info, document assumptions
2. Identify any gaps in the plans and specifications (e.g., fenestration properties, fan bhp, sequence of operations, etc.) and request clarifications
3. For life-cycle cost analysis or value engineering identify efficiency measures already incorporated into the design and use parametrics to show performance without these measures
4. Identify and analyze efficiency measures not analyzed in earlier phases
5. Fine-tune efficiency measures in design:
   - Control parameters
   - Exterior shade depths
   - Chiller selection (using part-load curves)
6. Verify equipment capacities will meet comfort conditions without jeopardizing energy efficiency

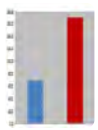
36

36

Modeling Procedures
Construction Documents



Ensure project efficiency strategies remain in the building design



Finalize performance and savings estimates

Document savings for LEED/EPACT/other

37

37

Modeling Procedures
Construction Documents

- Check for changes to building form, orientation, or thermal zones
- Verify envelope input parameters
- Identify any changes to LPD, EPD, or schedules
- Identify any changes to fan bhp, airflow, and other HVAC equipment
- Identify any changes to controls
- Revise model to reflect current design
- Check results against DD results, metrics, targets
- Ensure that documentation appropriately responds to information requested by authority having jurisdiction
- Provide full justification for all savings claimed
- Provide a narrative justifying any non-standard inputs or outputs

38

38

Construction Documents

LEED Submittal Requirements

Input Summary	Output Summary	Renewable / Exceptional Calculations	Backup Documents
• Identify each major baseline and proposed case input. Examples: • R-13+R3.8ci steel-framed walls, U-0.064 • Supply temperature reset based on worst case zone between 55°F and 60°F • Identify where exceptions have been taken (e.g., system type exceptions, no energy recovery modeled for 100% OSA system, etc.)	• Enter energy consumption by end-use • Enter peak demand by end-use (for month with highest peak demand) • Enter energy cost by energy type	• Renewable calculations: • EAc2: full explanation of calcs • Explain variations between virtual energy cost for energy model and average energy cost offset by renewables • Exceptional calculations: • Provide detailed narrative with justification for all assumptions made • Provide a copy of studies used • Provide calculations	• Simulation output summary reports: • Energy consumption by end-use • Energy cost by energy type • Unmet load hours • Envelope summary • Simulation input summary reports: • Envelope • Sample system • Sample thermal zone • Mechanical schedule

39

39

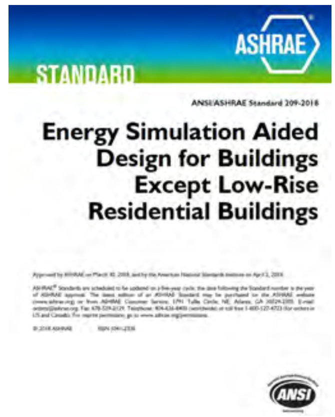
ASHRAE Standard 209

40

40

ASHRAE STANDARD 209

- Process standard
- Minimum requirements
  1. Four specific activities
  2. Two modeling cycles
     1. Load-reduction
     2. Additional design-phase cycle
- Optional modeling cycles
  - Construction phase
  - Occupancy phase

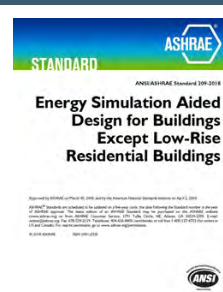


41

41

ASHRAE STANDARD 209

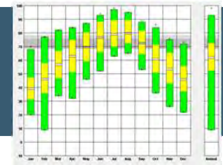
1. Purpose
2. Scope
3. Definitions
4. Utilization
5. General Requirements
6. Design Modeling Cycles
7. Construction and Operations Modeling
8. Post-Occupancy Energy Performance Comparison



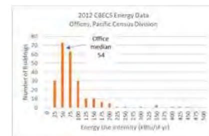
42

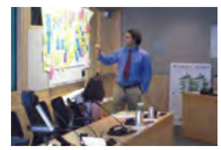
42

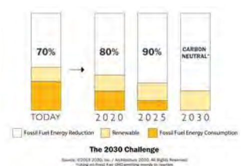
ASHRAE STANDARD 209



5. General Requirements
   - 5.1 Software Requirements
   - 5.2 Modeler Credentials
   - 5.3 Climate and Site Analysis
   - 5.4 Benchmarking
   - 5.5 Energy Charrette
   - 5.6 Establish Energy Performance Goals
   - **5.7 General Modeling Cycle Requirements**
     - 5.7.1 Energy Baselines and Goals
     - 5.7.2 Input Data
     - 5.7.3 Reporting
     - 5.7.4 Quality Assurance







43

43

ASHRAE STANDARD 209

6. Design Modeling Cycles	**Timing**
6.1 #1 Simple Box Model 6.2 #2 Conceptual Design	Conceptual Design
6.3 #3 Load Reduction ⇐ 6.4 #4 HVAC System Selection	Schematic Design
6.5 #5 Design Refinement 6.6 #6 Design Integration & Optimization	Design Development
6.7 #7 Energy Simulation-Aided Value Engineering	Construction Documents

44

44

ASHRAE Standard 209

6.1 Modeling Cycle # 1—Simple Box Modeling

6.1.1 Purpose. Identify the distribution of energy by end use. Evaluate *energy end uses* and demand characteristics that affect building conceptual design.

6.1.2 Applicability. This *modeling cycle* applies before the building's geometry and site orientation have been set in the design process. This must be completed before or during the energy *charrette* described in Section 5.5.

6.1.3 Analysis. Create *energy models* to calculate annual building energy by end use and peak heating and cooling loads with identical *HVAC systems*. Perform a sensitivity analysis by varying the following building characteristics:

a. Building geometry
b. Window-to-wall ratio, by orientation, and shading options (if applicable)
c. Orientation
d. Thermal performance of the envelope and structure

Informative Note: See Informative Appendix C for guidance.

45

45

ASHRAE Standard 209

7. Construction and Operations Modeling
   - 7.1 #8 As-Designed Performance
   - 7.2 #9 Change Orders
   - 7.3 #10 As-Built Energy Performance

8. Post-Occupancy Energy Performance Comparison
   - 8.1 #11 Post-Occupancy Energy Performance Comparison

46

46

ASHRAE Standard 209 - Compliance

Required

- 5.3 Climate and Site Analysis
- 5.4 Benchmarking
- 5.5 Energy Charrette
- 5.6 Energy Performance Goals in OPR
- 5.7 General Modeling Cycle Requirements + 6.3 Modeling Cycle #3 Load Reduction Modeling
- 5.7 General Modeling Cycle Requirements + One additional design-phase modeling cycle (earlier or later)

47

47

MODELING FUNDAMENTALS

48

48

Modeling Fundamentals
SOFTWARE

Whole-Building Simulation Tools
- EnergyPlus
- eQuest (DOE 2.2, DOE2.3)
- TRNSYS
- Trane TRACE
- Carrier HAP
- TAS
- IES (Apache)
- Bentley (AECOsim Energy Simulator and Hevacomp)
- Autodesk GBS
- Simergy

Useful Support Tools
- Window/Therm/Optics
- ASHRAE Comfort Tool
- Climate Consultant
- Elements
- DView
- And more…

www.buildingenergysoftwaretools.com/

49

49

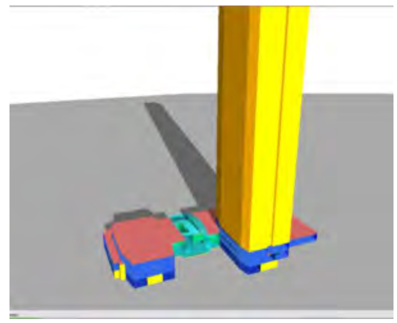
Modeling Fundamentals
SOFTWARE

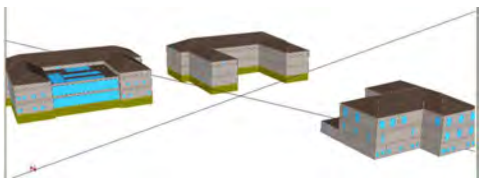
Engine	Interface	Free
DOE-2.1E	EnergyPro	
DOE-2.2	Autodesk GBS	
	eQUEST	✓
DOE-2.3	eQUEST	✓
EnergyPlus	Bentley Hevacomp and AECOsim Energy Simulator	
	Trane Trace	
	DesignBuilder	
	OpenStudio	✓
	Simergy	
	CBECC Com	✓
HAP	Carrier HAP	
Apache	IES-VE	
TRNSYS	TRNSYS	

50

50

Shell Geometry
General Concepts



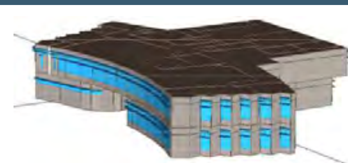


51

51

Shell Geometry
Rules of Thumb for Simplification

Simplify



REALITY

ENERGY MODEL

- Thermodynamically, only 3 things matter for modeling heat transfer surfaces:
  1. Area
  2. Orientation
  3. Tilt
- Total volume matters ***if*** infiltration is specified in ACH

ANSI/ASHRAE/IES
Standard 90.1 Appendix G

- Table G3.1, #5 Building Envelope, Exceptions (a) and (b)
  - Uninsulated assemblies
  - Exterior surfaces whose azimuth, orientation and tilt differ by <45°

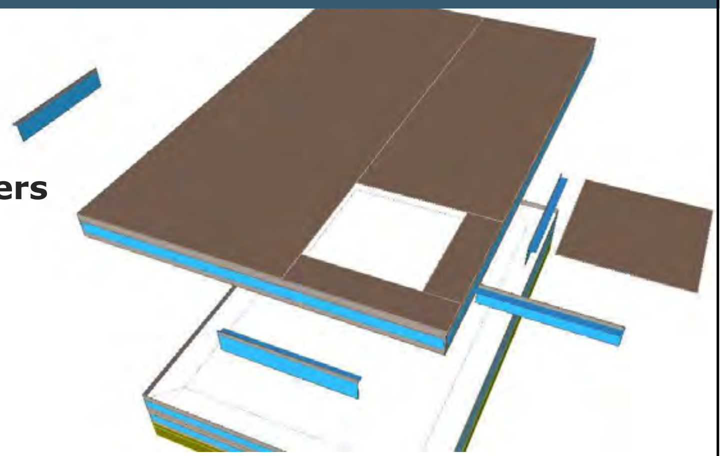
52

52

Shell Geometry
Relative Placement of Surfaces

What Matters

- Area
- Orientation
- Tilt

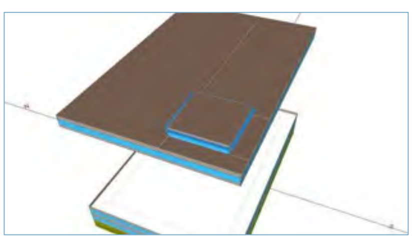


Note: With daylighting and some shading situations, the building form is important.

53

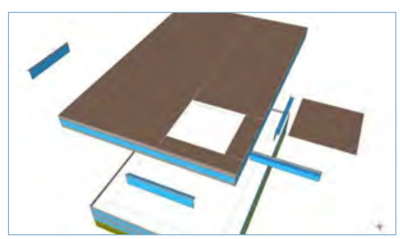
53

Shell Geometry
Relative Placement of Surfaces



Annual Energy by End-Use

	Electricity kWh (x000)	Natural Gas MBtu
Space Cool	587.6	-
Heat Reject.	50.2	-
Refrigeration	-	-
Space Heat	-	3,439.8
HP Supp.	-	-
Hot Water	-	344.1
Vent. Fans	232.9	-
Pumps & Aux.	101.3	-
Ext. Usage	529.8	-
Misc. Equip.	1,601.2	-
Task Lights	-	-
Area Lights	1,422.9	-
Total	4,525.8	3,783.9



Annual Energy by End-Use

	Electricity kWh (x000)	Natural Gas MBtu
Space Cool	587.6	-
Heat Reject.	50.2	-
Refrigeration	-	-
Space Heat	-	3,439.8
HP Supp.	-	-
Hot Water	-	344.1
Vent. Fans	232.9	-
Pumps & Aux.	101.3	-
Ext. Usage	529.8	-
Misc. Equip.	1,601.2	-
Task Lights	-	-
Area Lights	1,422.9	-
Total	4,525.8	3,783.9

54

54

Shell Geometry
Geometry Interfaces

SketchUp Plugins

- Open Studio for EnergyPlus
- IES Virtual Environment

BIM and CAD (dwg files)

- 2-D and 3-D CAD plans may be imported into energy modeling programs
- gbXML and IFC streamlines the transfer of building information to and from engineering models

55

55

Shell Geometry
Geometry Interfaces

Building Information Modeling (BIM)

- Generating and managing building data
- Well developed for architecture; needs improvement on MEP side
- Early development phase for energy modeling

Goals

- Automatic model generation from 3-D renderings
- Architects/engineers will specify "properties" of materials and equipment for automatic modeling

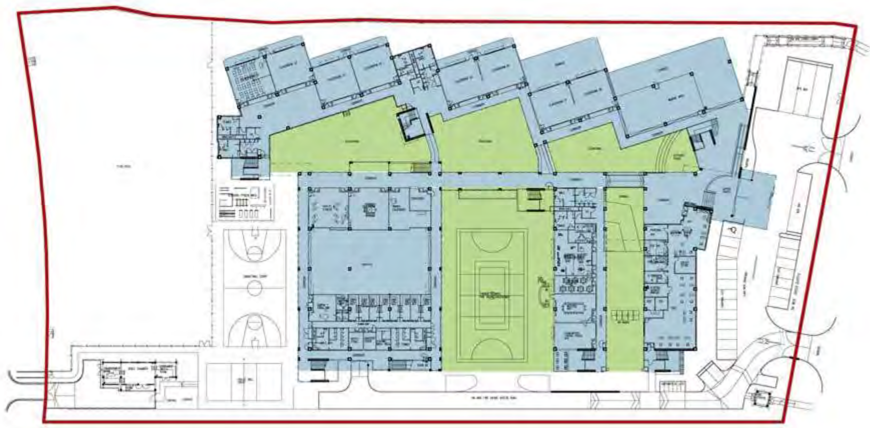
Barriers

- BIM needs work in some segments (i.e., electrical engineering)
- ***Danger of "black box" energy modeling***

56

56

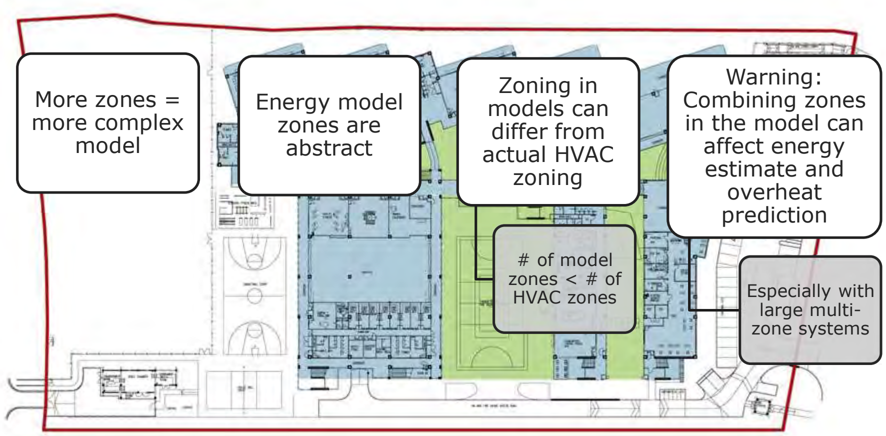
Effective Zoning
General Concepts



57

57

Effective Zoning
General Concepts



58

58

Effective Zoning

Criteria for Zoning an Energy Model

Usage
- All rooms should have similar internal loads and usage schedules

Temperature Control
- All rooms should have the same thermostat schedules

Solar Gains
- Perimeter zones with windows: Min. one zone for each compass direction
- Unglazed exterior zones can be combined
- Consider shading!

Perimeter or Interior Location
- 12–15 ft perimeter zones often require winter heating
- Core spaces can require year-round cooling

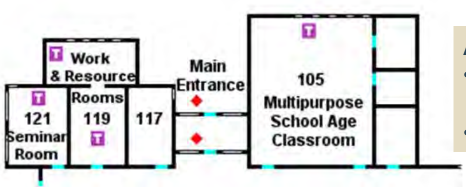
Distribution System Type
- Combine rooms served by the same type of distribution system (i.e., fan-coil units)

59

59

Effective Zoning

Spaces vs. Thermal Zones



Actual Building
- Thermal zone = area controlled by a single thermostat
- May include more than one space

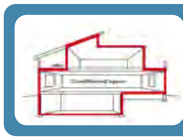
Energy Modeling
- Typically one zone for each modeled space
- Some programs permit zones defined as a set of spaces

60

60

Effective Zoning

Zone Types Within an Energy Model

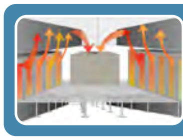


Conditioned

- Space is heated or cooled

Unconditioned

- Space is neither heated nor cooled
- Examples are false ceiling spaces not used as return air plenums, attics, crawl spaces, and garages



Plenum

- Return air space
- Atrium as return plenum
- Heat transfer within plenums

61

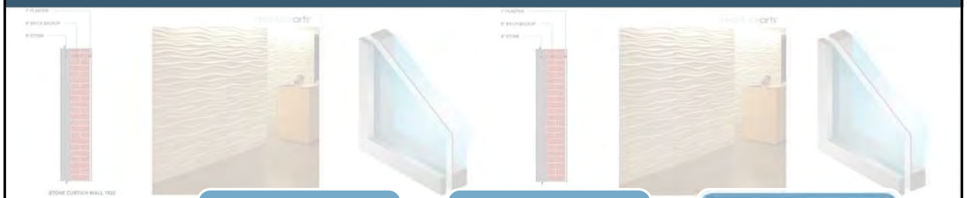
61

Break

62

62

Constructions
Overview



Types of Constructions

- Exterior opaque (walls, roofs, slabs, underground walls, etc.)
- Interior (mass, air, layers, etc.)
- Exterior glazed

~~Quick~~ vs. *D e l a y e d*

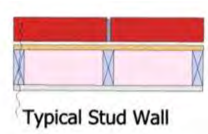
63

63

Constructions
Exterior (Delayed) Constructions—Opaque

Material Properties	Layers	Constructions
• Conductivity • Density • Specific heat • Thickness	• Materials are "layered" from outside to inside • Outside and inside air films	• Layers determine U-factor • Surface roughness • Solar reflectivity

What about construction assemblies with parallel heat transfer paths?



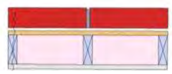
64

64

CONSTRUCTIONS

PARALLEL PATH CALCS FOR WOOD STUD WALL

Wall Section



Typical Stud Wall

ORNL Online Calculator

ASHRAE 90.1 Appendix A

R-Value of Insulated Section = **R-Value (brick)** + **R-Value (Sheathing)** + **R-Value (Insulation)** + **R-Value (Gyp. Board)** + **R-Value (Inside Air Film)**

R-Value of Stud Section = **R-Value (brick)** + **R-Value (Sheathing)** + **R-Value (Stud)** + **R-Value (Gyp. Board)** + **R-Value (Inside Air Film)**

Overall Weighted R-Value of Wall Assembly = **1/ [(% area studs / $R_{insulation}$) + (% area studs / R_{studs})]**

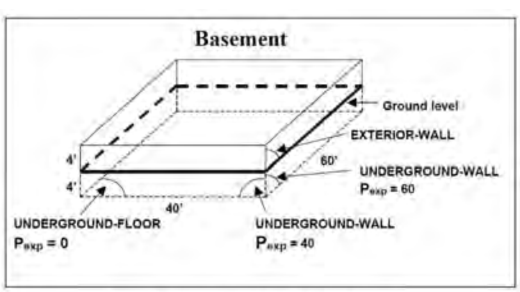
65

CONSTRUCTIONS

SLAB HEAT TRANSFER

Do you need to perform outside calculations?

Underground Surfaces: How to get a better underground heat transfer calculation in DOE-2.1 by Fred Winkelman

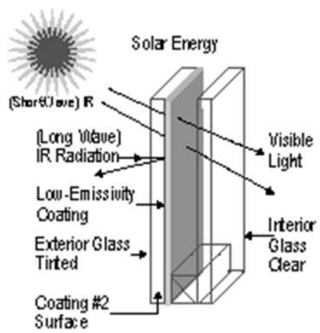


Exposed perimeter calculation for slab-on-grade examples

1) Choose F-factor from a series of tables
2) Calculate the exposed perimeter and area of slab. Use equation $R_{effective} = A/(F*P_{exposed})$
3) Set $U_{effective} = 1/R_{effective}$.
4) Create a material with $R_{effective}$

66

CONSTRUCTIONS
GLAZING CONSTRUCTIONS



Glazing Properties:

- Center of glass U-factor
- Solar heat gain coefficient (SHGC), ***or*** shading coefficient (SC)
- Visible light transmission (VLT)
- Light-to-solar heat gain ratio (LSG)

Common Pitfall:
Outside Air Films

67

67

CONSTRUCTIONS
GLAZING CONSTRUCTIONS

Includes spectral data: varies SHGC and T_{vis} with solar angles

3 Options for Modeling Glazing

- Simplified
- Library Glazing
- Window 7 (LBNL)

68

68

CONSTRUCTIONS
WINDOW FRAMING

2 Options for Modeling Framing

Include framing effects in glazing construction

- Model large bands of glass
  or
- Model windows individually

Common Pitfall:
Window 7 does not include framing when you export files

Model framing explicitly

- Works well with Window 7 option
- Use window multipliers

Common Pitfall:
Modeling large bands of glass

69

69

LIGHTING OCCUPANCY AND PLUG LOADS
GENERAL CONCEPTS

Peak Power and Occupancy
- Total watts of all connected power
- Peak number of occupants
- Can be input with density values

Fractional Schedules
- Daily/weekly/annual occupancy schedules
- Hourly fractional multiplier for peak values
- Daylight dimming or occupancy sensors

Fraction of Heat Gain to Space
- Assign proportional amounts of heat to space vs. plenum

Radiative/ Convective Split
- Fraction of heat entering the space via radiative vs. convective heat transfer

Sensible/ Latent Split
- Fraction of heat gain that is sensible versus latent (moisture)

70

70

LIGHTING OCCUPANCY AND PLUG LOADS
GENERAL CONCEPTS

Important Point

Simulation inputs
≠
HVAC load calculation inputs

Why not?

71

71

LIGHTING OCCUPANCY AND PLUG LOADS
GENERAL CONCEPTS

Important Question

What fraction of the electricity consumed by equipment in the space ends up as heat in the space?

72

72

LIGHTING OCCUPANCY AND PLUG LOADS
PEAK POWER AND OCCUPANCY

Peak values include all connected loads

- Electric lighting (total fixture wattage)
- Emergency lighting
- Plug loads
- Kitchen equipment, elevators, servers, etc.

Sources for estimating equipment power density and peak occupancy

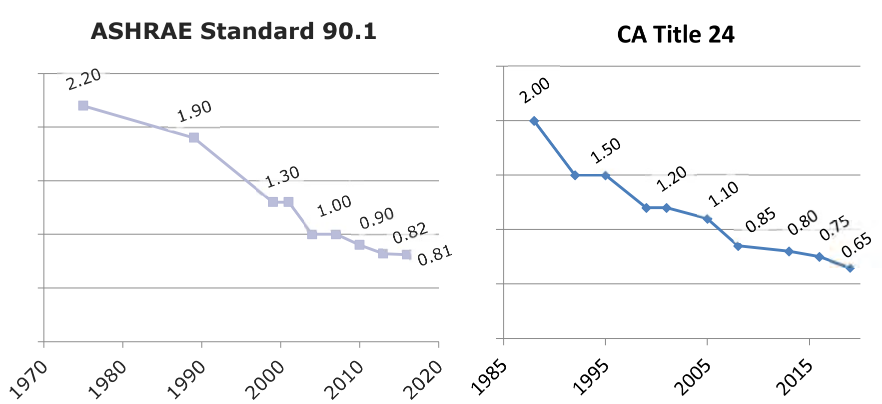
- ANSI/ASHRAE/IES Standard 90.1 User's Manual
- California Title 24 Alternative Calculation Method (ACM) Manual
- Commercial Energy Services Network (COMNET)
- *ASHRAE Handbook—Fundamentals*
- ANSI/ASHRAE Standard 62.1, *Ventilation for Acceptable Indoor Air Quality* (Occupancy)

73

73

LIGHTING OCCUPANCY AND PLUG LOADS PEAK LIGHTING POWER

Office Building Maximum Allowed Lighting Power (W/ft^2)



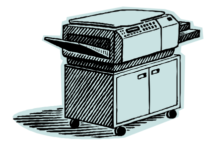
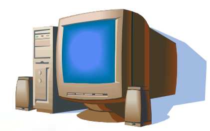
74

74

Lighting Occupancy and Plug Loads
Peak Plug Load Power

Resources for typical values:

- 90.1 User's Manual
  - Whole building values
- Advanced Energy Design Guides
  - e.g., Office: standard and efficient
- COMNET
  - Whole building and space-by-space defaults
  - Custom equation
- *ASHRAE Handbook—Fundamentals*
  - Office: low, medium, high usage
  - Individual equipment: office, kitchen, lab


75

75

Lighting Occupancy and Plug Loads Peak Plug Load Power

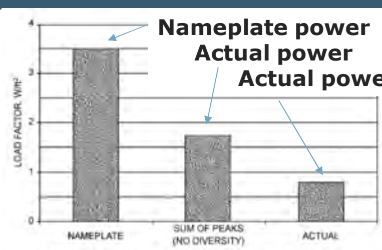
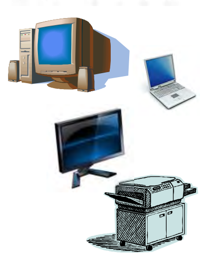


Fig. 4 Office Equipment Load Factor Comparison (Wilkins and McGaffin 1994)

Nameplate power
Actual power
Actual power + diversity



Source: *ASHRAE Handbook—Fundamentals*, Chapter 18

Typical Equipment Power and Radiant/Convective Splits

	Actual Power	Convective/ Radiant Split
Desktop computer	26-151W **82W avg**	90 / 10
Laptop computer	46-59W **53W avg**	75 / 25
Flat panel monitor 23 in.	14-26W **21W avg**	60 / 40
Laser printer	65-89W **74W avg**	70 / 30
Large copier	303-540W **425 avg**	70 / 30

76

76

Lighting Occupancy and Plug Loads

Peak Plug Load Power

Source: *ASHRAE Handbook—Fundamentals*, Chapter 18

Table 11 Recommended Load Factors for Various Types of Offices

Load Density of Office	Load Factor, W/ft²	Description
Light	0.5	Assumes 167 ft²/workstation (6 workstations per 1000 ft²) with computer and monitor at each plus printer and fax. Computer, monitor, and fax diversity 0.67, printer diversity 0.33.
Medium	1	Assumes 125 ft²/workstation (8 workstations per 1000 ft²) with computer and monitor at each plus printer and fax. Computer, monitor, and fax diversity 0.75, printer diversity 0.50.
Medium/ Heavy	1.5	Assumes 100 ft²/workstation (10 workstations per 1000 ft²) with computer and monitor at each plus printer and fax. Computer and monitor diversity 0.75, printer and fax diversity 0.50.
Heavy	2	Assumes 83 ft²/workstation (12 workstations per 1000 ft²) with computer and monitor at each plus printer and fax. Computer and monitor diversity 1.0, printer and fax diversity 0.50.

Source: Wilkins and Hosni (2000).

Table 12 Cooling Load Estimates for Various Office Load Densities

Load Density*	Number	Each, W	Total, W	Diversity	Load, W
Light					
Computers	6	55	330	0.67	220
Monitors	6	55	330	0.67	220
Laser printer—small desk top	1	130	130	0.33	43
Fax machine	1	15	15	0.67	10
Total Area Load					493
Recommended equipment load factor = 0.5 W/ft²					
Medium					
Computers	8	65	520	0.75	390
Monitors	8	70	560	0.75	420
Laser printer—desk	1	215	215	0.5	108
Fax machine	1	15	15	0.75	11
Total Area Load					929
Recommended equipment load factor = 1.0 W/ft²					
Medium/Heavy					
Computers	10	65	650	1	650
Monitors	10	70	700	1	700
Laser printer—small office	1	320	320	0.5	160
Fax machine	1	30	30	0.5	15
Total Area Load					1525
Recommended equipment load factor = 1.5 W/ft²					
Heavy					
Computers	12	75	900	1	900
Monitors	12	80	960	1	960
Laser printer-small office	1	320	320	0.5	160
Fax machine	1	30	30	0.5	15
Total Area Load					2035
Recommended equipment load factor = 2.0 W/ft²					

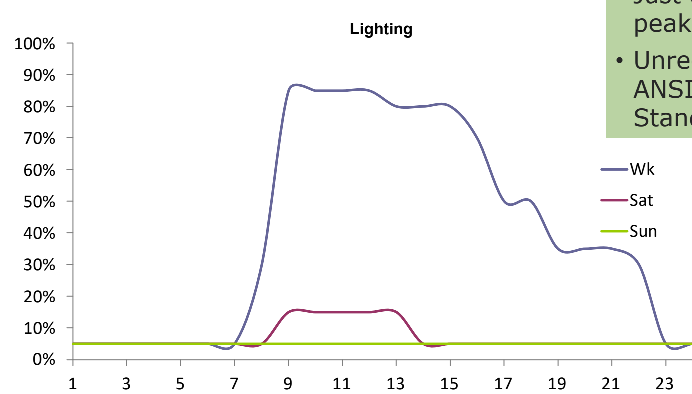
Source: Wilkins and Hosni (2000).
*See Table 11 for descriptions of load densities.

77

77

Lighting Occupancy and Plug Loads

Schedules



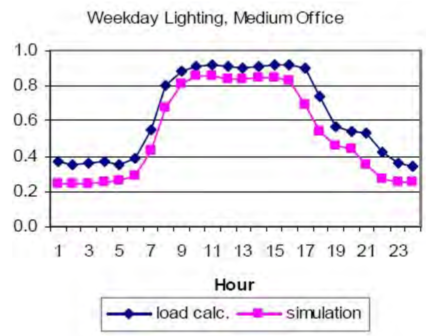
- Just as important as peak values!
- Unregulated by ANSI/ASHRAE/IES Standard 90.1

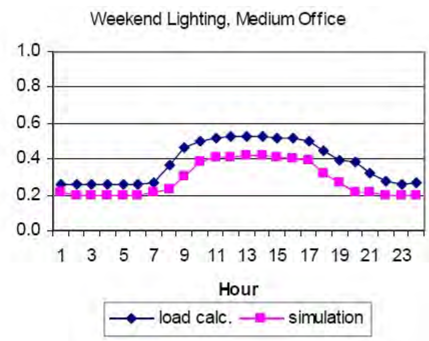
78

78

Lighting Occupancy and Plug Loads
Lighting Schedules

Source:
ASHRAE Research Project 1093-RP



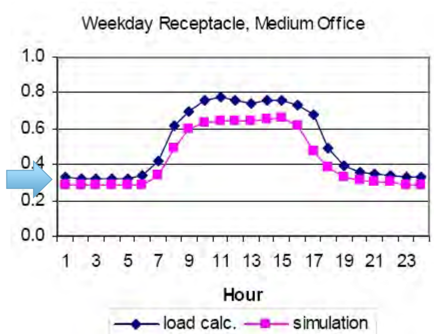


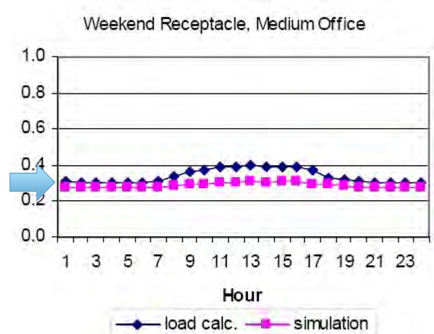
79

79

Lighting Occupancy and Plug Loads
Plug Load Schedules

Source:
ASHRAE Research Project 1093-RP



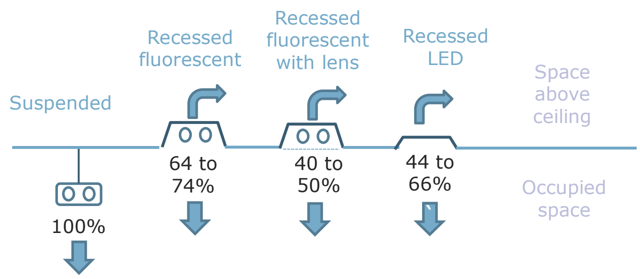


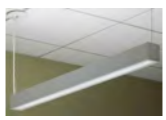
80

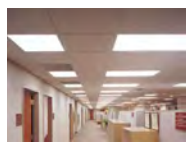
80

Lighting Occupancy and Plug Loads
Fraction to Space and Radiative Fraction

Source: *ASHRAE Handbook—Fundamentals*, Chapter 18



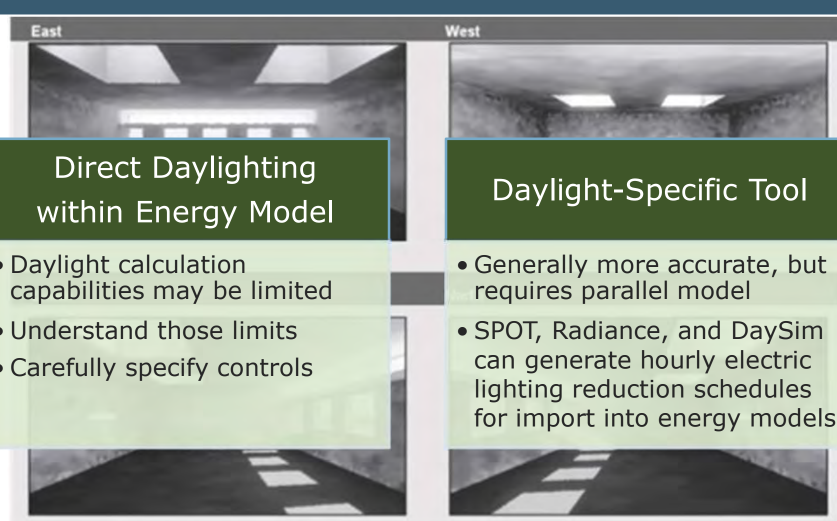




81

81

Lighting Occupancy and Plug Loads
Daylighting



Direct Daylighting within Energy Model

- Daylight calculation capabilities may be limited
- Understand those limits
- Carefully specify controls

Daylight-Specific Tool

- Generally more accurate, but requires parallel model
- SPOT, Radiance, and DaySim can generate hourly electric lighting reduction schedules for import into energy models

82

82

LIGHTING OCCUPANCY AND PLUG LOADS EXTERIOR LIGHTING

Exterior lighting modeled separately from interior lighting

Controlled via photosensors or with schedules

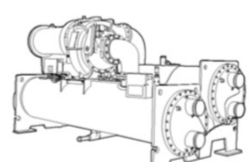
83

83

MECHANICAL SYSTEMS OVERVIEW

Topics

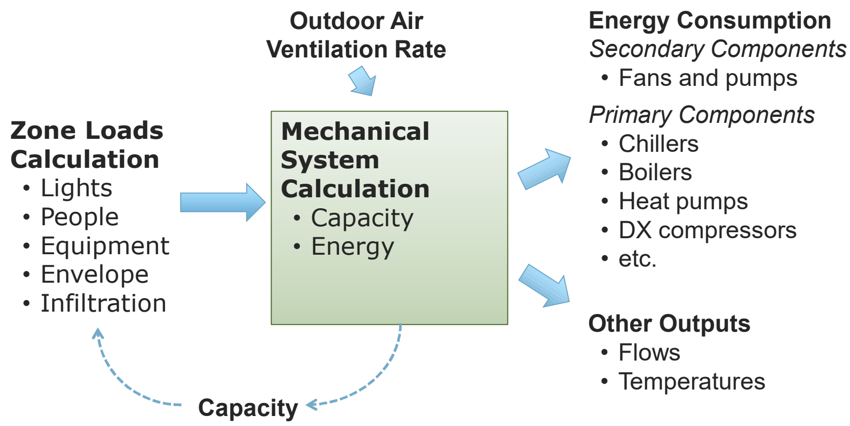
- Introduction
- Packaged systems
- Central systems
- Terminal units
- Fans
- Chillers
- Boilers
- Outside air ventilation
- Thermal comfort



84

84

Mechanical Systems
In Simulation Programs



85

85

Mechanical Systems
Modeling Approaches

Choose System Types

- Packaged single zone
- VAV reheat
- Packaged terminal air conditioner
- Etc.

• Typically quicker, easier

• May need "work arounds"

Build From Components

- Fans
- Coils
- Terminal units
- Etc.

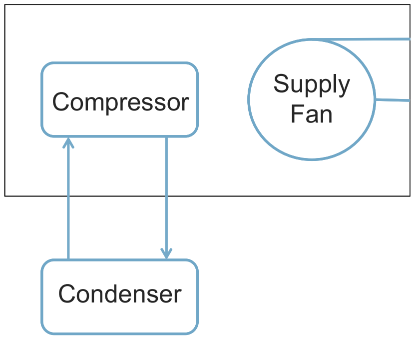
• More flexible

• May take more time
• More inputs, more chance for errors

86

86

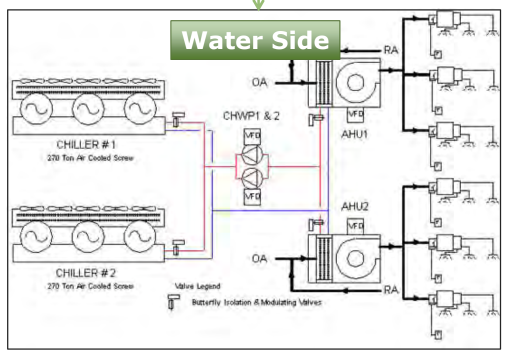
Mechanical Systems
Terminology



Packaged System

Air Side

Central Plant



87

Mechanical Systems
Packaged Systems

Common inputs
- Cooling efficiency
- Condenser type
  - Air cooled
  - Water cooled
  - Evaporatively cooled
- Airflow
- Supply air temperature
- Airside economizer
- Fan power/pressure
- Heating source
  - Furnace
  - Heat pump
  - Hot water
- Heating efficiency

88

MECHANICAL SYSTEMS
PACKAGED SYSTEMS

Advanced inputs
- Cooling part-load efficiency
- Evaporative cooling
- VAV fan power vs. flow
- Demand control ventilation
- Heat recovery

89

89

MECHANICAL SYSTEMS
PACKAGED SYSTEM EFFICIENCY

Challenge:
Translate manufacturer/ code values to model inputs

You get:

SEER or EER (at standard rating conditions, ***including*** fan power and fan heat)

You need:

EIR or COP (at standard rating conditions, ***excluding*** supply fan and fan heat)

90

90

Mechanical Systems
Packaged System Efficiency

Step 1. Estimate fan power

$$Fan_{kw} = 0.365 \times \frac{Q_{rated}}{30{,}000}$$

Step 2. Adjust the EER

$$EER_{adj} = \frac{Q_{t,rated} + BHP_{supply} \times 2.545}{\frac{Q_{t,rated}}{EER} - BHP_{supply} \times 0.7457}$$

Step 3. Calculate EIR

$$EIR = \frac{3.413}{EER_{adj}}$$

Source: COMNET, Section 6.7.3
Q is in units of kBTU/h

91

91

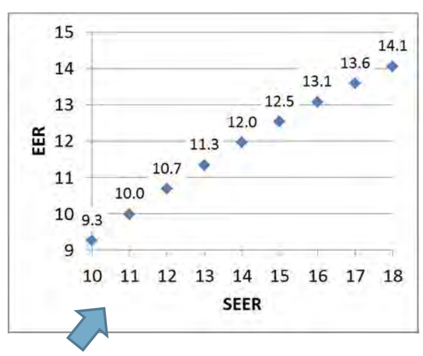
Mechanical Systems
Packaged System Efficiency

Challenge:
Translate SEER to EER

COMNET Section 6.7.5

EER = 10.0 if SEER ≥ 11.5

ASHRAE Research Project 1197-RP



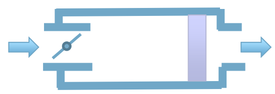
$EER = -0.0182*SEER^2 + 1.1088*SEER$

92

92

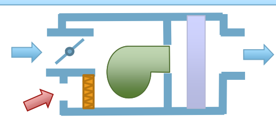
MECHANICAL SYSTEMS
TERMINAL UNITS

Standard VAV box with reheat coil



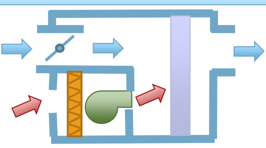
Variable airflow

Series fan-powered VAV box with reheat coil



Constant airflow, fan always on

Parallel fan-powered VAV box



Variable airflow, fan on when reheat needed

Important Inputs

- Min. airflow fraction
  - Fixed or scheduled
- Control type
  - Direct acting only vs. Direct + reverse
- Terminal unit fan power

Reference:
Advanced VAV Design Guideline, Appendix 8, How to Model Different VAV Zone Controls in DOE-2.2
https://energydesignresources.com/

93

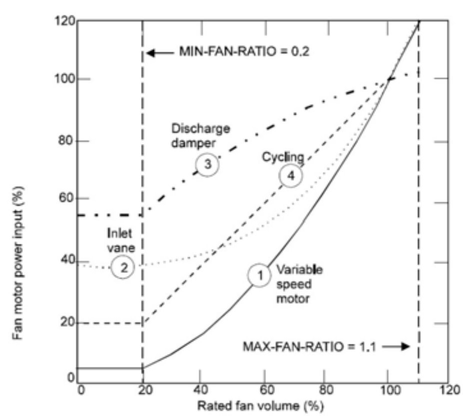
93

MECHANICAL SYSTEMS
FAN CURVES

- Fan power = $f_{(airflow)}$ for VAV systems
- "Canned" and custom curves

Fan Curve Issues:

- "Canned" VSD fan curves are often optimistic
- If creating a custom curve, plot it and check it, set appropriate minimum value
- ANSI/ASHRAE/IES Standard 90.1 Appendix G specifies the curve to be used for VAV systems



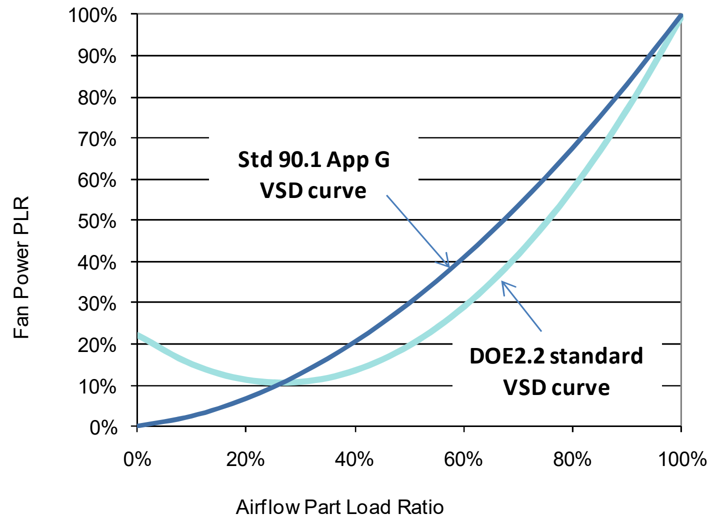
Source: *DOE2.2 Volume 2 Dictionary.*

94

94

Mechanical Systems

Fan Curves—ANSI/ASHRAE/IES Standard 90.1 Appendix G Curve



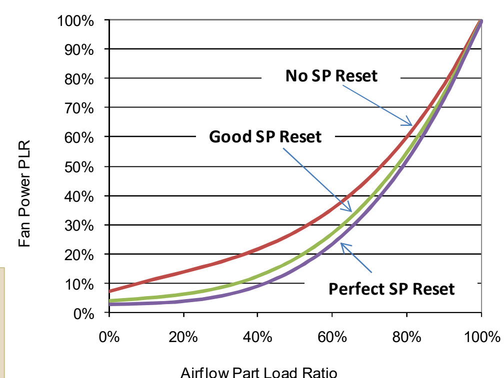
95

95

Mechanical Systems

Fan Curves—Static Pressure Reset Control

- Static Pressure Reset
  - Continuously adjust pressure to lowest setting that provides adequate zone airflow
  - Simulate using fan curve



Reference:
Advanced VAV Design Guideline, Appendix 5

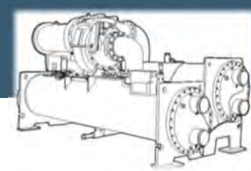
Includes fan curve coefficients

https://energydesignresources.com/

96

96

Mechanical Systems
Chiller Curves



- Chiller performance model
  - Capacity = $f_{(temp)}$
  - Efficiency = $f_{(temp,\ part\text{-}load\ ratio)}$
- Represent chiller types
  - Centrifugal, rotary, reciprocating…
  - Variable speed, multi-compressor…
- Default vs. custom coefficients

$$
\begin{aligned}
Elec_{in} &= Cap_{FullLoad} \\
&\times EIR_{FullLoad} \\
&\times CAPf(T) \\
&\times EIRf(T) \\
&\times EIRf(PLR, dT)
\end{aligned}
$$

1.0 at full load and rated temp.

References
Cool Tools Chilled Water Design Guide

Chiller Bid and Performance Tool (Excel spreadsheet)

https://energydesignresources.com/

Issues
Part-load efficiency curve typically includes PLR:

$$EIRf(PLR, dT) = PLR \times \frac{EIR_{Part\,Load}}{EIR_{Full\,Load}}$$

(EIR = energy input ratio = 1/COP)

97

97

Mechanical Systems
Boilers

Modeling issues

1. Efficiency rating conditions
2. Off-design efficiency calculation
   - Part load
   - Varying hot-water entering/leaving temperature

98

98

Mechanical Systems
Boilers

1. Efficiency rating conditions

Boiler Type	Entering Water Temperature	Typical Efficiency Range
Non-condensing	160°F	80%–85%
Condensing	**80°F**	92%–98%

Check what your program expects

99

99

Mechanical Systems
Boilers

2. Off-design efficiency calculation methods
   - Function of load
   - Function of load and temperature
     - Boiler entering temperature
     - Boiler leaving temperature

Some programs provide multiple options

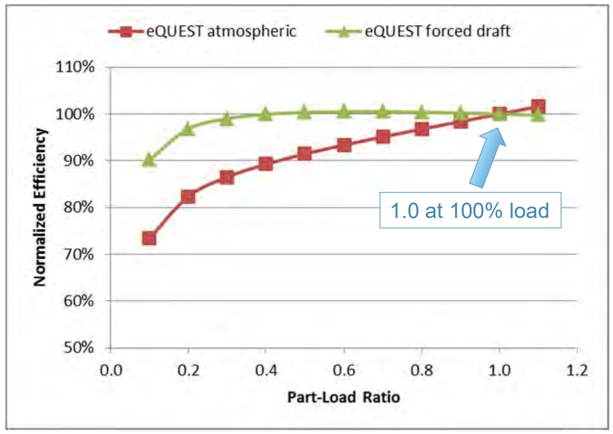
100

100

MECHANICAL SYSTEMS
BOILERS

Boiler Curve Example #1

eQUEST defaults for ***non-condensing*** boilers



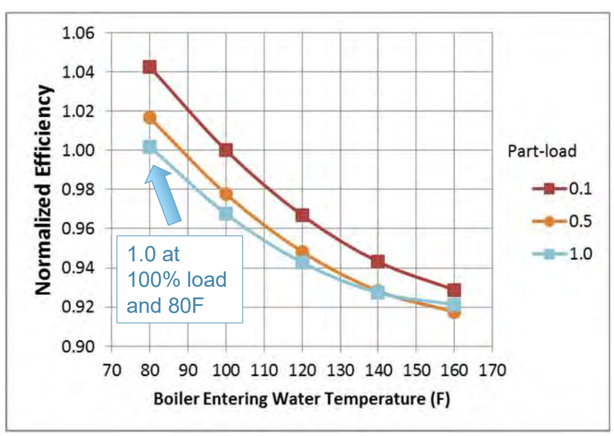
101

101

MECHANICAL SYSTEMS
BOILERS

Boiler Curve Example #2

eQUEST defaults for ***condensing*** boilers



102

102

Mechanical Systems
Outside Air Requirements

- Significant energy impact
- Input methods
  - cfm/person, cfm/ft² or cfm
- Information sources
  - Design documents
  - ASHRAE Standard 62.1
  - Healthcare: ANSI/ASHRAE/ASHE Standard 170

103

103

Mechanical Systems
ASHRAE Std 62.1: Ventilation Rate Procedure

$$V_{bz} = (R_p \times P_z) + (R_a \times A_z)$$

V_{bz} = cfm of outdoor air required in breathing zones
R_p = outdoor cfm/person from ANSI/ASHRAE Standard 62.1 Table 6-1
P_z = largest number of people expected to occupy the zone during typical usage
R_a = outdoor cfm/ft² from Table 6-1
A_z = occupied ft² floor area of zone

- Used to determine design OA for energy models
- Calculating OA for multizone VAVs: huge energy implications
- At part load/occupancy, the minimum OA intake flow ≥ $R_a * A_z$

104

104

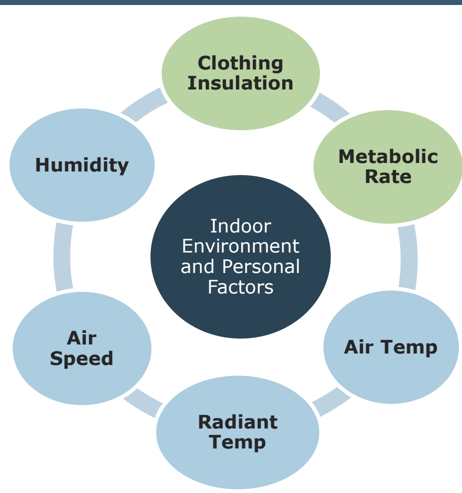
Mechanical Systems
Demand Control Ventilation (DCV)

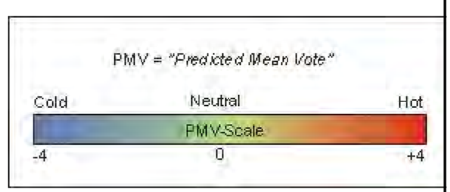
- **Ventilation airflow resets** based on occupancy
  - Using CO_2 sensors, timers, occupancy sensors, or schedules
- **Higher energy savings** for buildings with large occupancy swings
  - Movie theaters
  - Conference rooms

105

105

Mechanical Systems
ANSI/ASHRAE Standard 55





Possible to assess within energy models that accurately simulate radiative heat transfer

106

106

Mechanical Systems
Specific Energy Modeling Notes

Common Energy Modeling Mistakes

- EER: breakout fan power and compressor power
- Part-load curves
- Altitude effects
- Auto-sizing
- Rated vs. design conditions

107

107

Utility Rates
Types of Charges and Rate Structures

Charge	Description	Example
Monthly Charge	Fixed fee for providing energy services	$35 per month
Energy Charge	Unit cost for total quantity of energy consumed	$0.06 per kWh
Demand Charge	Fee for highest or peak amount of energy used	$7.53 per kW
Power Factor Charge	Penalty for lower than optimum power factor	$0.40 per KVAR
Block Charge	Unit cost based on different energy use/demand blocks	
Time-of-Use Rate	Prices change during peak and off-peak times	

0–350 kWh	$0.06 per kWh
350–700 kWh	$0.04 per kWh
700+ kWh	$0.02 per kWh

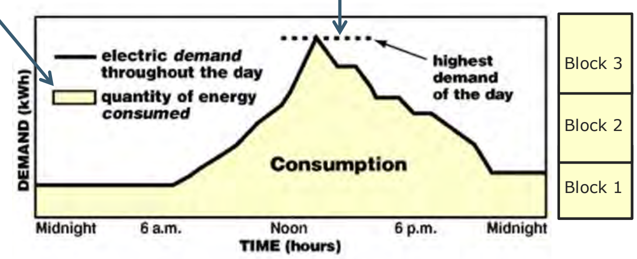
Peak Time	$0.24 per kWh
Off-Peak Time	$0.06 per kWh

108

108

Utility Rates
Types of Charges and Rate Structures

Energy Charge | **Demand Charge** | **Block Charge**



Time-of-Use Rate

Summer (June–Sept)	Peak	1pm–6pm (M–F)	$0.16 per kWh
	Mid	11am–1 pm and 6pm–8 pm (M-F)	$0.06 per kWh
	Off-Peak	All other hours, and holidays	$0.02 per kWh
Winter (Oct–May)	All Days	All Hours	$0.03 per kWh

109

109

Utility Rates
Energy Modeling Implications

ANSI/ASHRAE/IES Standard 90.1 Appendix G Applications

- Same energy rates must be used for proposed and baseline
- Use either actual utility rates or EIA state averages, except:
  - Actual utility rates must be used for purchased hot water, steam, and chilled water
- On-site renewables and site-recovered energy are ***not*** included with purchased energy

110

110

Utility Rates
Energy Modeling Implications

Case Study: Adam Joseph Lewis Center at Oberlin College

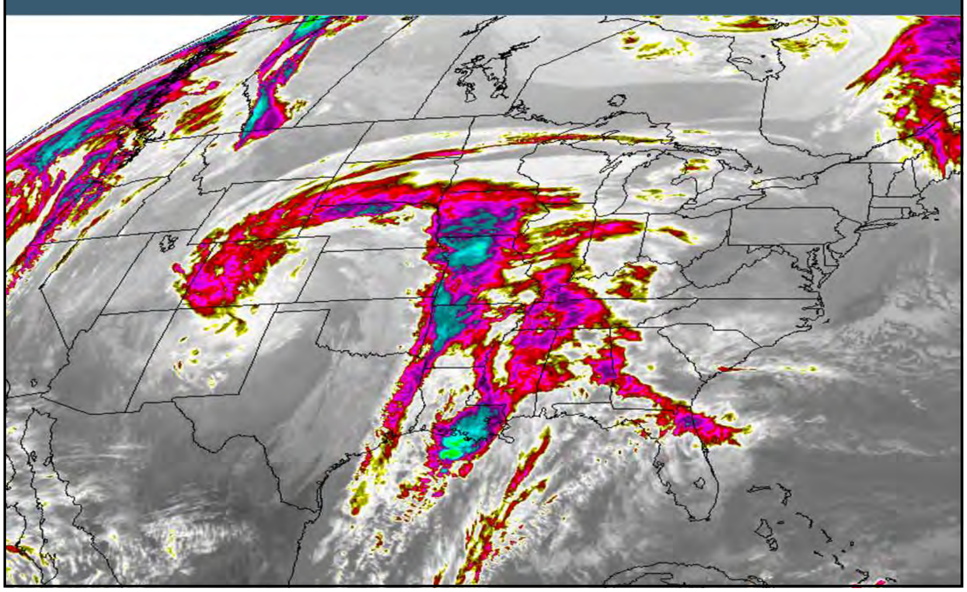
- Project Goals
  - Set an example for energy efficiency and sustainable design
  - Net-zero energy building
- The project achieved significant reductions in total energy use
- However, no efforts were made to lower the peak demand, which resulted in a much lower energy cost savings

79% Total Energy Savings → **35%** Energy Cost Savings → Utility Rates Can Be Crucial!

111

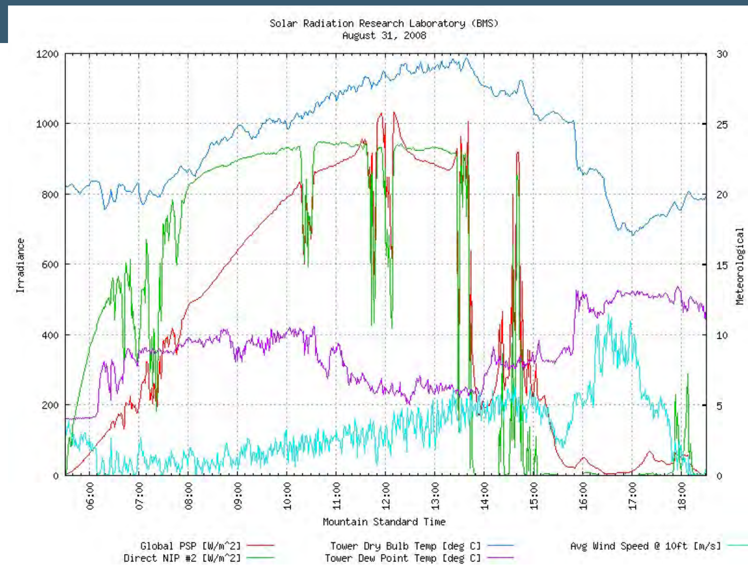
111

Weather Data



112

WEATHER IS VARIABLE!



One-minute temperature, wind, and solar radiation observations for 31 August 2008 at National Renewable Energy Laboratory, Golden, Colorado.

113

113

WEATHER ≠ CLIMATE

- Weather:

  The state of the atmosphere with respect to wind, temperature, cloudiness, moisture, pressure, etc.

- Climate:

  The composite or generally prevailing weather conditions of a region, as temperature, air pressure, humidity, precipitation, sunshine, cloudiness, and winds, throughout the year, averaged over a series of years.

Source: www.dictionary.com.

114

114

BUILDING USES FOR CLIMATIC DATA

Building design and performance modeling require weather data to represent climatic conditions of the building location. This may include:

- Building design conditions for peak heating and cooling calculations (temperature, humidity, solar, and wind conditions for design calculations)
- Building performance simulation
  - Typical hourly weather data
  - Actual hourly weather data for calibration to utility bills
  - Future hourly weather data

115

115

DESIGN CONDITIONS

- Used for design sizing of heating, ventilating, air-conditioning, and dehumidification equipment, as well as for other energy-related processes in residential, agricultural, commercial, and industrial applications.
- Includes as a minimum dry-bulb, wet-bulb, and dew-point temperature, and wind speed with direction at various frequencies of occurrence.
- Typical annual percentiles* used: 99.6% heating dry-bulb temperature and 1% cooling dry-bulb temperature with coincident wet bulb.
- Depending on the application, use other percentiles (99, 0.4, 2, 5) or variables (wind speed, dewpoint, wet bulb, etc.). Monthly cooling percentiles also available (0.4, 2, 5, 10).

*Percentiles represent number of hours that the design condition can be expected to be exceeded in a typical year, based on 15-30 years of data. 99.6% ≈ 35 annual hours [8760 – (99.6% * 8760)]. 1% ≈ 88 annual hours [8760 – (1% * 8760)].

116

116

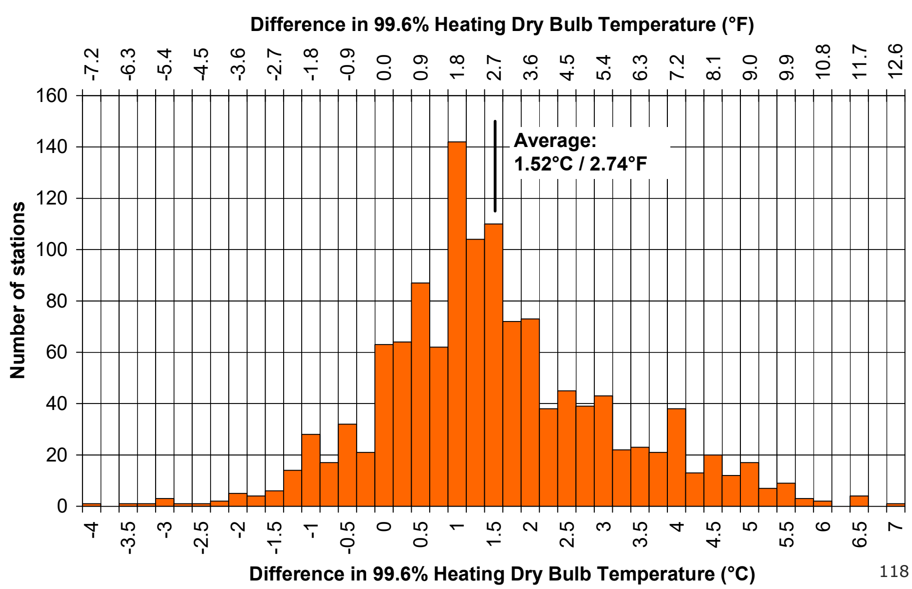
Design Conditions *(cont.)*

- Best source for design conditions: Chapter 14 Climatic Design Information, 2017 *ASHRAE Handbook—Fundamentals*
  - 8118 locations through the world
  - >1900 locations in the U.S.
- Climate changing! Comparing design conditions for 1274 locations between 1977–1986 and 1997–2006:
  - 99.6% annual dry-bulb temperature increased 1.52°C (2.75°F)
  - 0.4% annual dry-bulb increased 0.79°C
  - Annual dew point increased by 0.55°C
  - HDD base 18.3°C decreased 237°C-days
  - CDD base 10°C increased 136°C-days

117

117

$$\Delta DB^{99.6} = DB^{99.6}_{1997-2006} - DB^{99.6}_{1977-1986}$$

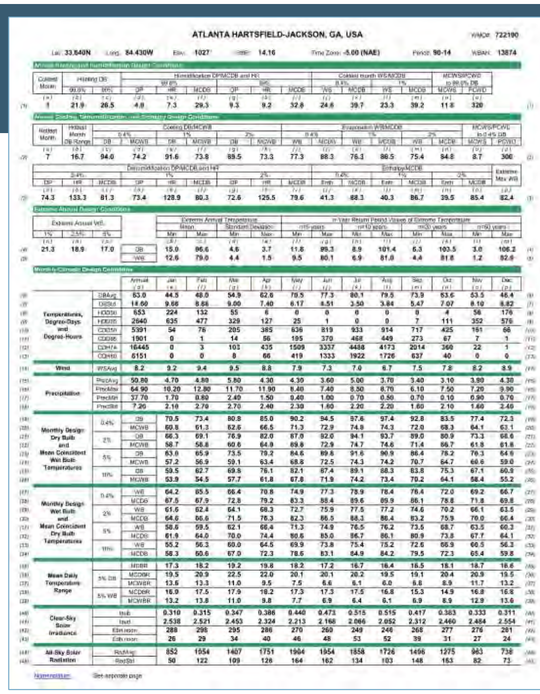


118

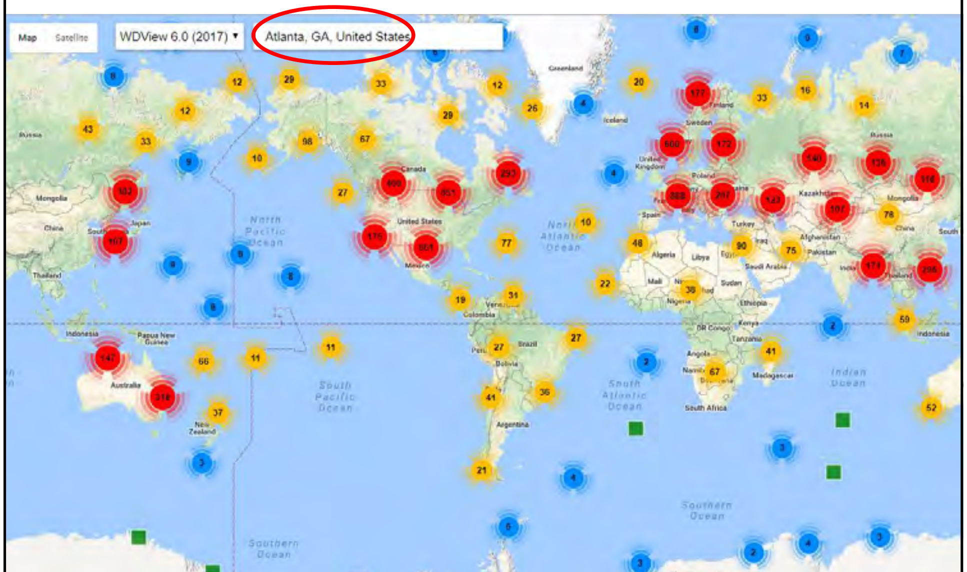
118

Climatic Design Conditions

- Summary statistical data calculated from 20–30 years of weather conditions
- Primary data source is the National Center for Environmental Information, which houses WMO data repository for the entire world
  - Integrated Surface Database 1982–2015
  - Stations in all countries (including Canada and U.S.)
- Stations in Canada: Environment Canada Data Set 1982–2014

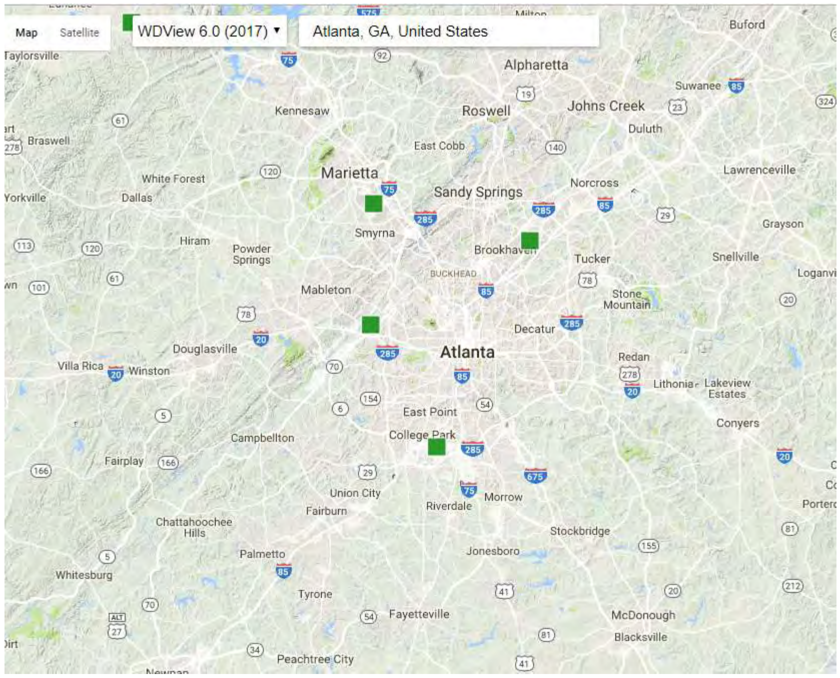


119



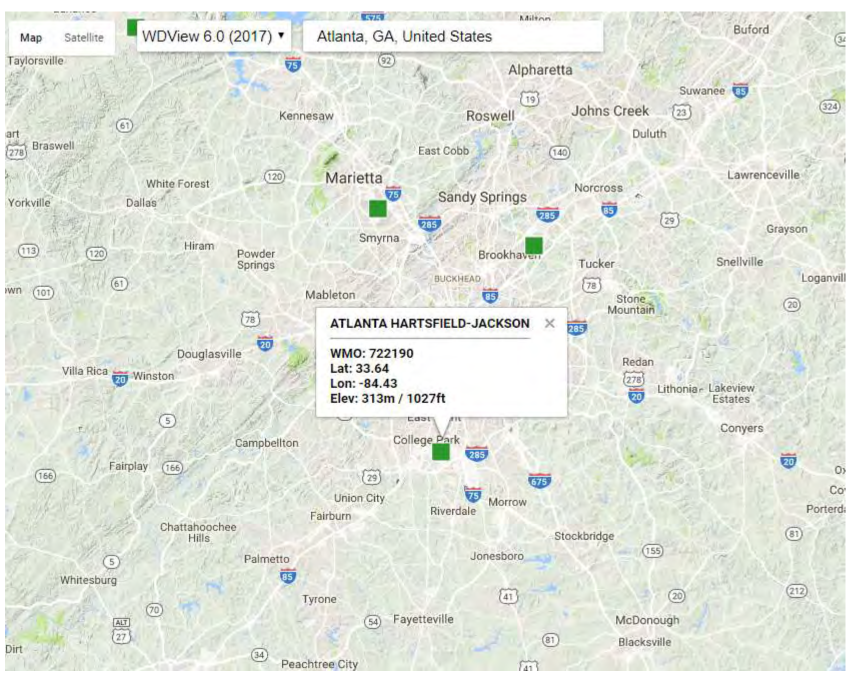
120

120



121

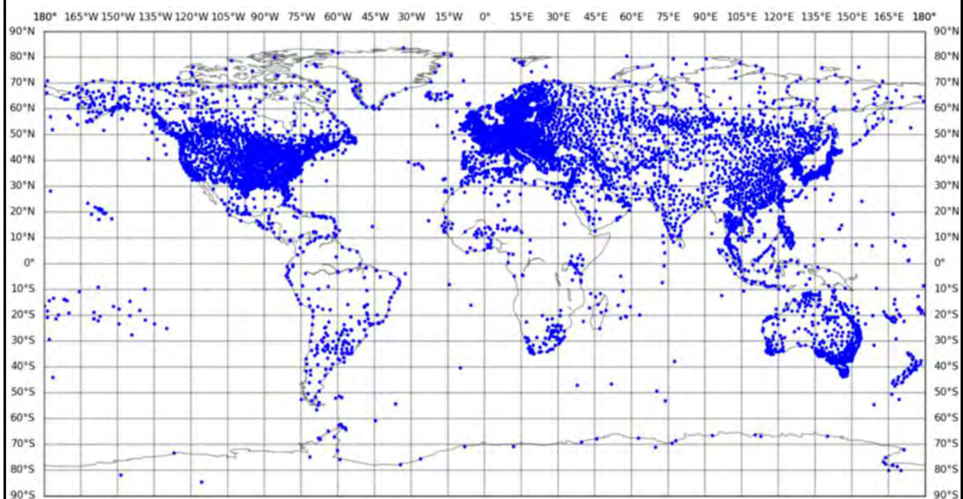
121



122

122

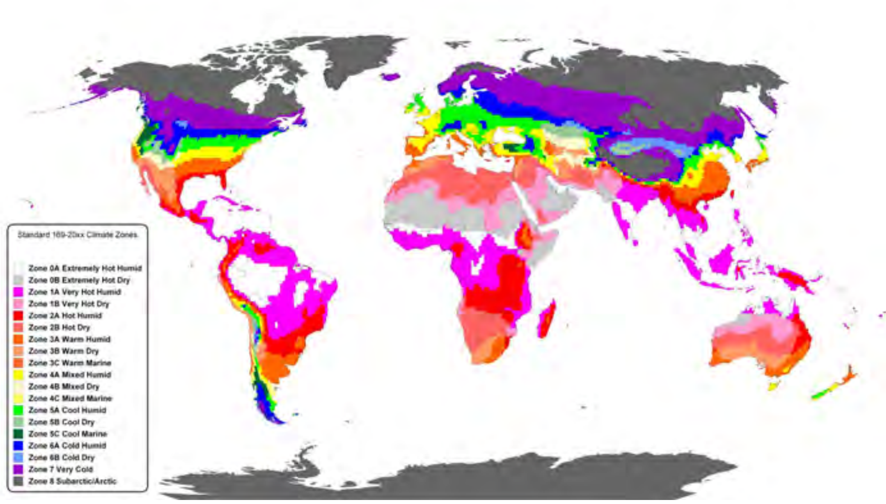
2017 *ASHRAE Handbook—Fundamentals* Weather Locations



123

123

ANSI ASHRAE Standard 169-2013 Climate Zone Maps



124

124

Typical Meteorological Year (TMY) Hourly Data Sets

- Best for:
  - Comparison of alternatives during design
  - Compliance with building standards/codes and green building rating system points
- Limitations:
  - No explicit effort to represent extreme conditions
  - Files not intended to represent design conditions (can be mild)

125

125

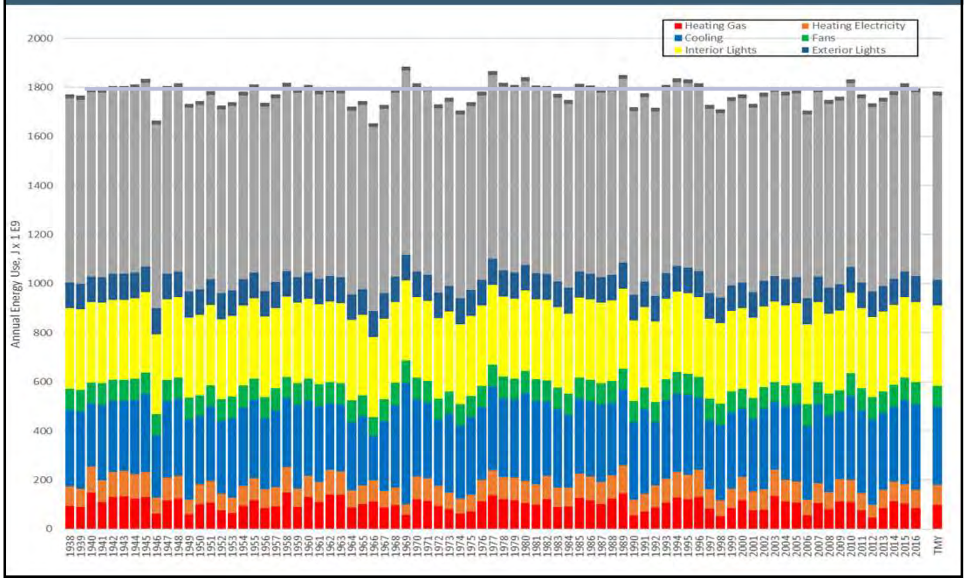
Actual Weather Data

- Actual hourly weather data required to calibrate to utility bills in existing buildings and subsequent evaluation of retrofit alternatives.
- Many sources—some providing near-real-time data and/or prediction:
  - NCEI/WMO Data Center
  - Weather Bank
  - Weather Source
  - Weather Underground
  - White Box Technologies
- Biggest issue: How complete are the data? Does it include temperature, humidity, wind, solar radiation—the variables that my program needs?

126

126

DOES IT MATTER? TMY VS. ACTUAL WEATHER AND ENERGY USE



127

QUESTIONS?

128

128

LUNCH

129

129

BEST PRACTICES

BUILDING SIMULATION MODELING

130

130

Overview

Modeling best practices are methods incorporated into everyday practice that support:

- Consistency in methods
- Reduction in input errors
- Generation of reasonable performance values

131

131

Destination

The art in energy modeling is to create a model that is as simple as possible while still providing reasonably accurate results. This requires judgment and experience.

132

132

SETTING EXPECTATIONS
ENERGY MODELING EXPERTISE

Experience Level	Skills/Capabilities
Trainee	1. Collect modeling input data 2. Perform input data calculations 3. Develop building geometry and zoning
Technician	1. Create building input file using software wizard 2. Build minimally code-compliant building model
Core Analyst	1. Review results for reasonableness 2. Complete calibrations 3. Perform complex modeling 4. Complete detailed QC 5. Complete system level calibration
Master	1. Understand the algorithms 2. Use supplemental analysis 3. Balance modeling level of detail against accuracy of results needed to support decision making

133

REAL-WORLD CHALLENGES

Challenges	Strategies
Model preparation time limits	•Education of industry •Robust scope of work •Modeling statement of requirements
What are the major features of a building that should be modeled accurately?	•Experience •Sensitivity studies •Published case studies
Minimal quality systems to help ensure relevance of results/recommendations	•Available metrics •Systems for making comparisons •Understand how the system is operating
Lack of quality assurance tools in the simulation	•Reduce input errors •Model represents design •Library of similar project results

Source: Donn, Michael. 1999. Quality assurance—Simulation and the real world. 1999 IBPSA Proceedings. See: www.ibpsa.org/proceedings/BS1999/BS99_P-05.pdf.

134

134

General Principles

1. Be knowledgeable of the inner workings of the simulation tool
2. Prioritize efforts
3. Understand the technologies being modeled
4. Follow modeling procedures that facilitate quality assurance

135

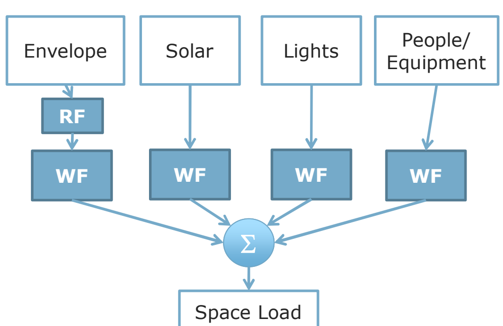
135

General Principles

Knowledge of Inner Workings—Load Calculations

DOE-2

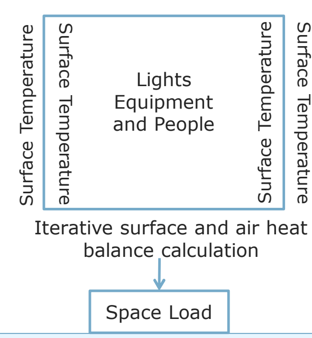
Response factor and weighting factor method



Benefits
- Proven accurate for most cases
- Fast calculations

EnergyPlus

Heat gain calculation method



Benefits
- Calculates surface temperatures, allowing comfort calculations and control
- Radiant heating/cooling model

136

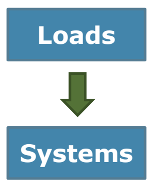
General Principles
Knowledge of Inner Workings—Annual Energy Calculations

DOE-2.2

Sequential Calculations

– Full-year loads, then systems

- Load calc at constant temperature



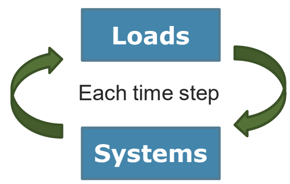
Benefits
- Proven accurate for most cases
- Fast calculations

EnergyPlus

Simultaneous Calculations

– Load and systems calculated for each time step

- Temperature can vary each hour per thermostat setpoint



Benefit
- Output reports show breakdown of loads by source

General Principles
Knowledge of Inner Workings

- Perform test runs
- Check standard reports
- Create and compare hourly output data
- Review documentation

Download documentation from DOE-2.2 page
- Use Edit-Search of DOE-2.2 Manuals
- http://doe2.com/download/DOE-21E/DOE-2EngineersManualVersion2.1A.pdf

Documentation included with engine
- InputOutputReference.pdf
- EngineeringReference.pdf

GENERAL PRINCIPLES

1. Be knowledgeable of the inner workings of the simulation tool
2. Prioritize efforts
3. Understand the technologies being modeled
4. Follow modeling procedures that facilitate quality assurance

139

139

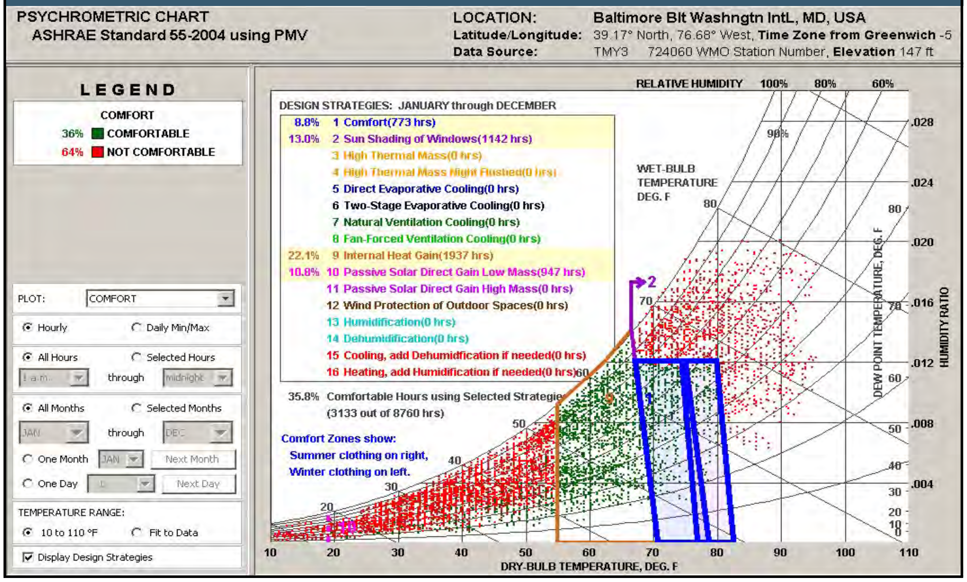
GENERAL PRINCIPLES
PRIORITIZING EFFORTS

Focus on most important building details	•Climate impact •Building size, massing, process loads, ventilation
Focus on inputs that will affect the evaluation	•Characterize in detail components that change between runs
Minimize number of spaces/zones	•Aggregate HVAC zones •Zones may be discontinuous
Minimize interior walls	•Relevant for daylighting, thermal mass, heat transfer between zones of different temperatures
Properly characterize HVAC and controls	•Supply Air, Chilled Water, Hot Water resets •OA flow control—occupied/unoccupied •Part-load curves

140

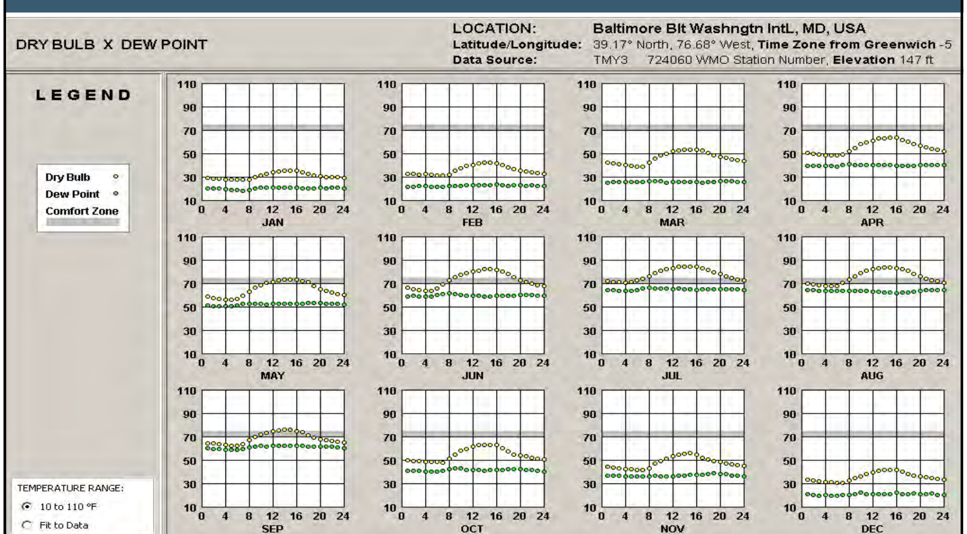
140

GENERAL PRINCIPLES
PRIORITIZING EFFORTS—CLIMATE DATA



141

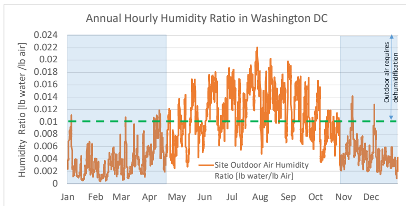
GENERAL PRINCIPLES
PRIORITIZING EFFORTS—CLIMATE DATA



142

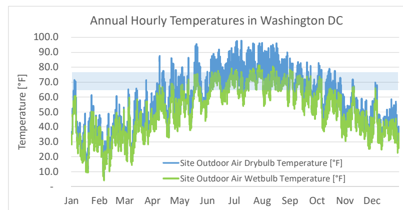
General Principles
Prioritizing Efforts—Climate Data Example

When do we need to dehumidify the air?



	Number of Hours	Number of hours dehumidification	% of time
WINTER (January - April and November - December)			
Total Hours	4343	125	3%
Occupied Hours	2353	87	4%
SUMMER (May – October)			
Total Hours	4417	2458	56%
Occupied Hours	2382	1327	56%

Number of hours during the year the outdoor air is between 65°F and 78°F	1939	22%
Number of hours during the year the outdoor air is between 68°F and 75°F	1053	12%
Number of hours during the year the outdoor air is between 65°F and 78°F and humidity < 0.0105 lb/lb	675	8%
Number of hours during the year the outdoor air is between 68°F and 75°F and humidity < 0.0105 lb/lb	369	4%



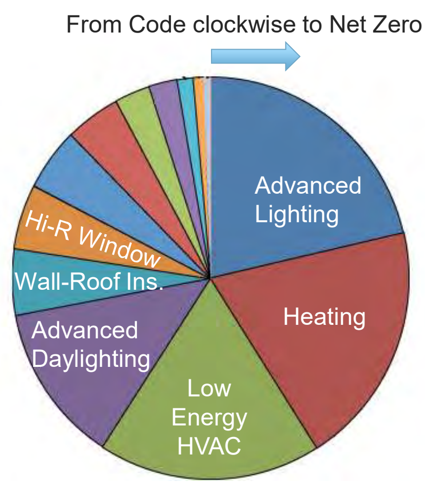
Can we use natural ventilation?

Washington, D.C. is a heating-dominated climate, **2223 heating** degree days in comparison with **847 cooling** degree days (base 65°F). **Humidity** control is only needed for **25% of the year** (Source: 2013 *ASHRAE Handbook—Fundamentals*). 143

143

General Principles: Prioritizing Efforts — Sequence for Integrated Design Approach

1. Improve Envelope
2. Reduce Loads
3. Select the appropriate mechanical system and improve on its efficiency
4. Use renewable technology



144

144

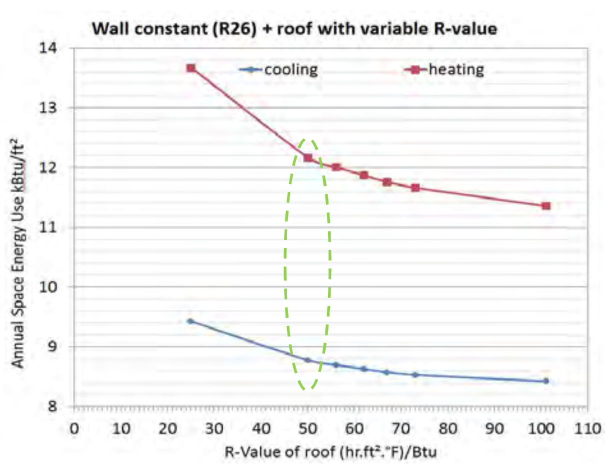
STEP 1: IMPROVE ENVELOPE

- Reduce External Loads
  - Exceed ASHRAE/ASNI/IES Standard 90.1-2016 Envelope Requirements
  - Building form and orientation
  - External shading—static and dynamic
  - Internal shading—static and dynamic
  - High-performance windows
  - High-performance roof and wall insulation

145

145

STEP 1: IMPROVE ENVELOPE—EXAMPLE



	total kBtu/ft²
Wall R26 Roof R25	23.108
Wall R26 Roof R50	21.0
Wall R26 Roof R56	20.7
Wall R26 Roof R62	20.5
Wall R26 Roof R67	20.3
Wall R26 Roof R73	20.2
Wall R26 Roof R101	19.8

146

146

STEP 2: REDUCE LOADS

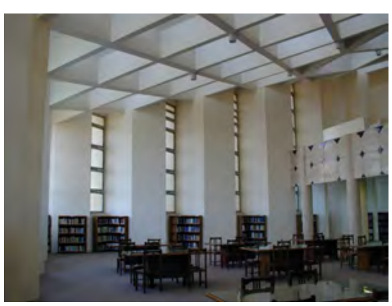
- Reduce Internal Loads
  - Lighting Loads:
    - Exceed lighting requirements for ANSI/ ASHRAE/IES Standard 90.1
    - Advanced lighting systems
    - Advanced lighting controls
    - Use daylighting
  - Plug Loads
    - Reduce plug loads

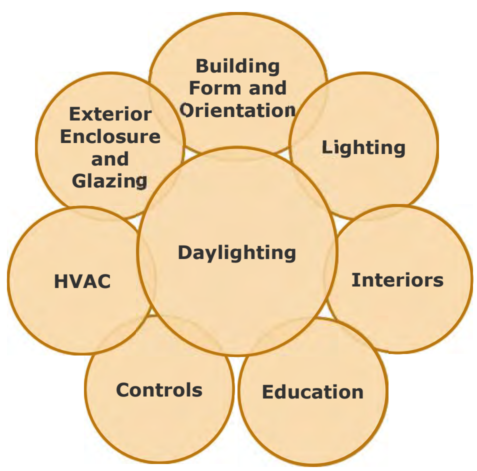
147

147

STEP 2: REDUCE LOADS—DAYLIGHTING

Daylighting cuts across systems to reduce loads

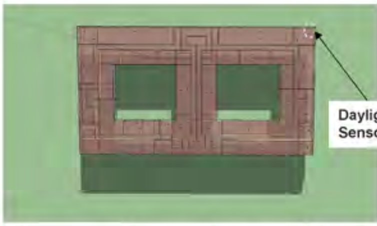




148

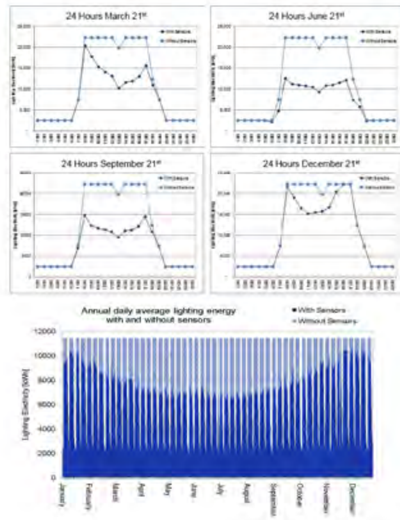
148

STEP 2: REDUCE LOADS—DAYLIGHTING EXAMPLE



	No Sensors [kWh]	With Sensors [kWh]	Energy Saved
Heating	1,158,772	1,143,352	1%
Cooling	553,065	527,046	5%
Interior Lighting	900,574	811,150	10%
Exterior Lighting	51,226	51,226	-
Interior Equipment	1,404,092	1,404,092	-
Fan	1,566,722	1,566,722	-
Pumps	14,134	12,464	12%
Water Systems	162,578	162,578	-

Interior Lighting	With Sensors	Without Sensors
one floor	55,618 kWh	78,071 kWh
% decrease	**29%**	
whole building	811,150 kWh	900,574 kWh
% decrease	**10%**	



149

149

STEP 3: SELECT APPROPRIATE MECHANICAL EQUIPMENT AND CONTROLS

- Exceed ASHRAE/ASNI/IES Standard 90.1 mechanical requirements
- Split outdoor air conditioning from space conditioning
- Use natural ventilation
- For dehumidification, use heat exchangers
- High-performance chillers and boilers
- Improve efficiency of components
- Understand and improve controls

150

150

General Principles
Prioritizing Efforts—Resources

- Advanced Energy Design Guides
  - Small to Medium Office Buildings
  - K-12 School Buildings
  - Medium to Big Box Retail Buildings
  - Large Hospitals
  - Grocery Stores
- All the AEDGs available as ***free*** PDF downloads from: www.ashrae.org/aedg

151

151

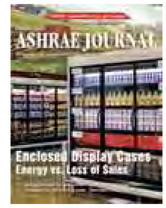
General Principles

1. Be knowledgeable of the inner workings of the simulation tool
2. Prioritize efforts
3. Understand the technologies being modeled
4. Follow modeling procedures that facilitate quality assurance

152

152

General Principles
Knowledge of Technologies



- Colleagues
- Manufacturers/distributors
- Technical journals and conference proceedings
- DOE Building Technologies Program website
  - http://energy.gov/eere/buildings/building-technologies-office
  - http://energy.gov/eere/buildings/resource-center
- Energy Design Resources website
  - Design Guidelines: HVAC Simulation Guidelines
  - Design Guidelines: Advanced Variable Air Volume (VAV) Systems
  - Design Guidelines: Cool Tools Chilled Water Plant
- List Serve: www.onebuilding.org or www.Unmethours.com
- IBPSA-USA www.ibpsa.us:
  - BEMBook Wiki: www.ibpsa.us/bembook-wiki
  - Methods & Processes Library: www.ibpsa.us/bem-library

153

153

General Principles

1. Be knowledgeable of the inner workings of the simulation tool
2. Prioritize efforts
3. Understand the technologies being modeled
4. Follow modeling procedures that facilitate quality assurance

154

154

General Principles
Facilitate Quality Assurance

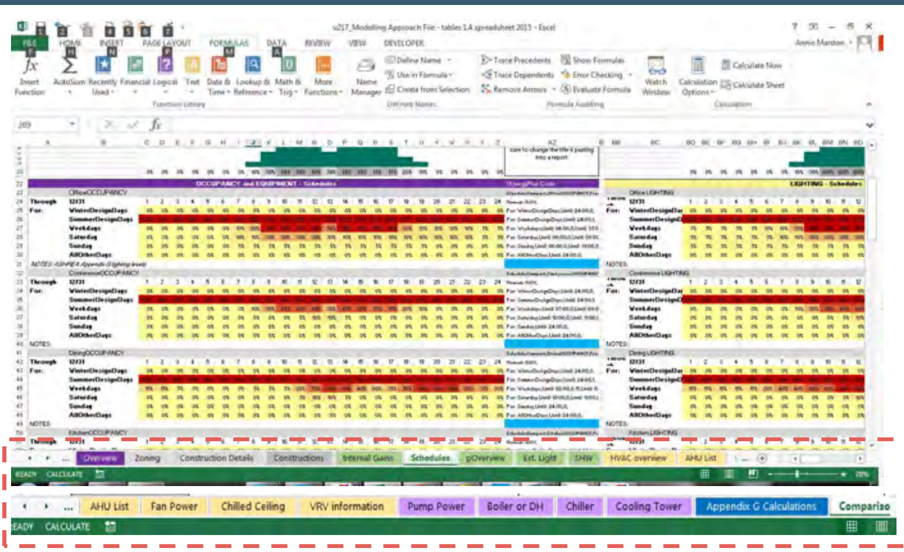
Checking model input:

- Document assumptions and input values
- Keep a log of model runs
- Use pre-processing tools/spreadsheets to convert component descriptions into modeling input values
- Use a “template” approach, whenever possible
- Import input file segments for complex components modeled often in projects
- Make design changes incrementally in the model

155

155

General Principles
Facilitate Quality Assurance—Example



156

General Principles

Facilitate Quality Assurance

Checking model output:

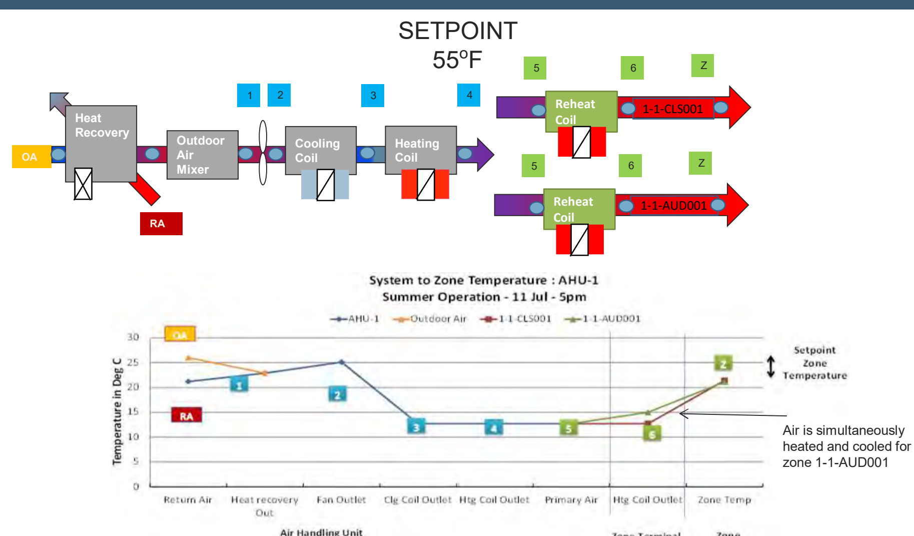
- Develop a review check list
- Extract data for evaluating reasonableness of results
  - Key output values
  - Metrics, back-of-the-envelope calculations, hourly data
- Extract results from output files and report side-by-side
  - Evaluate against rules-of-thumb metrics
  - Evaluate against performance of actual buildings
  - Evaluate against each run—is the change as expected?

157

157

General Principles

Facilitate Quality Assurance—Example



158

158

General Principles

Facilitate Quality Assurance—Partial Checklist

Input	Output
ASHRAE climate zone	Zone and plant loads met
Weather data	Building EUI
Effective underground R-value	Building plugs—W/ft^2
Overall window U-factor	Building lighting—W/ft^2
Plug loads	Building occupant density
System type, plant type	Cooling—design ft^2/ton, kW/ton, loading
Baseline fan per PRM	Cooling loop—gpm/ton
VAV—min box turn down, central heating coil	Heating—Btu/ft^2, average efficiency, loading
Outside air—fixed, % supply or cfm/person, DCV; off at night	Supply air—design CFM/ft^2
Controls—SAT reset, humidity, loop temp resets	Ventilation air—% design flow, CFM/ft^2

159

159

General Principles

Facilitate Quality Assurance—Key Metrics*

Metric	Units	Low	Medium	High
Building EUI	kBtu/ft^2 yr	25	60	95
Cooling design	ft^2/ton	600	400	250
Cooling design	kW/ton	0.6	0.9	1.2
Cooling loop	gpm/ton	2.5	2.5	2.5
Heating design	Btu/ft^2	15	20	30
Fans	W/cfm	0.8	1.00	1.2
Supply air	cfm/ft^2	0.6	1.00	1.4
Ventilation air	cfm/ft^2	0.1	0.2	0.3
Lighting	W/ft^2	0.7	1.0	1.8
Plugs	W/ft^2	0.5	1.0	1.5

*Typical of office buildings:
low–very energy efficient, medium–code, high–existing buildings.

160

160

General Principles
Facilitate Quality Assurance

Reconciliation

- Look for careless errors in input
- Examine simulation output for explanation
- Make sure you understand simulation algorithms
- Make sure the model captures actual process and systems
- Increase model detail if needed
- Tweak uncertain inputs within a reasonable range of values
- Peer review

161

161

Modeling Best Practices
Presenting Results

Documenting Assumptions, EEMs, Packages

Activity	Baseline & Proposed Design				Baseline		Proposed Design	
	Space Areas		Outside Ventilation		LPD	EPD	LPD	EPD
	Area	%	(ft^2/PER)	(OA - CFM/PER)	(W/ft^2)	(W/ft^2)	(W/ft^2)	(W/ft^2)
Lobby	6,642	6	40	11	1.6	0.25	1.0	0.25
Retail	1,902	2	67	16	1.6	0.25	1.0	0.25
Corridor/Storage	38,318	33	1000	0	1.6	0.00	1.0	0.00
Exhibit*	16,321	14	25	9	8.0	4.00	4.0	4.00
Classroom	14,679	13	28	12	1.6	0.50	1.0	0.50
Dining	5,707	5	10	9	1.6	0.10	1.0	0.10
Computer Lab	13,600	12	40	15	1.6	5.00	1.0	5.00
Office	13,315	12	200	17	1.6	0.75	1.0	0.75
Restrooms	5,072	4	150	50	1.6	0.10	1.0	0.10
TOTAL	115,556	100						

162

162

Modeling Best Practices

Presenting Results

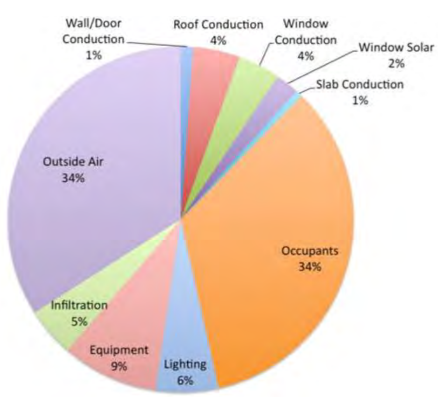
Documenting Assumptions, EEMs, Packages

ECM	Description	90.1-2004	As-Design	30% Below	Description
Envelope Strategies					
BASE	Envelope and Windows	X			Walls: 4" batts in 4" studs 16" o.c. + R-3.8 c.i. (effective R-7 clear wall + R-3.8) Roof: R-15 c.i. above deck Glazing: Thermally broken alum. frames, clear uninsulated (GHs), U-0.57 Btu/h·ft^2·°F and SHGC-0.39 (all other)
1	Roof Insulation		X	X	Roof: R-30 batts between steel joists
2	Exterior Wall Insulation		X	X	Walls: 6" batts in 8" studs 16" o.c. + R-3.8 c.i.
3	Window Performance		X	X	Glazing: Thermally broken alum. frames, Low-e IGU w/gray exterior lite, U-0.4 Btu/h·ft^2·°F and SHGC-0.32 (all other)
Lighting					
BASE	ASHRAE 2004 LPDs	X			Maximum allowable LPDs per ASHRAE 90.1-2004, corresponds with LEED Baseline lighting
AD	As Designed LPDs		X		LPDs as designed
4	15% Lower than ASHRAE 90.1-2004			X	LPDs are 15% lower than those allowable per ASHRAE 90.1-2004
Heating, Cooling, and Ventilation					
BASE	Baseline HVAC Systems	X			Packaged VAV with hot Water Reheat
AD	As-Designed HVAC Systems		X		VAV with Hot Water Reheat + DirectEvaporative
5	Indirect/Direct Evaporative Cooling			X	Add blow-through Indirect/Direct Evaporative cooling section to AHU
6	Condensing Boiler			X	Hot Water Boilers (Forced draft, sealed combustion) 93% (Std Rating @ 80F HWRT). Terminal boxes set to 10% and baseboard used for perimeter heating
7	High-Efficiency Fans			X	Premium efficiency motors on fans. Evaporative section in AHU may increase static pressure and required fan BHP.

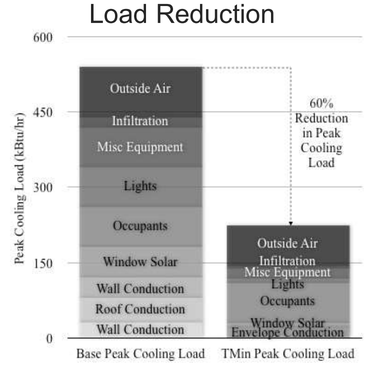
163

Modeling Best Practices

Presenting Results



Potential Cooling Load Reduction



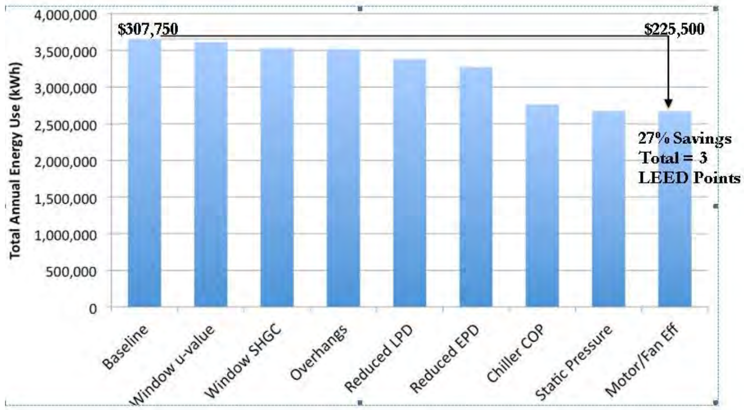
Evaluate heating and cooling load breakdowns to identify impactful load reduction measures. This is how you can downsize HVAC systems!

** Use “Design Day” Feature

164

164

Modeling Best Practices
Presenting Results



Show a path to a desired goal—communicate to the owner/architect early on that this is important!

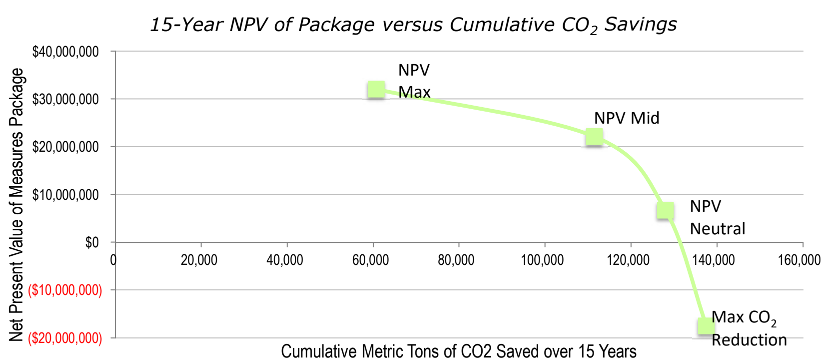
165

165

Modeling Best Practices
Presenting Results

- Include all cash flows
- Identify "business as usual" baseline

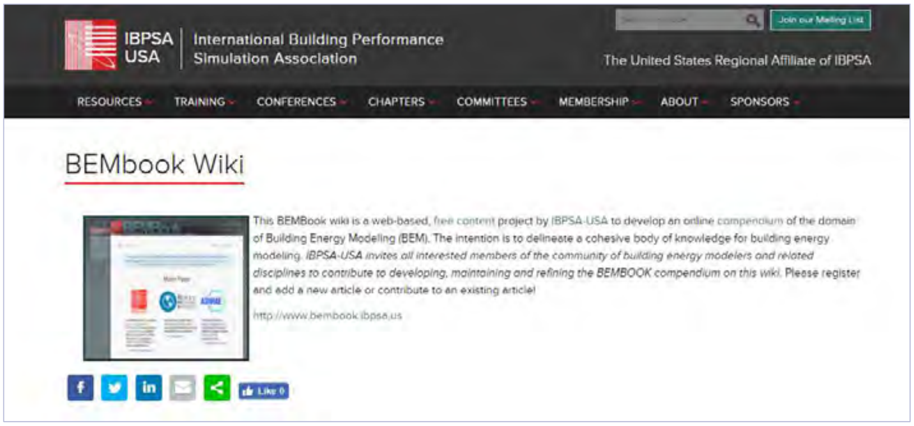
- Packages of measures
  - Downsize HVAC equipment
- Identify packages that meet various goals



166

166

Modeling Best Practices
Resources



www.ibpsa.us/bembook-wiki

167

167

Modeling Best Practices
Resources

Free web-based tools for simulation, Cx, equipment specifications, etc.

https://energydesignresources.com/resources/software-tools.aspx

Shared QC checklists, pre- and post-processing spreadsheet-based tools

www.rmi.org/tools_and_resources#building_energy_software

Info and links for more than 450 tools

www.buildingenergysoftwaretools.com

168

168

ANSI/ASHRAE/IES
Standard 90.1
Performance Rating Method (PRM)

PRM Phase 1: 90.1-2004,
90.1-2007,
90.1-2010,
90.1-2013

PRM Phase 2: 90.1-2016 +

169

169

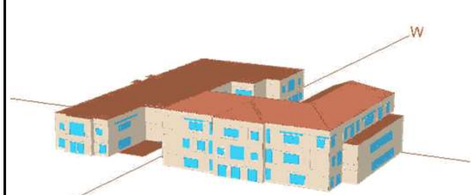
Performance Rating Method (PRM)
Appendix G Overview

Purpose

Intended to show relative performance compared against a minimally compliant ANSI/ASHRAE/IES 90.1 building that represents standard practice

Not Code Compliance

Not intended to show minimum code compliance, but some state energy efficiency programs accept it. In 90.1-2016, a minimum code compliance path was also added.



Function

Credits or penalizes many measures that are held constant for minimum code compliance

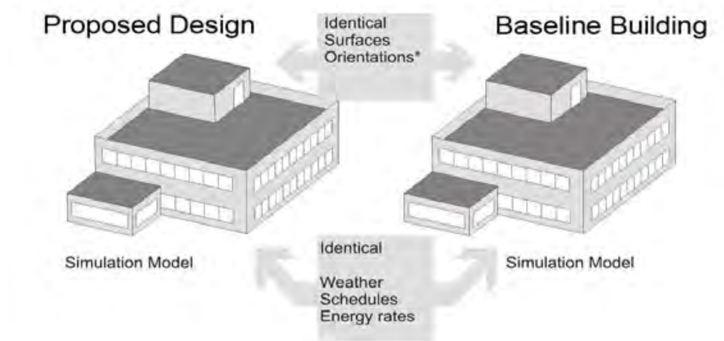
170

APPENDIX G: PERFORMANCE RATING METHOD *(THROUGH 90.1-2013)*

Appendix G: Modeling Requirements

90.1 Mandatory Requirements (§ 5.4, 6.4, 7.4, 8.4, 9.4, 10.4)

90.1 Prescriptive Requirements



Adapted from ASHRAE Learning Institute 2017

171

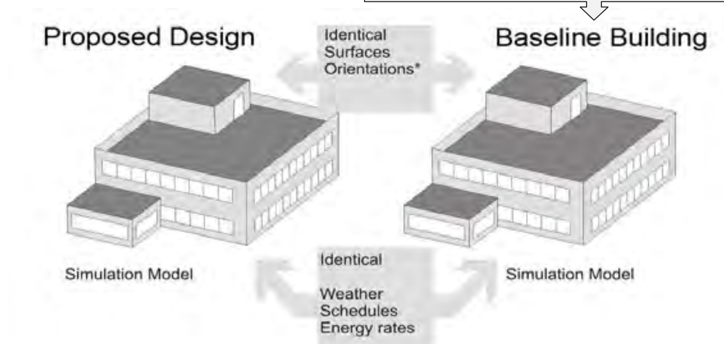
APPENDIX G: PERFORMANCE RATING METHOD *(NEW IN 90.1-2016)*

Appendix G: Modeling Requirements

90.1 Mandatory Requirements (§ 5.4, 6.4, 7.4, 8.4, 9.4, 10.4) (as applied by App. G 2016)

90.1 Prescriptive Requirements (from 90.1-2004, listed in App. G. 2016)

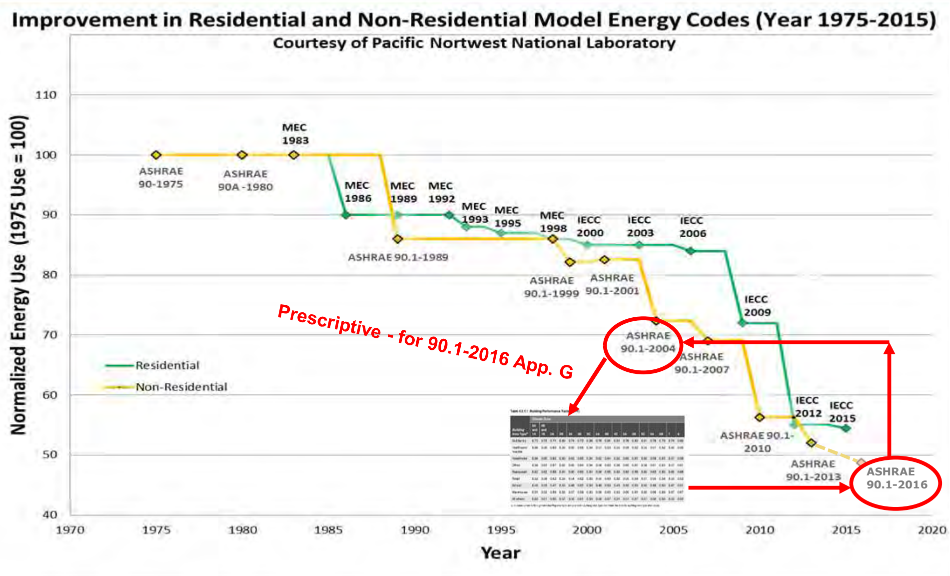
Baseline Energy Cost Adjusted by 90.1-2004



Adapted from ASHRAE Learning Institute 2017

172

90.1 Historical Efficiency Improvements



173

Table 4.2.1.1 2016 Building Performance Factors (BPF)

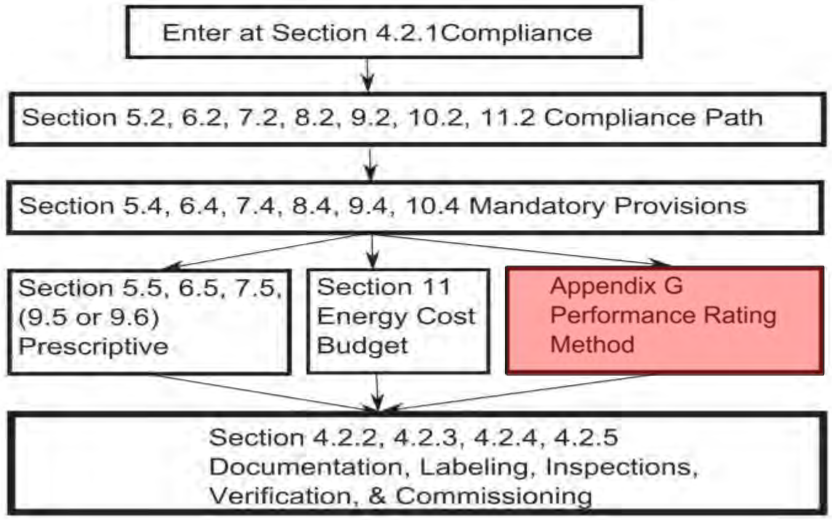
Table 4.2.1.1 *Building* Performance Factor (BPF)

Building Area Type[a]	Climate Zone 0A and 1A	0B and 1B	2A	2B	3A	3B	3C	4A	4B	4C	5A	5B	5C	6A	6B	7	8
Multifamily	0.73	0.73	0.71	0.69	0.74	0.73	0.68	0.78	0.81	0.81	0.76	0.80	0.81	0.76	0.79	0.74	0.80
Healthcare/ hospital	0.64	0.56	0.60	0.56	0.60	0.56	0.54	0.57	0.53	0.55	0.59	0.52	0.55	0.57	0.52	0.56	0.56
Hotel/motel	0.64	0.65	0.62	0.60	0.63	0.65	0.64	0.62	0.64	0.62	0.60	0.61	0.60	0.59	0.61	0.57	0.58
Office	0.58	0.62	0.57	0.62	0.60	0.64	0.54	0.58	0.60	0.58	0.60	0.61	0.58	0.61	0.61	0.57	0.61
Restaurant	0.62	0.62	0.58	0.61	0.60	0.60	0.61	0.58	0.55	0.60	0.62	0.58	0.60	0.63	0.60	0.65	0.68
Retail	0.52	0.58	0.53	0.58	0.54	0.62	0.60	0.55	0.60	0.60	0.55	0.59	0.61	0.55	0.58	0.53	0.53
School	0.46	0.53	0.47	0.53	0.49	0.52	0.50	0.49	0.50	0.49	0.50	0.50	0.50	0.49	0.50	0.47	0.51
Warehouse	0.51	0.52	0.56	0.58	0.57	0.59	0.63	0.58	0.60	0.63	0.60	0.61	0.65	0.66	0.66	0.67	0.67
All others	0.62	0.61	0.55	0.57	0.56	0.61	0.59	0.58	0.57	0.61	0.57	0.57	0.61	0.56	0.56	0.53	0.52

a. In cases where both a general *building* area type and a specific *building* area type are listed, the specific *building* area type shall apply

174

90.1-2016 ADDS APPENDIX G PATH



175

APPENDIX G COMPLIANCE

Performance Cost Index (PCI)

$$PCI = \frac{\text{Proposed Building Energy Cost}}{\text{Baseline Building Energy Cost}}$$

176

APPENDIX G COMPLIANCE

For compliance

$$PCI \leq PCI_t$$

target

For savings

$$\% \text{ Savings} = 100 \times \left(\frac{PCI_t - PCI}{PCI_t}\right)$$

177

APPENDIX G COMPLIANCE

Table 4.2.1.1 ***Building*** **Performance Factor (BPF)**

Building Area Type[a]	Climate Zone																
	0A and 1A	0B and 1B	2A	2B	3A	3B	3C	4A	4B	4C	5A	5B	5C	6A	6B	7	8
Multifamily	0.73	0.73	0.71	0.69	0.74	0.73	0.68	0.78	0.81	0.81	0.76	0.80	0.81	0.76	0.79	0.74	0.80
Healthcare/ hospital	0.64	0.56	0.60	0.56	0.60	0.56	0.54	0.57	0.53	0.55	0.59	0.52	0.55	0.57	0.52	0.56	0.56
Hotel/motel	0.64	0.65	0.62	0.60	0.63	0.65	0.64	0.62	0.64	0.62	0.60	0.61	0.60	0.59	0.61	0.57	0.58
Office	0.58	0.62	0.57	0.62	0.60	0.64	0.54	0.58	0.60	0.58	0.60	0.61	0.58	0.61	0.61	0.57	0.61
Restaurant	0.62	0.62	0.58	0.61	0.60	0.60	0.61	0.58	0.55	0.60	0.62	0.58	0.60	0.63	0.60	0.65	0.68
Retail	0.52	0.58	0.53	0.58	0.54	0.62	0.60	0.55	0.60	0.60	0.55	0.59	0.61	0.55	0.58	0.53	0.53
School	0.46	0.53	0.47	0.53	0.49	0.52	0.50	0.49	0.50	0.49	0.50	0.50	0.50	0.49	0.50	0.47	0.51
Warehouse	0.51	0.52	0.56	0.58	0.57	0.59	0.63	0.58	0.60	0.63	0.60	0.61	0.65	0.66	0.66	0.67	0.67
All others	0.62	0.61	0.55	0.57	0.56	0.61	0.59	0.58	0.57	0.61	0.57	0.57	0.61	0.56	0.56	0.53	0.52

a. In cases where both a general *building* area type and a specific *building* area type are listed, the specific *building* area type shall apply

178

APPENDIX G COMPLIANCE

Performance Cost Index Target (PCI_t)

$$PCI_t = \frac{\text{Baseline building } \textbf{unregulated} \text{ energy cost} + \left[\text{BPF} \times \text{Baseline building } \textbf{regulated} \text{ energy cost} \right]}{\textbf{Total} \text{ baseline building energy cost}}$$

179

APPENDIX G COMPLIANCE

Regulated energy cost (HVAC, lighting, DHW, …)

$$\text{Regulated electricity cost} = \text{Total electricity cost} \times \left[\frac{\text{Regulated kWh}}{\text{Total kWh}} \right]$$

$$\text{Regulated gas cost} = \text{Total gas cost} \times \left[\frac{\text{Regulated therms}}{\text{Total therms}} \right]$$

Unregulated energy cost (plug loads, process, …)

$$\text{Unregulated energy cost} = \text{Total energy cost} - \text{Regulated energy cost}$$

180

Appendix G Compliance Example

Chicago (CZ-5A) office building

- Proposed Building Performance = $32,000/year
- Baseline Building Performance = $49,000/year
  - $34,000/year regulated
  - $15,000/year unregulated

Building Performance Factor (BPF)

- From Table 4.2.1.1, Office, Climate Zone 5A
- BPF = 0.60

Table 4.2.1.1 *Building* Performance Factor (BPF)

Building Area Type[a]	Climate Zone																
	0A and 1A	0B and 1B	2A	2B	3A	3B	3C	4A	4B	4C	5A	5B	5C	6A	6B	7	8
Multifamily	0.73	0.73	0.71	0.69	0.74	0.73	0.68	0.78	0.81	0.81	0.76	0.80	0.81	0.76	0.79	0.74	0.80
Healthcare/ hospital	0.64	0.56	0.60	0.56	0.60	0.56	0.54	0.57	0.53	0.55	0.59	0.52	0.55	0.57	0.52	0.56	0.56
Hotel/motel	0.64	0.65	0.62	0.60	0.63	0.65	0.64	0.62	0.64	0.62	0.60	0.61	0.60	0.59	0.61	0.57	0.58
Office	0.58	0.62	0.57	0.62	0.60	0.64	0.54	0.58	0.60	0.58	0.60	0.61	0.58	0.61	0.61	0.57	0.61
Restaurant	0.62	0.62	0.58	0.61	0.60	0.60	0.61	0.58	0.55	0.60	0.62	0.58	0.60	0.63	0.60	0.65	0.68
Retail	0.52	0.58	0.53	0.58	0.54	0.62	0.60	0.55	0.60	0.60	0.55	0.59	0.61	0.55	0.58	0.53	0.53
School	0.46	0.53	0.47	0.53	0.49	0.52	0.50	0.49	0.50	0.49	0.50	0.50	0.50	0.49	0.50	0.47	0.51
Warehouse	0.51	0.52	0.56	0.58	0.57	0.59	0.63	0.58	0.60	0.63	0.60	0.61	0.65	0.66	0.66	0.67	0.67
All others	0.62	0.61	0.55	0.57	0.56	0.61	0.59	0.58	0.57	0.61	0.57	0.57	0.61	0.56	0.56	0.53	0.52

a. In cases where both a general *building* area type and a specific *building* area type are listed, the specific *building* area type shall apply

181

Appendix G Compliance Example

$$PCI = \frac{\text{Proposed Building Energy Cost}}{\text{Baseline Building Energy Cost}} = \frac{\$32{,}000}{\$49{,}000} = 0.65$$

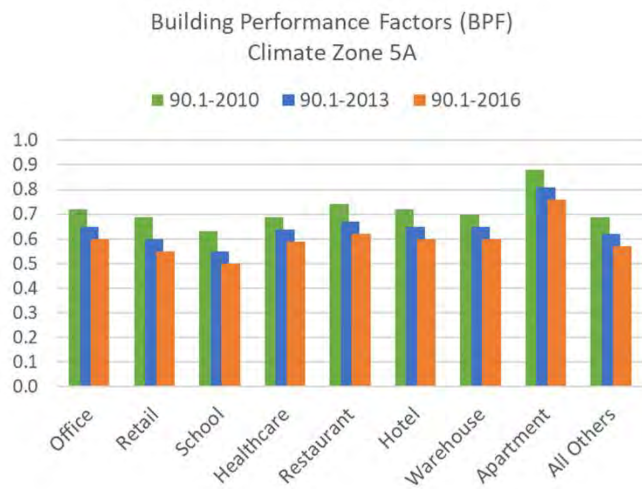
$$PCI \leq PCI_t$$

$$PCI_t = \frac{\text{Baseline building \textbf{unregulated} energy cost} + \left[\text{BPF} \times \text{Baseline building \textbf{regulated} energy cost}\right]}{\text{\textbf{Total} baseline building energy cost}} = \frac{\$15{,}000 + 0.60 * \$32{,}000}{\$49{,}000} = 0.72$$

$$\text{\% Savings} = 100 \times \left(\frac{PCI_t - PCI}{PCI_t}\right) = 100 \times \left(\frac{0.72 - 0.65}{0.72}\right) = 9.7\%$$

182

2010, 2013 & 2016 BPFs

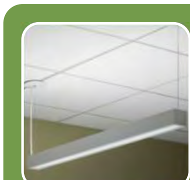


Data source: https://www.pnnl.gov/main/publications/external/technical_reports/PNNL-25202.pdf

183

Performance Rating Method

Standard 90.1 Standard Sections and Appendix G



Mandatory Provisions

- Must be included in the project
- Should be reflected in the baseline and proposed case energy models

Prescriptive Requirements

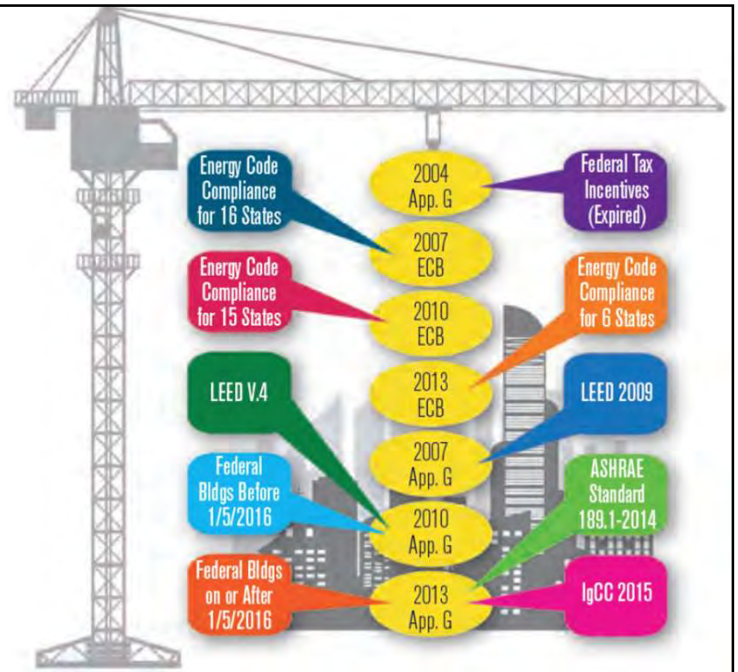
- Used to define Appendix G baseline parameters
- Tables or formulas are often referenced by Appendix G

184

184

90.1's ECB and Appendix G have had changing uses over time.

The 2016 addition is changed to serve all of them!

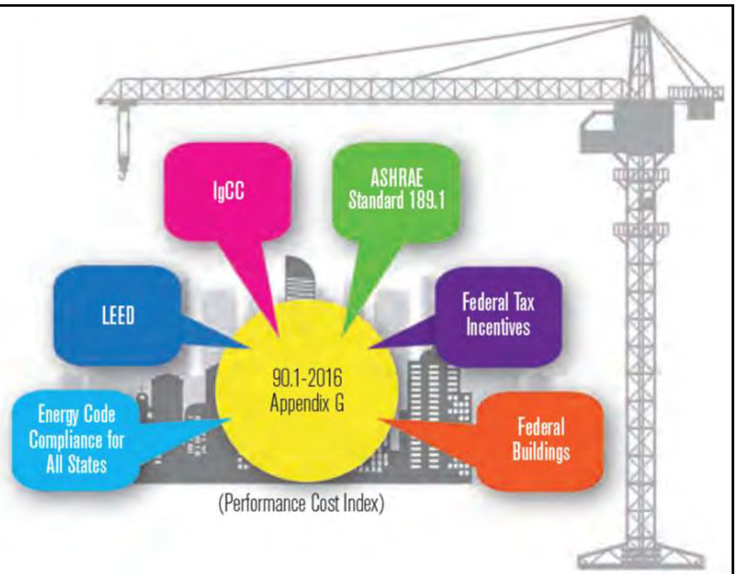


Thanks to : Michael Rosenberg PNNL - Jun 2016 ASHRAE Journal

185

Appendix G has many uses.

The 2016 version is changed to better serve all of them!



Thanks to : Michael Rosenberg PNNL - Jun 2016 ASHRAE Journal

186

ANSI/ASHRAE/IES
Standard 90.1
Performance Rating Method

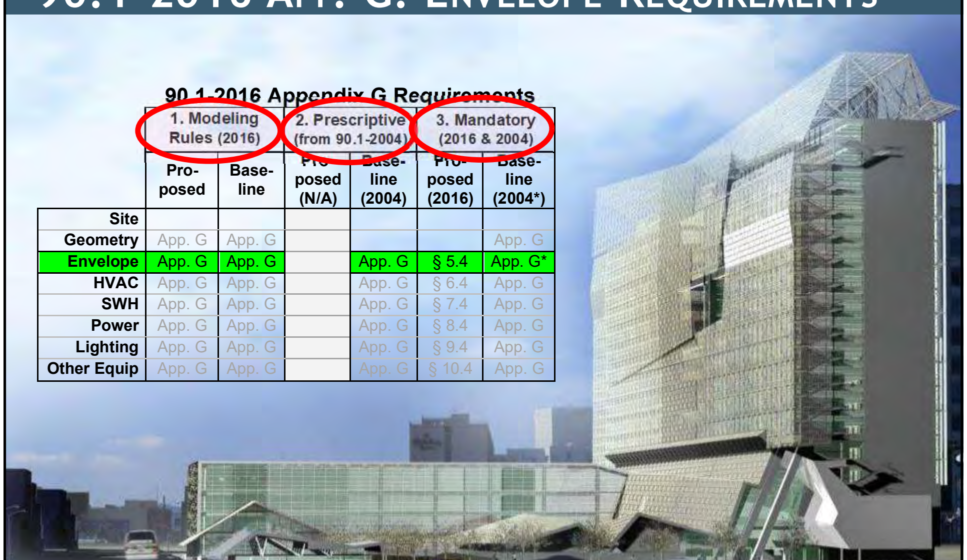
Building Envelope

187

Building Envelope
90.1-2016 App. G: Envelope Requirements

90.1-2016 Appendix G Requirements

	1. Modeling Rules (2016)		2. Prescriptive (from 90.1-2004)		3. Mandatory (2016 & 2004)	
	Pro-posed	Base-line	Pro-posed (N/A)	Base-line (2004)	Pro-posed (2016)	Base-line (2004*)
Site						
Geometry	App. G	App. G				App. G
Envelope	App. G	App. G		App. G	§ 5.4	App. G*
HVAC	App. G	App. G		App. G	§ 6.4	App. G
SWH	App. G	App. G		App. G	§ 7.4	App. G
Power	App. G	App. G		App. G	§ 8.4	App. G
Lighting	App. G	App. G		App. G	§ 9.4	App. G
Other Equip	App. G	App. G		App. G	§ 10.4	App. G



188

Performance Rating Method

Building Envelope—*Proposed Design* (90.1-2010 Table G3.1 #5)

General Principles
- Modeled to reflect actual building design
- Model actual building form and orientation

Orientation of Exterior Surfaces
- Less than 45° differences may be modeled as single surface

Shading
- Exterior surfaces shall be modeled as self shading
- All permanent exterior shading shall be modeled

Shades or Blinds
- Automated shades or blinds may be modeled
- Manual shades or blinds are not modeled

Fenestration
- Use *assembly* U-factors that account for the frames effects

189

189

Performance Rating Method

Building envelope—*Baseline Design* (90.1-2010 Table G3.1 #5)

- **Walls:** Modeled as steel framed
- **Roofs:** Modeled with continuous insulation above deck
- **Raised floors:** Exposed to the environment or above unconditioned spaces: modeled as steel joist
- **Windows:** Modeled with same window-to-wall ratio as proposed case up to 40%
- **Performance parameters:** Modeled based on building envelope requirements table for the appropriate Climate Zone (5.5-1–5.5-8)
- **Existing envelope:** Modeled with existing conditions prior to renovation

190

190

Performance Rating Method

Building Envelope: 90.1-2010 *Baseline Design*— Residential and Semi-heated

Residential
(e.g., dwelling units, hospital rooms, etc.)

- Exterior surfaces for residential spaces are modeled using criteria from Tables 5.5
- Exterior surfaces adjacent to other space functions in a residential building may be modeled using the nonresidential values

Semi-heated; Semi-exterior

- Exterior surfaces for semiconditioned spaces may be modeled using the semiheated criteria from Tables 5.5
- Semi-exterior: Should be modeled using semiheated criteria from Tables 5.5

191

191

Determine Vertical Fenestration Amount For *Baseline Building*

New for 2016

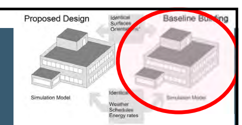


Table G3.1.1-1 Baseline Building Vertical Fenestration Percentage of Gross Above-Grade-Wall Area

Building Area Types[a]	Baseline Building Gross Above-Grade-Wall Area
Grocery Store	7%
Healthcare (outpatient)	21%
Hospital	27%
Hotel/motel (≤75 rooms)	24%
Hotel/motel (>75 rooms)	34%
Office (≤5000 ft^2)	19%
Office (5000 to 50,000 ft^2)	31%
Office (>50,000 ft^2)	40%
Restaurant (quick service)	34%
Restaurant (full service)	24%
Retail (stand alone)	11%
Retail (strip mall)	20%
School (primary)	22%
School (secondary and university)	22%
Warehouse (nonrefrigerated)	6%

a. In cases where both a general building area type and a specific building area type are listed, the specific building area type shall apply.

192

Opaque Stringency Increases From 2004 to 2016 - *Roofs*

Roofs		Climate Zones (CZ) CZ 0	CZ 1	CZ 2	CZ 3	CZ 4	CZ 5	CZ 6	CZ 7	CZ 8
Insulation Entirely above Deck	90.1-2004		R-15.0 ci	R-15.0 ci	R-15.0 ci	R-15.0 ci	R-15.0 ci	R-15.0 ci	R-15.0 ci	R-20.0 ci
	90.1-2007		R-15.0 ci	R-20.0 ci	R-20.0 ci	R-20.0 ci	R-20.0 ci	R-20.0 ci	R-20.0 ci	R-20.0 ci
	90.1-2010		R-15.0 ci	R-20.0 ci	R-20.0 ci	R-20.0 ci	R-20.0 ci	R-20.0 ci	R-20.0 ci	R-20.0 ci
	90.1-2013		R-20.0 ci	R-25.0 ci	R-25.0 ci	R-30.0 ci	R-30.0 ci	R-30.0 ci	R-35.0 ci	R-35.0 ci
	90.1-2016	R-25.0 ci	R-20.0 ci	R-25.0 ci	R-25.0 ci	R-30.0 ci	R-30.0 ci	R-30.0 ci	R-35.0 ci	R-35.0 ci
Metal Building	90.1-2004		R-19.0	R-19.0	R-19.0	R-19.0	R-19.0	R-19.0	R-19.0	R-13.0 + R-19.0
	90.1-2007		R-19.0	R-19.0	R-19.0	R-19.0	R-19.0	R-19.0	R-19.0	R-13.0 + R-19.0
	90.1-2010		R-19.0	R-13.0 + R-13.0	R-13.0 + R-13.0	R-13.0 + R-13.0	R-13.0 + R-13.0	R-13.0 + R-19.0	R-13.0 + R-19.0	R-13.0 + R-19.0 Ls
	90.1-2013		R-10.0 + R-19 FC	R-10.0 + R-19 FC	R-10.0 + R-19 FC	R-19 + R-11 Ls or R-25 + R-8 Ls	R-19 + R-11 Ls or R-25 + R-8 Ls	R-25 + R-11 Ls	R-30 + R-11 Ls	R-25 + R-11 + R-11 Ls
	90.1-2016	R-10.0 + R-19 FC	R-10.0 + R-19 FC	R-10.0 + R-19 FC	R-10.0 + R-19 FC	R-19 + R-11 Ls or R-25 + R-8 Ls	R-19 + R-11 Ls or R-25 + R-8 Ls	R-25 + R-11 Ls	R-30 + R-11 Ls	R-25 + R-11 + R-11 Ls
Attic and Other	90.1-2004		R-30.0	R-30.0	R-30.0	R-30.0	R-30.0	R-38.0	R-38.0	R-38.0
	90.1-2007		R-30.0	R-38.0	R-38.0	R-38.0	R-38.0	R-38.0	R-38.0	R-49.0
	90.1-2010		R-30.0	R-38.0	R-38.0	R-38.0	R-38.0	R-38.0	R-38.0	R-49.0
	90.1-2013		R-38.0	R-38.0	R-38.0	R-49.0	R-49.0	R-49.0	R-60.0	R-60.0
	90.1-2016	R-38.0	R-38.0	R-38.0	R-38.0	R-49.0	R-49.0	R-49.0	R-60.0	R-60.0

193

Opaque Stringency Increases From 2004 to 2016 - *Walls*

Walls, Above Grade		Climate Zones (CZ) CZ 0	CZ 1	CZ 2	CZ 3	CZ 4	CZ 5	CZ 6	CZ 7	CZ 8
Mass	90.1-2004		NR	NR	R-5.7 ci[a, b]	R-5.7 ci[a, b]	R-7.6 ci	R-9.5 ci	R-11.4 ci	R-13.3 ci
	90.1-2007		NR	R-5.7 ci[a, b]	R-7.6 ci	R-9.5 ci	R-11.4 ci	R-13.3 ci	R-15.2 ci	R-15.2 ci
	90.1-2010		NR	R-5.7 ci[a, b]	R-7.6 ci	R-9.5 ci	R-11.4 ci	R-13.3 ci	R-15.2 ci	R-15.2 ci
	90.1-2013		NR	R-5.7 ci[a, b]	R-7.6 ci	R-9.5 ci	R-11.4 ci	R-13.3 ci	R-15.2 ci	R-19.0 ci
	90.1-2016	NR	NR	R-5.7 ci[a, b]	R-7.6 ci	R-9.5 ci	R-11.4 ci	R-13.3 ci	R-15.2 ci	R-19.0 ci
Metal Building	90.1-2004		R-13.0	R-13.0	R-13.0	R-13.0	R-13.0	R-13.0	R-13.0 + R-13.0	R-13.0 + R-13.0
	90.1-2007		R-13.0	R-13.0	R-13.0	R-13.0	R-13.0	R-13.0	R-13.0 + R-13.0	R-13.0 + R-13.0
	90.1-2010		R-16.0	R-16.0	R-19.0	R-19.0	R-13.0 + R-5.6 c.i.	R-13.0 + R-5.6 c.i.	R-19.0 + R-5.6 c.i.	R-19.0 + R-5.6 c.i.
	90.1-2013		R-0 + R-9.8 c.i.	R-0 + R-9.8 c.i.	R-0 + R-9.8 c.i.	R-0 + R-15.8 c.i.	R-0 + R-19.0 c.i.	R-0 + R-19.0 c.i.	R-0 + R-22.0 c.i.	R-0 + R-25.0 c.i.
	90.1-2016	R-0 + R-9.8 c.i.	R-0 + R-9.8 c.i.	R-0 + R-9.8 c.i.	R-0 + R-9.8 c.i.	R-0 + R-15.8 c.i.	R-0 + R-19.0 c.i.	R-0 + R-19.0 c.i.	R-0 + R-22.1 c.i.	R-0 + R-25.0 c.i.
Steel Framed	90.1-2004		R-13.0	R-13.0	R-13.0	R-13.0	R-13.0 + R-3.8 ci	R-13.0 + R-3.8 ci	R-13.0 + R-7.5 ci	R-13.0 + R-7.5 ci
	90.1-2007		R-13.0	R-13.0	R-13.0 + R-3.8 c.i.	R-13.0 + R-7.5 c.i.	R-13.0 + R-7.5 c.i.	R-13.0 + R-7.5 c.i.	R-13.0 + R-7.5 c.i.	R-13.0 + R-7.5 c.i.
	90.1-2010		R-13.0	R-13.0	R-13.0 + R-3.8 c.i.	R-13.0 + R-7.5 c.i.	R-13.0 + R-7.5 c.i.	R-13.0 + R-7.5 c.i.	R-13.0 + R-7.5 c.i.	R-13.0 + R-7.5 c.i.
	90.1-2013		R-13.0	R-13.0 + R-3.8 c.i.	R-13.0 + R-5.0 c.i.	R-13.0 + R-7.5 c.i.	R-13.0 + R-10.0 c.i.	R-13.0 + R-12.5 c.i.	R-13.0 + R-12.5 c.i.	R-13.0 + R-18.8 c.i.
	90.1-2016	R-13.0	R-13.0	R-13.0 + R-3.8 c.i.	R-13.0 + R-5.0 c.i.	R-13.0 + R-7.5 c.i.	R-13.0 + R-10.0 c.i.	R-13.0 + R-12.5 c.i.	R-13.0 + R-12.5 c.i.	R-13.0 + R-18.8 c.i.
Wood Framed and Other	90.1-2004		R-13.0	R-13.0	R-13.0	R-13.0	R-13.0	R-13.0	R-13.0	R-13.0 + R-7.5 ci
	90.1-2007		R-13.0	R-13.0	R-13.0	R-13.0	R-13.0 + R-3.8 c.i.	R-13.0 + R-7.5 c.i.	R-13.0 + R-7.5 c.i.	R-13.0 + R-15.6 c.i.
	90.1-2010		R-13.0	R-13.0	R-13.0	R-13.0	R-13.0 + R-3.8 c.i.	R-13.0 + R-7.5 c.i.	R-13.0 + R-7.5 c.i.	R-13.0 + R-15.6 c.i.
	90.1-2013		R-13.0	R-13.0	R-13.0	R-13.0 + R-3.8 c.i.	R-13 + R-7.5 c.i. or R-19 + R-5 c.i.	R-13 + R-7.5 c.i. or R-19 + R-5 c.i.	R-13 + R-7.5 c.i. or R-19 + R-5 c.i.	R-13.0 + R-18.8 c.i.
	90.1-2016	R-13.0	R-13.0	R-13.0	R-13.0	R-13.0 + R-3.8 c.i. or R-20	R-13 + R-7.5 c.i. or R-19 + R-5 c.i.	R-13 + R-7.5 c.i. or R-19 + R-5 c.i.	R-13 + R-7.5 c.i. or R-19 + R-5 c.i.	R-13.0 + R-18.8 c.i.

Building Opaque Envelope Nonresidential Insulation Minimum R-Value Requirements

194

FENESTRATION PRESCRIPTIVE REQ.: 90.1-2004 THRU 90.1-2016

Vertical Fenestration, <= 40% 0f wall		Max. U, of fenestration assembly: CZ 0	CZ 1	CZ 2	CZ 3	CZ 3C	CZ 4	CZ 5	CZ 6	CZ 7	CZ 8
90.1-2004	Fixed, all, <= 40%		1.2	1.2	0.6	1.22	0.6	0.6	0.6	0.6	0.5
	Fixed, north, <= 40%										
	Operable, all, <= 40%		1.3	1.3	0.7	1.27	0.7	0.7	0.7	0.7	0.5
	Operable, north, <= 40%										
90.1-2007	Nonmetal framing, all		1.20	0.75	0.65		0.40	0.35	0.35	0.35	0.35
	Metal framing, curtainwall etc.		1.20	0.70	0.60		0.50	0.45	0.45	0.40	0.40
	Metal framing, all other		1.20	0.75	0.65		0.55	0.55	0.55	0.45	0.45
	Metal framing, entrance door		1.20	1.10	0.90		0.85	0.80	0.80	0.80	0.80
90.1-2010	Nonmetal framing, all		1.20	0.75	0.65		0.40	0.35	0.35	0.35	0.35
	Metal framing, curtainwall etc.		1.20	0.70	0.60		0.50	0.45	0.45	0.40	0.40
	Metal framing, all other		1.20	0.75	0.65		0.55	0.55	0.55	0.45	0.45
	Metal framing, entrance door		1.20	1.10	0.90		0.85	0.80	0.80	0.80	0.80
90.1-2013	Nonmetal framing, all		0.5	0.4	0.35		0.35	0.32	0.32	0.32	0.32
	Metal framing, fixed		0.57	0.57	0.50		0.42	0.42	0.42	0.38	0.38
	Metal framing, operable		0.65	0.65	0.60		0.50	0.50	0.50	0.40	0.40
	Metal framing, entrance door		1.10	0.83	0.77		0.77	0.77	0.77	0.77	0.77
90.1-2016	Nonmetal framing, all	0.32	0.5	0.37	0.31		0.31	0.31	0.3	0.28	0.25
	Metal framing, fixed	0.5	0.57	0.54	0.45		0.38	0.38	0.36	0.33	0.29
	Metal framing, operable	0.65	0.65	0.65	0.60		0.46	0.46	0.45	0.40	0.35
	Metal framing, entrance door	0.83	1.10	0.83	0.77		0.68	0.68	0.68	0.68	0.68

195

FENESTRATION PRESCRIPTIVE REQ.: 90.1-2004 THRU 90.1-2016

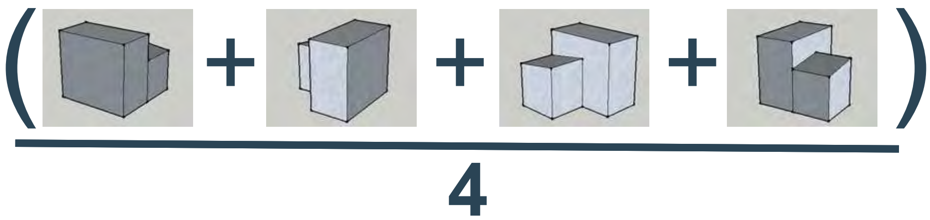
Vertical Fenestration, <= 40% 0f wall		Max. SHGC, of fenestration assembly: CZ 0	CZ 1	CZ 2	CZ 3	CZ 3C	CZ 4	CZ 5	CZ 6	CZ 7	CZ 8
90.1-2004	All at 20%		0.25	0.25	0.25	0.39	0.39	0.39	0.39	0.49	NR
	N at 20%		0.61	0.61	0.49	0.61	0.49	0.49	0.49	0.64	NR
	All at 40%		0.25	0.25	0.25	0.34	0.39	0.39	0.39	0.49	NR
	N at 40%		0.44	0.61	0.39	0.61	0.49	0.49	0.49	0.64	NR
90.1-2007	Nonmetal framing, all		0.25	0.25	0.25		0.40	0.40	0.40	0.45	0.45
	Metal framing, curtainwall etc.										
	Metal framing, all other										
	Metal framing, entrance door										
90.1-2010	Nonmetal framing, all		0.25	0.25	0.25		0.40	0.40	0.40	0.45	0.45
	Metal framing, curtainwall etc.										
	Metal framing, all other										
	Metal framing, entrance door										
90.1-2013	Nonmetal framing, all		0.25	0.25	0.25		0.40	0.40	0.40	0.45	0.45
	Metal framing, fixed										
	Metal framing, operable										
	Metal framing, entrance door										
90.1-2016	Nonmetal framing, all	0.2	0.25	0.25	0.25		0.36	0.38	0.40	0.45	0.45
	Metal framing, fixed										
	Metal framing, operable										
	Metal framing, entrance door										

196

Performance Rating Method

Building Envelope—*Baseline Design* (Table G3.1 #5)

- Building form identical in baseline and proposed cases
- Windows distributed per façade in same proportion as proposed case
- Average of four rotations: 0°, 90°, 180°, and 270°
  (unless glazing is ~ same)
- Building surfaces modeled without self shading
- Infiltration modeled the same in baseline and proposed cases
- Roof modeled with reflectivity of 0.3



197

197

Performance Rating Method

Building Envelope—Methods for Documenting Credit

Form and Orientation
- Self shading
- Natural daylight
- Passive heating
- Passive cooling
- Natural Ventilation
- Distribution of fenestration

Shades
- Exterior shading
- Automated blinds or shades

Construction Assemblies
- Thermal mass
- Wood framed
- Window frames

Windows
- Thermal conductivity
- Solar heat gain

198

Performance Rating Method

Envelope Error Checking

- When using wizards—verify that interior surfaces are not modeled with exterior surfaces
- Compare proposed case properties to Appendix A in 90.1-2010/90.1-2013/90.1-2016 (account for thermal bridging)
- Verify that baseline properties use appropriate construction assembly types
- Verify that proposed windows use framed-assembly U-factors

In results data:

- Verify equal distribution of exterior wall area north-to-south and east-to-west or justify differences
- Verify total window area (including window frames)
- Verify peak load components to known values or hand calculations

199

199

ANSI/ASHRAE/IES Standard 90.1 Performance Rating Method (PRM)

Lighting

200

PERFORMANCE RATING METHOD

INTERIOR LIGHTING POWER DENSITY (90.1-2010 TABLE G3.1 #6)

Building Area Method (9.5)

- One lighting power density per major building function (e.g., office/parking garage/retail)
- Average LPD across entire building function modeled for both baseline and proposed case
- No additional lighting power allowed

Space-by-Space Method (9.6)

- One LPD per space function
- Separate LPD modeled for each space or space function in both baseline and proposed cases
- Additional lighting power allowed (9.6.2)

- ➢ A single method (9.5 or 9.6) must be used for the entire building
- ➢ For either method, exempt lighting is equal for baseline and proposed cases
- ➢ Task lighting is exempted when furniture mounted and shutoff automatically 201

201

90.1-2016 APPENDIX G:

REQUIREMENTS *FOR* LIGHTING

90.1-2016 Appendix G Requirements

	1. Modeling Rules (2016)		2. Prescriptive (from 90.1-2004)		3. Mandatory (2016 & 2004)	
	Pro-posed	Base-line	Pro-posed (N/A)	Base-line (2004)	Pro-posed (2016)	Base-line (2004*)
Site						
Geometry	App. G	App. G				App. G
Envelope	App. G	App. G		App. G	§ 5.4	App. G
HVAC	App. G	App. G		App. G	§ 6.4	App. G
SWH	App. G	App. G		App. G	§ 7.4	App. G
Power	App. G	App. G		App. G	§ 8.4	App. G
Lighting	App. G	App. G		App. G	§ 9.4	App. G
Other Equip	App. G	App. G		App. G	§ 10.4	App. G

Source of image: eLAD, LBNL, SuPerB, Vaidya, Deringer, *et al*.

202

LPD STRINGENCY FROM 2001 TO 2016

Building Area Method, Table 9.5.1

Building Area	2001	2004	2007	2010	2013	2016	2016 Pct Less than 2001	2016 Pct Less than 2013
Automotive facility	1.50	0.90	0.90	0.82	0.80	0.71	53%	11%
Convention center	1.40	1.20	1.20	1.08	1.01	0.76	46%	25%
Courthouse	1.40	1.20	1.20	1.05	1.01	0.90	36%	11%
Dining: Bar lounge/leisure	1.50	1.30	1.30	0.99	1.01	0.90	40%	11%
Dining: Cafeteria/fast food	1.80	1.40	1.40	0.90	0.90	0.79	56%	12%
Dining: Family	1.90	1.60	1.60	0.89	0.95	0.78	59%	18%
Dormitory	1.50	1.00	1.00	0.61	0.57	0.61	59%	-7%
Exercise center	1.40	1.00	1.00		0.84	0.65	54%	
Fire station				0.71	0.67	0.53		21%
Gymnasium	1.70	1.10	1.10	1.00	0.94	0.68	60%	28%
Health-care clinic	1.60	1.00	1.00	0.87	0.90	0.82	49%	9%
Hospital		1.20	1.20	1.21	1.05	1.05		0%
Hotel/Motel	1.70	1.00	1.00	1.00	0.87	0.75	56%	14%
Library	1.50	1.30	1.30	1.18	1.19	0.78	48%	34%
Manufacturing facility	2.20	1.30	1.30	1.11	1.17	0.90	59%	23%
Motel	2.00	1.00	1.00	0.88				
Motion picture theater	1.60	1.20	1.20	0.83	0.76	0.83	48%	-9%
Multifamily	1.00	0.70	0.70	0.60	0.51	0.68	32%	-33%
Museum	1.60	1.10	1.10	1.06	1.02	1.06	34%	-4%
Office	1.30	1.00	1.00	0.90	0.82	0.79	39%	4%
Parking garage	0.30	0.30	0.30	0.25	0.21	0.15	50%	29%
Penitentiary	1.20	1.00	1.00	0.97	0.81	0.75	38%	7%
Performing arts theater	1.50	1.60	1.60	1.39	1.89	1.18	21%	38%
Police station	1.30	1.00	1.00	0.96	0.87	0.80	38%	8%
Post office	1.60	1.10	1.10	0.87	0.87	0.67	58%	23%
Religious building	2.20	1.30	1.30	1.05	1.00	0.94	57%	6%
Retail	1.90	1.50	1.50	1.40	1.26	1.06	44%	16%
School/university	1.50	1.20	1.20	0.99	0.87	0.81	46%	7%
Sports arena	1.50	1.10	1.10	0.78	0.91	0.87	42%	4%
Town hall	1.40	1.10	1.10	0.92	0.89	0.80	43%	10%
Transportation	1.20	1.00	1.00	0.77	0.70	0.61	49%	13%
Warehouse	1.20	0.80	0.80	0.66	0.66	0.48	60%	27%
Workshop	1.70	1.40	1.40	1.20	1.19	0.90	47%	24%

203

LPDs: 2004-2016

Space by Space Method Table 9.6.1 *(Part 1)*

Space Types	2004 From App G)	2016	Pct Chg from 2004
Audience Seating Area			
Auditorium	0.90	0.63	30%
Convention center	0.70	0.82	-17%
Gymnasium	0.40	0.65	-63%
Motion picture theatre	1.20	1.14	5%
Penitentiary	0.70	0.28	60%
Performing arts theatre	2.60	2.03	22%
Religious building	1.70	1.53	10%
Sports arena	0.40	0.43	-7%
All other audience seating areas	0.90	0.43	52%
Banking Activity Area	1.50	0.86	43%
Breakroom (See Lounge/Breakroom)			
Classroom/Lecture Hall/Training Room			
Penitentiary	1.30	1.34	-3%
All other classrooms/Lecture halls/training rooms	1.40	0.92	34%
Conference/Meeting/Multipurpose Room	1.30	1.07	18%
Confinement Cells	0.90	0.81	10%
Copy/Print Room	0.90	0.56	38%
Corridor2			
Facility for the visually impaired (and not used pri	1.15	0.92	20%
Hospital	1.00	0.92	8%
Manufacturing facility	0.50	0.29	42%
All other corridors	0.50	0.66	-32%
Courtroom	1.90	1.39	27%
Computer Room	2.14	1.33	38%
Dining Area			
Penitentiary	1.30	0.96	26%
Facility for the visually impaired (and not used pri	3.32	2.00	40%
Bar/lounge or leisure dining	1.40	0.93	34%
Cafeteria or fast food dining	0.90	0.63	30%
Family dining	2.10	0.71	66%
All other dining areas	0.90	0.63	30%
Electrical/Mechanical Room7	1.50	0.43	71%
Emergency Vehicle Garage	0.80	0.41	49%
Food Preparation Area	1.20	1.06	12%
Guest Room	1.10	0.77	30%

204

LPDs: 2004-2016

Space by Space Method

Table 9.6.1 *(Part 2)*

Space Types	2004 From App G)	2016	Pct Chg from 2004
Laboratory			
In or as a classroom	1.40	1.20	14%
All other laboratories	1.40	1.45	-4%
Laundry/Washing Area	0.60	0.43	28%
Loading Dock, Interior	0.59	0.58	2%
Lobby			
Facility for the visually impaired (and not used pri	2.26	2.03	10%
Elevator	0.80	0.69	14%
Hotel	1.10	1.06	4%
Motion Picture theatre	1.10	0.45	59%
Performing arts theatre	3.30	1.70	48%
All other lobbies	1.30	1.00	23%
Locker Room	0.60	0.48	20%
Lounge/Breakroom			
Healthcare facility	0.80	0.78	3%
All other lounges/breakrooms	1.20	0.62	48%
Office			
Enclosed and <= 250 ft2	1.11	0.93	16%
Enclosed and > 250 ft2	1.11	0.93	16%
Open plan	1.10	0.81	26%
Parking Area, Interior	0.20	0.14	30%
Pharmacy Area	1.20	1.34	-12%
Restroom			
Facility for the visually impaired (and not used pri	1.21	0.96	21%
All other restrooms	0.98	0.85	13%
Sales Area	1.70	1.22	28%
Seating Area, General	0.68	0.42	38%
Stairwell	0.60	0.58	3%
Storage Room			
<50 ft2	0.80	0.97	-21%
>50 ft2 and <=1000 ft2	0.80	0.46	43%
All other storage rooms	0.80	0.46	43%
Vehicular Maintenance Area	0.70	0.56	20%
Workshop	1.90	1.14	40%
Facility for the visually impaired			
Chapel (used primarily by residents)	2.77	1.06	62%
Recreation room/common living room (and not us	3.02	1.80	40%
Automotive			
Convention Center - Exhibit Space	1.30	0.88	32%
Dormitory—Living Quarters	1.11	0.54	51%
Fire Station - sleeping quarters	0.30	0.20	33%

205

LPDs: 2004-2016

Space by Space Method

Table 9.6.1 *(Part 3)*

Space Types	2004 From App G)	2016	Pct Chg from 2004
Gymnasium/Fitness Center			
Exercise area	0.90	0.50	44%
Playing area	1.40	0.82	41%
Healthcare Facility			
Exam/treatment room	1.50	1.68	-12%
Imaging room		1.06	#DIV/0!
Medical supply room	1.40	0.54	61%
Nursery	0.60	1.00	-67%
Nurse's station	1.00	0.81	19%
Operating room	2.20	2.17	1%
Patient room	0.70	0.62	11%
Physical therapy room	0.90	0.84	7%
Recovery room	0.80	1.03	-29%
Library			
Reading area	1.20	0.82	32%
Stacks	1.70	1.20	29%
Manufacturing Facility			
Detailed manufacturing area	2.10	0.93	56%
Equipment room	1.20	0.65	46%
Extra high bay area (>50 ft floor-to-ceiling height)	1.32	1.05	20%
High bay area (25-50 ft floor-to-ceiling height)	1.70	0.75	56%
High bay area (<25 ft floor-to-ceiling height)	1.20	0.96	20%
Museum			
General exhibition area	1.00	1.05	-5%
Restoration room	1.70	0.85	50%
Performing Arts Theatre - Dressing Room	0.61	0.36	41%
Post Office - Sort Area	1.20	0.68	43%
Religious Buildings			
Fellowship hall	0.90	0.55	39%
Worship/pulpit/choir area	2.40	1.53	36%
Retail Facilities			
Dressing/fitting room	0.89	0.50	44%
Mall concourse	1.70	0.90	47%
Sports Arena - Playing Area8			
Class I facility	4.61	2.47	46%
Class II facility	3.01	1.96	35%
Class III facility	2.26	1.70	25%
Class IV facility	1.50	1.13	25%
Transportation Facility			
Baggage/carousel area	1.00	0.45	55%
Airport concourse	0.60	0.31	48%
Terminal ticket counter	1.50	0.62	59%
Warehouse—Storage Area			
Medium to bulky palletized items	0.90	0.35	61%
Smaller, hand-carried items	1.40	0.69	51%

206

PERFORMANCE RATING METHOD

RESIDENTIAL INTERIOR LIGHTING

Unregulated:
- Dwelling Units (Condos/ Apartments)

Regulated:
- Common Areas
- Dormitory Living Quarters
- Residential Spaces with Transient Occupancies

General principle: *If an LPD is listed for the residential space under the space-by-space method (Table 9.6.1), the interior lighting is regulated.*

Portable Lighting: *All portable lighting shown in design should be included in proposed LPD*

207

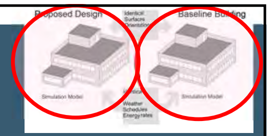
207

90.1 INTERIOR LIGHTING CONTROL REQ. OVER TIME

	Interior Lighting Controls	Version of 90.1 2004	2007	2010	2013
a.	Local Control	Yes (§9.4.1.2)	Yes (§9.4.1.2)	Yes (§9.4.1.2)	Yes (§9.4.1.2)
	Occupancy sensor		New (§9.4.1.2)	Yes (§9.4.1.2)	Yes (§9.4.1.2)
b.	Restricted to Manual On				New (§9.4.1)
c.	Restricted to partial automatic ON				New (§9.4.1)
d.	Bi-level lighting control		New (§9.4.1.2)	Yes (§9.4.1.2)	Yes (§9.4.1.2)
e.	Automatic daylight responsive controls for sidelighting			New (§9.4.1.4) Primary only	Revised (§9.4.1.4) Primary & Secondary
f.	Automatic daylight responsive controls for toplighting			New (§9.4.1.5) Primary only	Revised (§9.4.1.5) Primary & Secondary
g.	Automatic partial OFF (full OFF complies)				New (§9.4.1.1)
h	Automatic full OFF	Yes (§9.4.1.1)	Yes (§9.4.1.1)	Yes (§9.4.1.1)	Revised (§9.4.1.1)
i	Scheduled shutoff	Option (§9.4.1.1)	Option (§9.4.1.1)	Option (§9.4.1.1)	Revised (§9.4.1.1)

208

2016 Appendix G: Interior Lighting
Nine Mandatory Controls
(§ 9.4.1.1 & App. G. Table G3.1.6.Lighting)



	Type of Control	Proposed Design (2016)	Baseline Building (per 90.1-2004)
a.	Local Control	Required*	Not Required
b.	Restricted to Manual On	Required*	Employee lunch & break rooms, Conf./mtg. rooms, & classrooms**
c.	Restricted to partial automatic ON	Required*	Employee lunch & break rooms, Conf./mtg. rooms, & classrooms**
d.	Bilevel lighting control:	Required*	Not Required
e.	Automatic daylight responsive controls for sidelighting:	Required*	Not Required
f.	Automatic daylight responsive controls for toplighting:	Required*	Not Required
g.	Automatic partial OFF (full OFF complies):	Required*	Employee lunch & break rooms, Conf./mtg. rooms, & classrooms**
h.	Automatic full OFF:	Required*	Employee lunch & break rooms, Conf./mtg. rooms, & classrooms**
i.	Scheduled shutoff:	Required*	Not Required

* Specific req. can depend on space use category

** Exceptions for some types of classrooms

209

Example Space-by-Space Method Table: Application of 9 Control Req. by Space Type

Table 9.6.1 Lighting Power Density Allowances Using the Space-by-Space Method and Minimum Control Requirements Using Either Method *(Continued)*

Informative Note: This table is divided into two sections; this first section covers space types that can be commonly found in multiple building types. The second part of this table covers space types that are typically found in a single building type.

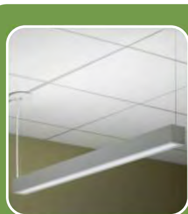
The control functions below shall be implemented in accordance with the descriptions found in the referenced paragraphs within Section 9.4.1.1. For each space type:
(1) All REQs shall be implemented.
(2) At least one ADD1 (when present) shall be implemented.
(3) At least one ADD2 (when present) shall be implemented.

			Local Control (See Section 9.4.1.1[a])	Restricted to Manual ON (See Section 9.4.1.1[b])	Restricted to Partial Automatic ON (See Section 9.4.1.1[c])	Bilevel Lighting Control (See Section 9.4.1.1[d])	Automatic Daylight Responsive Controls for Sidelighting (See Section 9.4.1.1[e[6]])	Automatic Daylight Responsive Controls for Toplighting (See Section 9.4.1.1[f[6]])	Automatic Partial OFF (See Section 9.4.1.1[g] [Full Off complies])	Automatic Full OFF (See Section 9.4.1.1[h])	Scheduled Shutoff (See Section 9.4.1.1[i])
Common Space Types[1]	LPD, W/ft²	RCR Threshold	a	b	c	d	e	f	g	h	i
Conference/Meeting/Multipurpose Room	1.07	6	REQ	ADD1	ADD1	REQ	REQ	REQ		REQ	
Confinement Cells	0.81	6	REQ	ADD1	ADD1	REQ	REQ	REQ		ADD2	ADD2
Copy/Print Room	0.56	6	REQ	ADD1	ADD1	REQ	REQ	REQ		REQ	
Corridor[2]											
Facility for the visually impaired (and not used primarily by the staff)[3]	0.92	width <8 ft	REQ				REQ	REQ	REQ	ADD2	ADD2
Hospital	0.92	width <8 ft	REQ				REQ	REQ	ADD2	ADD2	ADD2
Manufacturing facility	0.29	width <8 ft	REQ				REQ	REQ		ADD2	ADD2
All other corridors	0.66	width <8 ft	REQ				REQ	REQ	REQ	ADD2	ADD2
Courtroom	1.39	6	REQ	ADD1	ADD1	REQ	REQ	REQ		ADD2	ADD2
Computer Room	1.33	4	REQ	ADD1	ADD1	REQ	REQ	REQ		ADD2	ADD2
Dining Area											
Penitentiary	0.96	6	REQ	ADD1	ADD1	REQ	REQ	REQ		ADD2	ADD2
Facility for the visually impaired (and not used primarily by staff)[3]	2.00	4	REQ	ADD1	ADD1	REQ	REQ	REQ		ADD2	ADD2
Bar/lounge or leisure dining	0.93	4	REQ	ADD1	ADD1	REQ	REQ	REQ		ADD2	ADD2
Cafeteria or fast food dining	0.63	4	REQ	ADD1	ADD1	REQ	REQ	REQ		ADD2	ADD2
Family dining	0.71	4	REQ	ADD1	ADD1	REQ	REQ	REQ		ADD2	ADD2
All other dining areas	0.63	4	REQ	ADD1	ADD1	REQ	REQ	REQ		ADD2	ADD2

210

Performance Rating Method

Interior Lighting Controls (Table G3.1 #6)



Occupant Sensor Controls

- LPD adjustment allowed for spaces not regulated by 9.4.1.2 (Table G3.2 – ~10%–15% credit)
- Schedule adjustments may be used in lieu of LPD adjustment if a strong case is made for the savings

Daylighting Controls

- Credit is allowed if modeled directly in simulation software (care is required if building area method is used for lighting power density analysis)
- Credit may be allowed by authority having jurisdiction for schedule adjustments associated with daylighting study performed outside of the simulation software

211

211

Performance Rating Method

Interior Lighting Schedules (Table G3.1 #4 and #6)

Mandatory Provisions
- 9.4.1.1—Automated Shutoff
- 9.4.1.2—Occupant sensor controls

Anticipated Operation
- Operating hours: Account for anticipated hours of operation
- After hours: Account for after-hours O&M and emergency lighting

Differing Space / Building Function
- Spaces/building categories with differing schedules (corridor, storage, parking)
- Decorative or display lighting (9.6.2)

90.1-2010 stated that, in general, schedules should be modeled identically in the baseline and proposed cases. Variations to this general statement are shown in the following slide.

212

212

AUTOMATIC INTERIOR LIGHTING CONTROLS: CHANGES OVER TIME TO PRM APPROACHES

	Proposed Building Design (Modeling Rules)	Baseline Building Design (Modeling Rules)
90.1-2004	Credit may be taken for the use of automatic controls for daylight utilization but only if their operation is modeled correctly either directly or indirectly. For additional automatic lighting controls to those required under Section 9.4.1, credit may be taken by reducing the ***connected lighting power*** by the applicable percentages listed in Table G3.2.	No automatic lighting controls shall be modeled
90.1-2007	Credit may be taken for the use of automatic controls for daylight utilization but only if their operation is modeled correctly either directly or indirectly. For additional automatic lighting controls to those required under Section 9.4.1, credit may be taken by reducing the ***connected lighting power*** by the applicable percentages listed in Table G3.2.	No automatic lighting controls (e.g., programmable controls or automatic controls for daylight utilization) shall be modeled, as the lighting schedules used are understood to reflect the mandatory control requirements in this standard.
90.1-2010	Credit may be taken for the use of automatic controls for daylight utilization but only if their operation is modeled correctly either directly or indirectly. For additional automatic lighting controls to those required under Section 9.4.1, credit may be taken by reducing the ***connected lighting power*** by the applicable percentages listed in Table G3.2.	Lighting shall be modeled having the automatic and manual controls required by Section 9.4. No additional automatic lighting controls (e.g., automatic controls for daylight utilization) shall be modeled.
90.1-2013	The lighting schedules in the proposed building design shall reflect the mandatory automatic lighting control requirements in Section 9.4.1 (e.g., programmable controls or occupancy sensors). For additional automatic lighting controls beyond those required under Section 9.4.1, credit may be taken for automatically controlled systems by ***making schedule adjustments*** by a separate analysis approved by the AHJ. (An alternative method for adjusting Lighting Power is also provided)	Mandatory automatic lighting controls required by Section 9.4.1 shall be modeled the same as the proposed building design. Additional interior lighting power for nonmandatory controls allowed under Section 9.6.2(c) shall not be included in the baseline building design.
90.1-2016	The proposed design shall contain at least the (nine) mandatory automatic lighting controls specified in Section 9.4.1. See 90.1-2016, Tbl G3.1.6 (g) & (h) for modeling details.	Make ***adjustments in the lighting schedules*** by: Using automatic shutoff controls in buildings >5000 ft2. and Using occupancy sensors in: employee lunch and break rooms, conference/meeting rooms, and classrooms (not including shop classrooms, laboratory classrooms, and preschool through 12th-grade classrooms). No additional automatic lighting controls shall be modeled, e.g., automatic controls for daylight utilization and occupancy sensors in space types not listed

Source: Joseph Deringer

213

PERFORMANCE RATING METHOD

TYPICAL SCHEDULES FOR REFERENCE

This is one of 10 sets of typical schedules listed in the 90.1 User Manual for the occupancies:

1. Assembly
2. Health
3. Light Manufacturing
4. Office
5. Parking Garage
6. Restaurant
7. Retail
8. School
9. Warehouse
10. Laboratory

TABLE G-H. OFFICE OCCUPANCY[1]

Hour of Day (Time)	Schedule for Occupancy			Schedule for Lighting[2]/Receptacle			Schedule for HVAC System			Schedule for Service Hot Water			Schedule for Elevator		
	Percent of Maximum Load			Percent of Maximum Load						Percent of Maximum Load			Percent of Maximum Load		
	Wk	Sat	Sun	Wk	Sat	Sun	Wk	Sat	Sun	Wk	Sat	Sun	Wk	Sat	Sun
1 (12 to 1 am)	0	0	0	5	5	5	Off	Off	Off	5	5	4	0	0	0
2 (1 to 2 am)	0	0	0	5	5	5	Off	Off	Off	5	5	4	0	0	0
3 (2 to 3 am)	0	0	0	5	5	5	Off	Off	Off	5	5	4	0	0	0
4 (3 to 4 am)	0	0	0	5	5	5	Off	Off	Off	5	5	4	0	0	0
5 (4 to 5 am)	0	0	0	5	5	5	Off	Off	Off	5	5	4	0	0	0
6 (5 to 6 am)	0	0	0	10	5	5	Off	Off	Off	8	8	7	0	0	0
7 (6 to 7 am)	10	10	5	10	10	5	On	On	Off	7	7	4	0	0	0
8 (7 to 8 am)	20	10	5	30	10	5	On	On	Off	19	11	4	35	16	0
9 (8 to 9 am)	95	30	5	65/90	30	5	On	On	Off	35	15	4	69	14	0
10 (9 to 10 am)	95	30	5	65/90	30	5	On	On	Off	38	21	4	43	21	0
11 (10 to 11 am)	95	30	5	65/90	30	5	On	On	Off	39	19	4	37	18	0
12 (11 to 12 pm)	95	30	5	65/90	30	5	On	On	Off	47	23	6	43	25	0
13 (12 to 1 pm)	50	10	5	55/80	15	5	On	On	Off	57	20	6	58	21	0
14 (1 to 2 pm)	95	10	5	65/90	15	5	On	On	Off	54	19	9	48	13	0
15 (2 to 3 pm)	95	10	5	65/90	15	5	On	On	Off	34	15	6	37	8	0
16 (3 to 4 pm)	95	10	5	65/90	15	5	On	On	Off	33	12	4	37	4	0
17 (4 to 5 pm)	95	10	5	65/90	15	5	On	On	Off	44	14	4	46	5	0
18 (5 to 6 pm)	30	5	5	35/50	5	5	On	On	Off	26	7	4	62	6	0
19 (6 to 7 pm)	10	5	0	30	5	5	On	Off	Off	21	7	4	20	0	0
20 (7 to 8 pm)	10	0	0	30	5	5	On	Off	Off	15	7	4	12	0	0
21 (8 to 9 pm)	10	0	0	20	5	5	On	Off	Off	17	7	4	4	0	0
22 (9 to 10 pm)	10	0	0	20	5	5	On	Off	Off	8	9	7	4	0	0
23 (10 to 11 pm)	5	0	0	10	5	5	Off	Off	Off	5	5	4	0	0	0
24 (11 to 12 am)	5	0	0	5	5	5	Off	Off	Off	5	5	4	0	0	0
Total/Day	920	200	60	800/ 1040	280	120	1600	1200	0	537	256	113	555	151	0
Total/Week	48.60 hours			44.00/56.00 hours			92.00 hours			30.54 hours			29.26 hours		
Total/Year	2534 hours			2288/2920 hours			4797 hours			1592 hours			1526 hours		

Wk = Weekday

1. Schedules for occupancy, lighting, receptacle, HVAC system, and service hot water are from Standard 90.1–1989 and addenda, except that 5% emergency lighting has been added for all off hours. Elevator schedules, except for restaurants, are from the U.S. Department of Energy Standard Evaluation Techniques, except they have been changed to 0% when occupancy is 0%. These values may be used only if actual schedules are not known.

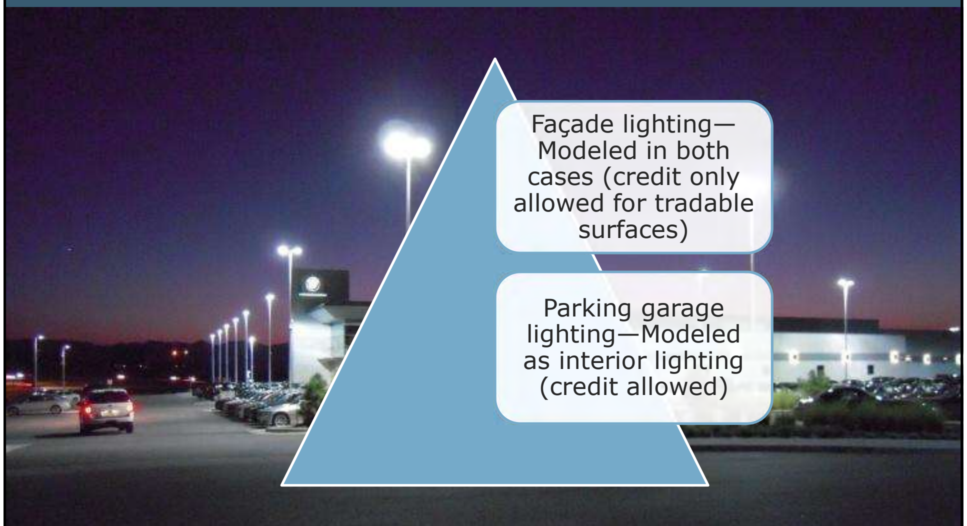
2. Lighting profiles are modified to reflect the requirement for occupancy sensors in Section 9.4.1 of Standard 90.1.

214

214

Performance Rating Method

Exterior Lighting



215

215

Questions?

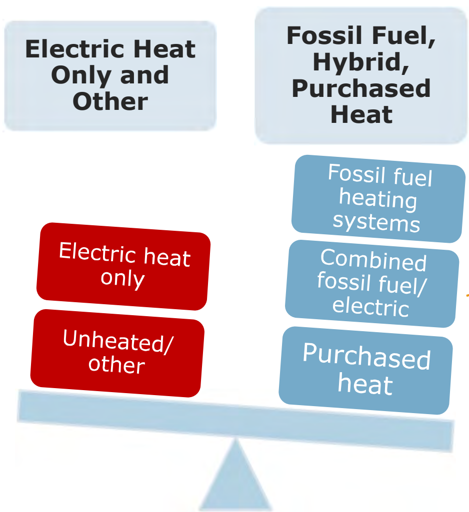
Next up…HVAC

216

216

Performance Rating Method

Baseline HVAC System Type—Heating Source (Table G3.1.1A)



Examples:

- VAV with fossil fuel furnace, electric reheat
- Water source heat pump with fossil-fuel boiler

217

217

Performance Rating Method

Baseline HVAC System Type—Non-Residential (Table G3.1.1A)

Based on total building conditioned area, number of floors, and heating source

< 4 floors ***and*** < 25,000 ft²: **Packaged Rooftop Constant Volume**

- **Fossil fuel/Hybrid*:** #3: Packaged AC with fossil fuel furnace
- **Electric/Other:** #4: Packaged heat pump

> 4 floors ***or*** ≥ 25,000 ft²: **Variable Air Volume**

- **Fossil Fuel/Hybrid*:** VAV boxes with hot-water heating
- **Electric /Other:** PFP Boxes with Electric Resistance Heating

	≤ 150,000 ft² and 4 or 5 floors **Packaged DX**	>150,000 ft² or > 5 floors **CHW**
Fossil Fuel/Hybrid*	#5	#7
Electric /Other	#6	#8

* Purchased heat should be modeled as purchased heat in baseline and proposed cases

218

218

PERFORMANCE RATING METHOD

BASELINE HVAC SYSTEM TYPE—RESIDENTIAL (TABLE G3.1.1A)

Most Residential Buildings

System Type #1: Packaged terminal air conditioners with hot water heating*

Heating = Electric/ Unheated/Other:

System Type #2: Packaged terminal heat pumps

* Purchased heat should be modeled as purchased heat in baseline and proposed cases

Cooling capacities to calculate cooling and heating efficiency should range between 7000 and 15,000 Btu/h

219

219

PERFORMANCE RATING METHOD

BASELINE HVAC SYSTEM TYPE – EXCEPTIONS (G3.1.1)

(a)

- Non-predominant conditions:
  - Residential space versus non-residential space
  - Portion of the building all electric; another portion is not

(b)

- Use system type #3 or #4 for spaces that vary from other spaces served by the same VAV system:
  - Varying peak thermal loads (more than 10 Btu/h·ft^2)
  - Varying schedules (more than 40 EFLH per week)

(c)

- Use system type #3 or #4 for spaces where VAV not feasible:
  - Special pressurization relationships
  - Code-required minimum circulation rates
  - Cross-contaminant requirements

(d)

- Laboratory spaces with at least 5000 cfm of exhaust:
  - Use system type 5 or 7 that reduce exhaust and makeup air to 50% of design values during unoccupied periods

220

220

Performance Rating Method

HVAC—Both Heating and Cooling

- ***Both*** heating and cooling must be modeled for all conditioned spaces (for baseline and proposed cases)
- Space is conditioned ***if*** it is cooled to more than 5 Btuh/ft^2 or heated above the values in Table 3.1

Baseline cooling type, efficiencies, and capacity ratio are modeled in proposed case if no cooling is installed.	Baseline heating type, efficiencies and capacity ratio are modeled in proposed case if no heating is installed.	Fan operation

221

221

Performance Rating Method

Baseline HVAC System Type—Grey Areas

Semi-heated spaces

- Not regarded as conditioned space.
- Heating system type, heating capacity ratios, fan power, and fan volume should be modeled the same in the baseline and proposed cases
- Heating efficiencies for the baseline case should reflect the values for the installed equipment type from Tables 6.8.1E and 6.8.1F

Makeup air units

- Baseline case systems should be modeled with outside air supplied directly to the units. No makeup air should be modeled.

Unenclosed spaces

- Systems should be modeled identically in the baseline and proposed cases, except when varying equipment efficiencies consistent with prescriptive baseline requirements.

Fans that aren't interlocked with air-handler operation

- Any fans not interlocked with the HVAC system operation (for baseline system types #1 through #8) should be modeled identically in the baseline and proposed cases, except for motor efficiencies.

222

222

Performance Rating Method

Non-Residential Thermal Blocks (Table G3.1.1 #7 and #8)

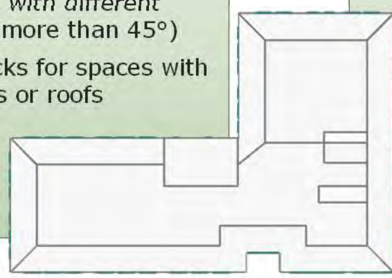
HVAC Zones Not Designed:

- Grouped based on similar internal loads
- Separate perimeter versus interior zones where perimeter zones end 15 feet from exterior wall
- Separate blocks for glazed exterior walls *with different* orientations (more than 45°)
- Separate blocks for spaces with exterior floors or roofs

HVAC Zones Designed:

1 thermal block per zone **except**—group zones into one thermal block, if following conditions are met:

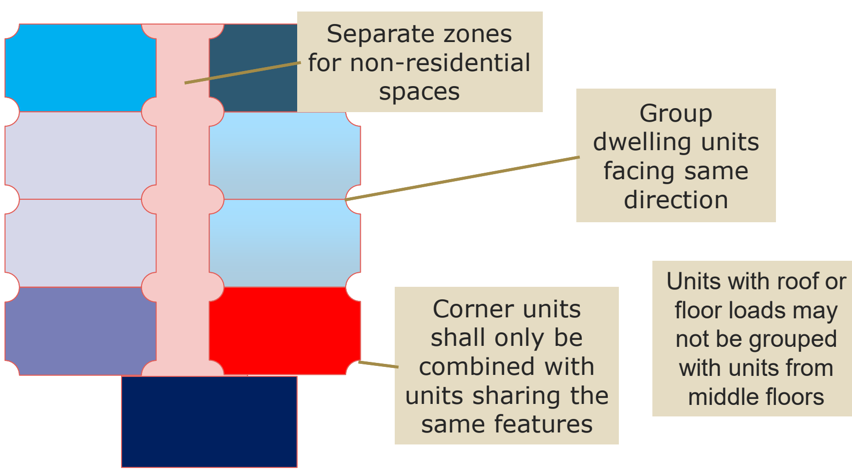
- Space use classification is the same for entire thermal block
- All zones adjacent to glazed exterior walls face the same orientation (within 45°)
- All zones are served by the same proposed case HVAC system or the same kind of HVAC system



223

Performance Rating Method

Residential Thermal Blocks (Table G3.1.1 #7 and #8)



224

Performance Rating Method
Baseline HVAC System Assignment (G3.1.1)

Single-Zone Constant Volume (System types #1 through #4)
- One system modeled per thermal block

Variable-Air Volume (System Types #5 through #8
- One system modeled per floor**

*Floors with identical thermal blocks can be grouped
**ANSI/ASHRAE/IES Standard 90.1-2007 and subsequent versions, not 2004

225

225

Performance Rating Method
Baseline HVAC System Capacities

Cooling Capacity Ratio: Oversized by 1.15

- Fan volume sized for 20°F supply air—room air ΔT
- Oversizing should generally be done at the cooling coils, but never both at the cooling coils and chiller plant

Use Auto-size function when possible (design day schedules are critical)

Heating Capacity Ratio: Oversized by 1.25

Oversizing should generally be done at the heating coils, but never both at the heating coils and boiler plant

Check output files to verify:

(a) Cooling operates at least a few hours in 70%–80% range

(b) Heating operates at least a few hours in 60%–70% range

226

226

Performance Rating Method
HVAC System Efficiencies

Table 6.8.1 Baseline Efficiency References	Packaged DX (System Types #1–#6)	Chilled Water (System Types #7 & #8)	Hot Water (System Types #5 & #7)
• 6.8.1A: DX AC Cooling (#3 and #5) • 6.8.1B: Heat Pump (#4) • 6.8.1D: PTACs and PTHPs (#1 and #2) • 6.8.1C: Chillers (#6 and #8) • 6.8.1E: Furnaces (#3) • 6.8.1F: Boilers (#5 and #7) • 6.8.1G: Axial cooling towers (#7 and #8)	• Generally input at ARI conditions (Baseline should always be at AHRI) • Cooling descriptor broken out from fans • Part-load conditions should be representative across all operating conditions • Baseline efficiency determined for each baseline system based on each system's capacity	• Generally input at ARI conditions (baseline should always be at AHRI) • Axial fan cooling tower efficiency for baseline case is 38.2 gpm/hp, two-speed fan controls • Part-load: baseline should be representative of the equipment type and IPLV/IEER. Proposed case should be representative of actual operating conditions	• Part-load should be representative of equipment type. Average baseline efficiency should not drop much below 75%. • Justification should be provided for varying equipment curves • Proposed case condensing boiler curves should account for anticipated operating temperatures

227

Performance Rating Method
Baseline System Fan Power (G3.1.2.10)

Residential PTACs or PTHPs (Systems #1, #2, #9, #10):
$P_{fan} = CFM_s * 0.3$

Non-residential constant volume systems (Systems #3 and #4):
$P_{fan} = (CFM_s \times 0.00094 + A) \times 746 / \eta_m$

Baseline Fan Power = sum of peak supply + return + exhaust + relief fans, where CFMs refers to Supply cfm for each Baseline system, P_{fan} is in units of Watts, and η_m refers to motor efficiency

A: Calculated from 6.5.3.1.1:
Use supply CFM for each Baseline system

Non-residential VAV systems (System Types #5 through #8):
$P_{fan} = (CFM_s * 0.0013 + A) \times 746 / \eta_m$

228

228

PERFORMANCE RATING METHOD

BASELINE SYSTEM FAN POWER—PRESSURE ADJUSTMENT (TABLE 6.5.3.1.1B)

Deductions

- Fume hood exhaust exception (if fume hoods excluded from baseline fan power allowance)

Credits

- Filters: MERV 9+
- Return/exhaust airflow devices
- Gas-phase air cleaners
- Ducted return/exhaust
- Sound attenuation
- Heat recovery*
- Evaporative humidifier*

A = Sum of $(PD \times CFM_D / 4131)$

*Credits for heat recovery and evaporative humidifier only taken if modeled in baseline

229

229

PERFORMANCE RATING METHOD

OUTSIDE AIR VENTILATION

Minimum Outside Air Volume (G3.1.2.5)

- Same in baseline and proposed cases
- Exception: DCV modeled for credit

Night-Time Ventilation (6.4.3.4.3)

- Minimum outside air rates modeled with zero flow or minimum required health safety ventilation for unoccupied periods
- Exception: Night purge

Demand Control Ventilation for Credit (G3.1.2.5)

- Method for taking credit must be approved by authority having jurisdiction
- GBCI (LEED) requires ANSI/ASHRAE 62.1 rates for baseline if DCV is modeled in proposed

230

230

Questions?
Up Next Are Controls

231

231

Performance Rating Method
Controls—Fan System Operation (G3.1.2.5)

Occupied Periods—Both Heated and Cooled	• Fans continuous for all fans providing outside air for ventilation
Occupied Periods—Heating or Cooling Only	• Fans cycling in proposed/ continuous in baseline
Unoccupied Periods	• Fans cycle on to meet load unless health regulations require continuous fans

232

232

Performance Rating Method
Baseline Controls—Economizers (G3.1.2.7-8)

Systems #1, 2, 9, 10

- Not Required

Systems #3–#8

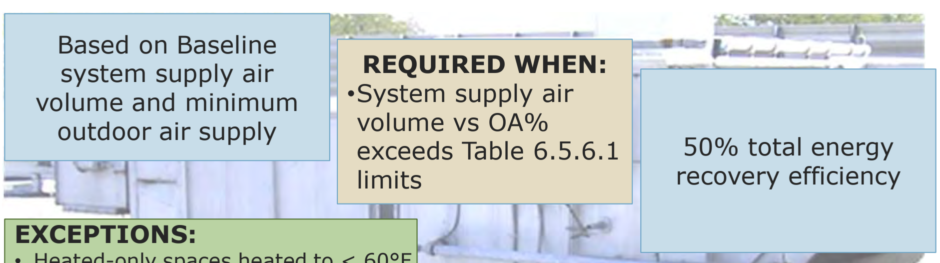
- Not required in warm humid climates
- 75°F dry-bulb shutoff in mild or warm marine or warm/dry climates
- 70°F dry-bulb shutoff in mild/humid climates
- 65°F dry-bulb shutoff in other climate zones

Exceptions:
- Economizer operation would interfere with refrigerated casework (exclusion only allowed if there are no proposed case economizers modeled)
- Gas-phase air cleaning is used to meet ANSI/ASHRAE Standard 62.1, Section 6.1.2

233

233

Performance Rating Method
Baseline Controls – Energy Recovery



Based on Baseline system supply air volume and minimum outdoor air supply

REQUIRED WHEN:
- System supply air volume vs OA% exceeds Table 6.5.6.1 limits

50% total energy recovery efficiency

EXCEPTIONS:
- Heated-only spaces heated to < 60°F
- Toxic, corrosive or flammable exhaust*
- Commercial kitchen grease hoods*
- Heating mode for climate zones 1 through 3
- Cooling mode for climate zones 3c, 4c, 5b, 5c, 6b, 7, 8
- Largest source of exhaust less than 75% design outdoor airflow*
- Systems requiring dehumidification that use energy recovery in series with cooling coil
- Systems serving labs with exhaust rates > 5,000 cfm (which requires VAV in Baseline)
- <20 hrs/ week operation

* Exception only applies if energy recovery is not included in proposed design

234

234

Performance Rating Method

Baseline Controls—Heat Pumps (G3.1.3.1)

Heat Pump Auxiliary Heat

- Auxiliary heat = Electric resistance
- Heat pumps controlled with multistage space thermostats
- Auxiliary heat only engages for < 40°F
- Auxiliary heating only engages for last stage of heating

235

235

Performance Rating Method

Baseline System Air-Side VAV Controls (G3.1.3.12-14)

Supply Air Temperature Reset	VAV Terminal Units (Systems #5 and #7)	PFP VAV Terminal Units (Systems #6 and #8)
• **Reset up to 5°F higher based on worst-case zone**	• **Minimum volume = larger of: 30% of design flow *or* minimum ventilation requirement**	• **Fans only on during heating mode** • **Sized for 50% of peak load** • **Minimum volume = larger of: 30% of design flow *or* minimum ventilation requirement**

VAV fan part-load performance curves: See Table G3.1.3.15.

236

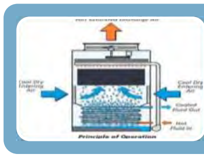
236

Performance Rating Method

Baseline Controls—Circulation Loop Temperature Reset

Hot-Water Loop
(G3.1.3.4: System Types #1, 5, 7)
- Outside air dry-bulb temperature reset
- 180°F at ≤ 20°F OSA temperature → ramped linearly → 150°F at ≥ 50°F OSA

Chilled-Water Loop
(G3.1.3.9: System Types #7, 8)
- Outside air dry-bulb temperature reset
- 54°F at ≤ 60°F OSA temperature → ramped linearly → 44°F at ≥ 80°F OSA



Condenser Water Loop
(G3.1.3.11: System Types #7, 8)
- 85°F leaving water temperature floating down to 70°F leaving water temperature

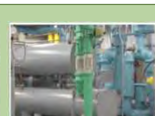
237

237

Performance Rating Method

Baseline Case—Plant Cooling Equipment Quantities and Types

Building Peak Cooling Load ≤ 300 tons:
1 water-cooled screw chiller, 1 constant speed primary CHW pump, 1 constant speed secondary CHW pump, 1 constant speed CW pump. Constant primary/variable secondary CHW flow with secondary pump riding the curve.

Building Peak Cooling Load: > 300, < 600 tons
2 equally sized water-cooled screw chillers, 2 constant speed primary CHW pumps, 1 variable speed secondary CHW pump, 2 constant speed CW pumps. Constant primary/variable secondary CHW flow





Building Peak Cooling Load: ≥ 600 tons
2 or more equally sized water-cooled centrifugal chillers with no chiller > 800 tons. 1 variable speed secondary CHW pump. Number of constant speed primary CHW pumps = Number of constant speed CW pumps = Number of chillers. Constant primary/variable secondary CHW flow

238

238

Performance Rating Method

Baseline Case—Plant HHW Equipment Quantities and Types

< 15,000 ft²
- 1 Natural draft boiler
- 1 Constant speed pump
- Variable primary flow with pump riding the curve

≥ 15,000 ft², < 120,000 ft²
- 2 Natural draft boilers
- 1 Constant-speed, variable primary flow with pump riding the curve

≥ 120,000 ft²
- 2 Natural draft boilers
- 1 Variable-speed pump
- Variable primary flow

239

239

Performance Rating Method

Typical HVAC Efficiency Measures

Passive Strategies
- Passive Cooling
- Passive Heating
- Natural Ventilation
- Massing
- Orientation
- Glazing Placement

System Type
- Ground-Source Heat Pump
- CHW vs. DX
- VRV
- UFAD/ Displacement Ventilation
- Chiller Type
- Evaporative cooling

System Efficiencies
- Packaged DX
- Chillers
- Condensing Boilers/ Furnaces
- Motors

Controls
- DCV
- Setbacks
- CHW ΔT
- Water-Side Economizer
- Pump/Chiller VSDs
- Var. Primary Flow
- Energy Recovery
- Min. Flows

240

240

Performance Rating Method
Service Water Heating

- Reflect designed system using actual system type, capacities, and efficiencies for proposed case
- Model combined DHW/HHW systems as separate systems in the baseline
- Model district steam/hot water identically in baseline and proposed cases (using purchased energy rates)
- Service water loads and usage should be equal to proposed design except:
  - Loads reduced by low-flow SHW fixtures or greywater heat recovery may be modeled in the proposed case. Assumptions must be justified.
- Condenser heat recovery must be modeled in the baseline case for large 24-h facilities:
  - If total installed heat rejection capacity > 6,000,000 Btu/h
  - If design service water heating load > 1,000,000 Btu/h
  - Model the system as preheating service hot-water draw to 85°F or model directly in software

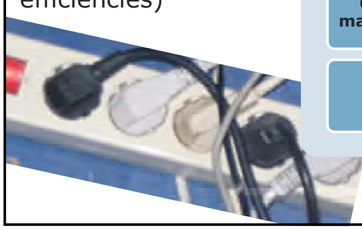
241

241

Performance Rating Method
Unregulated Energy

All process loads must be included in the model.

Baseline and proposed cases should be identical, except where minimum equipment efficiencies are regulated (e.g., motor efficiencies)



Receptacles
- Computers
- Monitors
- Copy machines
- Etc.

Process Loads
- Server rooms
- Refrigeration
- Cooking
- Manufacturing

Transport
- Elevators
- Escalators
- Moving walkways

Other
- Swimming pools
- Parking ventilation fans
- Snow melt

242

242

Performance Rating Method
COMNET Instructional Guides

- Energy savings modeling and inspection guidelines for commercial building federal tax deductions
- COMNET commercial buildings energy modeling guidelines and procedures

www.comnet.org

243

243

Questions?
Up Next is LEED

244

244

Performance Rating Method

LEED V4 and ANSI/ASHRAE/IES Standard 90.1-2010 Appendix G

Allows credit for process efficiency measures using the "exceptional calculation method"

Includes all exterior lighting, and allows credit for tradable exterior lighting surfaces

LEED V4 Performance Improvements

Category			Points		
New Constr'n	Major Renov'n	Core & Shell	Health-care	Schools	Other
6%	4%	3%	3	1	1
8%	6%	5%	4	2	2
10%	8%	7%	5	3	3
12%	10%	9%	6	4	4
14%	12%	11%	7	5	5
16%	14%	13%	8	6	6
18%	16%	15%	9	7	7
20%	18%	17%	10	8	8
22%	20%	19%	11	9	9
24%	22%	21%	12	10	10
26%	24%	23%	13	11	11
29%	27%	26%	14	12	12
32%	30%	29%	15	13	13
35%	33%	32%	16	14	14
38%	36%	35%	17	15	15
42%	40%	39%	18	16	16
46%	44%	43%	19		17
50%	48%	47%	20		18

245

245

Performance Rating Method

LEED: Major Renovations

Envelope
- Baseline: Existing conditions prior to renovation
- Proposed: Includes renovations

Lighting
- Baseline: Building area or space-by-space method
- Proposed: Actual lighting power (including unrenovated spaces)

HVAC
- Baseline: Appendix G system types and requirements
- Proposed: Actual HVAC system types and controls

247

247

Performance Rating Method

LEED: Core and Shell

Envelope: Model as designed

Lighting: Model core spaces as designed with baseline modeled using space-by-space method; model tenant spaces identically in the baseline and proposed cases unless tenant requirements are provided.

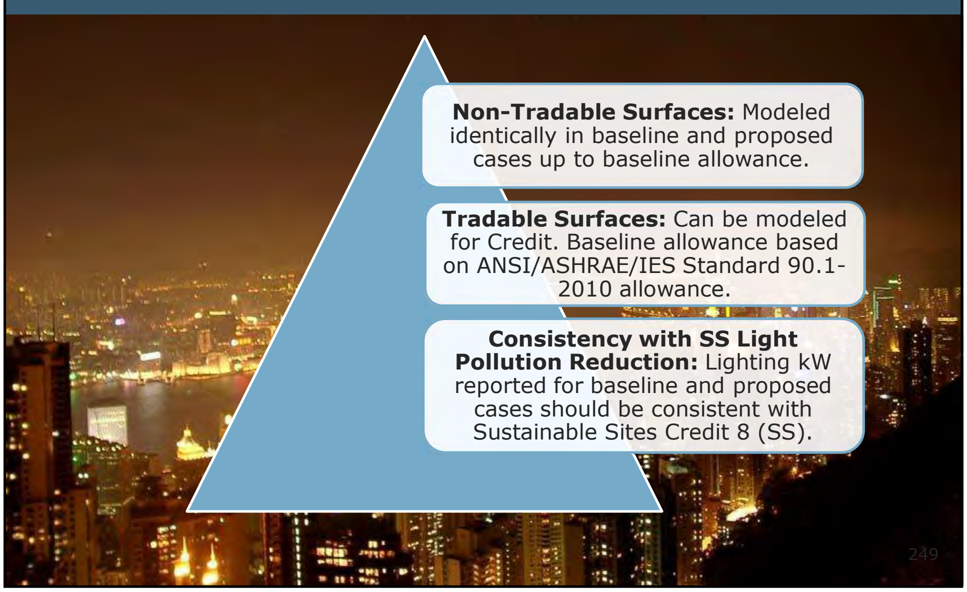
HVAC: Model all HVAC components included in the design. For HVAC components not yet included in the design, model the proposed case identically to the baseline case.

248

248

Performance Rating Method

LEED V4: Exterior Lighting



Non-Tradable Surfaces: Modeled identically in baseline and proposed cases up to baseline allowance.

Tradable Surfaces: Can be modeled for Credit. Baseline allowance based on ANSI/ASHRAE/IES Standard 90.1-2010 allowance.

Consistency with SS Light Pollution Reduction: Lighting kW reported for baseline and proposed cases should be consistent with Sustainable Sites Credit 8 (SS).

249

249

Performance Rating Method
LEED: Process (Unregulated) Loads

Exceptional Calculation Method

- The savings should be calculated separately from the main baseline/proposed models
- Calculations should be provided
- Narrative should explain calculation and justify assumptions

Baseline Assumptions

- Should be consistent with standard practice for a similar, newly constructed facility where the project is located
- Should be justified with published data or monitoring
- Referenced equipment should show consistent function and performance as designed equipment

Proposed Assumptions

- Should reflect the actual designed equipment

250

250

Performance Rating Method
LEED: Demand Control Ventilation

Baseline:

- Use ANSI/ASHRAE Standard 62.1 minimum rates for spaces where DCV credit is taken
- Schedule unoccupied periods with zero outside air or minimum health/safety rates required when unoccupied

Proposed:

- Generally modelable within energy software
- Maintain minimum floor air volumes during "occupied" periods, even when space is unoccupied

251

251

QUESTIONS?
UP NEXT IS CALIBRATION AND M&V

252

252

Calibration and M&V

Calibration Overview
Measurement and Verification Overview
Case Studies
Calibration Guidance

253

253

VALUE OF CALIBRATING AN EXISTING BUILDING MODEL

Calibration can help answer key questions:

- How good are my modeling assumptions?
- Are the savings estimates reliable?
- Did the building perform as expected?
- Are there opportunities for operational improvements?

254

254

CALIBRATION APPROACH

255

255

Effective Calibration

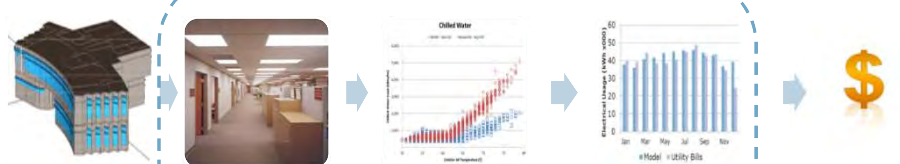
Follow "best practices" process
- Information collection
- Data review
- Calibration check

Learn from case studies
- Define appropriate scope of work
- Inform model input
- Investigate solutions
- Provide value

256

256

Calibration Process



Existing Building Model → **1. Inform Model Input Values** → **2. Investigate and Tune** ⇄ **3. Check Calibration** → Add Value through Findings

See ASHRAE Guideline 14, Section 6.3 for detailed process outline

257

257

Calibration Process
1. Inform Model Input Values

Information Resources
- Utility data
- Weather data
- As-built documents
- Submittals
- Operator interview
- Comfort survey data
- Survey data
- Audit data
- Sequence of operations
- Trend logs
- Short-term monitoring

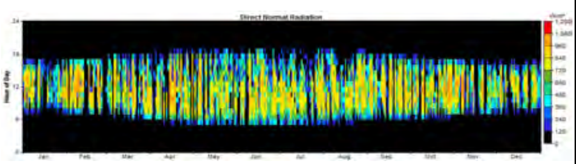
Nominal Input Checks
- Operating schedules
- HVAC start/stop times
- VAV box minimum airflow
- Supply air temperature control
- Set point temperatures
- Economizer operation
- Day, night, and weekend plug loads and lighting loads
- Exterior lighting, other miscellaneous loads

258

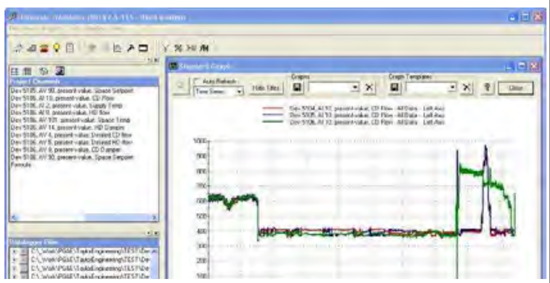
258

Calibration Process
2. Investigate and Tune

- Utility load shapes
- "Energy signature"
- Schedules
- Equipment load shapes
- Performance
  - CHW load vs. OA
  - Fan W/CFM vs. flow
- Controls
  - HW temp vs. OA
  - AHU MAT vs. OA



DView - https://beopt.nrel.gov/downloadDView

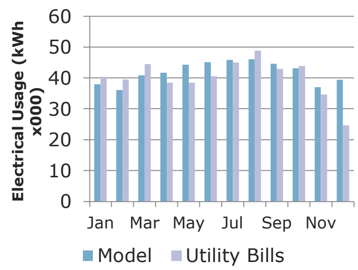


Universal Translator: http://utonline.org

259

259

Calibration Process
3. Check Calibration



From FEMP M&V Guidelines v. 2.2 and ASHRAE Guideline 14

Criteria	Equation*	Monthly Data	Hourly Data
ERR_{month}	100 * (M-S) / M	±15%	
Mean ERR_{month}	$\sum ERR_{month}$ / 12	±5%–10%	±7%–10%
CV($RMSE_{year}$)	$(\sum [(M-S)^2/12])^{0.5}$	±10%	±30%

* M => measured S=> simulated

260

260

M&V Overview
The Path to Improved Performance

M&V is part of a performance feedback loop that benefits:

- Facility Managers
- Designers
- Energy Modelers

261

261

M&V Overview

Benefits

Building Owner
- Targeted vs. projected building performance
- Value of potential improvements

Facility Manager
- Understanding measures
- Make "quantifiable" cases for change

Modeler
- Better understanding of model assumptions

Design Engineer
- How measures/systems really perform
- Impact of design considerations

262

262

M&V Overview

Predicted vs. Actual

"…a quarter of the new buildings that have been certified do not save as much energy as their designs predicted..."

"If you're not reducing carbon, you're not doing your job." Scott Horst, Senior Vice President, USGBC

New York Times, August 31, 2009, *Some Buildings Not Living Up to Green Label.*

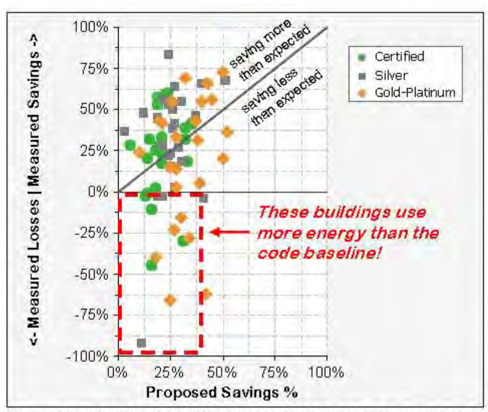


Figure ES- 5: Measured versus Proposed Savings Percentages

Source: NBI/USGBC. 2008. Energy Performance of LEED for New Construction Buildings. March 2008.

263

263

M&V Overview
Definition

"Transparent reporting of energy savings relative to historical or some normal reference baseline."

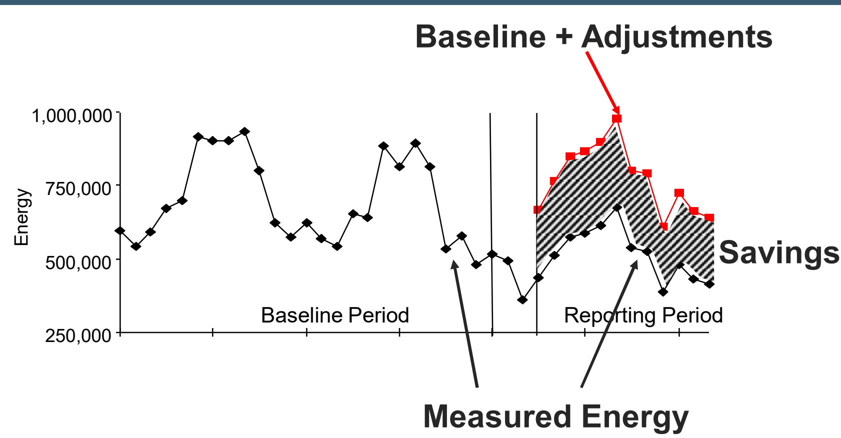
"A procedure to quantify avoided energy use or demand resulting from energy conservation measures."

Source: EVO/IPMVP.

264

264

M&V Overview
Determination of Savings

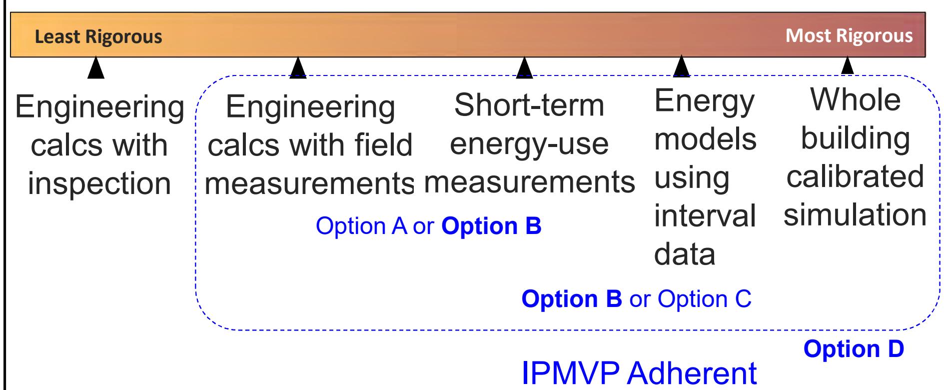


Source: IPMVP Training Materials.

265

265

M&V Overview
Approaches



Adapted from CCC "Method Evaluation Matrix".

266

266

M&V Overview
IPMVP Option D Process

Collect building data, weather data
- Create weather file, update model inputs

Calibrate simulation model to utility billing data
- Inform calibration with inspection, Cx, performance data

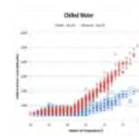
Apply adjustments to baseline model
- Occupancy, equipment schedules, set points

Calculate savings
- Method 1 or Method 2

267

267

M&V Overview
Option D Baseline Adjustments

Design Model	Model relies on **many** operating assumptions	
Calibrated Model	Tuned input values based on observations and performance data	
Adjusted Baseline	Baseline adjusted for occupancy, schedules, set points, unregulated loads, etc.	

268

268

M&V Overview
Option D Savings Calculations

Option D, Method 2

Savings = Adjusted Baseline Energy – Actual Energy

("Would have used" vs "Actual use")

Option D, Method 1

Savings = Adjusted Baseline Energy – ***Modeled*** Actual Energy

("Would have used" vs "Predicted use")

269

269

M&V Overview
LEED

Advanced Energy Metering*

Intent	Support energy management and identify opportunities for additional energy savings by tracking building-level and system-level energy use.
Requirements	Install advanced energy metering for • All whole-building energy sources • Individual energy end uses that ≥ 10% of the building's total annual consumption.
Details	• Permanent meters, ≤ 1 hour data, transmit via BMS or equivalent, to remote location • Energy AND demand (electricity) • Minimum 36 month storage • Meters record hourly, daily, monthly, annual use

* Leed V4 credit which "replaces" V3 M&V

270

270

Calibration/M&V Case Studies
Acknowledgments

Thank you for sharing your project information

1. Elementary School …… NORESCO
2. Federal Office Building ..Group14 Engineering
3. High-Rise Office ………. Kolderup Consulting
4. University Laboratory ….Taylor Engineering
5. High-Rise Office ………. Grumman/Butkus Associates

271

271

Calibration Case Studies

Introduction

Objectives impact level of complexity

Design Feedback → LEED NC M&V → ECM Analysis → M&V → Optimize Performance

Project	Building Floor Area	Annual Energy Costs	Objective	Level of Effort
Elementary School	63,000 ft^2	$36,540	Design feedback	2 days
High-Rise Office	400,000 ft^2	$940,000	LEED M&V	20 days
Federal Office	735,000 ft^2	$2,090,000	ECM evaluation	35 days
University Laboratory	125,000 ft^2	$1,300,000	Optimize performance	60 days
High-Rise Office	922,000 ft^2	$1,000,000	Investment	40 days

272

Elementary School Case Study

Project	Building	Energy Costs	Scope	Effort
New school	63,000 ft^2	$36,540	Modeling feedback	2 days

Inform
- Cx report
- Interview
- Monthly utility data

Investigate
- **Sensitivity studies**

Check
- **Visual check**
- Criteria check

Add Value
- Gross reality check
- Inform future models

See ASHRAE *High Performing Buildings*, Winter 2009

273

273

Bethke Elementary Case Study

Owner: Poudre School District
Location: Timnath, CO
Principal Use: 10-month school with classrooms, gym, media center, office
School Capacity: 525
Completion Date: Aug 2008
Cost: $151/ft^2
Size: 63,000 ft^2

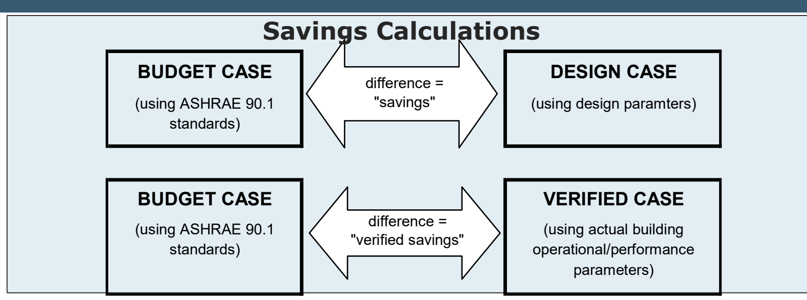
Energy Costs: $0.58/ft^2·yr
Energy Use: 47 kBtu/ft^2·yr

Awards: LEED for Schools Gold, 3 of 4 Green Globes, Energy Star Label of 99

274

274

Bethke Elementary
M&V – EAc5 M&V Plan



Operation Verification

3	Cooling tower (CT -1)	VFD. Occupied / Unoccupied mode	- Cooling tower fan operation interlocked with cooling water pump operation - VFD will modulate fan speed to maintain chilled water supply at 60°F (adj.)
4	Cooling water circulation loop (P -4)	Pump interlocked with chilled water pump	- Pump operation interlocked with chilled water distribution pump operation

275

275

Bethke Elementary
M&V—Implementation

Owner's (Alternative) Approach

- Commission building
- Compare actual against anticipated
- Compare actual against other prototypes

OK

2010 Fiscal Year (July 2009 - June 2010)						
Building	Year Constructed	Floor Area [ft^2]	Max Peak Demand [W/ft^2]	Energy Cost [$/ft2 Year]	Energy Use [kBtu/ft2 year]	Energy Star Rating
Operations Office	2002	8,753	3.4	0.44	19.0	99
Zach Elementary*	2002	67,412	1.7	0.54	42.6	96
Bacon Elementary	2003	65,299	1.6	0.54	45.7	97
Fossil Ridge High School	2004	296,375	2.3	0.56	40.9	94
Kinard Middle	2006	112,735	2.6	0.39	21.6	98
Rice Elementary	2007	62,691	1.4	0.75	41.5	99
Bethke Elementary	2008	62,691	1.5	0.58	41.7	99

*Includes 7,200 sq.ft. of modular classrooms

276

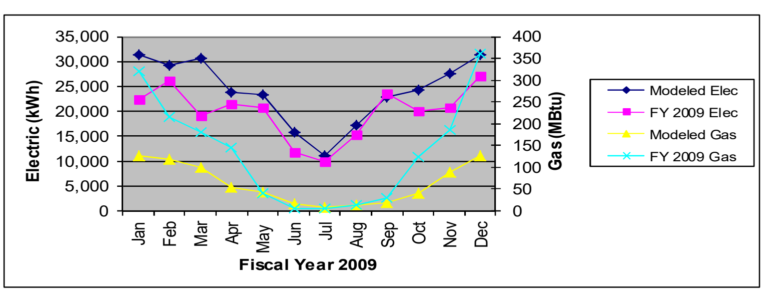
Bethke Elementary
M&V—Implementation

Option D Approach

- Collect performance data*
- Update proposed design energy model
- Adjust baseline model for independent variables such as occupancy, schedules, ...
- Calculate energy savings

* Assumes building is operating as intended

Risk vs. Value?



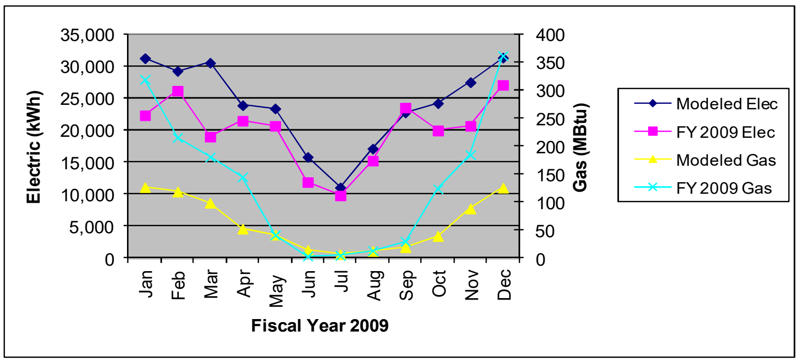
277

277

Bethke Elementary
M&V—Calibration

Monthly utility billing data can give insight into

- DHW from gas use in summer
- Heating from gas in winter
- Cooling from electric in summer
- Swing season for schedules, plugs

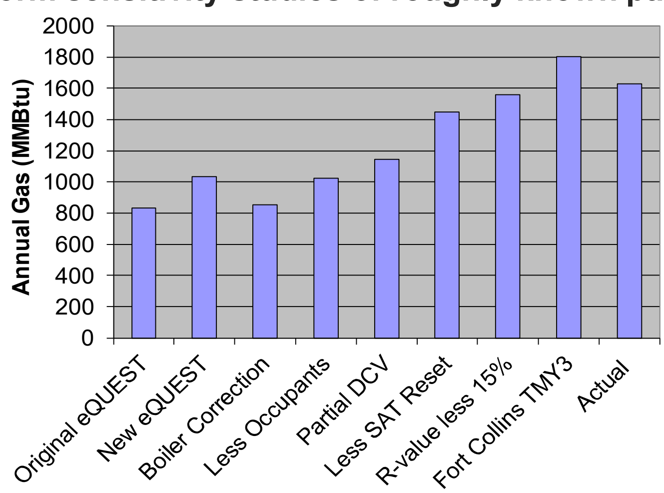


278

278

Bethke Elementary
M&V—Calibration

Perform sensitivity studies of roughly known parameters



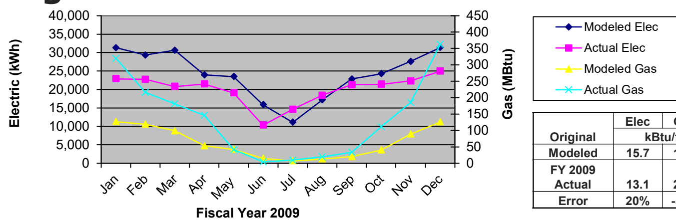
279

279

Bethke Elementary

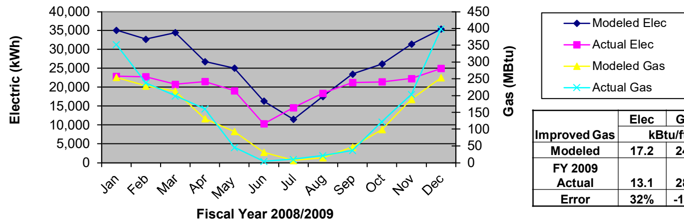
M&V—Calibration

Original Model



Original	Elec	Gas	Total	Cost
	kBtu/ft² year			$
Modeled	15.7	12.0	27.7	34,590
FY 2009 Actual	13.1	26.0	39.1	36,387
Error	20%	-54%	-29%	-5%

Improved Gas Modeling Assumptions



Improved Gas	Elec	Gas	Total	Cost
	kBtu/ft² year			$
Modeled	17.2	24.9	42.1	42,900
FY 2009 Actual	13.1	28.6	41.7	36,387
Error	32%	-13%	1%	18%

280

280

Bethke Elementary

M&V—Calibration

Checking calibration criteria (monthly data)*

- Mean ERR_{month} ± 15% $100 * (M-S) / M$
- Mean ERR_{year} ± 10% $\Sigma\ ERR_{month}\ /\ 12$
- $CV(RMSE_{year})$ ± 10% $(\Sigma\ [(M-S)^2 / 12])^{0.5}$

* From FEMP M&V Guidelines v. 2.2 and ASHRAE Guideline 14-2002

	Elec	Gas
Min ERR_{month}	5%	-2%
Max ERR_{month}	-66%	-658%
Mean ERR_{year}	-32%	4%
$CV(RMSE_{month})$	40%	31%

CALIBRATION DATA	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year	Average
Model (MMBtu)	254	229	213	131	93	31	7	15	47	99	189	253	1,560	130
Utility FY 2009 (MMBtu)	320	216	181	146	42	4	10	20	33	111	185	363	1,631	136
Mean ERR	21%	-6%	-18%	10%	-124%	-658%	27%	24%	-41%	11%	-2%	30%	4%	
MSE	366	14	84	19	221	60	1	2	15	12	1	1,002		
RMSE													42	
CV(RMSE)													31%	

281

Federal Office Case Study

Project	Building	Energy Costs	Scope	Effort
1960s office building	735,000 ft^2	$2,090,000	ECM evaluation	35 days

Inform

- As-built drawings
- Cut sheets
- Audit data
- Interviews
- Monthly utility data
- BMS data

Investigate

- **Identify known and unknown values**
- **Tweak with low impact to ECM analysis**

Check

- Visual check
- Criteria check

Add Value

- $634,000 ECM savings identified
- Analysis efforts increased LCC by 0.7%

See *ASHRAE Journal*, Nov. 2011

282

282

Federal Office Case Study

Roughly Known	Source	Approach
Ventilation airflow	Damper position, MEP schedules	Fixed—best estimate
Wall, roof R-values	As-built drawings	Fixed—as indicated
Data Center airflow	CRAC capacities, site survey	Fixed—best estimate
Elevator energy use	Published research	Fixed—typical values
Weather	Published TMY2	Baltimore TMY2—based on sensitivity analysis

Unknown	Source	Approach
Plug loads and schedules	Occupant density, published values, experience	Used for electricity calibration
Kitchen energy use	Interviews, typical values	Fixed—minor use
Building infiltration	Typical values	Used for CHW calibration
Parking garage ventilation	Observation, typical values	Used for steam calibration
Steam valve leakage	Observation	Fixed—best guess

283

High-Rise Office Case Study

Project	Building	Energy Costs	Scope	Effort
New office building	400,000 ft²	$940,000	LEED M&V	20 days

Inform
- As-built drawings
- Cut sheets
- Survey data
- Interviews
- Utility data
- BAS data
- EMS data
- Monitored data

Investigate
- **Compare utility data**
- **Compare load shapes**
- **Check equipment energy consumption**
- **Consider other end-uses**

Calibrate
- Check visually
- Calculate criteria

Add Value
- Met LEED NC 2.1 M&V credit requirements
- Identified some savings opportunities

284

284

High-Rise Office M&V Example

LEED NC 2.1 M&V Implementation

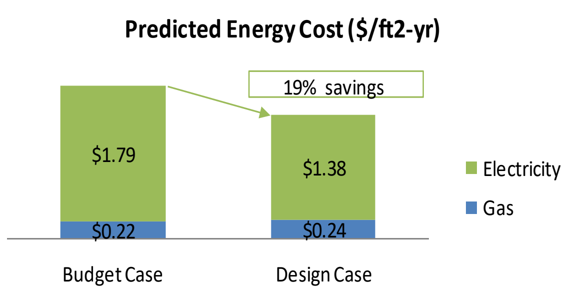
New Construction

Principal Use:
Office, Cafe, Parking Garage, Fitness Center, Data Center
Size: Approx. 400,000 ft²

Energy Costs:$2.35/ft²·yr
Site Energy:69 kBtu/ft²·yr
Source Energy:
209 kBtu/ft²·yr

Awards:
LEED NC 2.1 Gold

Efficiency Features:
- Underfloor air distribution
- Chiller efficiency, 0.51 kW/ton
- Variable-speed chiller
- Low lighting power, <0.7 W/ft²
- Daylighting controls

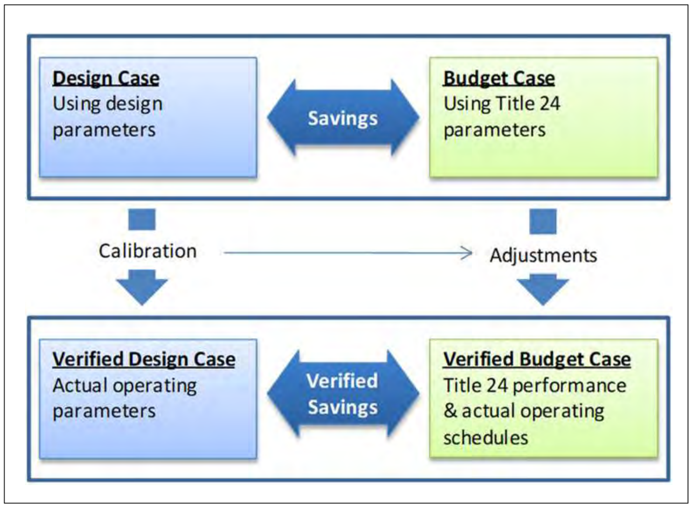


285

285

High-Rise Office M&V Example

LEED NC 2.1 M&V Implementation



- Project used IPMVP Option D, Method 1
- "Would have used" vs "Predicted (modeled) use"

286

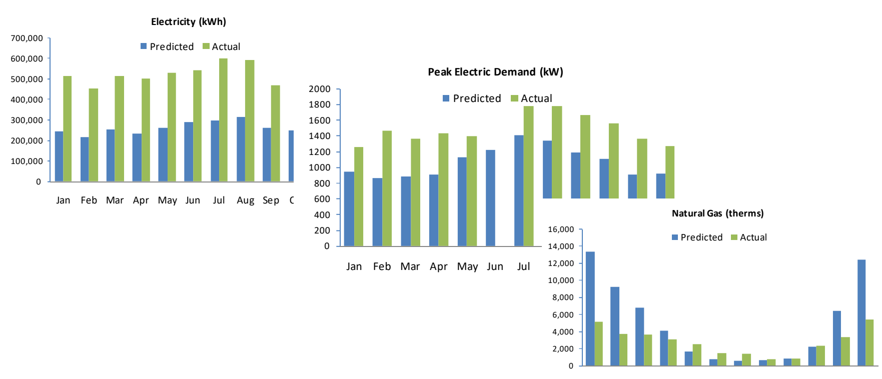
286

High-Rise Office M&V Example

Predicted vs. Actual

Step #1 Compare design model to utility bills

➔ ***Not very close*** (details on following slides)

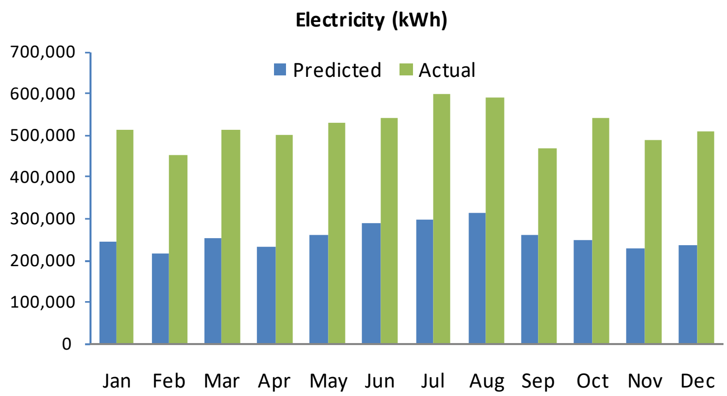


287

287

High-Rise Office M&V Example
Predicted vs. Actual

Electricity

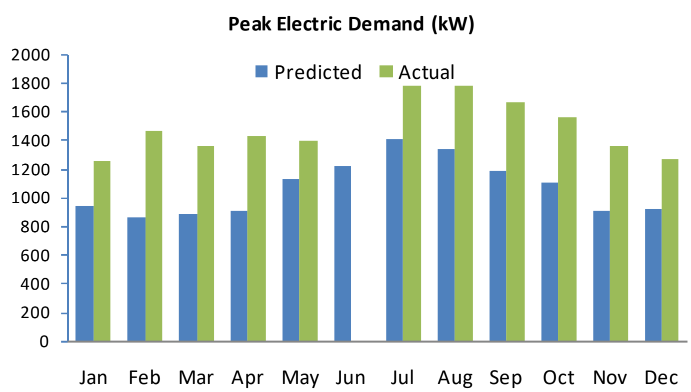


288

288

High-Rise Office M&V Example
Predicted vs. Actual

Peak Electric Demand

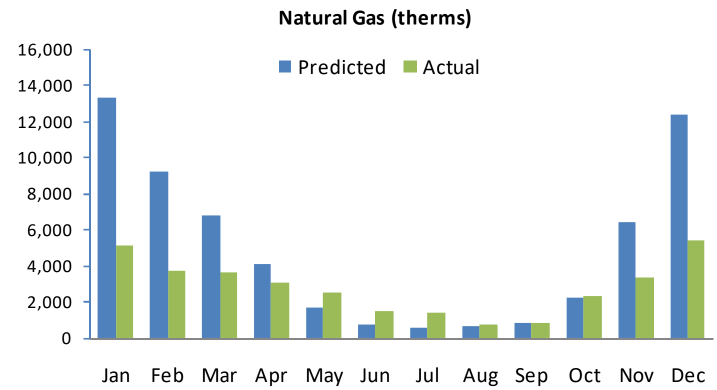


289

289

High-Rise Office M&V Example
Predicted vs. Actual

Natural Gas



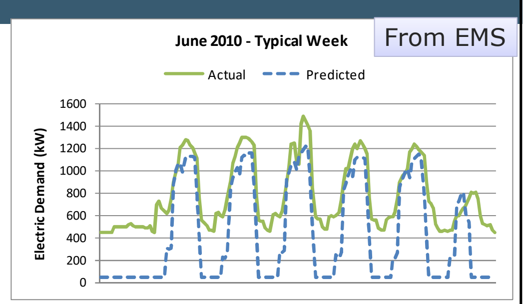
290

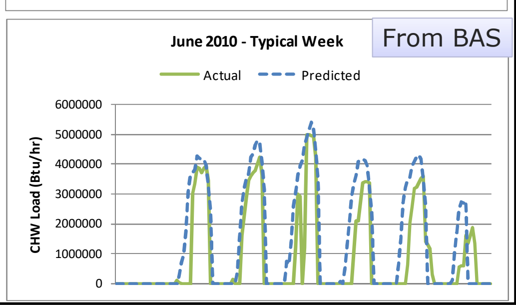
290

High-Rise Office M&V Example
Predicted vs. Actual

Step #2

- Dig deeper…
- Data sources in this case
  - Building automation system (BAS)
  - Separate energy monitoring system (EMS)
  - Short-term monitoring
    - Chiller kW





291

HIGH-RISE OFFICE M&V EXAMPLE

DATA COLLECTION

BAS Trend Data

- 15-minute averages
- Gathered point-by-point at operator terminal
- Exported as 80 CSV files
- **Tedious and time consuming (but valuable)**

timestamp	avg
01-Jan-10 12:00:00 AM PST	378.5
01-Jan-10 12:15:00 AM PST	383.3
01-Jan-10 12:30:00 AM PST	339.7
01-Jan-10 12:45:00 AM PST	363.9
01-Jan-10 1:00:00 AM PST	412.4
01-Jan-10 1:15:00 AM PST	378.5
01-Jan-10 1:30:00 AM PST	378.5
01-Jan-10 1:45:00 AM PST	383.3
01-Jan-10 2:00:00 AM PST	359.1
01-Jan-10 2:15:00 AM PST	368.8
01-Jan-10 2:30:00 AM PST	378.5
01-Jan-10 2:45:00 AM PST	378.5
01-Jan-10 3:00:00 AM PST	73429.2
01-Jan-10 3:15:00 AM PST	98607.6
01-Jan-10 3:30:00 AM PST	98923
01-Jan-10 3:45:00 AM PST	98559.1
01-Jan-10 4:00:00 AM PST	98588.2
01-Jan-10 4:15:00 AM PST	98762.9
01-Jan-10 4:30:00 AM PST	99354.9
01-Jan-10 4:45:00 AM PST	99733.3
01-Jan-10 5:00:00 AM PST	30651.7
01-Jan-10 5:15:00 AM PST	72.8
01-Jan-10 5:30:00 AM PST	169.8
01-Jan-10 5:45:00 AM PST	296

292

292

HIGH-RISE OFFICE M&V EXAMPLE

DATA COLLECTION

EMS Trend Data

- <!-- Trend viewer exported data -->
- <trends>
- <attributes name="**Real Power (Networks/SMech-UPS PXGateway/INCOM/CRAC Unit 1)**">
<data time="**07/27/2010 19:58:35.143**" value="**10990.000**" quality="**0XC0**" />
<data time="**07/27/2010 20:03:21.862**" value="**3394.000**" quality="**0XC0**" />
<data time="**07/27/2010 20:04:45.116**" value="**3185.000**" quality="**0XC0**" />
<data time="**07/27/2010 20:06:46.257**" value="**3363.000**" quality="**0XC0**" />
<data time="**07/27/2010 20:07:46.300**" value="**3191.000**" quality="**0XC0**" />
<data time="**07/27/2010 20:11:38.115**" value="**10712.000**" quality="**0XC0**" />
<data time="**07/27/2010 20:14:27.511**" value="**11271.000**" quality="**0XC0**" />
<data time="**07/27/2010 20:15:19.177**" value="**3314.000**" quality="**0XC0**" />
<data time="**07/27/2010 20:22:37.679**" value="**10927.000**" quality="**0XC0**" />
<data time="**07/27/2010 20:26:16.195**" value="**3316.000**" quality="**0XC0**" />
<data time="**07/27/2010 20:32:37.894**" value="**11035.000**" quality="**0XC0**" />

Analysis completed by Kolderup Consulting

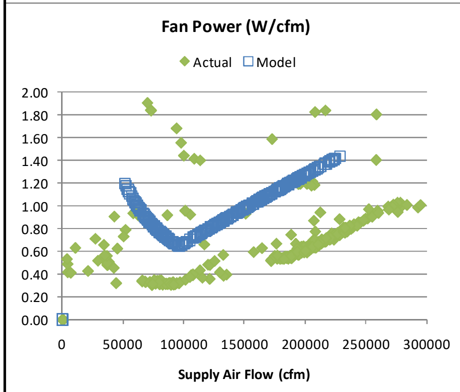
293

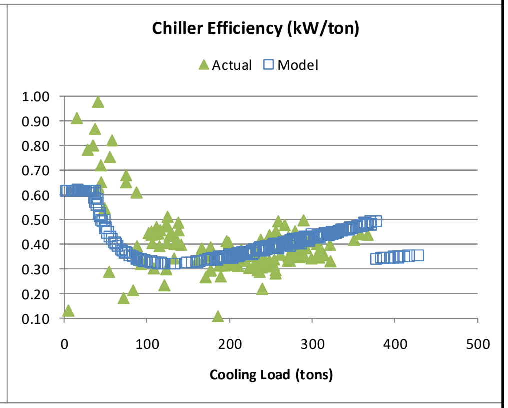
293

HIGH-RISE OFFICE M&V EXAMPLE
MODEL CALIBRATION

Step #3 Calibrate Model

- Verify ***system*** performance: chillers and air handlers



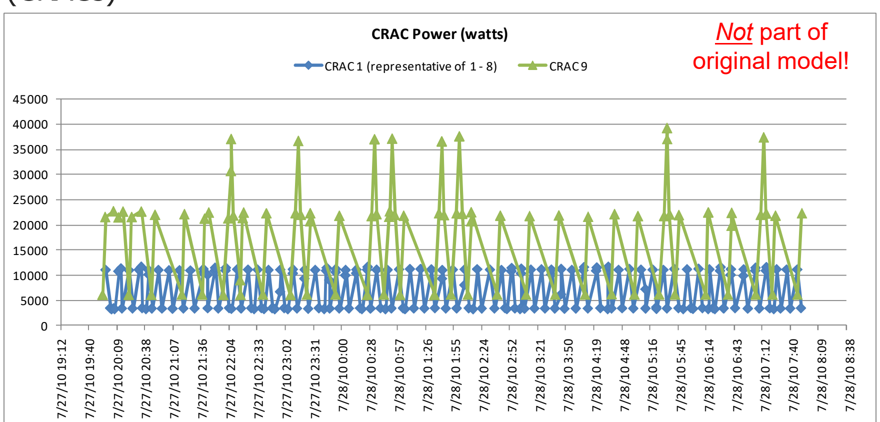


294

HIGH-RISE OFFICE M&V EXAMPLE
MODEL CALIBRATION

Step #3 *(cont.)*

- Verify system performance: computer room air conditioners (CRACs)



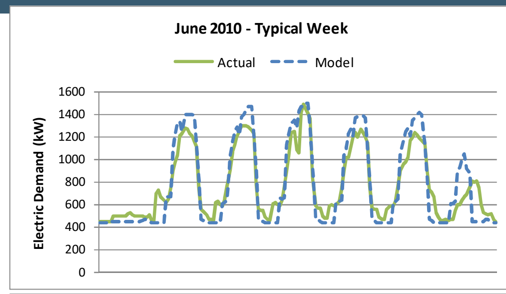
Not part of original model!

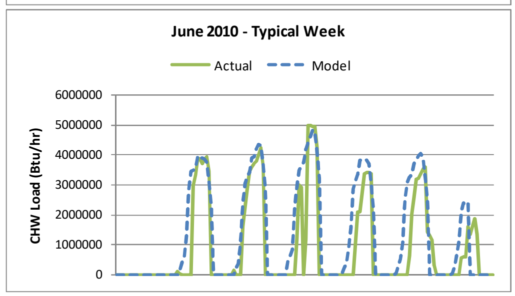
295

High-Rise Office M&V Example
Model Calibration

Step #3 *(cont.)*

- Make adjustments
  - Data center and CRACs
  - Parking garage nighttime lighting
  - Telecom/electrical room loads
  - Off-hour plug loads
  - Exterior lighting
  - Outdoor air ventilation rate





296

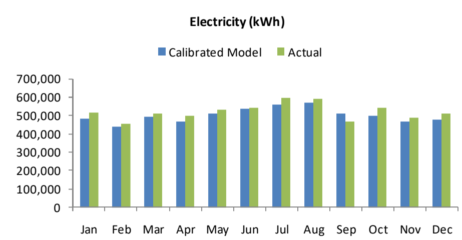
High-Rise Office M&V Example
Model Calibration

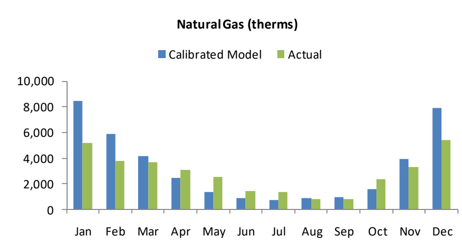
Step #3 *(cont.)*

- Monthly calibrated model results

	Elec kWh	Gas
Min ERRmonth	-1%	64%
Max ERRmonth	-7%	13%
ERRyear	-4%	16%
CV(RMSEmonth)	6%	51%
Meet Criteria?	Yes	No

Criteria:
Mean ERRmonth ± 15
Mean ERRyear ± 10%
CV(RMSEmonth) ± 10%





297

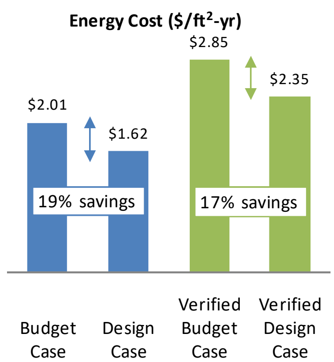
297

High-Rise Office M&V Example
Calculate Savings

Step #4
- Adjust ***budget*** model
  - Add data center, other loads..
  - Match schedule adjustments
  - Match OA ventilation rate

Step #5
- Calculate ***verified*** savings

Step #6
- Think about results…
  - Savings opportunities



298

University Laboratory

Project	Building	Energy Costs	Scope	Effort
2001 Lab Building	125,000 ft²	$1,300,000	Optimize operation	60 days

Inform
- **As-built drawings**
- Cut sheets
- Sequence of operation
- **Survey data**
- Interviews
- Utility data
- TAB data
- BAS data

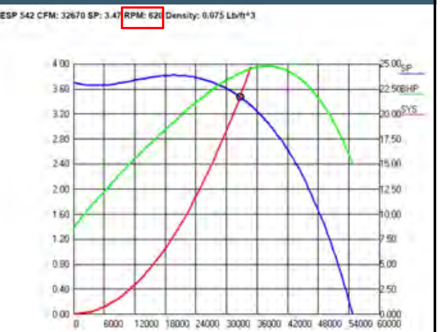
Investigate
- Compare utility data
- Compare load shapes
- Check equipment energy consumption
- **Check controls and operation**

Calibrate
- Check visually

Add Value
- Identified operational cost savings totaling over $500,000
- **Verified savings**

299

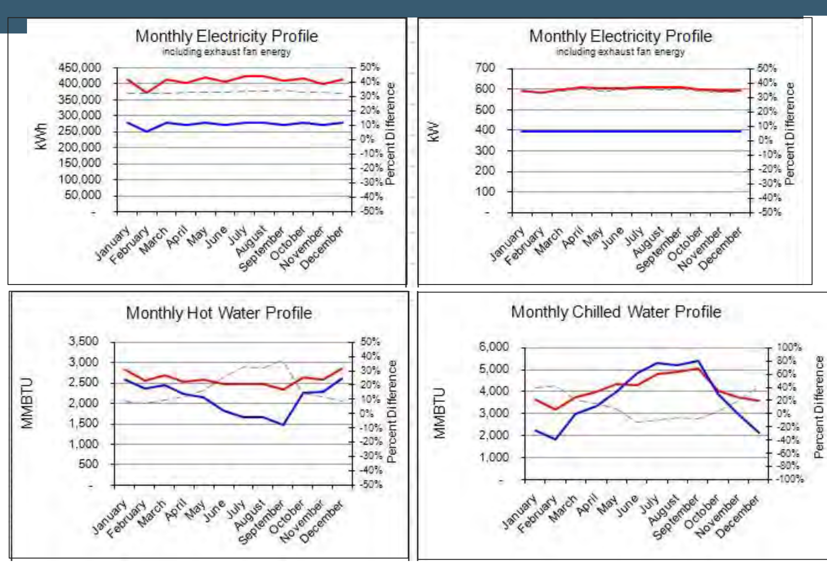
University Laboratory



System & Zone Name	System Type Principal Zone Activity	Type* Ret Zn	Area sqft	Design Flow Supply cfm	Supply cfm/sf	Min Flow	Design Ventilation OSA cfm	OSA %	OSA cfm/sf	OSA cfm/per	Design Capacity Cool tons	Cool sf/ton	Cool cfm/ton	Cool Btuh/sf	Heat Btuh/sf	Hrs Outside Thrl-Range Cool Hrs	Heat Hrs
AHU-1 LAB VAV	Variable Air Volume	D	67,012	122,368	1.83	70%	122,368	100%	1.826	365.2	419	160	292	75.1	40.0	0	0
··· MISC EL2 North Perim Zn (B.N3)	Office (General)	C	390	243	0.62	70%	243	100%	0.623	124.5	1	469	292	25.6	13.6	0	0
··· MISC EL2 NNE Perim Zn (B.NNE4)	Office (General)	C	622	387	0.62	70%	387	100%	0.622	124.4	1	469	292	25.6	13.6	0	0
··· HALL EL2 Core Zn (B.C7)	Office (General)	C	540	449	0.83	70%	449	100%	0.832	166.4	2	351	292	34.2	18.2	0	0
··· OFC EL2 Core Zn (B.C9)	Office (General)	C	628	738	1.18	70%	738	100%	1.175	235.0	3	248	292	48.3	25.8	0	0
··· MISC EL2 East Perim Zn (B.E10)	Office (General)	C	378	235	0.62	70%	235	100%	0.623	124.5	1	469	292	25.6	13.6	0	0
··· MISC EL2 East Perim Zn (B.E11)	Office (General)	C	801	498	0.62	70%	498	100%	0.623	124.5	2	469	292	25.6	13.6	0	0
··· MISC EL2 Core Zn (B.C12)	Office (General)	C	6,140	3,848	0.63	70%	3,848	100%	0.627	125.3	13	466	292	25.8	13.7	0	0
··· MAG EL2 West Perim Zn (B.W14)	Office (General)	C	797	2,761	3.46	70%	2,761	100%	3.463	692.5	9	84	292	142.3	75.9	0	0
··· MISC EL2 Core Zn (B.C15)	Office (General)	C	5,212	3,266	0.63	70%	3,266	100%	0.627	125.3	11	466	292	25.8	13.7	0	0
··· HALL EL2 North Perim Zn (B.N16)	Office (General)	C	760	625	0.82	70%	625	100%	0.822	164.3	2	355	292	33.8	18.0	0	0

300

University Laboratory



Actual Modeled ------ Difference

301

301

UNIVERSITY LABORATORY

302

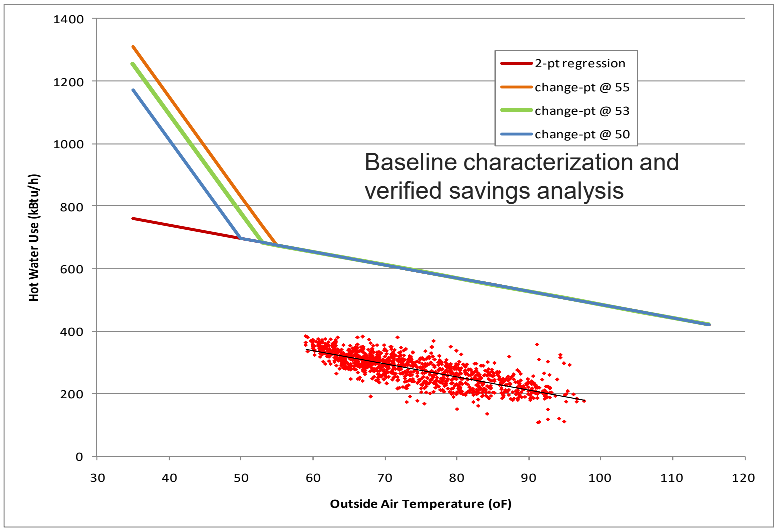
UNIVERSITY LABORATORY

	<Modeled Cost Saving>					
Measure	Electricity ($/yr)	CHW ($/yr)	HW/Steam ($/yr)	Total ($/yr)	Implementation Costs ($)	SPB (yrs)
ST						
Modified Baseline						
AHU-1 Fix/Replace HW Leaky Valve	$1,008	$85,448	$72,396	$158,852	$1,050	0.01
AHU-1 SAT Reset on OAT	-$1,299	$30,717	$23,258	$52,676	$300	0.01
AHU-1 DDC at the Zones	$50,044	$47,834	$40,899	$138,777	$1,239,000	8.9
AHU-1 Static Pressure Reset	$14,761	$3,656	-$420	$17,997	$75,000	4.2
AHU-1 Wireless Thermostats	$67	$407	$14,001	$14,475	$107,600	7.4
Convert Belt Drive to Direct Drive on AHU-1	$4,124	$1,021	-$121	$5,024		0.0
AHU-1 Manual Night setback/setup	$67	$407	$14,001	$14,475	$4,000	0.3
AHU-2 Chilled Water Valve	-$249	$3,567	$2,639	$5,956	$1,050	0.2
AHU-2 Time of Day Change	$7,183	$6,571	$7,578	$21,332	$100	0.0
AHU-2 SAT Reset	-$104	$1,517	$1,436	$2,850	$300	0.1
AHU-2 Air Balance	-$102	-$340	-$32	-$474	$600	-1.3
AHU-2 Static Pressure Reset	$707	$170	$0	$877	$20,000	22.8
AHU-2 DCV	$3	$673	-$8	$668	$1,200	1.8
AHU-2 DDC at Zones	$2,031	$2,235	$1,913	$6,179	$126,000	20.4
AHU-2 Restroom Supply Air	$610	$1,125	$516	$2,251	$11,500	5.1
AHU-2 Wireless Thermostats	-$1,378	-$1,265	-$1,211	-$3,854	$17,500	-4.5
Convert Belt Drive to Direct Drive on AHU-2	$233	$74	$0	$307		0.0
AHU-3 SAT Reset base on Zone Demand	$1	$15,703	$12,065	$27,769	$1,800	0.06
Convert Belt Drive to Direct Drive on AHU-3	$3,958	$925	-$121	$4,762		0.0
AHU-4 DDC controls to air system	$3,983	$5,513	$5,294	$14,790	$8,500	0.6
AHU-4 Convert to VAV System	$5,023	$6,016	$5,431	$16,470	$2,100	0.1
Install Economizer on AHU-4	$0	$1,695	-$629	$1,065	$8,130	7.6
AHU-4 DDC to System & Zones	$5,891	$7,134	$6,488	$19,513	$81,400	4.2

303

303

University Laboratory



304

304

High-Rise Investment Project

Project	Building	Energy Costs	Scope	Effort
1991 High-Rise Office	922,000 ft²	$1,000,000	Investment	40 days

Inform

- **As-built drawings**
- Cut sheets
- Sequence of operation
- **Survey data**
- Interviews
- Utility data
- TAB data
- BAS data

Investigate

- Compare utility data
- Compare load shapes
- Check equipment energy consumption
- **Check controls and operation**
- "Exterior" models including **CONTAM**

Calibrate

- Check visually
- Run ASHRAE Metrics for:
- **MBE**
- **CV(RMSE)**
- Trend data
- Data loggers
- Field observations
- CONTAM results

Add Value

- Identified operational cost savings totaling over 7,000,000 kWh
- Project in implementation now, starting with physical barriers

305

305

High-Rise Investment Project—Calibration of the Energy Model

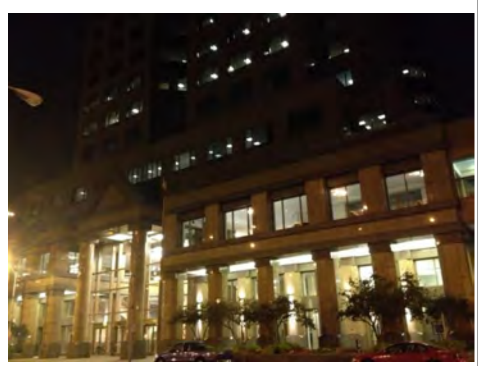
- Building has pneumatic controls, equipment operated manually
- Some trending available
- Utility company provided interval data
- Infiltration/stack effect a major issue during cold weather

306

306

High-Rise Investment Project—Calibration Tools

- Nighttime survey (see photo)
- Data loggers
  - Space conditions
  - AHU schedules
  - Economizers
- Process loads
  - Elevators
  - Air compressors
- ***Extensive*** trend data



307

307

High-Rise Investment Project—Measures Evaluated

- Change custodial schedule
- Run restroom exhaust during occupied hours
- De-energize chillers overnight
- AHU static pressure reset
- Seasonal adjustment of AHU and chiller schedules
- Tighten lighting schedules
- High-speed garage door
- Loading dock vestibule
- Skyway doors
- Convert fans to VFD from variable pitch
- Enthalpy economizers
- Sensors for "smart recovery" over weekends
- VSDs on main cooling towers
- VSDs on secondary CTs
- Upgrade CHW plant to DDC
- Relamp lobby with LEDs
- Parking garage lighting
- Elevator machine room thermostats
- Window film
- Chiller rebuild
- Floor-by-floor DDC upgrade
- Stairwell/elevator shaft pressurization (more energy)

308

308

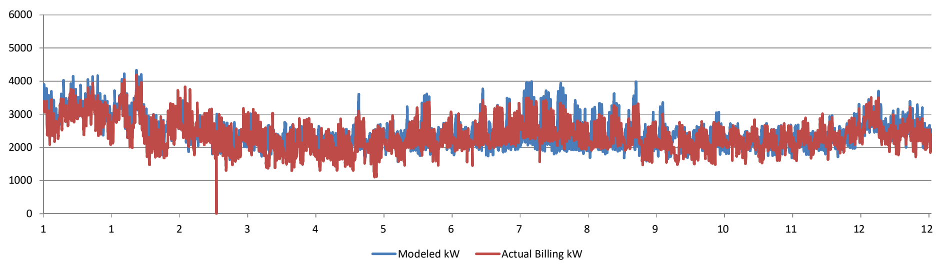
High-Rise Investment Project – Calibration Metrics

Calibration Metric	Modeled Result	M&V Target	Comment
Average Monthly Usage	-2.1 to 11.4%	±5% to 10%	Only April outside of range
Annual Usage Variance	4.96%	5%	Achieved
Annual Data C_V(RMSE)	6.0%	15%	Achieved, good seasonal match
Hourly Data MBE_{month}	4.6%	±10%	Per ASHRAE Guideline 14, good match
Hourly Data $C_V(RMSE_{month})$	14.2%	30%	Per ASHRAE Guideline 14, good match

309

309

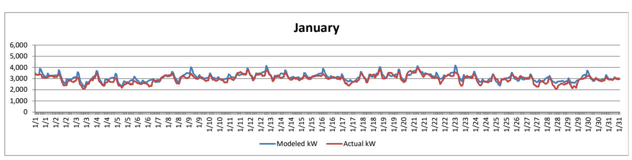
High-Rise Investment Project—Visual Calibration

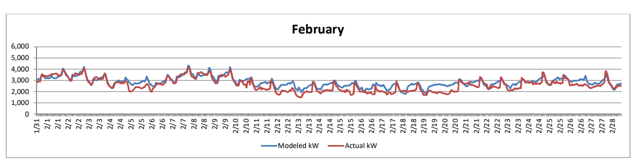


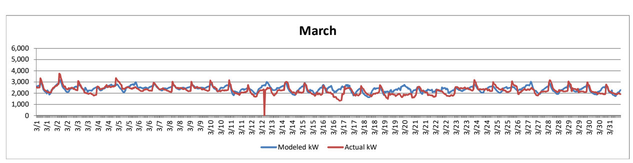
310

310

High-Rise Investment Project—Visual Calibration



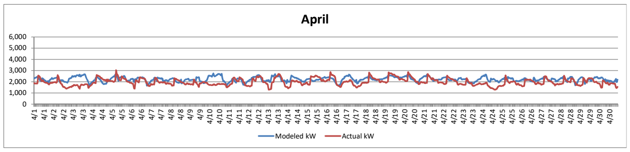


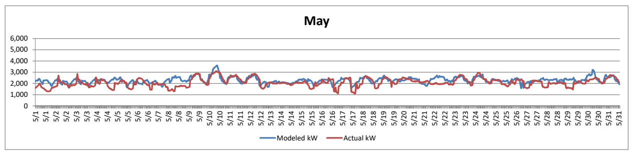


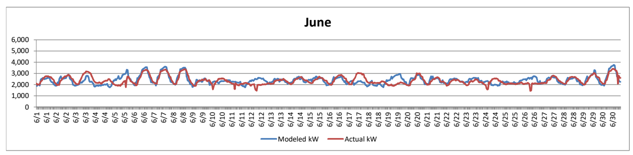
311

311

High-Rise Investment Project—Visual Calibration



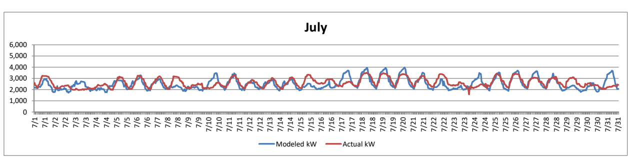


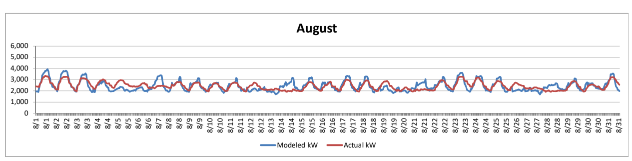


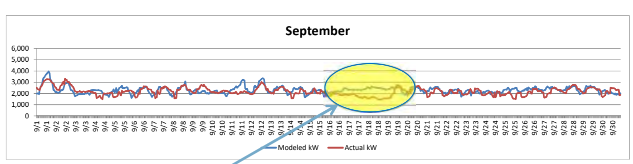
312

312

High-Rise Investment Project—Visual Calibration





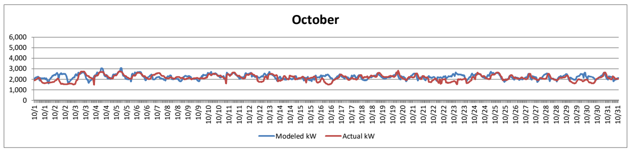


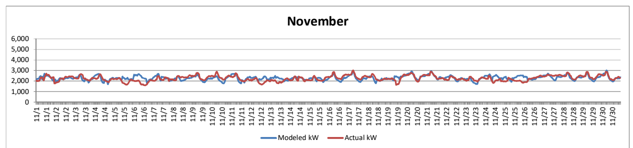
Irregular operation

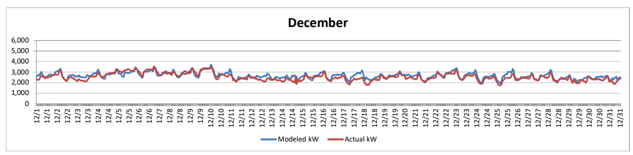
313

313

High-Rise Investment Project—Visual Calibration







314

314

High-Rise Investment Project

- Result: Client proceeded with implementation of selected measures
- Keyword: ***Confidence***
- Currently in verification stages

315

315

CALIBRATION GUIDANCE
TOPICS

- Getting weather data
  - Commercial services now available
- Calibration process suggestions
- Typical model adjustments
- Reconciling with hourly data

316

316

CALIBRATION GUIDANCE
PROCESS

Model Calibration Process

Identify and Classify Known and Unknown Parameters → Estimate Ranges for Unknown Parameters → Create and Analyze Initial Model → Calibrate Model to Individual Loads → Calibrate Remaining Parameters

317

317

Calibration Guidance
Process

Identify and Classify Known and Unknown Parameters → Estimate Ranges for Unknown Parameters → Create and Analyze Initial Model → Calibrate Model to Individual Loads → Calibrate Remaining Parameters

- Identify and classify known and unknown model parameters
  - Audit checklist should minimize unknown data
  - Despite the best efforts some data will be missing or unknown

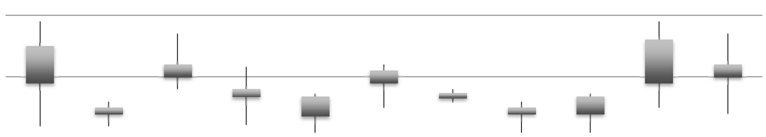
318

318

Calibration Guidance
Process

Identify and Classify Known and Unknown Parameters → Estimate Ranges for Unknown Parameters → Create and Analyze Initial Model → Calibrate Model to Individual Loads → Calibrate Remaining Parameters

- Estimate values for unknown parameters and create feasible ranges
  - Manufacturers' data sheets from equipment model numbers
  - Equipment maintenance contracts and depreciation schedules
  - *ASHRAE Handbook—Fundamentals*: guidelines for equipment and lighting loads
  - Equipment efficiencies: Reference local building codes and equipment ages



319

319

Calibration Guidance

Process

Identify and Classify Known and Unknown Parameters → Estimate Ranges for Unknown Parameters → **Create and Analyze Initial Model** → Calibrate Model to Individual Loads → Calibrate Remaining Parameters

- Create and analyze initial model
  - Baseline model that includes all known parameters and initial values for unknown parameters
  - Compare model against utility bills and building indexes (CBECS)
  - Perform a "gut check" by asking questions like:

"Why does this model use much less energy than similar buildings in CBECS?"

"If we know this building is often undercooled, then why does the model show all loads being satisfied?"

320

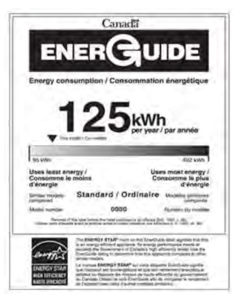
320

Calibration Guidance

Process

Identify and Classify Known and Unknown Parameters → Estimate Ranges for Unknown Parameters → Create and Analyze Initial Model → **Calibrate Model to Individual Loads** → Calibrate Remaining Parameters

- Calibrate model to address individual loads
  - Parameters that can be isolated on the utility bills (i.e., DHW in the summer)
  - Appliances and miscellaneous equipment can be calibrated to expected values from DOE and ENERGY STAR
  - Lighting can be individually calibrated using energy model submeters compared to a simple, "kWh = kW*h" calculation
  - Any parameter that is submetered should be individually calibrated



321

321

Calibration Guidance
Process

- Calibrate remaining parameters
  - Start with the swing seasons (fall and spring)
    - Heating use is minimal and cooling is related only to internal loads
    - Adjust schedules, fan power, and internal loads (equipment)
  - Calibrate heating system in the winter months
    - Adjust heating system efficiency and heating set points
    - System parameter adjustment may coincide with slight changes to wall U-factors
  - Calibrate the cooling system in the summer months
    - Adjust cooling efficiencies and other cooling system parameters
    - Double-check fan power during this step

322

322

Calibration Guidance
Common Model Adjustments

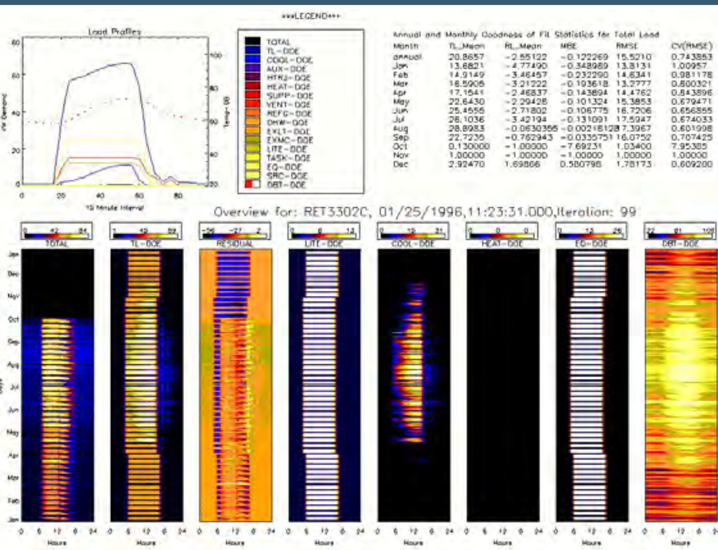
- HVAC start/stop times
- VAV box minimum airflow setpoint
- Supply air temperature control
- Economizer operation
- Plug loads
- Night and weekend plug load fraction
- Night and weekend lighting
- Exterior lighting, other loads…

323

323

Calibration Guidance

Reconciliation with Hourly Data

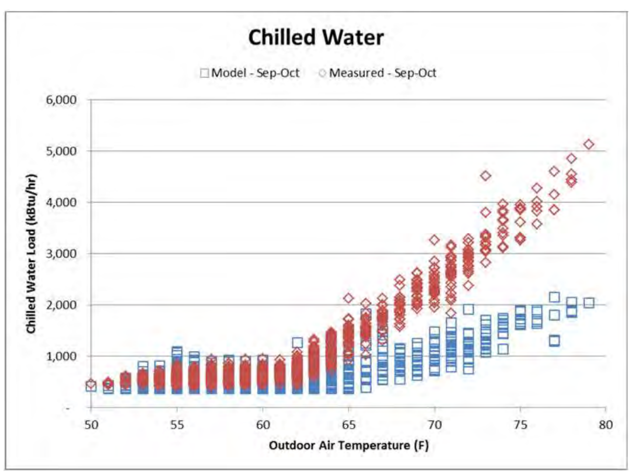


324

324

Calibration Guidance

Reconciliation with Hourly Data

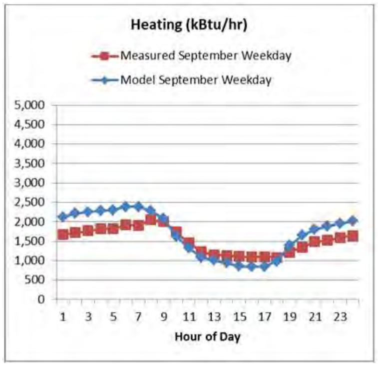


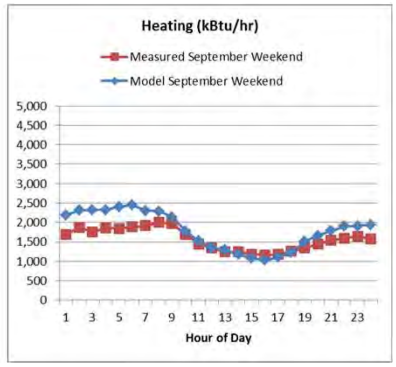
325

325

Calibration Guidance

Reconciliation with Hourly Data





326

326

Model Calibration Summary

Calibration Process	Refer to ASHRAE Guideline 14, Section 5.3
Scope	Wide continuum driven by objectives
Inform	True-up design assumptions, direct process based on importance of unknowns
Investigate	Dig down as needed, drive investigation based on objectives and findings; identify data collection needs in calibration plan
Check	State method in calibration plan
Value	Depends on savings potential and/or owner's objectives

327

327

M&V Resources

Document	Description	Links
IPMVP Volume I	Basic concepts and methods, measurement, uncertainty, examples	evo-world.org/en/
IPMVP Volume III – New Construction	Baseline definition, overview of methods	evo-world.org/en/
FEMP M&V Guidelines, version 2.2	ESCO focus, owner support; application document, calibration methodology, sample selection	www.nrel.gov/docs/fy05osti/34909CD.zip (download zip, version 2.2 is 26265.pdf)
FEMP M&V Guidelines, version 4.0		http://energy.gov/sites/prod/files/2016/01/f28/mv_guide_4_0.pdf
ASHRAE Guideline 14	IPMVP concepts +, calibration criteria, instrumentation, data management, regression techniques, examples	www.techstreet.com/ashrae/standards/guideline-14-2014-measurement-of-energy-demand-and-water-savings?product_id=1888937

328

CLOSING AND Q&A

329

329

CLOSING
SURVEYS, CONTINUING EDUCATION, RESOURCES

IBPSA-USA websites for Workshop Materials:

- www.ibpsa.us/energy-modeling-best-practices-and-applications-1
- www.ibpsa.us/bembook-wiki
- www.ibpsa.us/instructors-training-materials

Get involved locally with IBPSA-USA

- www.ibpsa.us and click on Chapters for a list

330

330

CLOSING
CONTACT INFO

Thank you for attending!

Sam Mason
sam.mason@encompassenergyllc.com

Erik Kolderup
erik@kolderupconsulting.com

331

331

Evaluation and Certificate

- ASHRAE values your comments about this course. You will receive your Certificate of Attendance when you finish the online course evaluation form at this URL:
  http://ali.ashrae.biz/2020winterconference/
  Access code: **j3z6**
  Be sure to add your appropriate license numbers.
- If you have any questions about ASHRAE Certificates, please contact Kelly Arnold, Coordinator Professional Development, at karnold@ashrae.org.
- If you have any questions about ASHRAE courses, please contact edu@ashrae.org.

332

332

Explore ASHRAE Learning Institute Courses

https://www.ashrae.org/instructor-led-courses

Find a Topic that Fits You

- Commissioning
- Energy Efficiency
- Environmental Quality
- HVAC&R Applications
- Standards and Guidelines

See all the ways to learn and grow with ASHRAE at
https://www.ashrae.org/professional-development/learning-portal

333

ASHRAE PROFESSIONAL CERTIFICATI

Over 2750 certifications earned to date.
Validation. Recognition. Pride.
Advance Your Career Today

Visit www.ashrae.org/certification to learn more about these seven programs:

- Building Commissioning Professional (BCxP)
- Building Energy Assessment Professional (BEAP)
- Building Energy Modeling Professional (BEMP)
- High-Performance Building Design Professional (HBDP)
- Healthcare Facility Design Professional (HFDP)
- Certified HVAC Designer (CHD)
- Operations and Performance Management Professional (OPMP)

334

RESOURCES, LINKS, MORE INFORMATION

335

335

MODELING RESOURCES/URLS

- ASHRAE Standard 55, *Environmental Conditions for Human Occupancy*
- ASHRAE Standard 62.1, *Ventilation for Acceptable Indoor Air Quality*
- ASHRAE Standard 90.1, *Energy Standard for Buildings Except Low-Rise Residential Buildings*
- ASHRAE Standard 170, *Ventilation of Health Care Facilities*
- ASHRAE Research Project 1093-RP Diversity Factors & Schedules
- *ASHRAE Handbook—Fundamentals*
  - Chapter 14 Climatic Information
  - Chapter 18 Load Calculation
  - Chapter 19 Energy Estimating and Modeling Methods
- ASHRAE Advanced Energy Design Guides www.ashrae.org/aedg
- ASHRAE *High Performing Buildings Magazine* www.hpbmagazine.org
- ASHRAE SPC 209P: Energy Simulation Aided Design for Buildings Except Low-Rise Residential Buildings spc209.ashraepcs.org/

336

336

MODELING RESOURCES/URLS

- Building Energy Software Tools Directory www.buildingenergysoftwaretools.com
- CEC Title 24 2013 ACM Manual www.energy.ca.gov/2012publications/CEC-400-2012-006/CEC-400-2012-006-CMF-REV.pdf
- CIBSE AM11 Building Performance Modelling www.cibse.org/knowledge/cibse-am/am11-building-performance-modelling-new-2015
- COMNET Modeling Guidelines http://comnet.org/modeling-guidelines
- DOE Building Technologies Program website energy.gov/eere/buildings/building-technologies-office
- DOE-2.2/eQUEST Manuals doe2.com/download/DOE-21E/DOE-2EngineersManualVersion2.1A.pdf

337

337

Modeling Resources/URLs

- Energy Design Resources website design guidelines energydesignresources.com
  - HVAC Simulation Guidelines
  - Advanced Variable Air Volume (VAV) Systems
  - Cool Tools Chilled Water Plant
  - Advanced VAV Design Guideline, App. 8, How to Model Different VAV Zone Controls in DOE-2.2
  - Advanced VAV Design Guideline, Appendix 5, Fan Coefficients
- EnergyPlus documentation https://github.com/NREL/EnergyPlus
- Empire State Building Sustainability www.esbsustainability.com
- IBPSA-USA
  - BEMBook Wiki: www.ibpsa.us/bembook-wiki
  - Methods & Processes Library: www.ibpsa.us/bem-library
- List Serves:
  - www.onebuilding.org
  - www.Unmethours.net
  - groups.yahoo.com/neo/groups/EnergyPlus_Support/info

338

338

Modeling Resources/URLs

- Rocky Mountain Institute
  - Energy Modeling Summit Pre-Read Documenting Energy Tools www.rmi.org/Content/Files/Summit_PreRead_Apr-19-2011(2).pdf
  - Shared QC checklists, pre- and post-processing spreadsheet-based tools www.rmi.org/tools_and_resources#building_energy_software
- UC Berkeley, Center for the Built Environment, "Energy Performance Modeling of Underfloor Air Distribution Systems" www.cbe.berkeley.edu/research/briefs-ufadmodel.htm
- UCLA Energy Design Tools www.aud.ucla.edu/energy-design-tools
- Window/Therm/Optic glazing construction windows.lbl.gov/software
- USGBC Advanced Energy Modeling for LEED Technical Manual, https://www.usgbc.org/resources/advanced-energy-modeling-leed-technical-manual-v20
- Quality Assurance: Michael Donn. "Quality Assurance – Simulation and the Real World." 1999 IBPSA Proceedings. www.ibpsa.org/proceedings/BS1999/BS99_P-05.pdf

339

Weather Data Resources / URLs

- 2013 *ASHRAE Handbook—Fundamentals* www.ashrae.org
- NCEI Integrated Surface Data www.ncdc.noaa.gov/isd
  - Documentation: ftp.ncdc.noaa.gov/pub/data/techrpts/tr200101/tr2001-01.pdf
- Typical Meteorological Year Data Sets
  - energyplus.net/weather
  - climate.onebuilding.org
- Drury B. Crawley. 1998. "Which Weather Data Should You Use for Energy Simulations of Commercial Buildings?" in *ASHRAE Transactions*, pp. 498-515, Vol. 104, Pt. 2. Atlanta: ASHRAE. climate.onebuilding.org/papers/1998_06_Crawley_Which_Weather_Data_Should_You_Use_for_Energy_Simulations_of_Commercial_Buildings.pdf
- Weather Bank www.weatherbank.com/archive.html
- Weather Source www.weather-source.com/
- Weather Underground www.weatherunderground.com
- DView (tool for displaying & comparing weather & CSV data) beopt.nrel.gov/downloadDView

340

340

M&V Resources

Document	Description	Links
IPMVP Volume I	Basic concepts and methods, measurement, uncertainty, examples	evo-world.org/en/ requires login
IPMVP Volume III – New Construction	Baseline definition, overview of methods	evo-world.org/en/ requires login
FEMP M&V Guidelines, version 2.2	ESCO focus, owner support; application document, calibration methodology, sample selection	www.nrel.gov/docs/fy05osti/34909CD.zip (download zip, version 2.2 is 26265.pdf)
FEMP M&V Guidelines, version 4.0		http://energy.gov/sites/prod/files/2016/01/f28/mv_guide_4_0.pdf
ASHRAE Guideline 14	IPMVP concepts +, calibration criteria, instrumentation, data management, regression techniques, examples	www.techstreet.com/ashrae/standards/guideline-14-2014-measurement-of-energy-demand-and-water-savings?product_id=1888937

341