ASHRAE®
Learning Institute

Commercial Building Energy Audits

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EDUCATION PARTNER

Commercial Building Energy Audits

By ASHRAE

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Course ID: 920022620

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 ☐

Acknowledgements

Many thanks to the members of SPC 211 whose work on ACCA/ASHRAE Standard 211-2018 has helped raise the bar for energy audits and from whom I've learned so much.

Jim Kelsey, SPC 211 Chair

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Learning Objectives

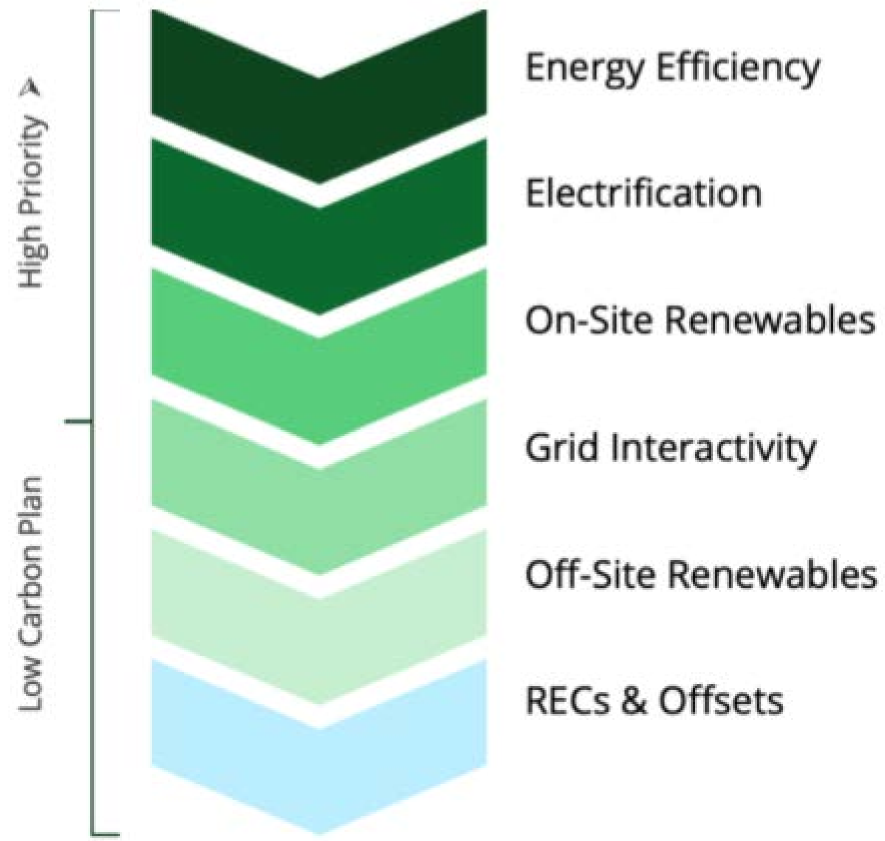
1. Understand the differences between ASHRAE Energy Audit Levels 1, 2, and 3.
2. Become familiar with the requirements of ACCA/ASHRAE Standard 211.
3. Learn the pros and cons of energy-efficiency measure calculation approaches.
4. Develop familiarity with some typical energy-efficiency measures.

Part 1

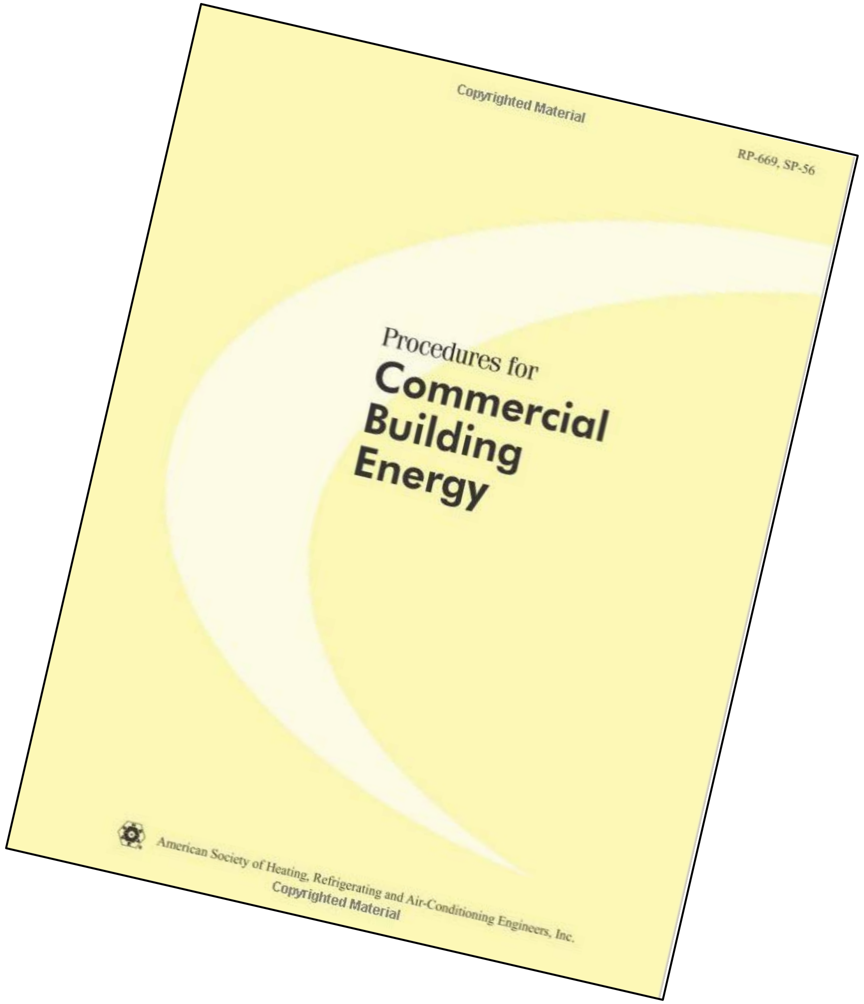
What We'll Cover—Part 1

- ❑Introduction
- ❑ASHRAE Standard 211
- ❑Summary of Audit Levels 1, 2, 3
- ❑Elements of each Audit Level
- ❑On-site techniques
- ❑How to hire an auditor


ASHRAE FORMS TASK FORCE FOR BUILDING DECARBONIZATION
Group will address the critical subject of reducing greenhouse gas emissions associated with buildings


High Priority
Low Carbon Plan
Energy Efficiency
Electrification
On-Site Renewables
Grid Interactivity
Off-Site Renewables
RECs & Offsets

ASHRAE Procedures for Commercial Building Energy Audits

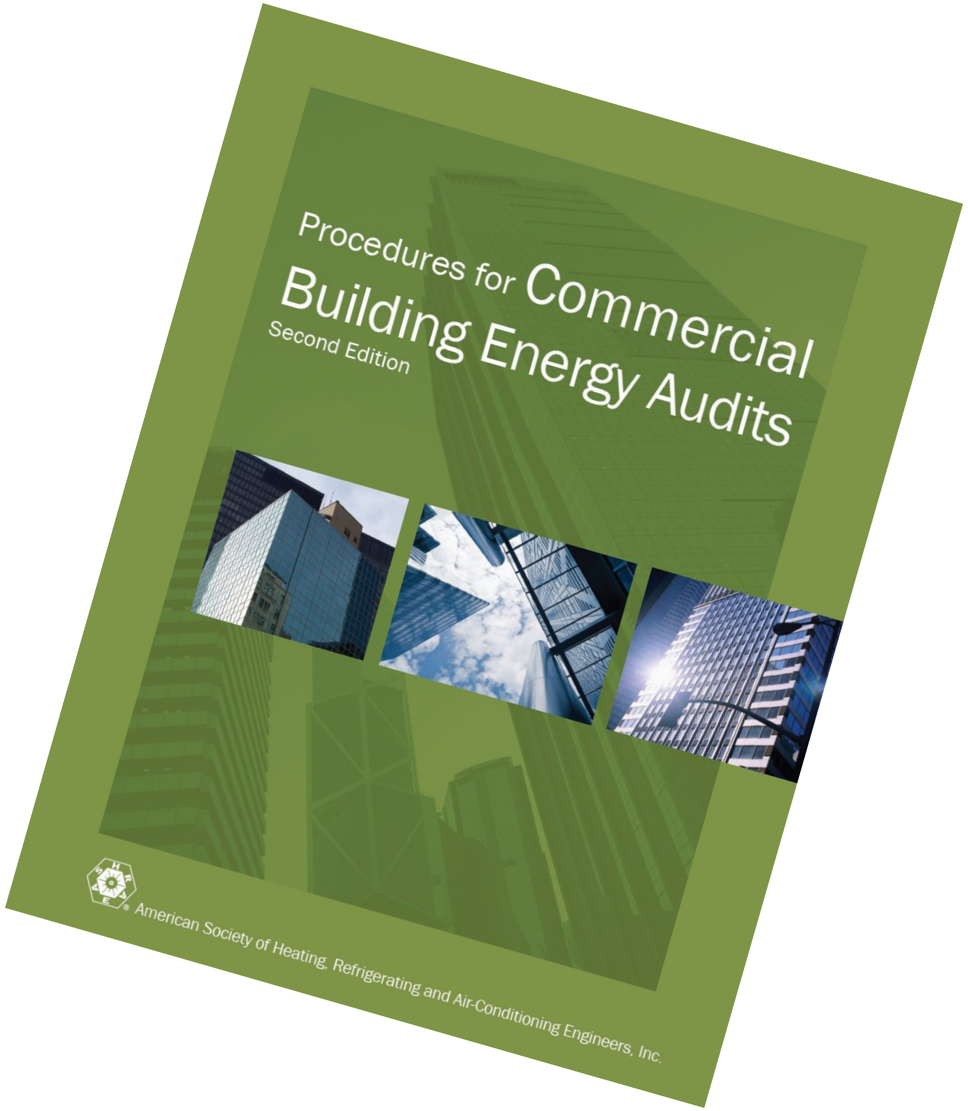


First edition emphasized:

- Defined Levels of Effort I, II, III
- Established forms
  - Audit forms
  - Site use

Became de facto standard, referenced by LEED, city ordinances, others

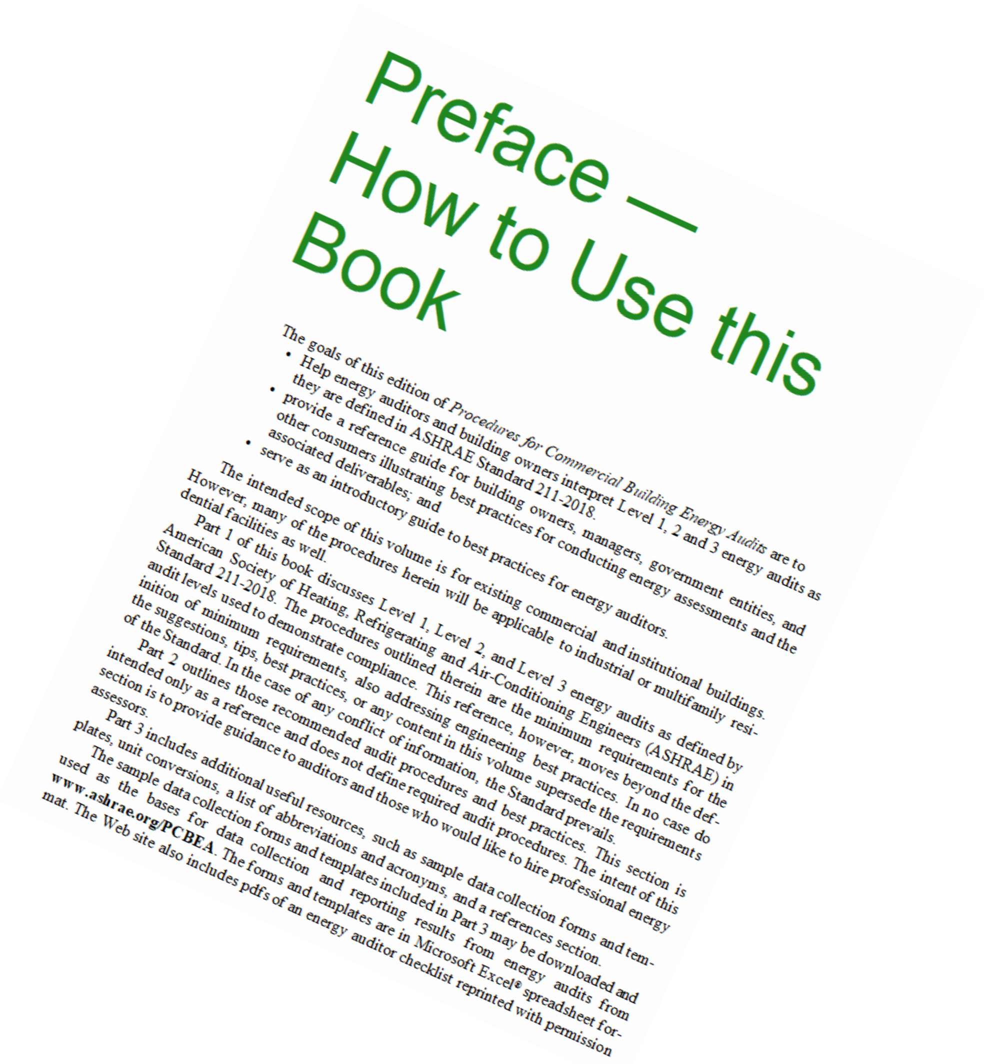
ASHRAE *Procedures for Commercial Building Energy Audits*, 2nd Edition



Second edition added:

- Established common vocabulary
- Best practice methods
  - Site visit methods
  - Measurement methods
  - Economic evaluation
  - How to get a good bid
- Resources
  - Audit forms
  - EEM ideas
  - Simulation checklists

ASHRAE *Procedures for Commercial Building Energy Audits*, 3rd Edition



Preface — How to Use this Book

The goals of this edition of *Procedures for Commercial Building Energy Audits* are to

- Help energy auditors and building owners interpret Level 1, 2 and 3 energy audits as they are defined in ASHRAE Standard 211-2018.
- provide a reference guide for building owners, managers, government entities, and other consumers illustrating best practices for conducting energy assessments and the associated deliverables; and
- serve as an introductory guide to best practices for energy auditors.

The intended scope of this volume is for existing commercial and institutional buildings. However, many of the procedures herein will be applicable to industrial or multifamily residential facilities as well.

Part 1 of this book discusses Level 1, Level 2, and Level 3 energy audits as defined by American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) in Standard 211-2018. The procedures outlined therein are the minimum requirements for the audit levels used to demonstrate compliance. This reference, however, moves beyond the definition of minimum requirements, also addressing engineering best practices. In no case do the suggestions, tips, best practices, or any content in this volume supersede the requirements of the Standard. In the case of any conflict of information, the Standard prevails.

Part 2 outlines those recommended audit procedures and best practices. This section is intended only as a reference and does not define required audit procedures. The intent of this section is to provide guidance to auditors and those who would like to hire professional energy assessors.

Part 3 includes additional useful resources, such as sample data collection forms and templates, unit conversions, a list of abbreviations and acronyms, and a references section.

The sample data collection forms and templates included in Part 3 may be downloaded and used as the bases for data collection and reporting results from energy audits from **www.ashrae.org/PCBEA**. The forms and templates are in Microsoft Excel® spreadsheet format. The Web site also includes pdfs of an energy auditor checklist reprinted with permission

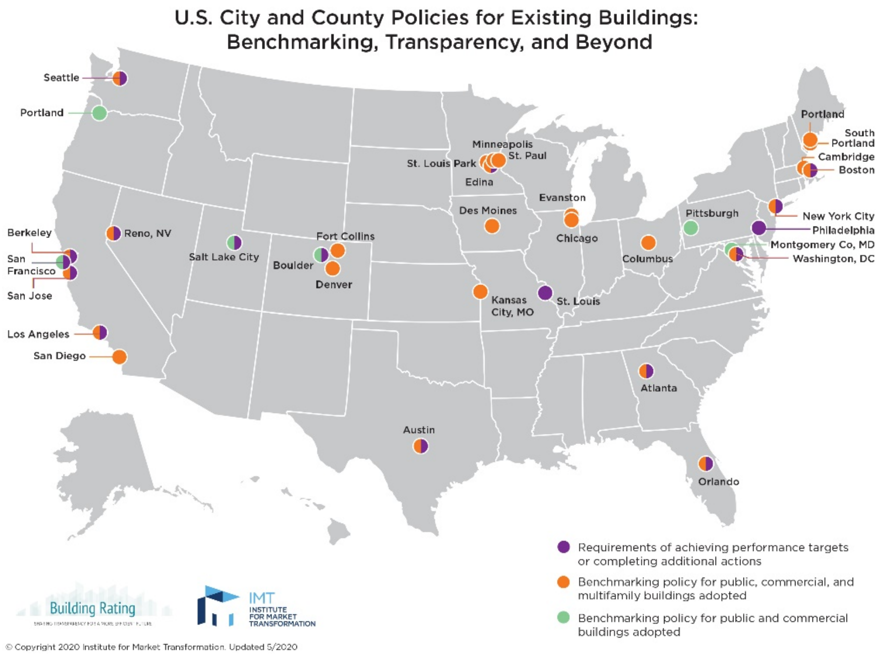
Third edition in progress:

- Help interpret Levels 1, 2 and 3
- Best practice reference for
  - Owners and managers
  - Government entities
- Best practice guide for
  - Energy auditors

Adoption/Reference

- Agencies—national

- ASHRAE/IES Standard 100, *Energy Efficiency in Existing Buildings*
- EDF Investor Confidence Project
- Cities
- Commercial PACE Programs
- Many others by reference in RFPs/RFQs



Victims of Our Own Success

Level 1

Level 2

Level 3

Why Write a Standard?


STANDARD

ANSI/ASHRAE/ACCA Standard 211-2018

Standard for Commercial Building Energy Audits

Approved by ASHRAE on April 30, 2018; by the Air Conditioning Contractors of America on April 5, 2018; and by the American National Standards Institute on May 1, 2018.

ASHRAE® Standards are scheduled to be updated on a five-year cycle; the date following the Standard number is the year of ASHRAE approval. The latest edition of an ASHRAE Standard may be purchased on the ASHRAE website (www.ashrae.org) or from ASHRAE Customer Service, 1791 Tullie Circle, NE, Atlanta, GA 30329-2305. E-mail: orders@ashrae.org. Fax: 678-539-2129. Telephone: 404-636-8400 (worldwide) or toll free 1-800-527-4723 (for orders in US and Canada). For reprint permission, go to www.ashrae.org/permissions.

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ASHRAE ACCA ANSI

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- Leeway → "apples and oranges" bidding
- Cities with mandatory ordinances found difficult to enforce—wrote their own
- Efficiency from consistent reporting

Purpose—ACCA/ASHRAE Standard 211-2018

The purpose of this standard is to establish consistent practices for conducting and reporting energy audits for commercial buildings. This standard

a. defines the procedures required to perform Energy Audit Levels 1, 2, and 3;
b. provides a common scope of work for these audit levels for use by building owners and others;
c. establishes consistent methodology and minimum rigor of analysis required; and
d. establishes minimum reporting requirements for the results of energy audits.

Not Goals

- Best practices
- Consistency of measures
  [which is ≠ quality]
- Overly prescriptive methods or recommendations
- “Virtual” or “remote” audits
- Prescriptive actions for owners

ACCA/ASHRAE Standard 211 sets the bar for the <u>minimum required</u> procedures and reporting requirements that can be called “ASHRAE Level X”

Scope—ACCA/ASHRAE Standard 211

"This standard applies to all buildings except single-family houses, multifamily structures of three stories or fewer above grade, manufactured houses (mobile homes), and manufactured houses (modular)."

Code-speak for "Commercial and Large Multifamily"

Organization—ACCA/ASHRAE Standard 211

Body

1. Purpose
2. Scope
3. Definitions
4. Compliance
5. Procedures
6. Reporting
7. References

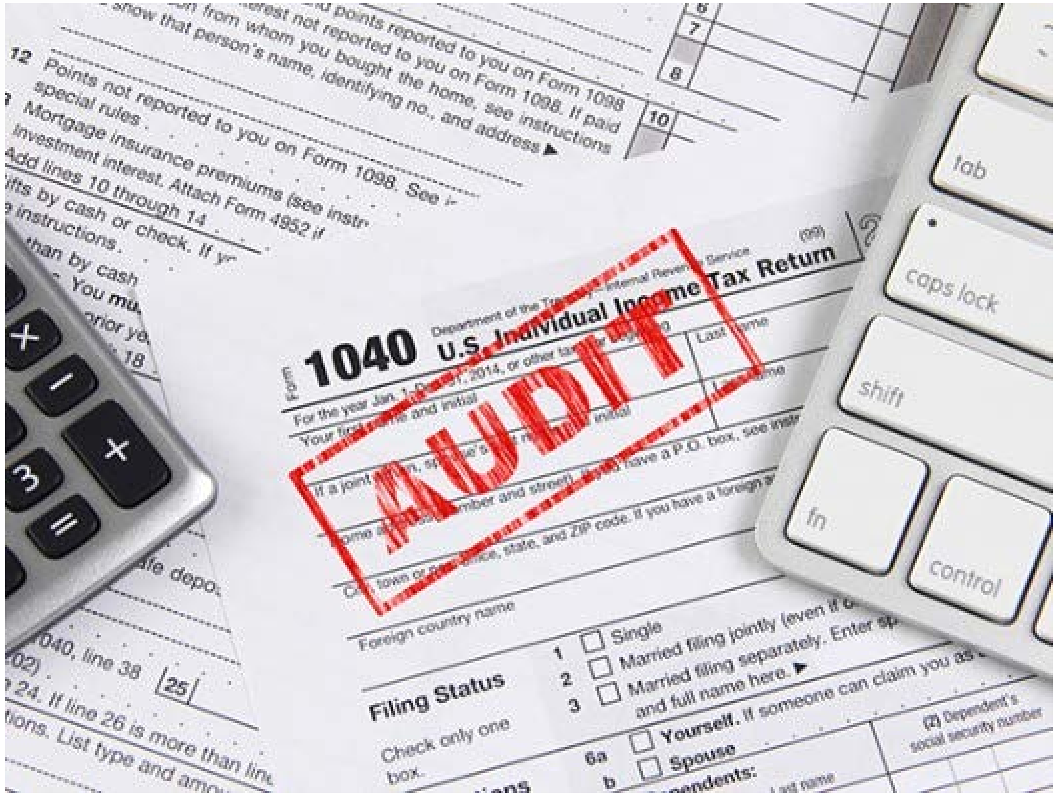
NORMATIVE

INFORMATIVE

Annexes

A. Compliance Form
B. Savings Calcs
C. Reporting Forms
D. Sample Outlines
E. Data Exchange
F. Model Calibration
G. Risk Assessment

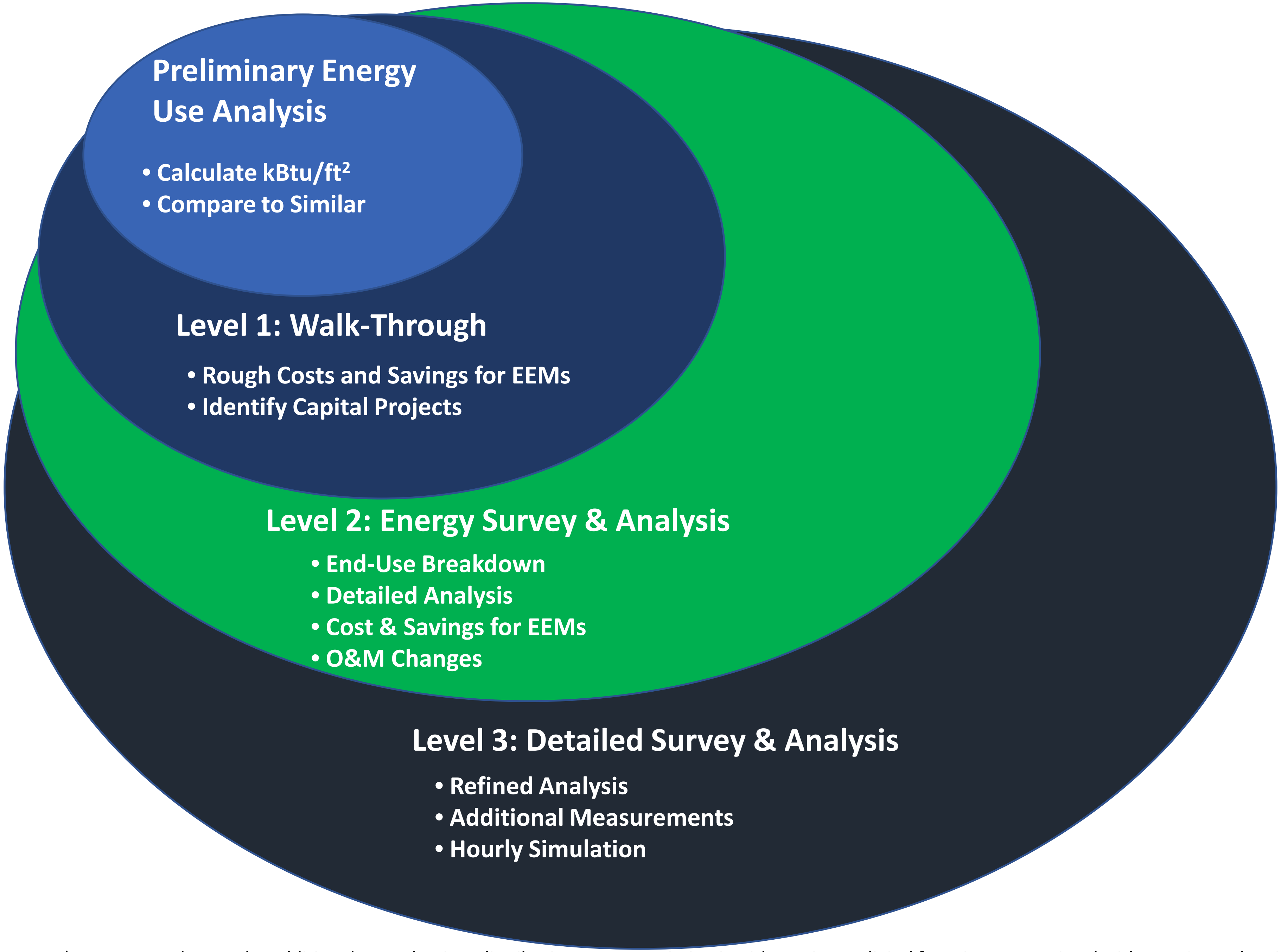

YOU'RE GETTING
AUDITED


AUDIT
1040
U.S. Individual Income Tax Return
Filing Status
Single
Married filing jointly
Married filing separately
tab
caps lock
shift
fn
control

What They're Not: Versions of the Same Thing

Audit Level Requirements

22


Preliminary Energy Use Analysis
• Calculate kBtu/ft²
• Compare to Similar
Level 1: Walk-Through
• Rough Costs and Savings for EEMs
• Identify Capital Projects
Level 2: Energy Survey & Analysis
• End-Use Breakdown
• Detailed Analysis
• Cost & Savings for EEMs
• O&M Changes
Level 3: Detailed Survey & Analysis
• Refined Analysis
• Additional Measurements
• Hourly Simulation

Levels in Brief

Preliminary Energy Use Analysis (Level 0—Informally)

Level 1

- ❑Determine the potential at the site
- ❑How much? In what systems?
- ❑Set overall plan

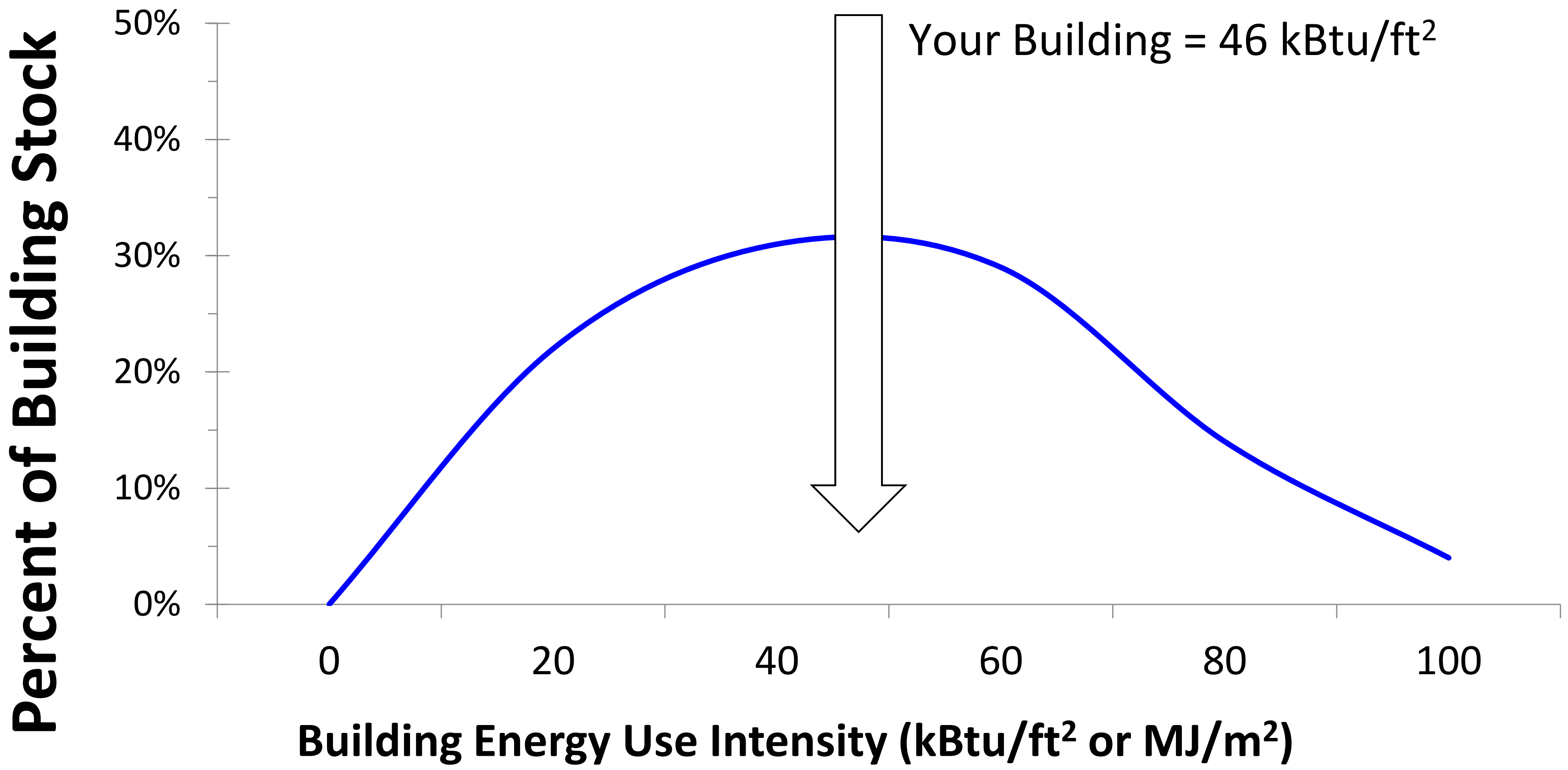
Level 2

- ❑Detailed analysis of energy costs
- ❑Explore details of specific opportunities

Level 3

- ❑Develop specific opportunities into plans
- ❑Reduce risk through honing costs and savings

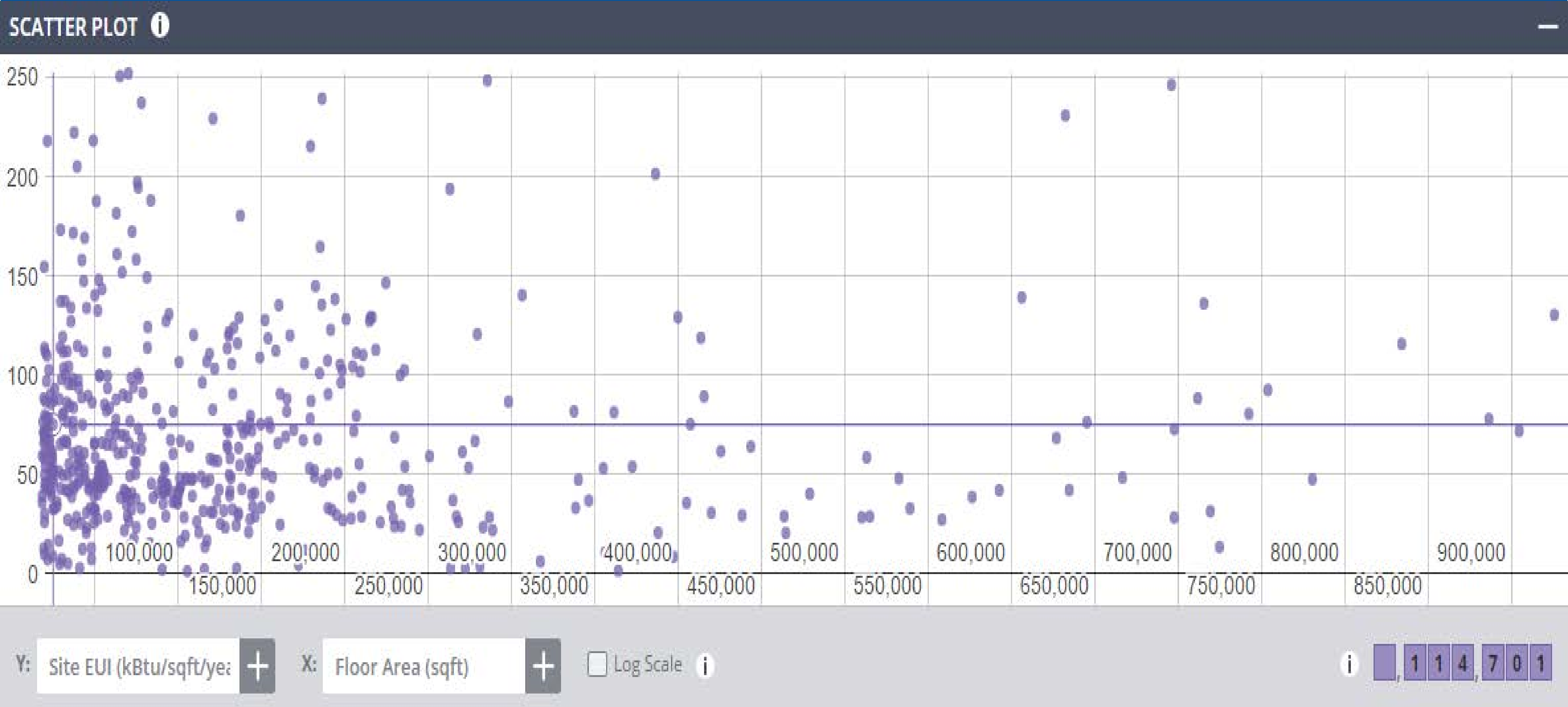
Preliminary Energy Analysis



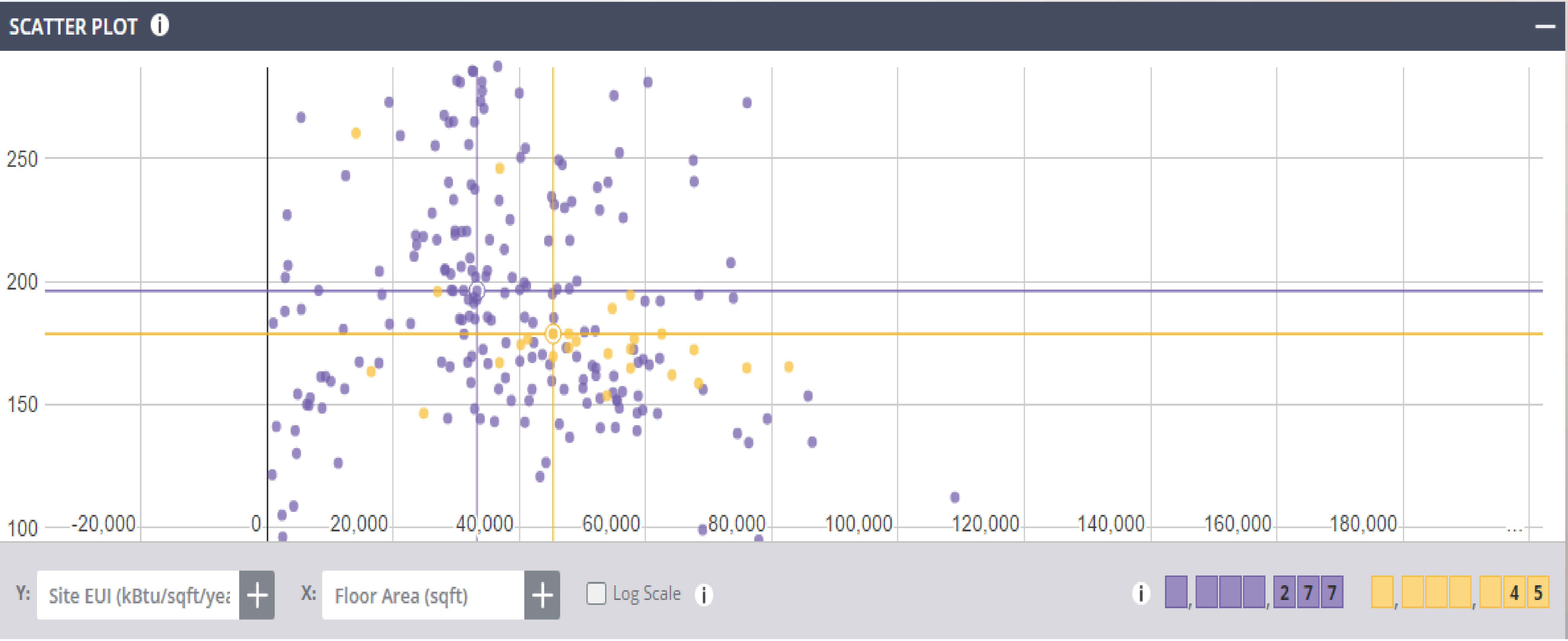
bpd.lbl.gov has great interface for visualizing peer groups

DOE Building Performance Database

bpd.lbl.gov



Compare Samples



This compares CA Grocery Stores (purple) to IL Grocery Stores (gold)

Level 1—Walk-Through

Process

- Conduct preliminary energy analysis (PEA)
- Conduct walk-through survey
- Meet with owner to review operations
- Space function analysis
- Identify low-cost/no-cost recommendations
- Identify capital improvements

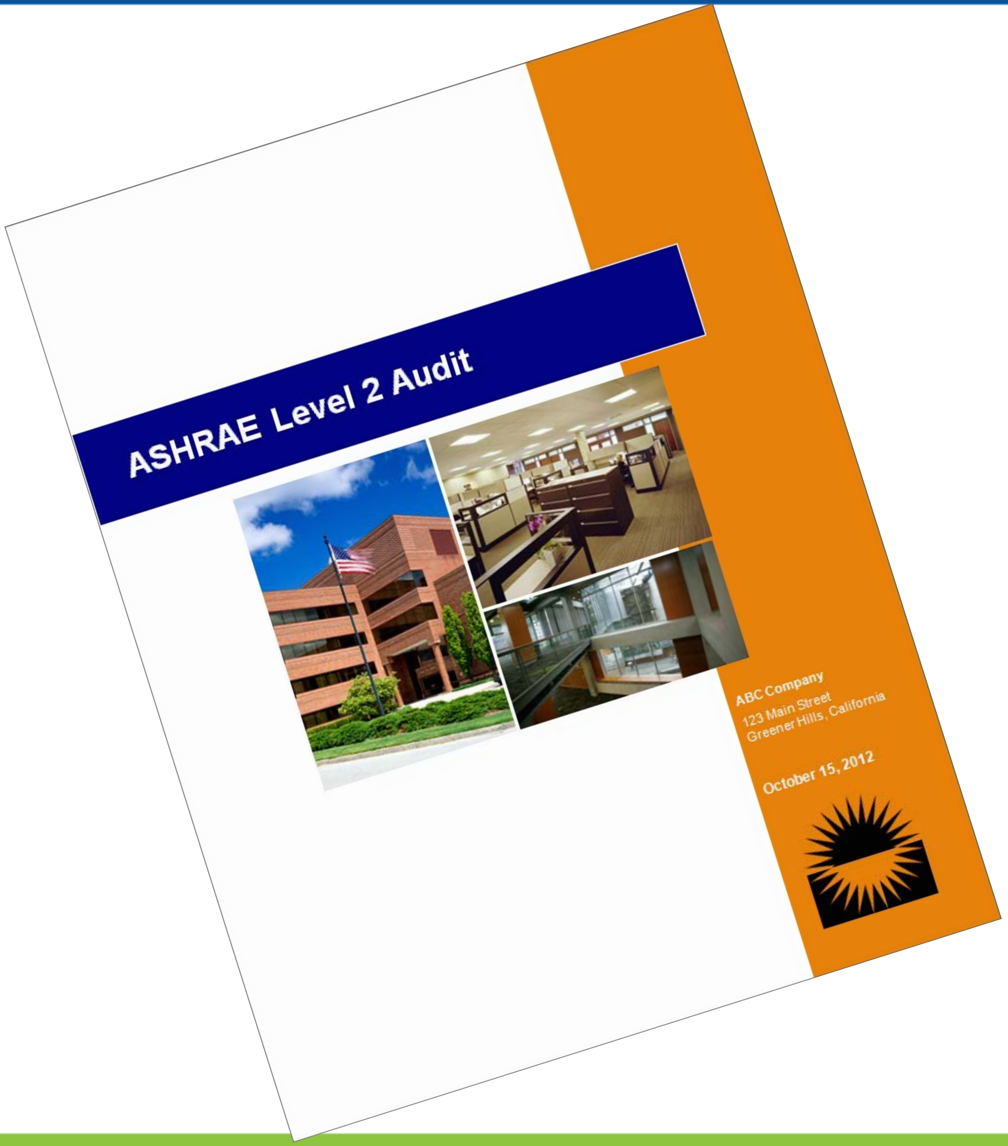
Level 1—Walk-Through

Report

- Summarize utility data
  - Determine load shape irregularities
- Compare EUI to that of similar sites
  - For example, ENERGY STAR® PM or Energy IQ
- Estimate savings if EUI met target
- Total energy costs by fuel type
- O&M deficiencies, safety deficiencies
- Low-cost/no-cost savings levels
- Capital project savings and cost levels

Level 2—Energy Survey and Analysis

Probably the most-cited audit level

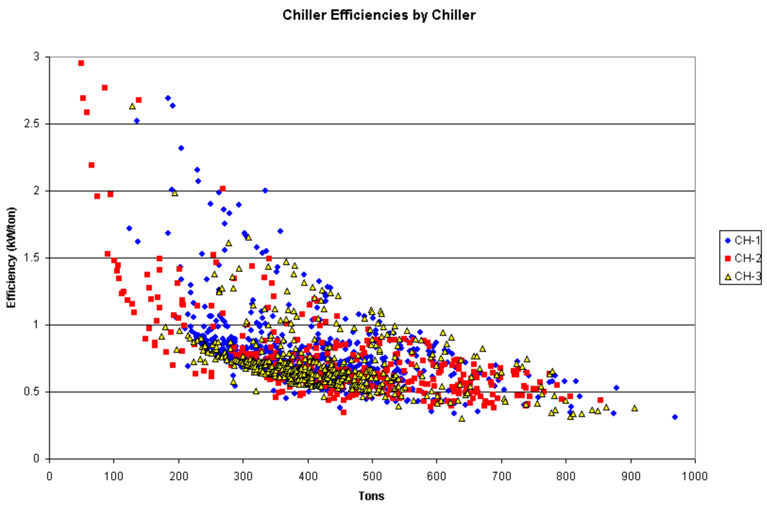


Level 2—Energy Survey and Analysis

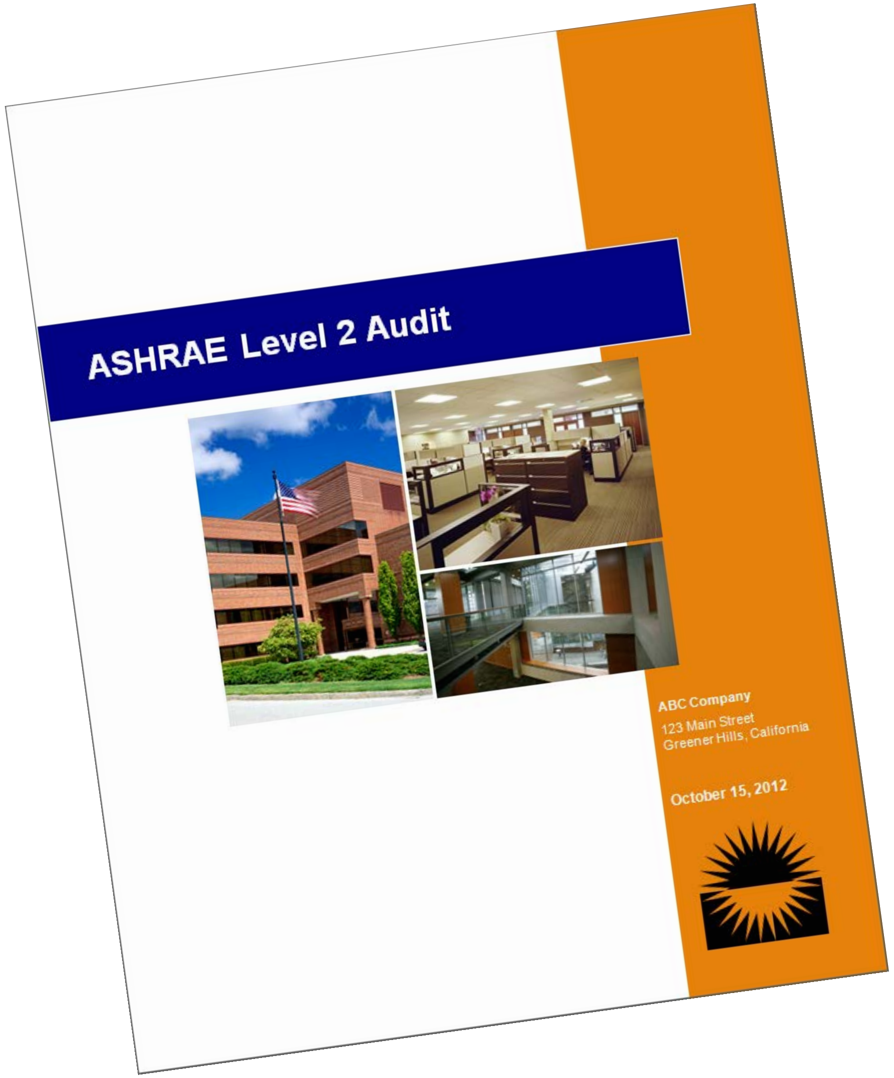
Process

Includes all Level 1 tasks plus:

- Detailed site visit
- Review mechanical and electrical design, condition, and O&M practices
- Measure key parameters
- List all potential recommendations (note those excluded and why)
- Analyze capital measures (savings and costs including interaction)
- Meet with owner/operators to review recommendations



Level 2—Energy Survey and Analysis



Report

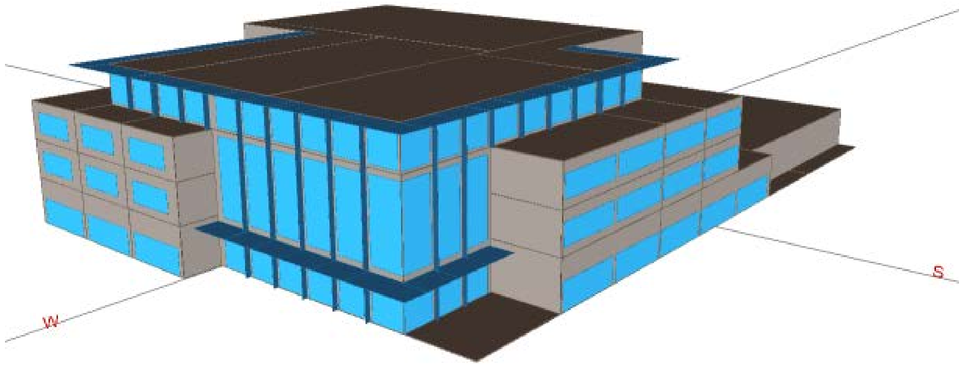
- Estimate low-cost/no-cost savings
- Perform detailed end-use breakdown
- Estimate capital project costs and savings
- Complete building description and equipment inventory
- General description of considered measures
- Financial analysis of recommended EEMs

Level 3—Required Elements

- Typically, get to this scope through requests for implementation assistance
- Beginning design development
- Individual measure focused

Level 3—Additional Scope and Value

Level 2 and then some…



Modeling or extensive measurement required

Report

- Detailed description of recommended measures (specs, cut sheets)
- Detailed EEM cost estimates
- LCCA
- "Investment Grade?" term not used in PCBEA or ACCA/ASHRAE Standard 211

Process	Level 1	Level 2	Level 3
Conduct preliminary energy analysis (PEA)	●	●	●
Conduct walk-through survey	●	●	●
Identify low-cost/no-cost recommendations	●	●	●
Identify capital improvements	●	●	●
Review M&E design, condition, and O&M practices		●	●
Measure key parameters		●	●
Analyze capital measures (savings, costs, interaction)		●	●
Meet with owner/operators to review recommendations		●	●
Conduct additional testing/monitoring			●
Perform detailed system modeling			●
Provided schematic layouts for recommendations			●

Report	Level 1	Level 2	Level 3
Compare EUI to that of similar sites	●	●	●
Summarize utility data	●	●	●
Estimate savings if EUI met target	●	●	●
Estimate low-cost/no-cost savings		●	●
Perform detailed end-use breakdown		●	●
Estimate capital project costs and savings		●	●
Complete building description and equipment inventory		●	●
General description of considered measures		●	●
Financial analysis of recommended EEMs		●	●
Detailed description of recommended measures			●
Detailed EEM cost estimates			●

Preliminary Energy Analysis

Preliminary Energy Use Analysis (PEA)

- Required first step for Level 1 audit
- Use ASHRAE Standard 105 definition for gross floor area
- Compile billing data
- Calculate energy use intensity (EUI)
  - $kBtu/ft^2$ or MJ/m^2
- Compare to similar buildings
  - ENERGY STAR®/CBECs
  - Building Performance Database (bpd.lbl.gov)
  - Your portfolio (don’t forget to correct for weather, schedules, etc.)

Preliminary Energy Use Analysis (PEA)

Use PEA template (see resources)

1. Determine gross conditioned floor area
2. Assemble billing data (preferable multi-year)
3. Calculate EUI and ECI
4. Compare with similar
5. Derive targets for building
6. Determine savings to meet targets

Gross Floor Area

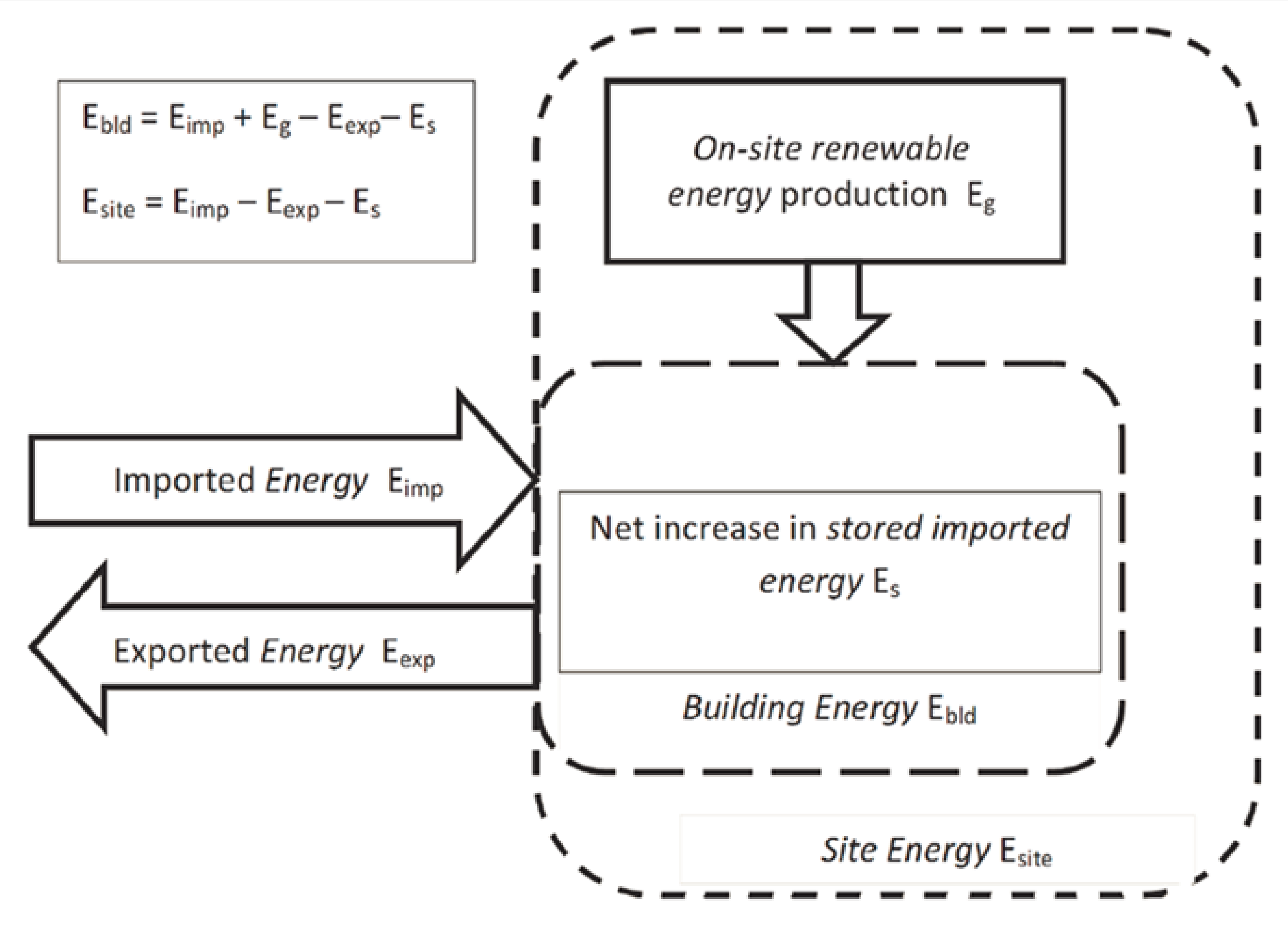
"the sum of the floor areas of all the spaces within the building with no deductions for floor penetrations other than atria. It is measured from the exterior faces of exterior walls or from the centerline of walls separating buildings, but it excludes covered walkways, open roofed-over areas, porches and similar spaces, pipe trenches, exterior terraces or steps, roof overhangs, parking garages, surface parking, and similar features."

Source: ASHRAE Standard 105-2014, *Expressing, and Comparing Building Energy Performance and Greenhouse Gas Emissions*, as referenced in ACCA/ASHRAE Standard 211-2018, *Standard for Commercial Building Energy Audits*.

Benchmarking—Comparing to Peers

- ASHRAE/IES Standard 100-2015
- DOE Commercial Building Energy Consumption Survey (CBECS)
- CIBSE benchmarks
- RECS statistics (EIA 2013) or EPMI 2016 (multifamily)
- ENERGY STAR
- ASHRAE Building Energy Quotient (Building EQ) in Operation Rating
- DOE Building Performance Database (BPD)
- Your favorite benchmarking system or peer sample (with selection criteria and total buildings in the sample)

OR


$E_{bld} = E_{imp} + E_g - E_{exp} - E_s$
$E_{site} = E_{imp} - E_{exp} - E_s$
On-site renewable energy production E_g
Imported *Energy* E_{imp}
Net increase in *stored imported energy* E_s
Exported *Energy* E_{exp}
Building Energy E_{bld}
Site Energy E_{site}

ASHRAE Standard 105 R **Form 2**
(This is a normative annex and is a part of this standard)

NORMATIVE ANNEX B: *SITE ENERGY PERFORMANCE* SUMMARY

Energy Form	Source of *Energy* Data[4]	*Energy Use* Numerical Value	Units	Conversion Factor[3] to kBtu (kWh)	Annual Site *Energy* (kBtu/yr) *(kWh/yr)*	*Energy Cost* ($)
1. Imported Electricity						
2. Imported Natural Gas						
3. Imported Steam						
4. Imported Hot Water						
5. Imported Chilled Water						
6. Imported Fuel Oil						
7. Imported Propane						
8. Other						
9. Non-Depletable Thermal – On-Site Production						
10. Non-Depletable Electricity – On-Site Production						
11. Exported Electricity						
12. Exported Steam						
13. Exported Hot Water						
14. Exported Chilled Water						
Building Energy [1] sum of 1 to 10 minus sum of 11 to 14					**A:**	
Site Energy [2] sum of 1 to 8 minus sum of 11 to 14					**B:**	**C:**
Notes						

Site Energy and Cost Indices

Building Energy Index (A÷*Gross Floor Area*) ____________ kBtu/ft^2·yr (kWh/m^2·yr)

Site Energy Index (B÷*Gross Floor Area*) ____________ kBtu/ft^2·yr (kWh/m^2·yr)

Energy Cost Index (C÷*Gross Floor Area*) ____________ \$/ft^2·yr (\$/m^2·yr)

EUI/ECI

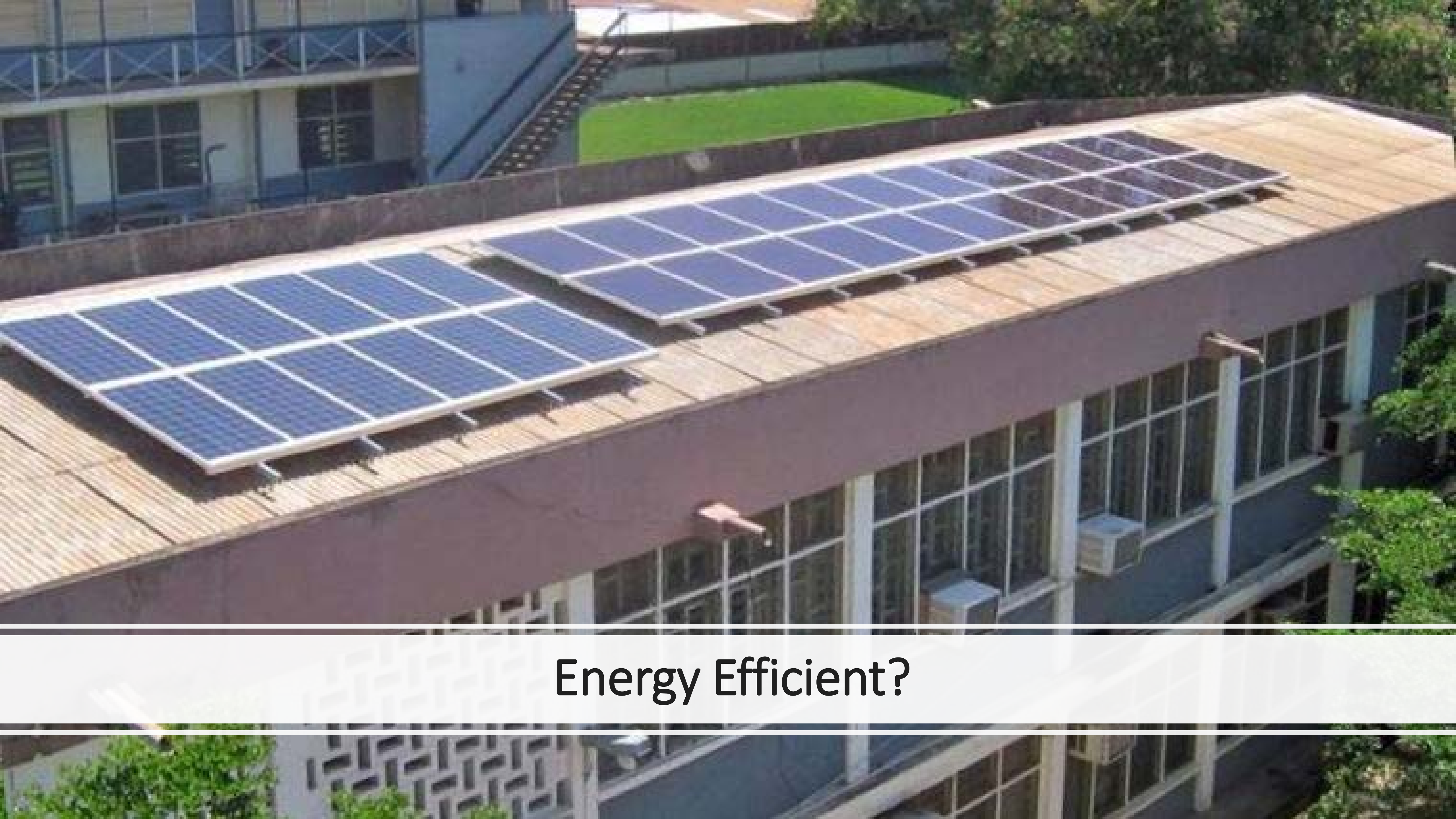
Existing Building EUI/ECI

Building Name	Acme Rocket Skates
Gross Conditioned Square Feet	94,241
EUI_{BLD} (kBtu/sf/yr)	147.6
EUI_{SITE} (kBtu/sf/yr)	77.4
Site ECI (energy cost index or $/sf/yr)	$ 3.21

*EUI: Energy Use Intensity

OR

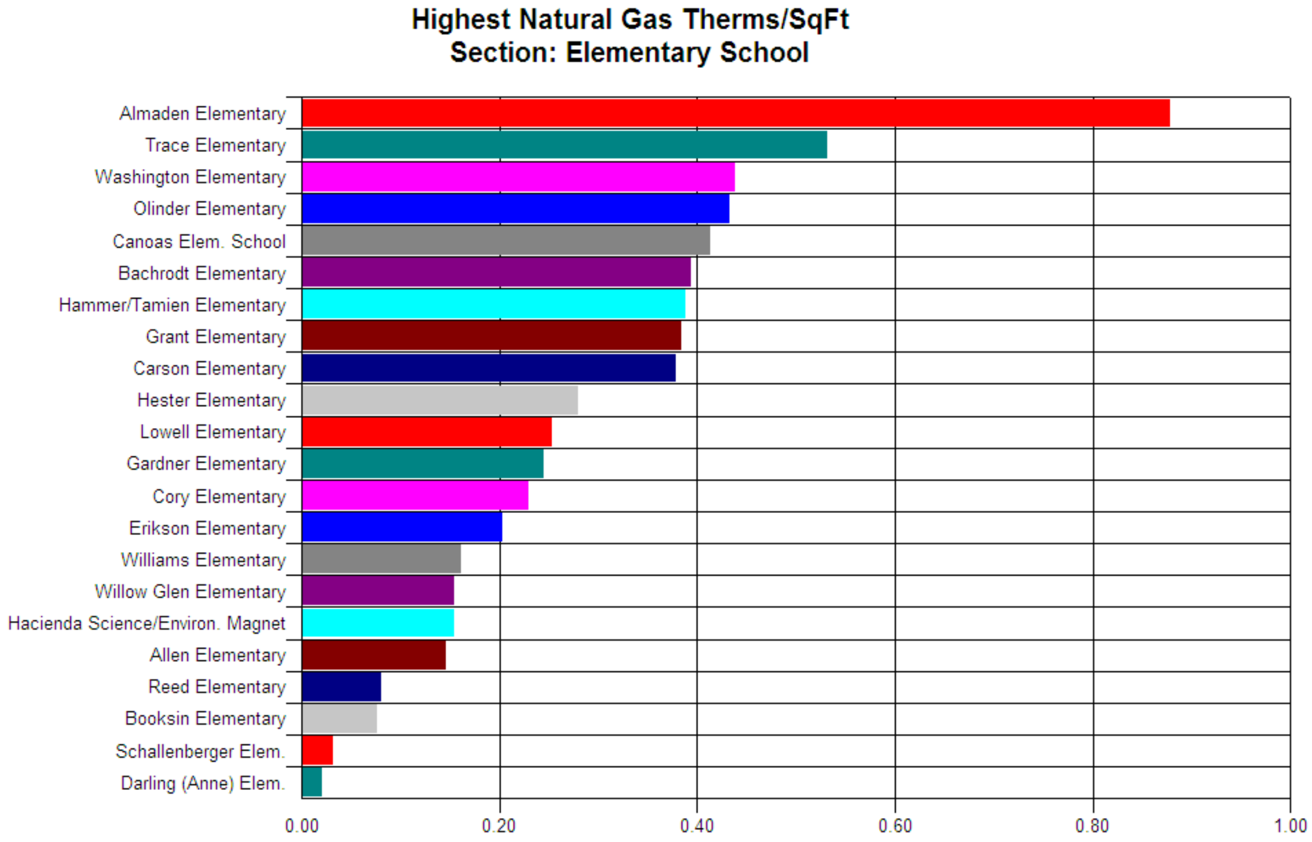
Which begs the question…



Energy Efficient?

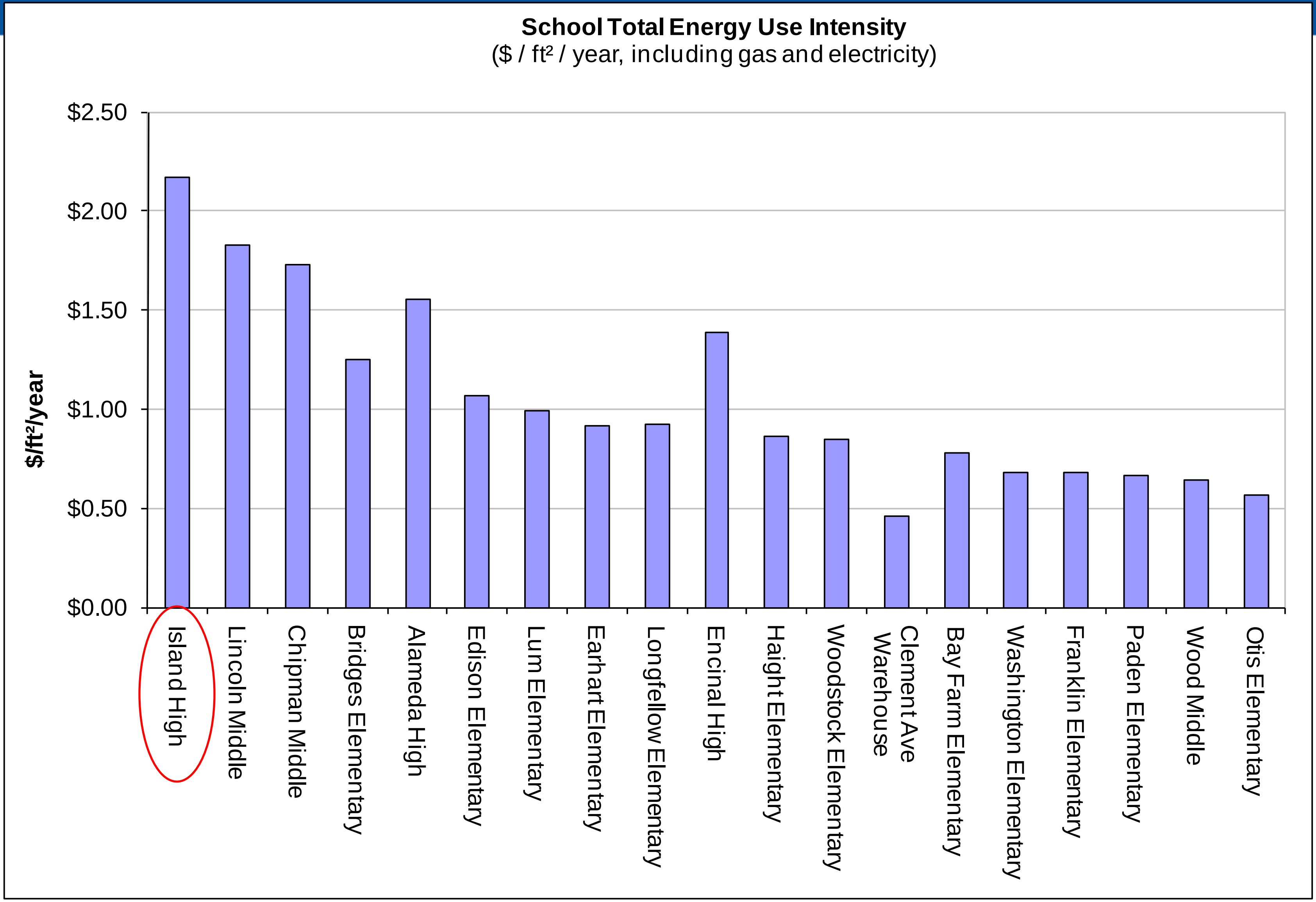
But Do Simple EUI's Encourage the Right Behavior? What is Green?

Benchmarking…against your own buildings



- Take sample over your campus or multiple campuses
- Compare buildings with similar occupancy, end uses
- For example:
  - ✓ labs vs. labs
  - ✓ data centers vs. data centers
  - ✓ classrooms vs. classrooms
  - ✓ dorms vs. dorms

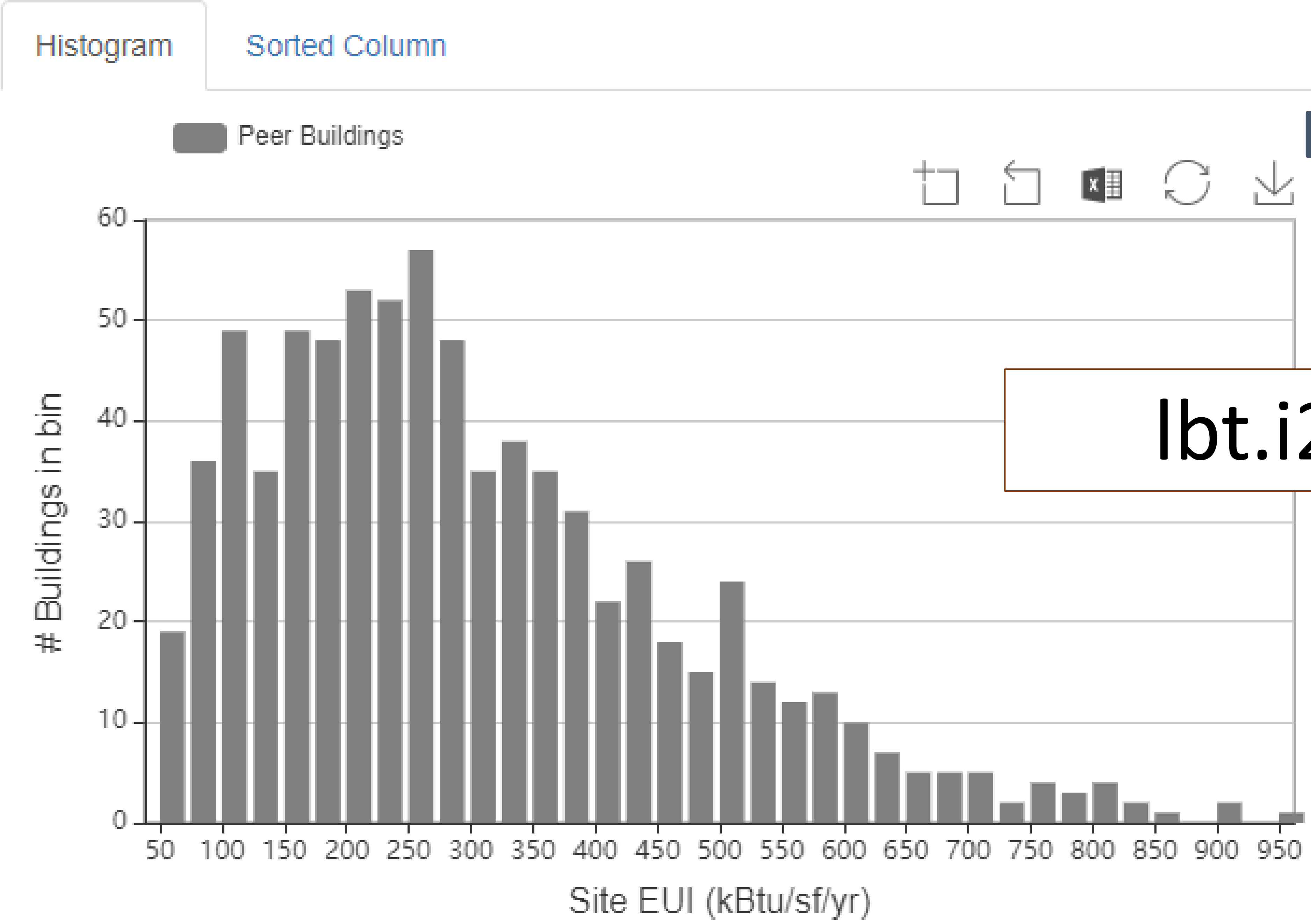
School District—Benchmarking



Laboratory Benchmarking Tool

lbt.i2sl.org

Laboratory Benchmarking Tool



lbt.i2sl.org

All Audit Levels - Annual Summary

Summary for Existing Building

user input
calculated

Imported Energy (E_{imp})

Energy Type	Total Annual Use	Units	Conversion Multiplier	Thousands BTU (kBtu)	Total Annual Cost ($)
Electricity	1,234,567	kWh	3.412	4,212,343	$ 179,863
Natural Gas	12,345	therms	100	1,234,500	$ 8,133
Purchased Steam	-	lbs District Steam	1.194	0	$ -
Purchased Hot Water	-	kWh	3.412	0	$ -
Purchased Chilled Water	-	MMBtu	1000	0	$ -
Oil	-	gallons (Fuel Oil #2)	139	0	$ -
Propane	-	gallons (Propane)	92	0	$ -
Coal	-	short ton (coal)	19622	0	$ -
			E_{imp} Total	**5,446,843**	**$ 187,995**

On-Site Renewable Energy Production (E_g)

Energy Type	Total Annual Use	Units	Conversion Multiplier	Thousands BTU (kBtu)	Total Annual Cost ($)
On-Site Generated - Thermal	-	MMBtu	1000	0	$ -
On-Site Generated - Electricity	-	kWh	3.412	0	$ -
			E_g Total	**-**	**$ -**

Utility #1 Electricity

MAIN DATA FOR ANALYSIS - Electricity						
Start Date	End Date	Days	Electricity Use (kWh)	Electricity Peak (kW)	Electricity Cost ($)	Electricity Load Factor
1/1/2010	2/1/2010	31				
2/1/2010	3/1/2010	28				
3/2/2010	4/1/2010	31				
4/2/2010	5/1/2010	30				
5/2/2010	6/1/2010	31				
6/2/2010	7/1/2010	30				
7/2/2010	8/1/2010	31				
8/2/2010	9/1/2010	31				
9/2/2010	10/1/2010	30				
10/2/2010	11/1/2010	31				
11/2/2010	12/1/2010	30				
12/2/2010	1/1/2011	31				
	Annual Total	365		-	$ -	

Utility #1: Definition

Units	kWh
kBtu/unit	3.412

All Audit Levels - Delivered Energy

Delivered Energy Type (if applicable)	Oil
Units	gallons (Fuel Oil #2)
Conversion to kBTU	139

Delivery date	Oil	Oil kBTU	Oil Cost ($)

user input
calculated

Annual Summary Totals

Estimated Annual Use**		gallons (Fuel Oil #2)
Estimated Annual Energy		kBTU
Unit Rate of Fuel	$0.00	$/gallons (Fuel Oil #2)
Estimated Annual Cost	$0	

**Auditor to estimate the annualized use, which may differ from delivered quantities.

Enter additional tables for more delivered energy types and modify summary table as needed

Enter additional rows for more deliveries

All Audit Levels - Delivered Energy

Delivered Energy Type (if applicable)	Oil
Units	gallons (Fuel Oil #2)
Conversion to kBTU	139

Delivery date	Oil	Oil kBTU	Oil Cost ($)

user input
calculated

Annual Summary Totals

Estimated Annual Use**		gallons (Fuel Oil #2)
Estimated Annual Energy		kBTU
Unit Rate of Fuel	$0.00	$/gallons (Fuel Oil #2)
Estimated Annual Cost	$0	

**Auditor to estimate the annualized use, which may differ from delivered quantities.

Enter additional tables for more delivered energy types and modify summary table as needed

Enter additional rows for more deliveries

Not eligible to apply for ENERGY STAR Certification

ENERGY STAR Score (1-100)

Current Score: 71

Baseline Score: 65

Metric	Jul 31 2016 (Energy Baseline)	Apr 30 2018 (Energy Current)	Target*	Median Property*
ENERGY STAR score(1-100)	65	71	66	50
Source EUI(kBtu/ft²)	126.1	111.0	119.8	149.9
Site EUI(kBtu/ft²)	54.5	47.2	51.8	63.8
Source Energy Use(kBtu)	52434664.8	46150324.3	49812931.6	62347888.6
Site Energy Use(kBtu)	22658156.1	19641650.1	21525248.3	26535361.1
Energy Cost($)	906576.99	844084.18	861248.14	1140335.79
Total GHG Emissions(Metric Tons CO2e)	1487.1	1296.0	1412.7	1750.8

* To compute the metrics at the target and median levels of performance, we will use the fuel mix associated with your property's current energy use.

Current Baselines & Targets

	Baselines	Target
Energy	07/31/2016	5%
Water	Not Available	Not Available
Waste/Materials	Not Available	Not Available

Set Baselines or Target

Savings to Meet Target

	Electricity	Steam
Current EUI	42.1	85.2
Average EUI	36.4	60.0
Potential Savings	721,980	3,176,769
Savings as % of current consumption	9%	11%

$$\text{Savings} = (\text{EUI}_{\text{my building}} - \text{EUI}_{\text{target}}) * \text{Area}_{\text{my building}}$$

Exercise #1:
Building Energy vs. Site Energy

Exercise 1a: Building Energy vs. Site Energy

Given:

- 900,000 kWh/yr electricity purchased from utility
- 100,000 kWh/yr produced by solar PV on roof
- All solar energy consumed by the building

Calculate:

1. Building energy kWh/yr
2. Site energy kWh/yr

Exercise 1b: Building Energy vs. Site Energy

Given:

- 900,000 kWh/yr electricity purchased from utility
- 100,000 kWh/yr produced by solar PV on roof
- 50,000 kWh/yr of the solar energy produced is exported to grid

Calculate:

1. Building energy kWh/yr
2. Site energy kWh/yr

Level 1 Elements

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Level 1—Walk-Through

Report

- Summarize utility data
  - Determine load shape irregularities
- Compare EUI to that of similar sites
  - For example, ENERGY STAR PM or Energy IQ
- Estimate savings if EUI met target
- Total energy costs by fuel type
- O&M deficiencies, safety deficiencies
- Low-cost/no-cost savings
- ~~Rough costs for capital projects~~

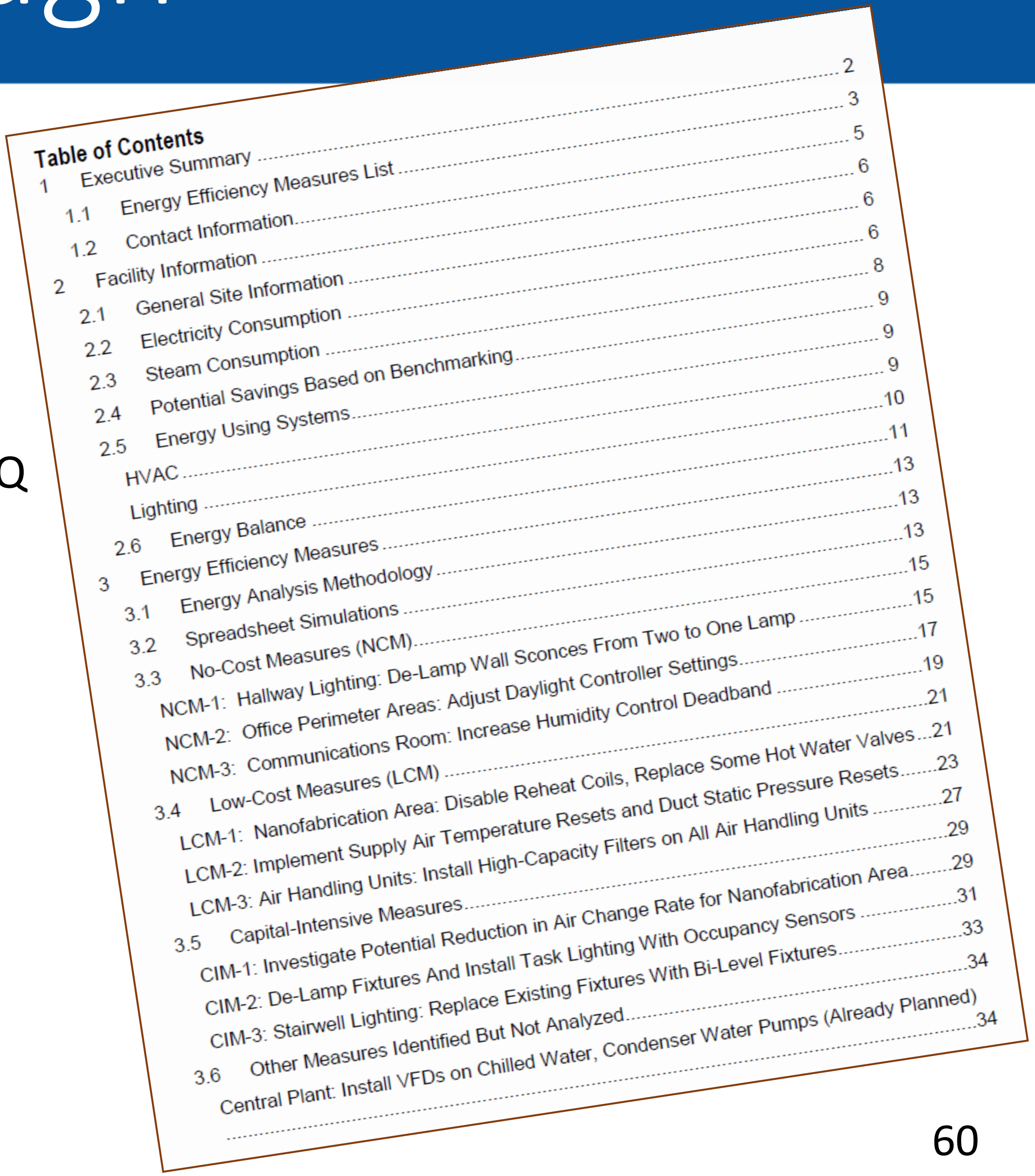
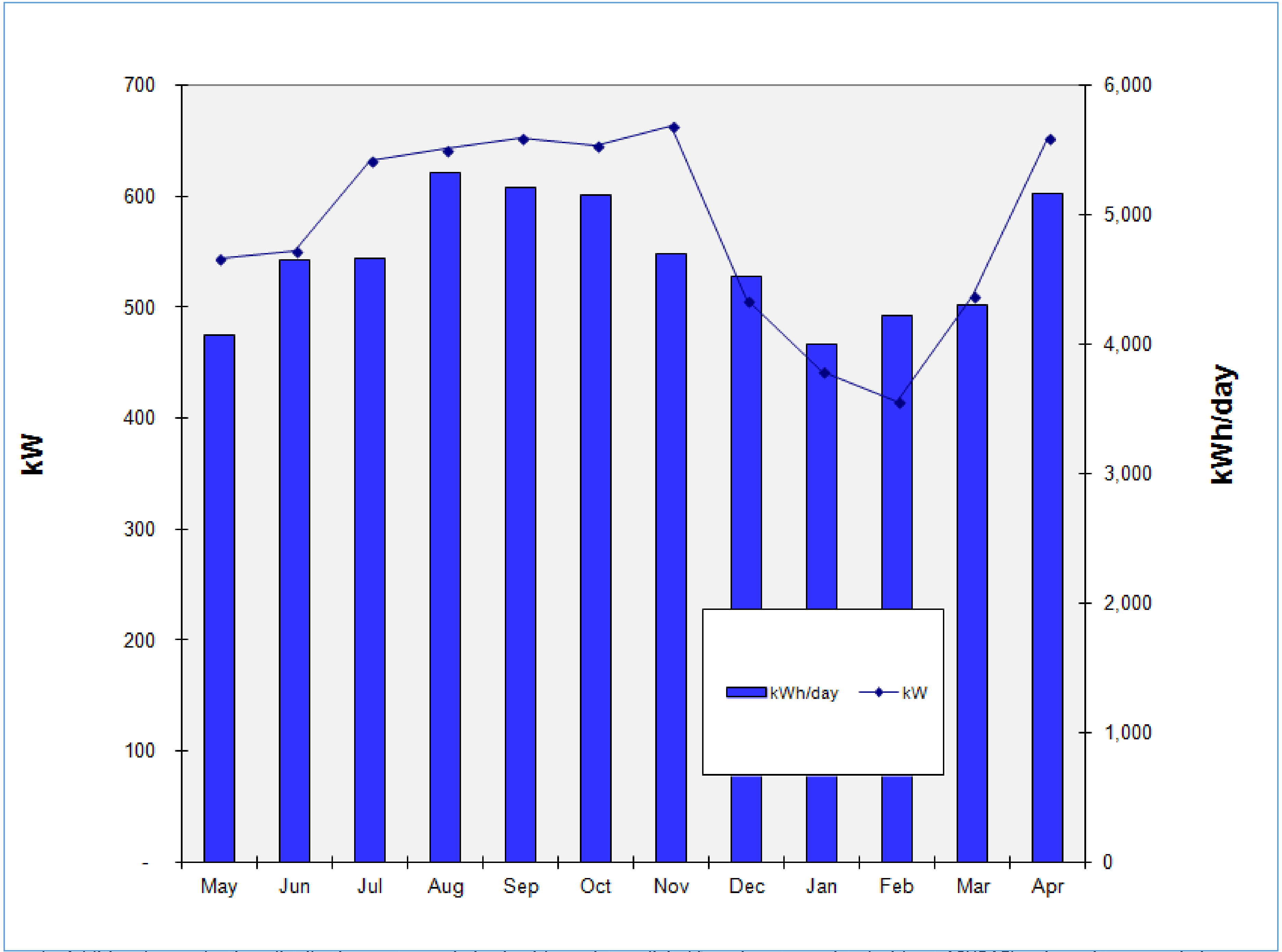
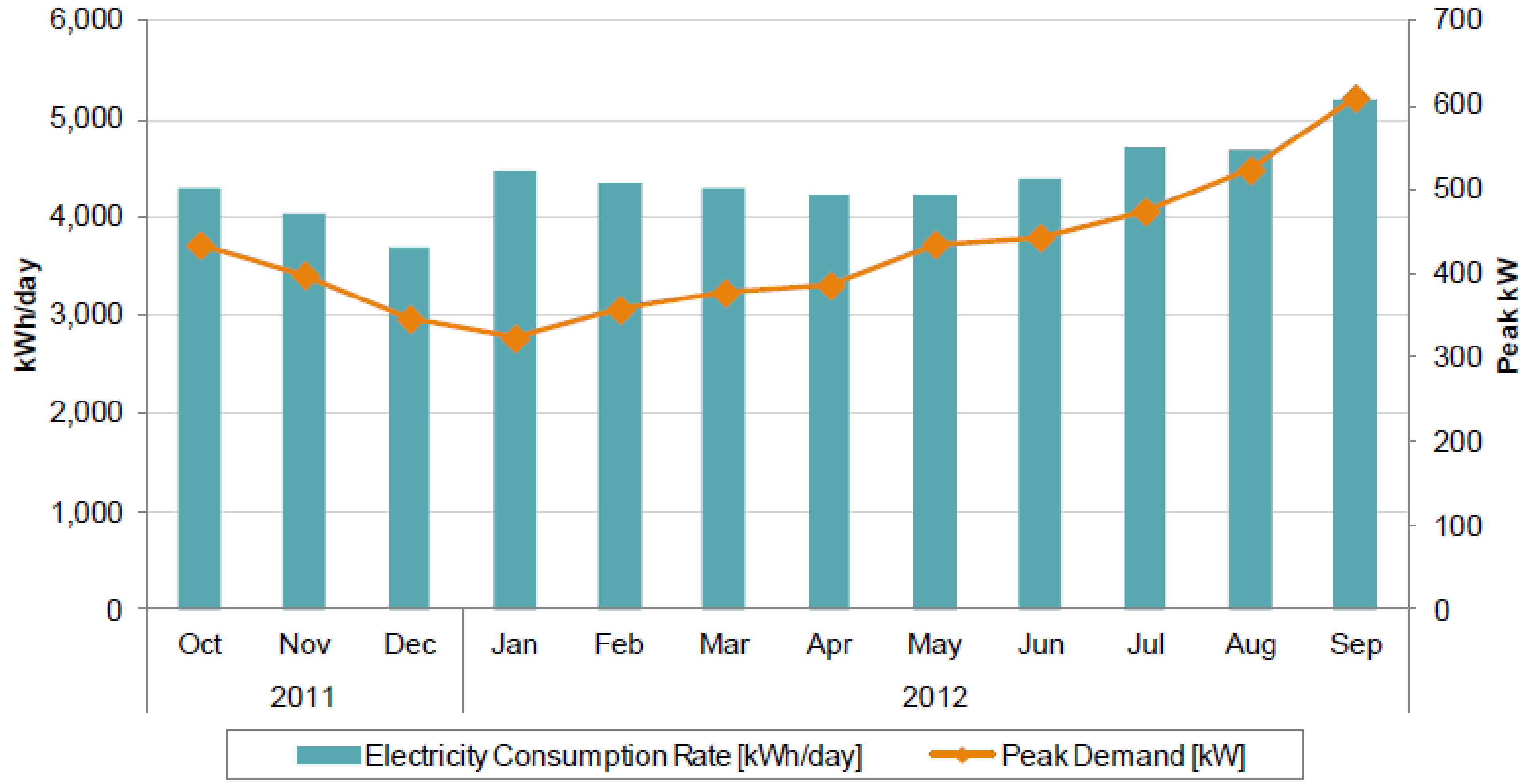


Table of Contents

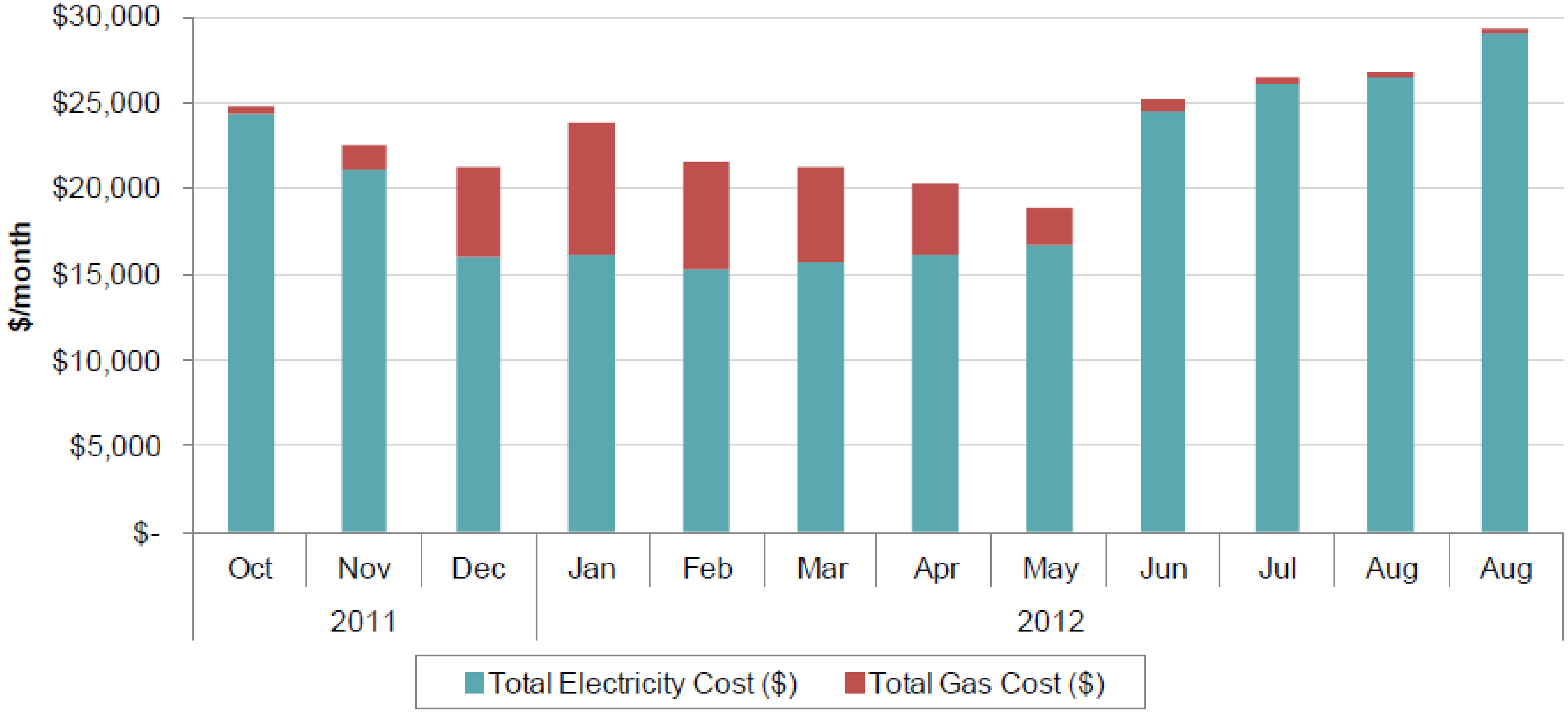
Utility Data Summary



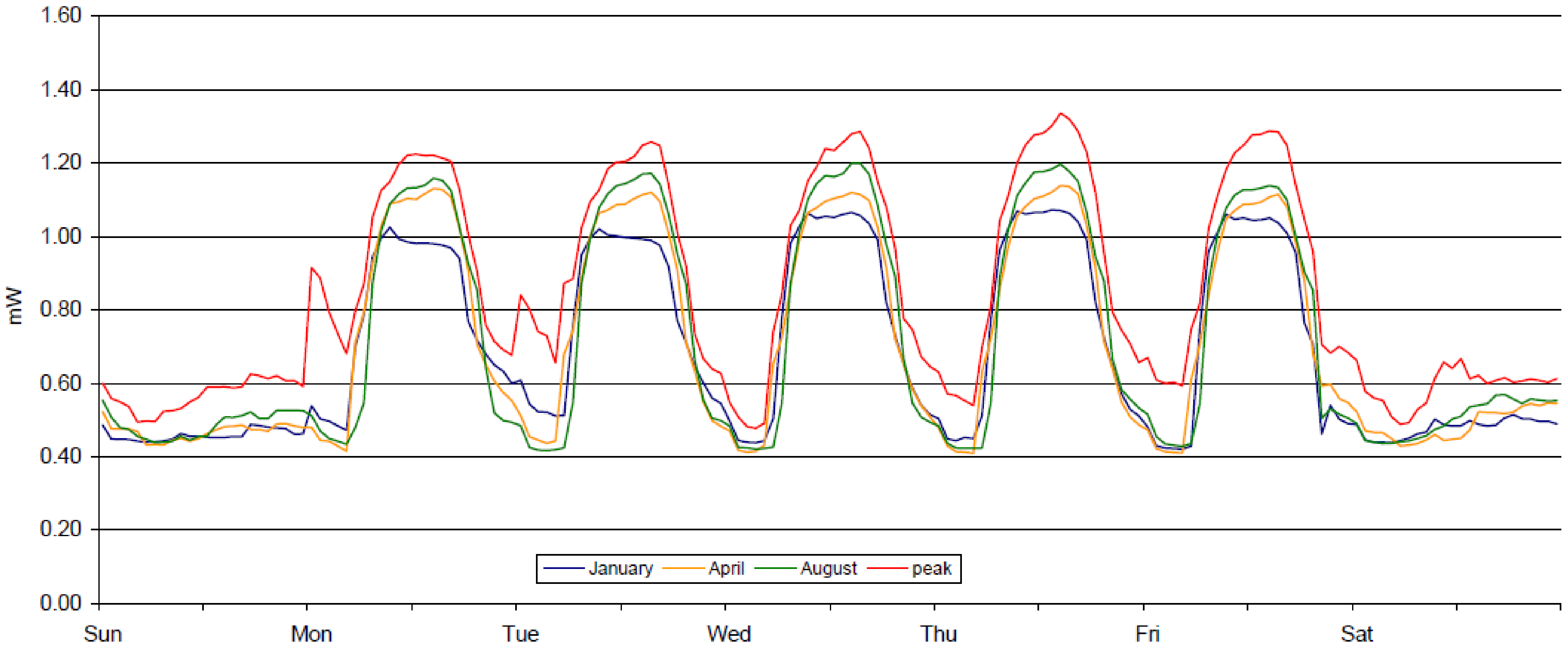
Monthly kWh and Peak Demand



Total Monthly Cost Summary

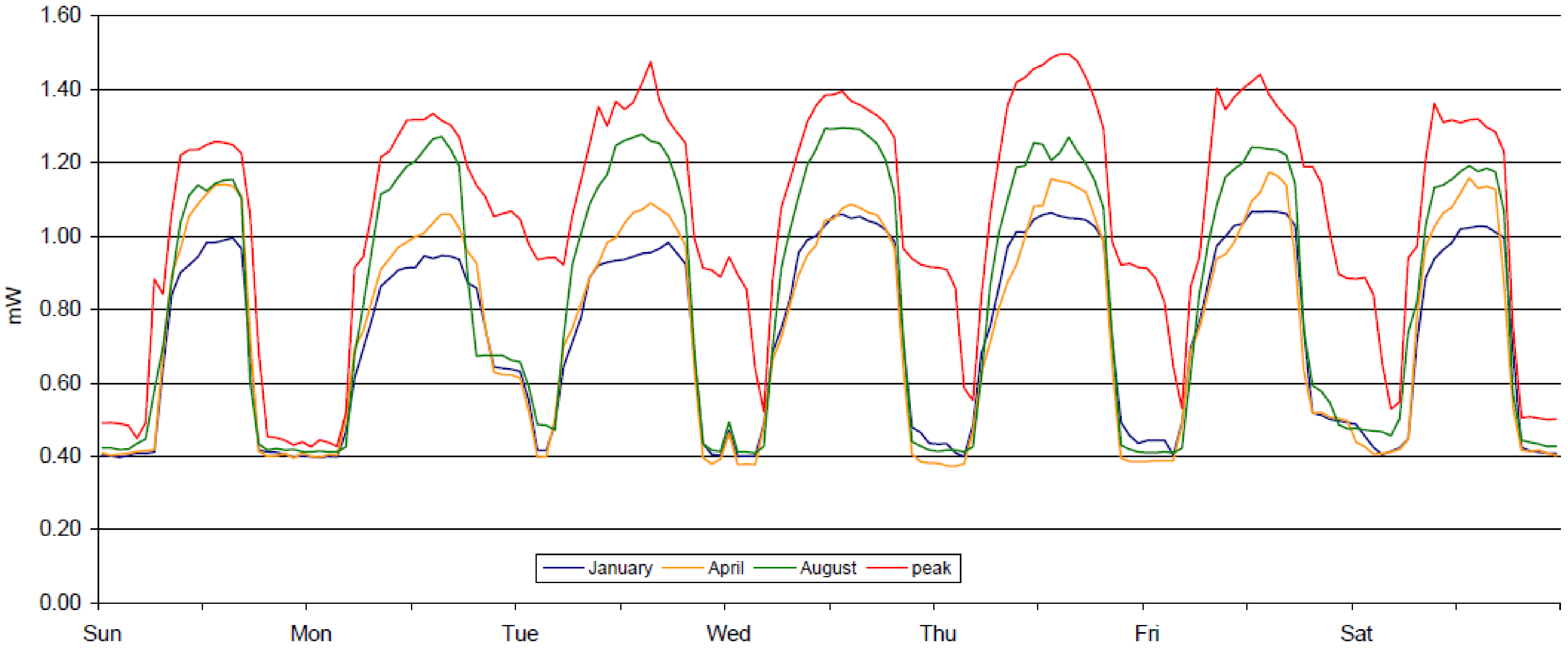


Sample Interval Plots

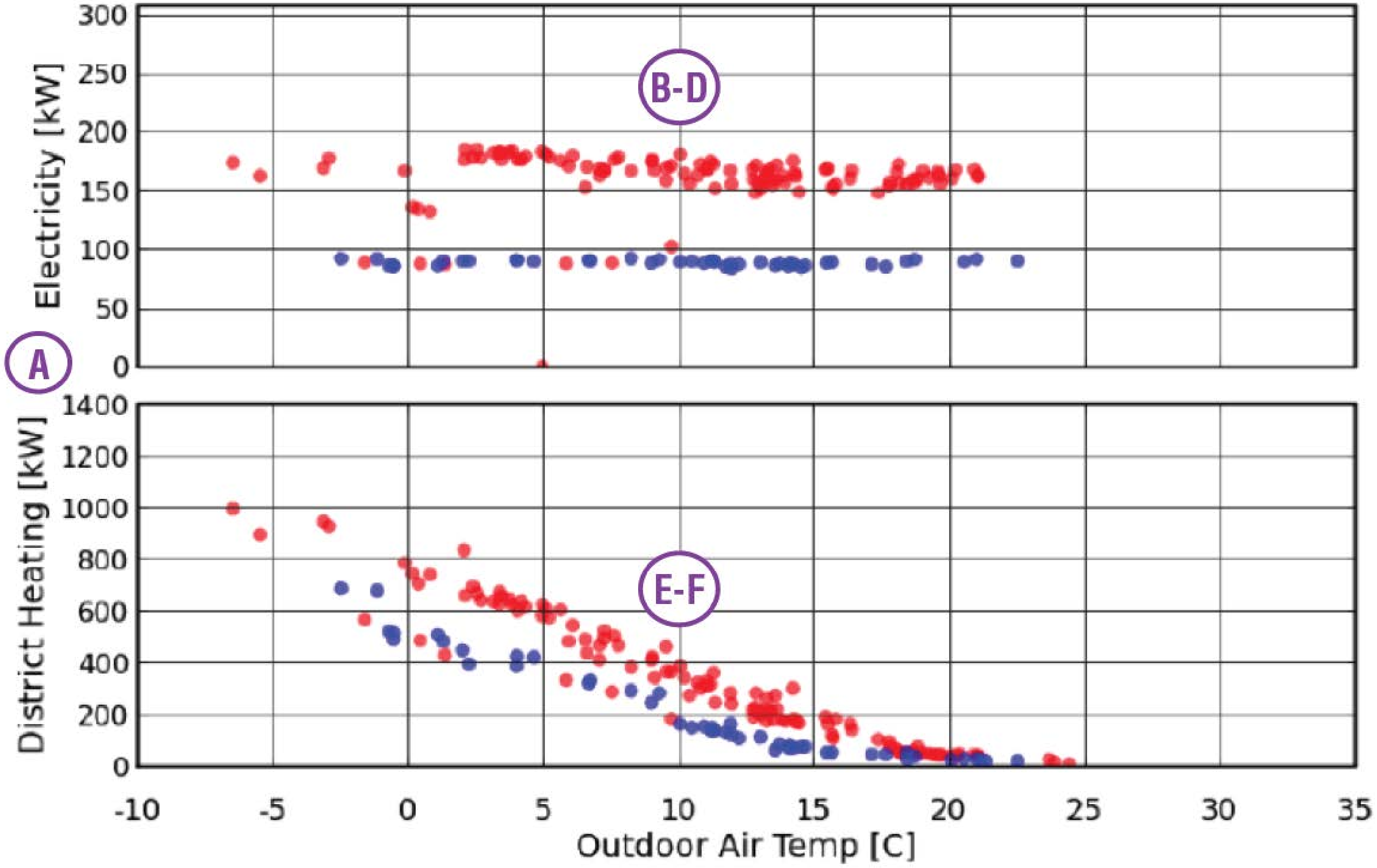


Note anything unusual, such as high night-time baselines

Sample Interval Plots



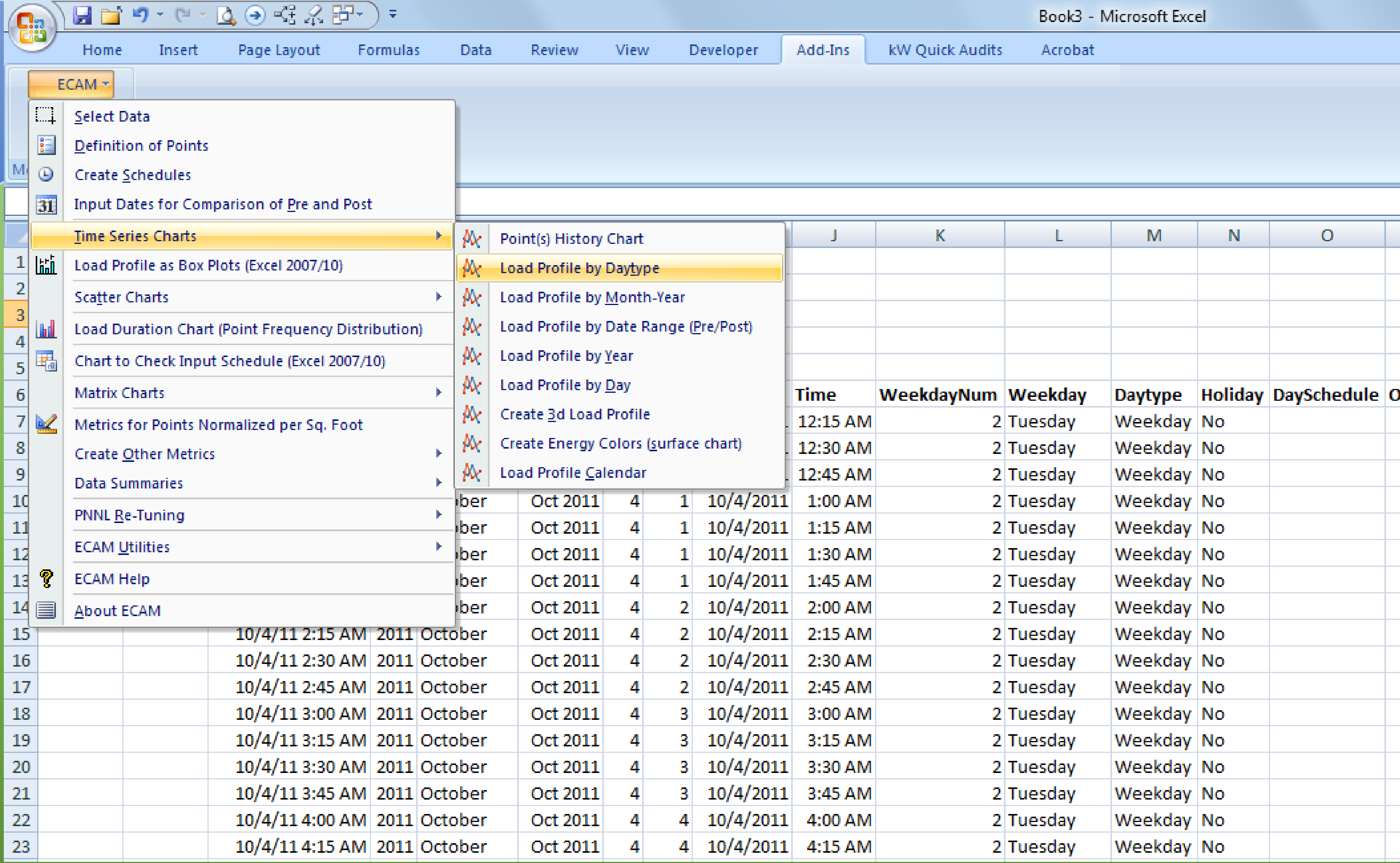
Sample Temperature-Dependent Plots



Source: Mazzarella, L, et al, eds. Description of european prototype tool for evaluation of building performance and the national tools. Fraunhofer Institute for Solar Energy Systems, Intelligent Energy Europe, 2009.

Granderson, J., *et al*. 2011. *Energy Information Handbook:, Applications for Energy-Efficient Building Operations*. Lawrence Berkeley National Laboratory, LBNL-5272E.

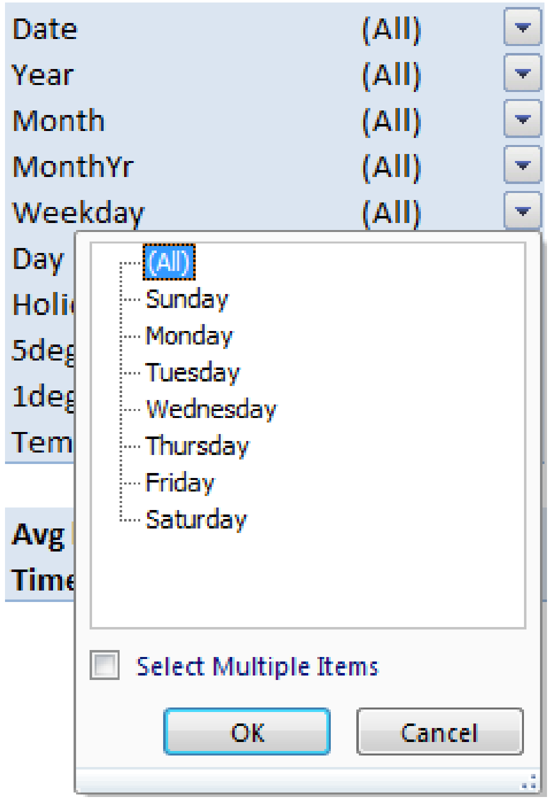
Great Resource

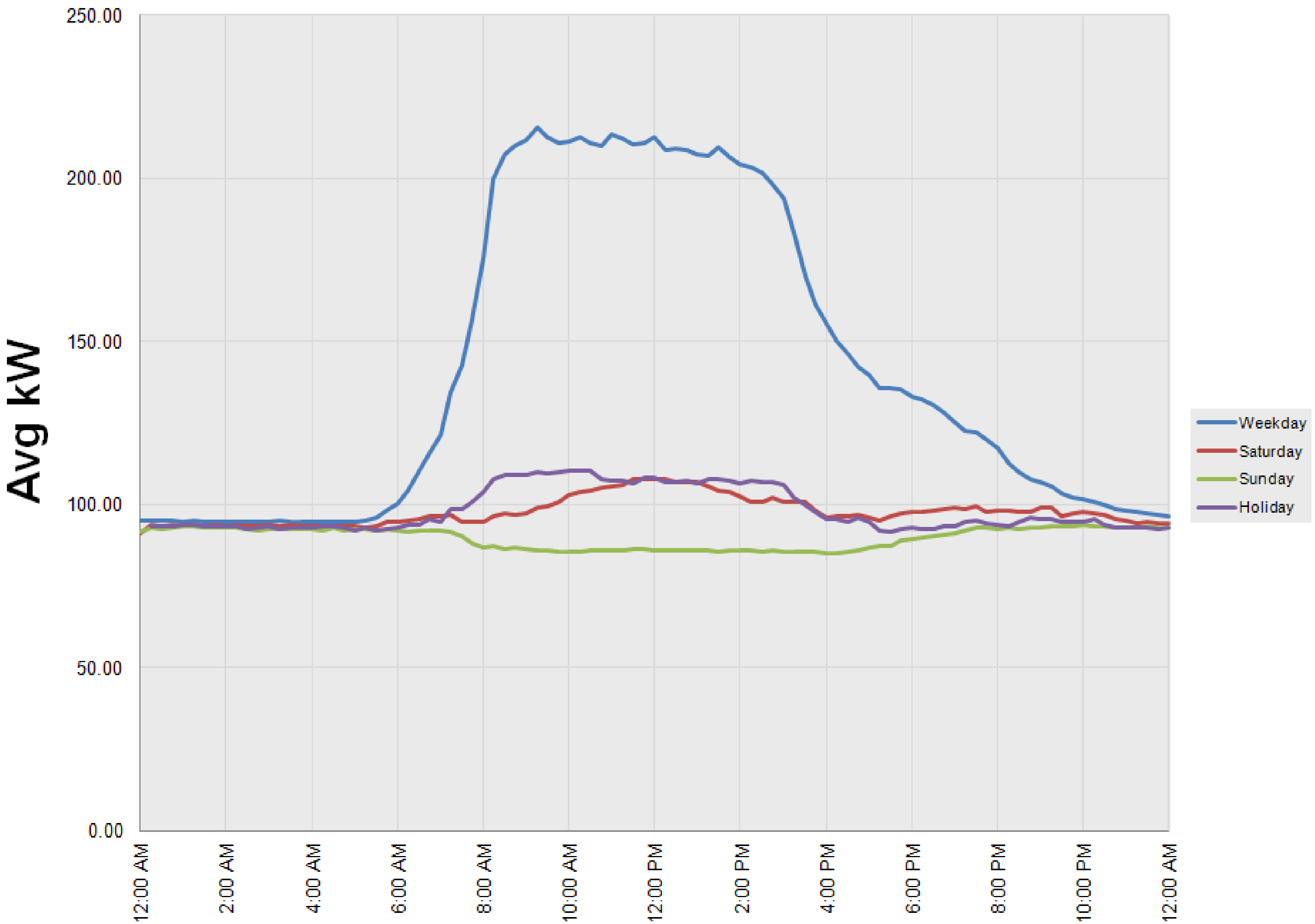


ECAM

www.cacx.org/PIER/ecam or www.sbwconsulting.com/ecam

Daily Profiles





www.cacx.org/PIER/ecam or www.sbwconsulting.com/ecam

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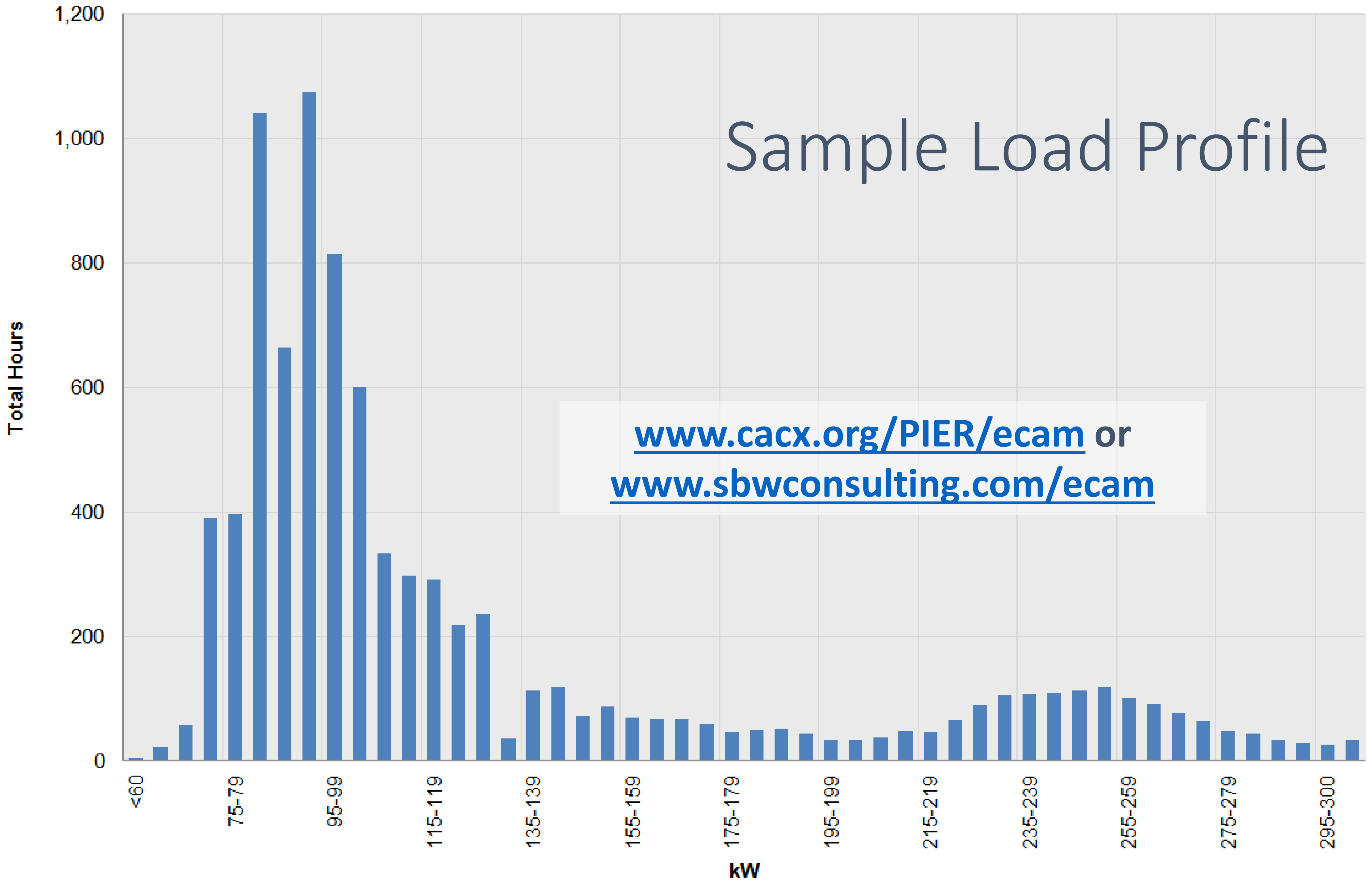
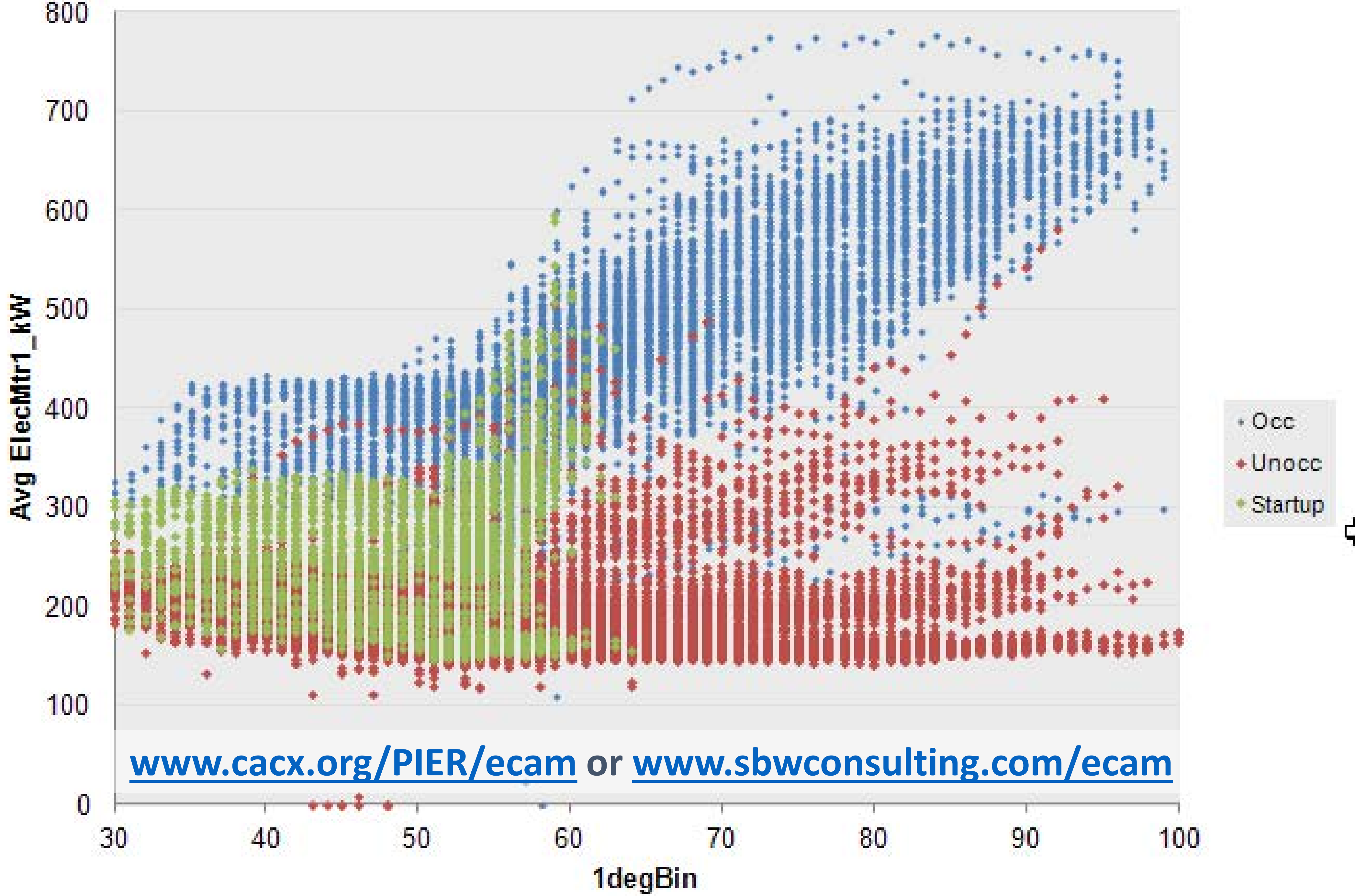


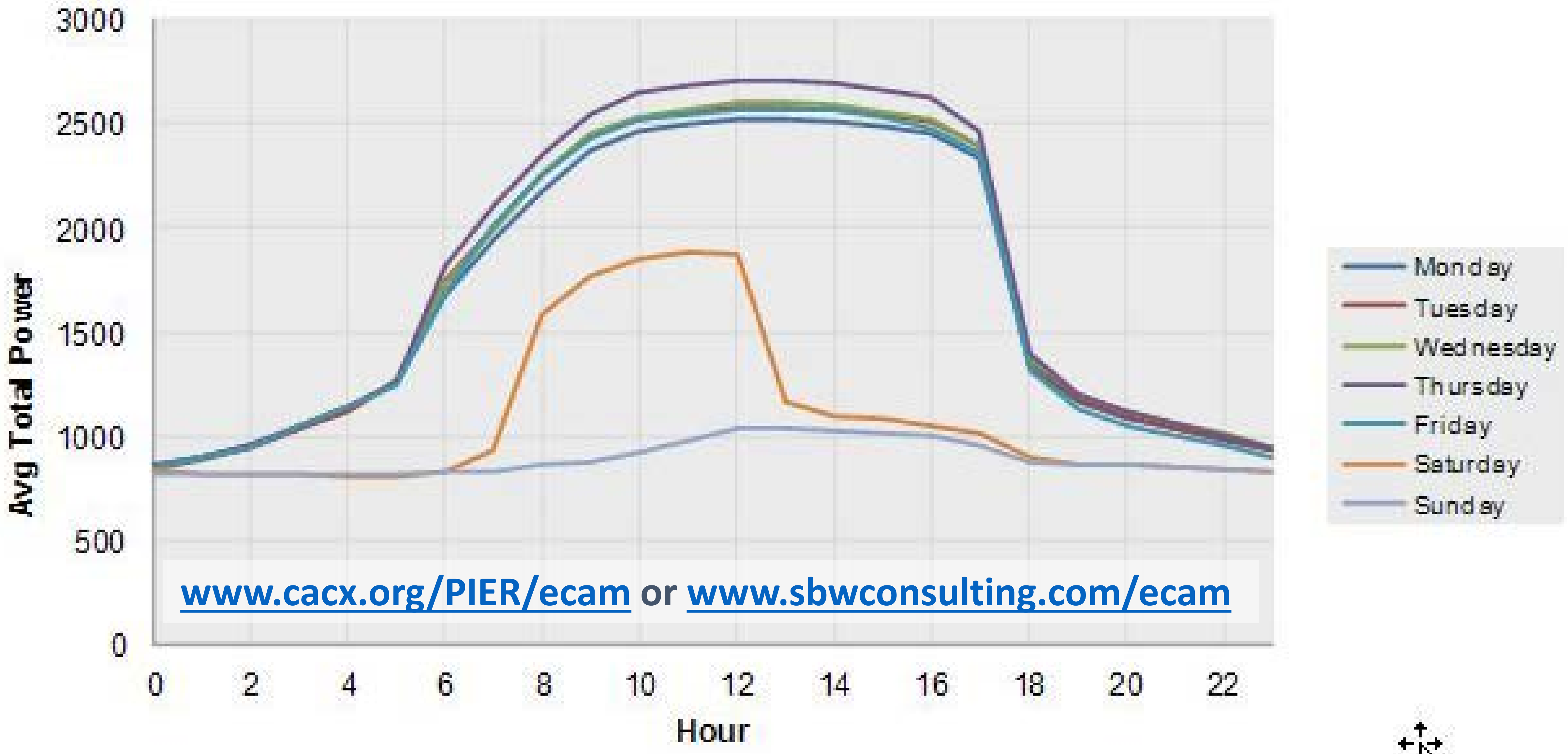
Sample Load Profile
www.cacx.org/PIER/ecam or
www.sbwconsulting.com/ecam
Total Hours
1,200
1,000
800
600
400
200
0
<60
75-79
95-99
115-119
135-139
155-159
175-179
195-199
215-219
235-239
255-259
275-279
295-300
kW

Scatter Plots



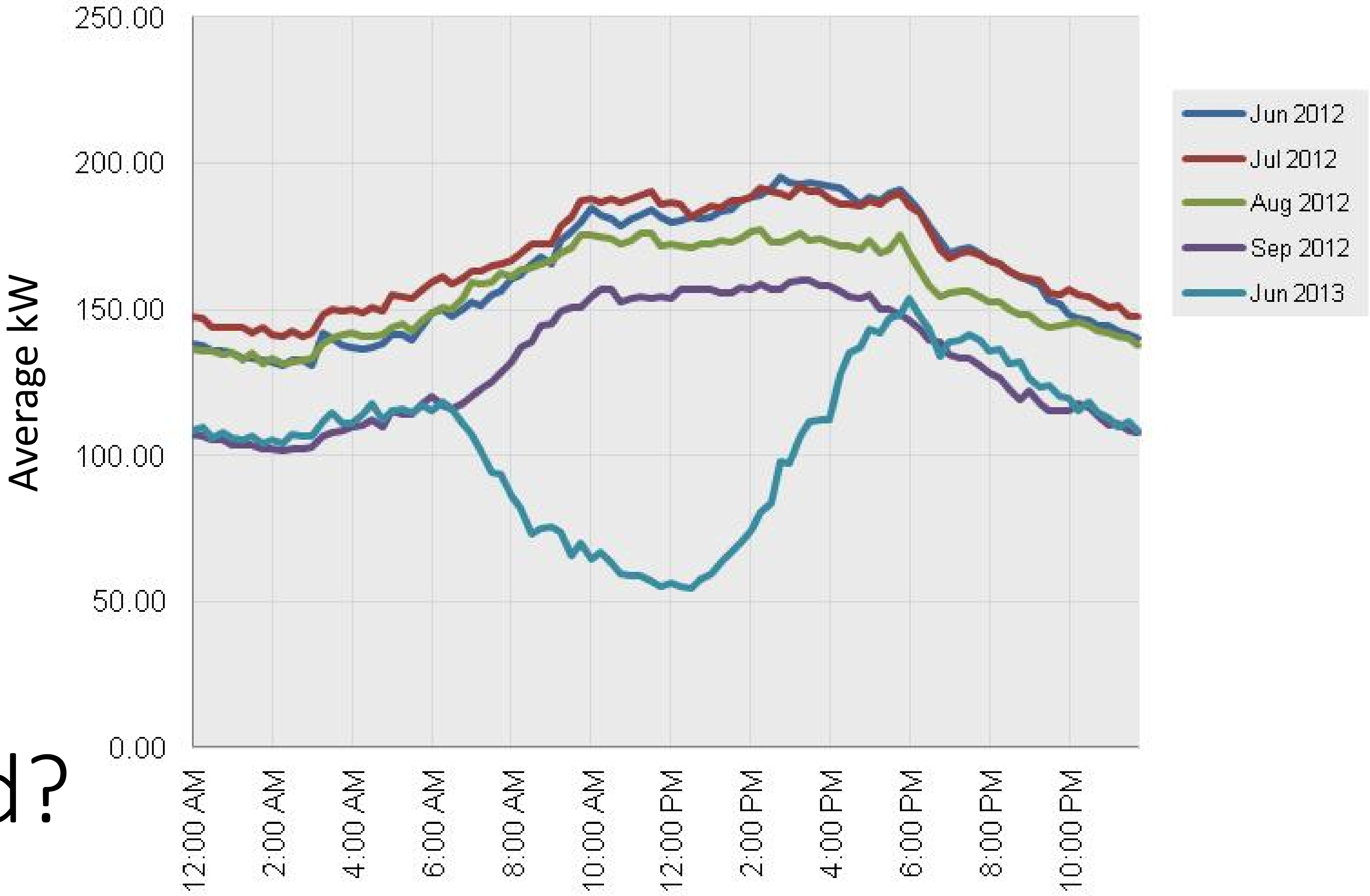
www.cacx.org/PIER/ecam or www.sbwconsulting.com/ecam

One of These Things is Not Like the Other…



www.cacx.org/PIER/ecam or www.sbwconsulting.com/ecam

Pop Quiz: What Happened?



All Audit Levels - Space Function Breakdown

For areas comprising > 20% of gross floor area

Space Number	A	B	C	D	E	Unaccounted
Function type*	Supermarket/Grocery Store Swimming Pool Transportation Terminal/Station Urgent Care/Clinic/Other Outpati Vacant Veterinary Office Vocational School Wastewater Treatment Plant					
Original intended use						
Gross Floor Area* (per space)						
Conditioned Area* (Approx % of total function space)						
Number of Occupants						
Approximate Plug Loads (W/sf)						
Use (hours/week)						
Use (weeks/year)						
Principal HVAC Type*						
Principal Lighting Type*						

Building Characteristics

Building ID	Sample Building			Date of Audit	6/18/2012
City	Sample City	State	CA	Zip	94014
Latitude	37.702	Longitude	-122.470	HDD	2,708
CDD	142 (Base 65°F)				2009 (Year of Data)
Gross Floor Area [1]	347,787 ft²			Total Conditioned Area [1]	347,787 ft²
Conditioned Area [1], heated only	ft²			Conditioned Area [1], cooled only	ft²
Conditioned Area [1], heated & cooled	347,787 ft²				
Number of conditioned floors	Above grade	9	Below grade	0	
Year of Construction [2]	2001				

Brief Building Description: Sample Bldg is a 350,000 square foot, 9-story, multi-tenant office tower located adjacent to Highway 1 in Daly City.

Primary Building Type [3]

13 Office Leased (5+ Tenants)

1. GROSS FLOOR AREA is all floor area contained within the outside finished surface of permanent outer building walls including basements, mechanical equipment floors, and penthouses (ANSI Standard Z65.1-1996, Construction Area). No exclusions are made for shafts, stairs, or atria. CONDITIONED AREA is that area provided with heating or cooling to maintain temperature between 50°F and 86°F (ANSI/ASHRAE Standard 105-1984).
2. THE MEDIAN YEAR for construction of at least 51% of the conditioned space.
3. BUILDING TYPE as characterized by at least 51% of the conditioned space.

Some O&M Deficiencies

For example:

- Belts need replacement
- Lubrication needed
- Refrigerant charge
- Damper actuator repair needed
- Sensor calibration
- Tower packing needs replacement
- Boiler tubes need replacement
- Etc., etc., etc.…

(Reference for maintenance standards: ASHRAE Standard 180)

List as applicable in your report

Health and Safety "if you see something, say something"

Capital Projects

CIM-3: Stairwell Lighting: Replace Existing Fixtures With Bi-Level Fixtures

Qualitative Measure Analysis			
Measure Priority	Savings Potential	Implementation Cost Estimate	Estimated Payback
Low	Low	Medium	6 – 8 years

Observations

The building features two stairwells that are lit by round wall sconces. The lights are on continuously for emergency egress lighting, regardless of whether the stairwell is being used.

Figure 3.8: Round Wall Sconces in Stairwell

Level 1 EEM Summary

Level 1 Audit - Recommended Energy Efficiency Measure Summary

Low-Cost and No-Cost Recommendations	Modified System	Impact on Occupant Comfort or IEQ	Other Non-Energy Impacts	Cost	Savings Impact	Typical ROI	Priority
Correct Economizer sequence	AHUs 1, 4	Improved ventilation		low	medium	high	high
Potential Capital Recommendations	**Modified System**	**Impact on Occupant Comfort**	**Other Non-Energy Impacts**	**Cost**	**Savings Impact**	**Typical ROI**	**Priority**
Add VFD to Chilled Water Pumps	Chilled water system	none	Improved motor lifetime	medium	medium	high	high
Demand Controlled Ventilation	AHUs 1-4	Improved ventilation	CO2 tracking	high	medium	medium	medium

Level 1 Sample Outline (Not Required by ACCA/ASHRAE Standard 211)

1. EXECUTIVE SUMMARY
   a. Overall assessment of benchmarking and energy performance
   b. Potential savings and return on investment (ROI)
   c. Table of recommended measures with estimated level of savings and ROI
2. INTRODUCTION
   a. Audit scope
   b. Key dates
   c. Contact information
3. FACILITY DESCRIPTION
   a. Site information
   b. Notable conditions
4. HISTORICAL UTILITY DATA
   a. Data summary and rate schedules
   b. Annual Energy Use Intensity (EUI), Energy Cost Index (ECI)
5. BENCHMARKING
6. ESTABLISH TARGET AND ESTIMATE SAVINGS
7. ENERGY SAVING OPPORTUNITIES
   a. Low-cost/no-cost savings measures
   b. Capital projects

APPENDICES

- Tabulated utility data (Annex C tables)
- Utility rate schedules (Annex C tables)
- Basis for savings and cost estimates
- Lighting and equipment inventory tables (optional)

Level 2 Elements

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Measurement Approaches

Increasing Accuracy and Value

Logged Over Time

- Stand-alone Loggers
- Building Automation Systems
- Interval Data

Single Point in Time

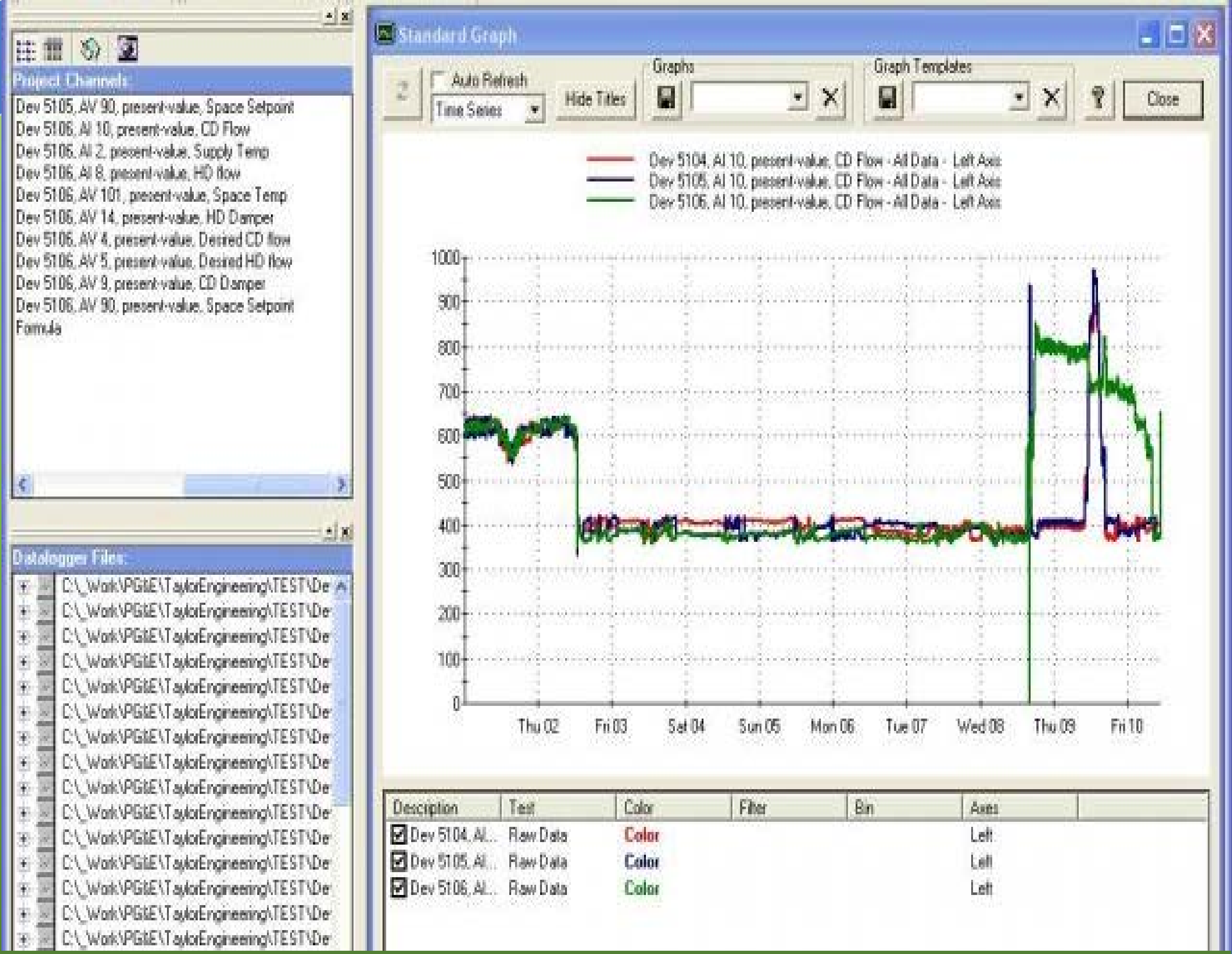
- Spot Measurements
- Site Gauges
- Assumptions / Manufacturers Specs

Increasing Cost and Complexity

Great Resource

Universal Translator

- Converts your data to common platform
- Includes common diagnostics and M&V



www.utonline.org

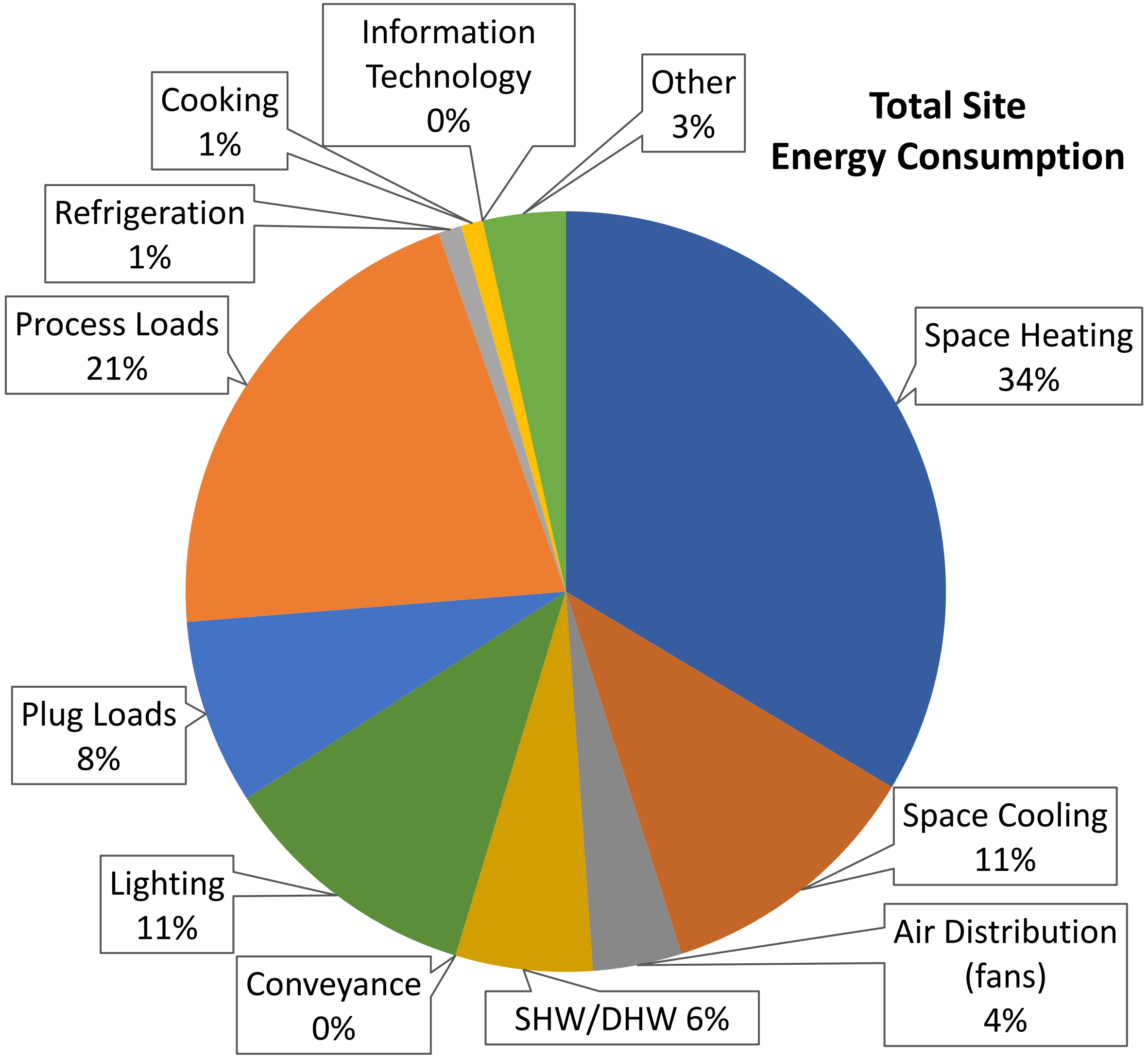
End-Use Allocation

Utility #1	Electricity
Units	kWh
kBTU/Unit	3.412
End Use (customize for subject building, items below include potential areas)	**Electricity**
Cooking	36,000
Space Cooling	445,996
Space Heating	699,993
Lighting	433,589
Other	136,500
Plug Loads	305,997
Water Distribution (pumps)	56,525
Refrigeration	38,500
Air Distribution (fans)	146,999
SHW/DHW	22,000
Total	2,322,099
Total from (annual summary)	2,321,899
Adjustment for On-Site Gen	-
Adjusted Total w/ Generation	2,321,899
Difference	200
% Difference	**0%**

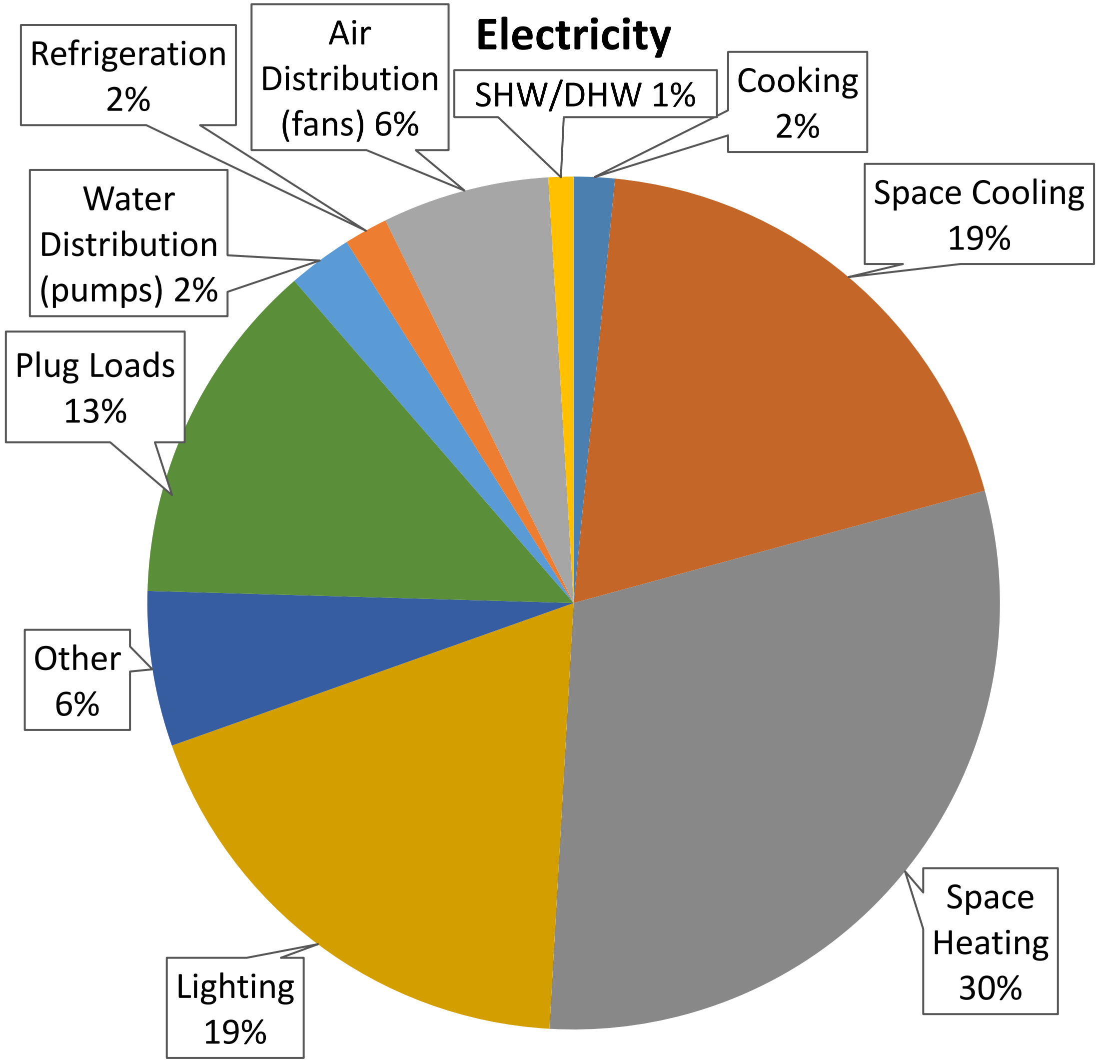
Utility #2	Natural Gas
Units	therms
kBTU/Unit	100
End Use (customize for subject building, items below include potential areas)	**Natural Gas**
Space Heating	20,640
Process Loads	27,620
SHW/DHW	6,970
Total	55,230
Total from (annual summary)	56,800
Adjustment for On-Site Gen	
Adjusted Total w/ Generation	56,800
Difference	-1,570
% Difference	**-3%**

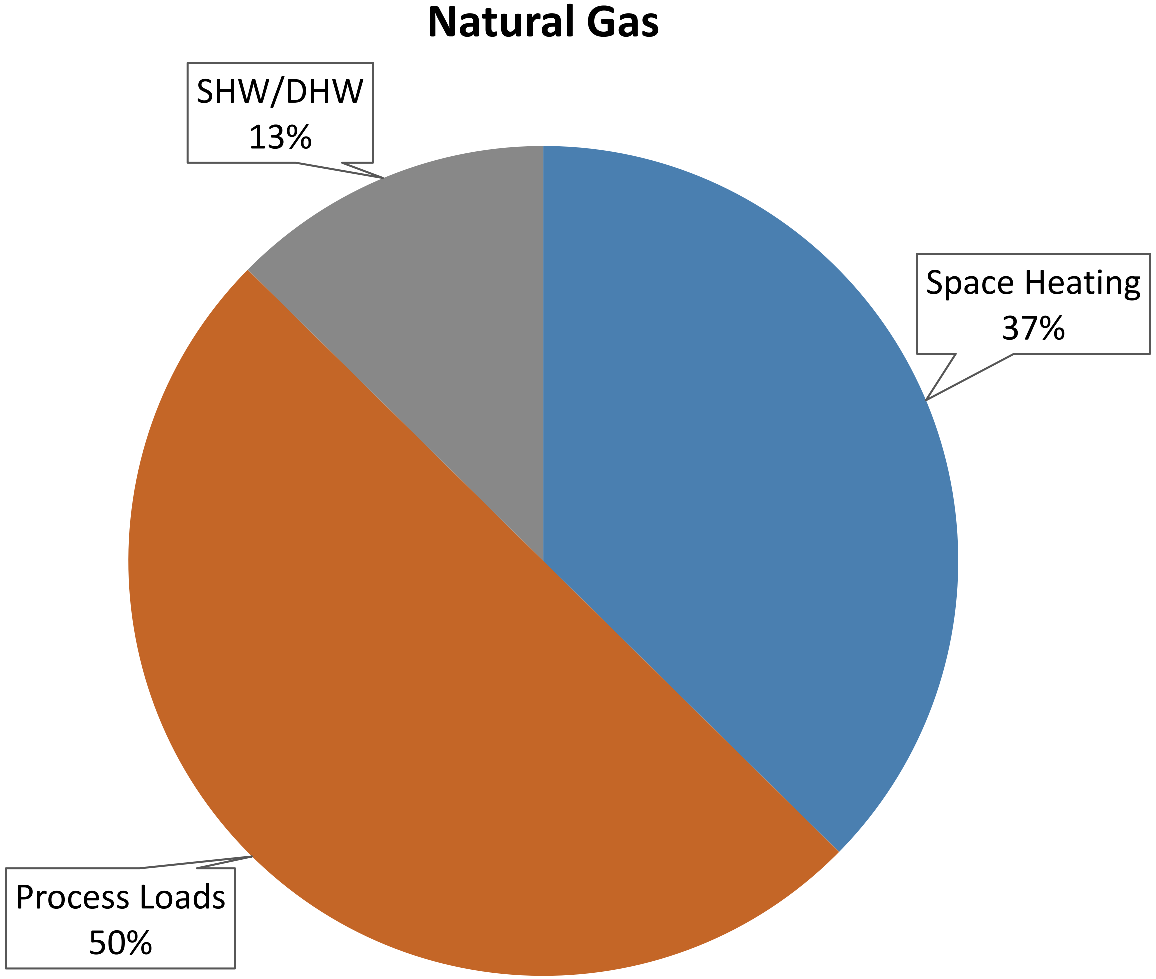
End-Use Allocation

End Use Summary		
End Use (customize for subject building, items below include potential areas)	**Total kBtu**	**% of Total kBtu**
Space Heating	4,452,376	34%
Space Cooling	1,521,738	11%
Air Distribution (fans)	501,561	4%
SHW/DHW	772,064	6%
Conveyance	0	0%
Lighting	1,479,406	11%
Plug Loads	1,044,062	8%
Process Loads	2,762,000	21%
Refrigeration	131,362	1%
Cooking	122,832	1%
Information Technology	0	0%
Other	465,738	4%
Total	13,253,138	100%
Total from (annual summary)	13,602,319	
Adjustment for On-Site Gen	0	
Adjusted Total w/ Generation	13,602,319	
Difference	-349,181	
% Difference	**-3%**	



End-Use Allocation





Measure Recommendations

- Be explicit and clear
- Organize lighting like lighting vendors do
- Organize HVAC like a scope
- Make it easy
- Remember this is a sales document
  - Motivate to action
  - Bundle projects to avoid cream skimming ←

Recommendation

We recommend replacing these fixtures with bi-level models such as the "SmartBrand" Monitor series. Bi-level fixtures use an occupancy sensor to detect occupants and go to a low-power mode after detecting no occupancy for a certain time. They will ensure that minimum light levels are provided at all times in the stairwells for safety, while providing the comparable light levels when the stairwells are occupied.

We estimate that this measure can save about 4000 kWh per year by reducing the full-power operating hours of the stairwell fixtures by about 45%. We estimated the cost of this measure at about $20,000, based on an installed cost of $300 per fixture.

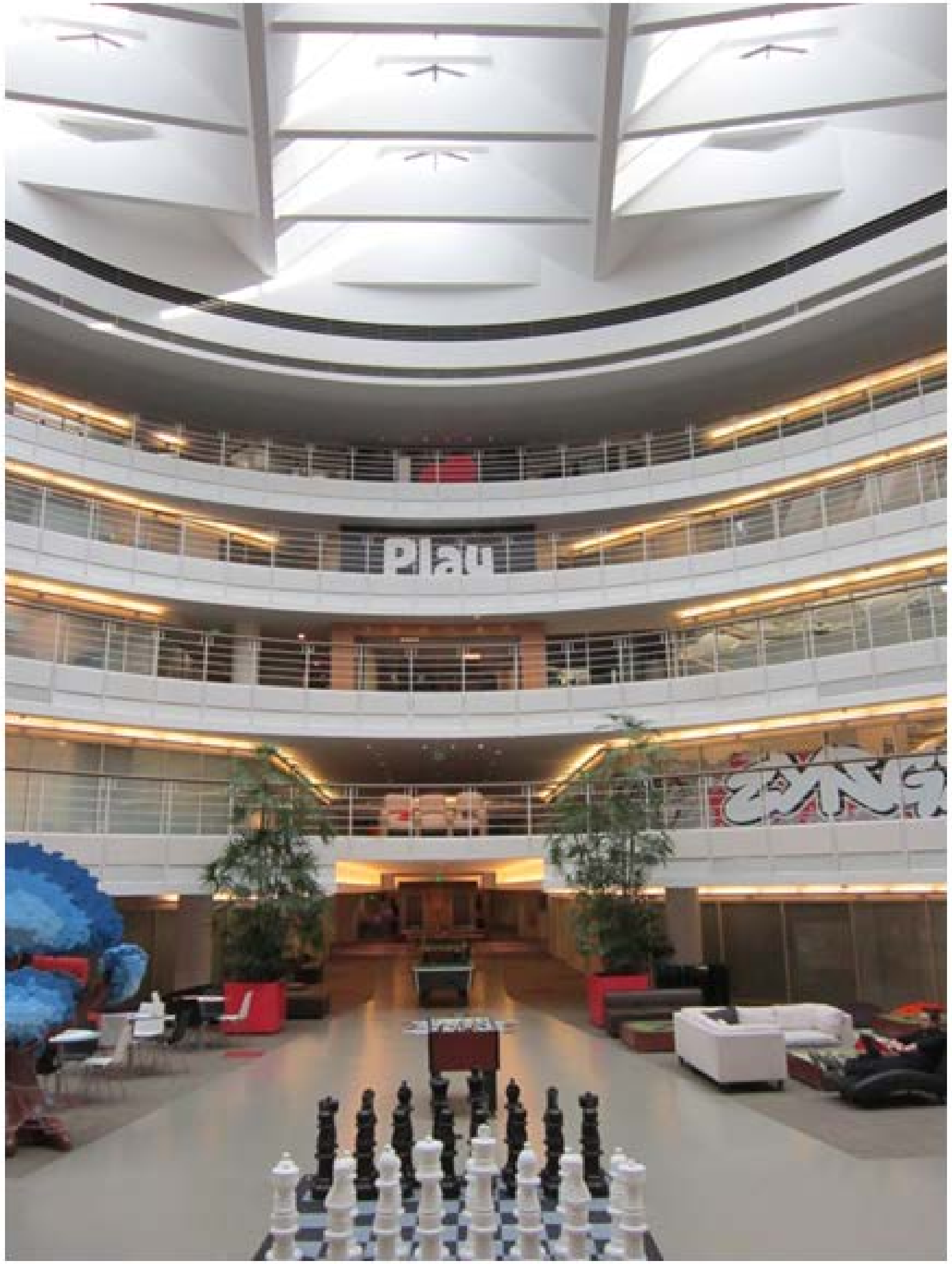
Measure Recommendations (Best Practice)

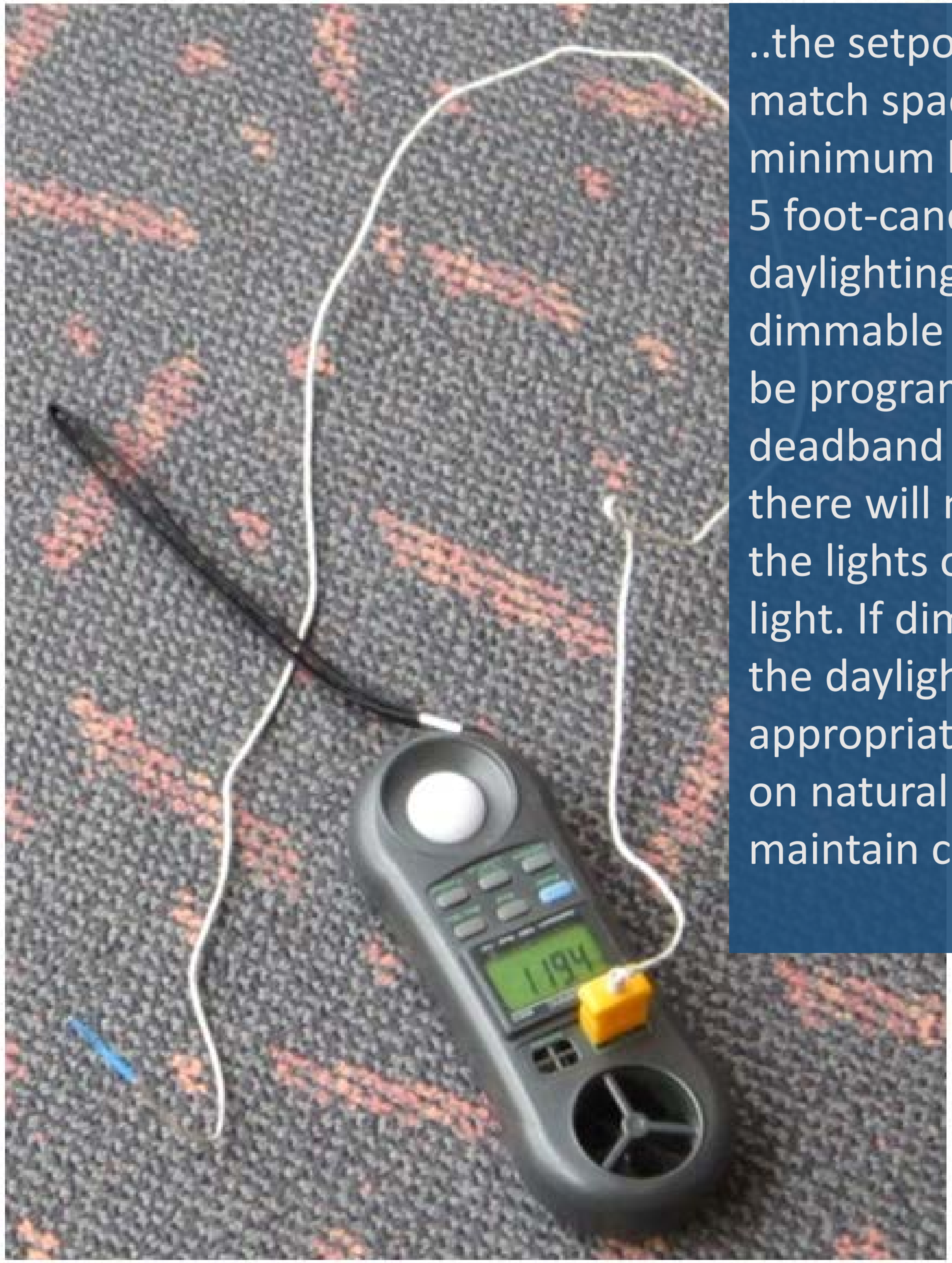
- Observations
- Recommendation
- Costs
- Assumptions
- Specific equipment changes
- Specific control set points or algorithms
- Other info:
  - Cut sheets, vendor contact, pricing info…
  - Sensitivity analysis for key inputs

Measure Recommendations

The explicit recommendation

- Bad example: “replace filters with high-capacity filters”
- Good example: “We recommend installing higher-capacity filters such as the NAMEBRAND Model 80-D. These high capacity filters have 84% greater dust holding capacity (media area) while being only approximately 40% more expensive. They have a slightly better initial pressure drop (0.26 in. vs. 0.30 in. w.c.), but more importantly, with their much higher dust holding capacity, their pressure drop will increase much more slowly through their service life. Please see the complete filter data sheets in Appendix B.”





..the setpoint should be adjusted to match space type. IESNA recommends minimum light levels of approximately 5 foot-candles for hallways. For daylighting control of fixtures without dimmable ballasts, the sensors should be programmed with a large enough deadband (at least 40%) to ensure that there will not be excessive switching of the lights on days with varying ambient light. If dimmable ballasts are installed, the daylight controller can appropriately dim the fixtures based on natural light levels in order to maintain constant light levels….

Figure 4.10 Main Atrium During the Day (left) with Light Levels Above 100 fc (right)

Capture Interactive Effects

- For example, reduced lighting loads result in smaller capacity HVAC
- Provide “integrated bundles” of recommendations when appropriate
- Analyze “up” from loads to heat rejection

Simple method:

$$\times 1 + \frac{1}{\mathrm{COP}}$$

Interactive Effects Cascade "Up and Out"

System	Examples
Heat rejection final	Cooling tower, evaporative condenser, air-cooled condensers
Heat rejection distribution	Condenser water loop, refrigeration condensing
Plant	Chillers, boilers, refrigeration compressors
Water distribution	Chilled water and hot water pumps
Air distribution	Air handlers, RTUs
Space load	Plug loads, lighting, people

From loads to distribution, to heat rejection

Initial Measures List (Best Practice)

- Review on-site with customer
- Discuss each recommendation

INITIAL MEASURES LIST

Priority	No.	Measure Description	Basis of Savings	Remarks	GO / No-Go	Customer Comments
High	1	**Gymnasium**: Replace metal halide lighting with T8 fluorescents and occupancy sensors	T8's use much less energy than metal halides when on. Sensor controls will reduce run hours.	Metal halides take several minutes to start so cannot be controlled with sensors; T8's start instantly. This measure can be installed during the holiday break.	GO	Want to proceed quickly
High	2	Retro-commission chiller plant	Optimized controls will reduce energy used per ton of cooling	Found issues with chiller staging, pump sizing, temperature resets	GO	Yes interested
High	3	Install VFDs on supply fans for AC-1 and AC-2 to enable zone level scheduling, supply air and duct static pressure resets. Schedule boiler pump when no call for heating	Duct reset will reduce fan energy, supply air temperature reset will reduce cooling and re-heat energy. Scheduling will reduce all of the above.	VFDs are required to allow fans to operate at lower flow rates, currently fan rides the curve with no direct control of duct static pressure. Site already employs zone level DDC control.	GO	
High	4	Install Economizer on 15 ton AC-4 unit serving data center; increase space temperature from 60F to 75F to enable free cooling most of the year	Reduce cooling energy when ambient conditions appropriate	Unit does not include an economizer currently but economizer retrofit kit available from the manufacturer	GO	May be tricky to convince site staff to increase space temp setpoint
Med	5	Install HW supply temperature reset and primary/secondary hot water distribution system	Less losses from boiler and distribution system.	Boiler located outdoors on the roof and appears to be in poor condition. Note that this site's gas use is nearly 3 times the average for small commercial offices according to CEUS data	GO	Add primary/secondary hot water distribution system to measure. Currently there is only a 5 degree delta T across some of the VAV boxes. Customer thinks this is a HW flow issue so they are in the process of changing the hot water distribution system.

Level 2 Sample Outline (Not Required)

1. EXECUTIVE SUMMARY
   a. Overall assessment of benchmarking and energy performance
   b. Aggregated savings and costs of recommended measures
   c. Table of recommended measures with savings and costs
2. INTRODUCTION
   a. Audit scope
   b. Key dates
   c. Contact information
3. FACILITY DESCRIPTION
   a. Building information
   b. Building envelope
   c. Heating, ventilating, and air conditioning (HVAC)
   d. Service hot water (SHW)/domestic hot water (DHW)
   e. Lighting
   f. Process and plug loads
4. HISTORICAL UTILITY DATA
   a. Data summary
   b. Utility rate structures
   c. Benchmarking
   d. Target and savings estimate
   e. End-use breakdown
5. ENERGY SAVING OPPORTUNITIES
   a. Low-cost/no-cost savings measures
   b. Capital projects
   c. Distributed/renewable energy opportunity
   d. Energy efficiency measures (EEMs) considered but not recommended
6. EEM COST ESTIMATES
7. EEM ECONOMIC ANALYSIS
8. QUALITY ASSURANCE

APPENDICES

- Tabulated utility data (Annex C tables)
- Utility rate schedules (Annex C tables)
- Calculation methodology
- Savings calculations
- Cost estimates
- Lighting and equipment inventory tables
- Operations and maintenance (O&M) logs
- Equipment specifications

Level 2 Supporting Information (Optional)

- Analysis
- Measured data or monitoring results
- Manufacturer's information or "cut sheets"
- Plans and sketches from site
- Additional information or specifications
- Utility incentive rates
- Utility rate summary
- Photos, photos, photos

For Each EEM (Required)

- Energy efficiency measure description
- Electricity and water consumption savings (kWh, kgal)
- Peak demand savings (kW)
- Fuel savings (kBtu, therms, lbs steam, etc.)
- Operating cost savings ($)
- Implementation cost estimate ($)
- Financial evaluation
  (for example, simple payback period, IRR, LCC, NPV)

Report May Include:

- Operations and maintenance cost savings ($)
- Life-cycle measure cost (present or future worth) (required in L3)
- Discounted payback period
- Utility incentives
- Internal rate of return (IRR)
- Return on investment (ROI)
- Recommendations for demand response measures
- Equipment useful life (years)
- Carbon emissions
- Cumulative savings totals

L2 EEM Summary Table (Required)

Measure Description	Annual Energy and Cost Savings					Payback with Incentive					
	Energy Cost Savings	Non-energy Cost Savings	Peak Demand Savings (kW)	Electricity [kWh]	Natural Gas [therms]	Measure Cost	Potential Incentives	Measure Life (years)	Net Measure Cost	Simple ROI	Simple Payback (yr)
Low-Cost and No-Cost Recommendations											
									$ -	N/A	N/A
									$ -	N/A	N/A
									$ -	N/A	N/A
									$ -	N/A	N/A
									$ -	N/A	N/A
Potential Capital Recommendations											
									$ -	N/A	N/A
									$ -	N/A	N/A
									$ -	N/A	N/A
									$ -	N/A	N/A

Level 2 Audit - Building Envelope Characteristics

Total exposed above grade wall area		sq ft	Insulation level (R-value)	
Below grade wall area		sq ft	Insulation level (R-value)	
Roof area		sq ft	Insulation level (R-value)	
Cool Roof (Y/N)				
Roof condition				
Fenestration Seal Condition				
Overall Enclosure Tightness Assessment				
Description of Exterior doors**				

Cool Roof: Yes = White, not asphalt shingle; No = Other, including all asphalt shingles

Glazing area, approx % of exposed wall area [10, 25, 50, 75, 90, 100]*	
Above grade wall common area with other conditioned buildings (ft2)	

General Building Shape*	

Construction Properties (check all that apply)

Roof Construction*	Floor Construction*	Wall Construction(s)*
☐ Built up with metal deck	☐ Concrete (above unconditioned space)	☐ Brick/stone on steel frame
☐ Built up with concrete deck	☐ Slab on grade	☐ Brick/stone on masonry
☐ Built up with wood deck	☐ Steel joist	☐ Brick/stone on wood frame
☐ Metal surfacing	☐ Wood frame	☐ Metal panel / Curtain wall
☐ Shingles/Shakes	☐ Other	☐ Sliding on steel frame
☐ Other		☐ Sliding on wood frame
		☐ Other
Fenestration Frame Type(s)*	**Fenestration glass type(s)***	**Foundation Type***
☐ Metal	☐ Single pane	☐ Slab on Grade
☐ Metal with thermal breaks	☐ Double pane	☐ Crawlspace
☐ Wood/Vinyl/Fiberglass	☐ Double pane with low e	☐ Basement
☐ Exterior Glass Doors***	☐ Triple pane	☐ Unknown
☐ Other	☐ Triple pane with low e	☐ Other
	☐ Other	

* Cells shown with an asterisk are required inputs for the Asset Score tool.

** only necessary when doors in aggregate represent more than 5% of the gross wall area

*** Doors where glazing of door area exceeds 50% of total door area shall be treated as windows.

NOTE - R-values or U-values of the walls and roof are required, where it can be established with non-invasive methods. If they cannot be established through non-invasive methods, it is valid to enter "N/A" into the Insulation Level field.

NOTE- To provide additional details for building dimentions and glazing area, use tab 'Asset Score Inputs (optional)'

Level 2 Audit - HVAC System

HVAC Properties (check all that apply)

Zone Controls	☐ Direct Digital (DDC) ☐ Pnuematic ☐ Progammable tstats ☐ Manual tstats	**Central Plant Controls**	☐ Building Automation System (BAS) ☐ Direct Digital (DDC) ☐ Pnuematic ☐ Other
Outside Air*	☐ Temperature Economizer ☐ Enthalpy Economizer ☐ No Functioning Economizer ☐ Dedicated OA System	**Heat Recovery**	☐ Enthalpy ☐ Sensible (Temp Only)
Exhaust Fans	☐ No Mechanical Exhaust (natural only, i.e. windows, doors or gravity shafts) ☐ Exhaust Fans Only ☐ Supply and Exhaust Fans		
Cooling Distribution Equipment Type*	☐ Air Handler Unit (AHU) ☐ Constant Volume ☐ VAV ☐ Hydronic to zone equipment (e.g. fan coil units, packaged terminal units or radiators) ☐ Refrigerant to zone equipment (e.g. fan coil units, packaged terminal units or radiators) ☐ Hydronic AHU ☐ DX AHU ☐ Other ☐ None (i.e. electrically driven PTAC, baseboards)		
Heating Distribution Equipment Type*	☐ Air Handler Unit (AHU) ☐ Constant Volume ☐ VAV ☐ Hydronic to zone equipment (e.g. fan coil units, packaged terminal units or radiators) ☐ Steam to zone equipment (e.g. fan coil units, packaged terminal units or radiators) ☐ None (i.e. electrically driven PTAc, baseboards) ☐ Other		
Cooling Source*	☐ No cooling ☐ DX cooling ☐ Central plant ☐ Chiller ☐ District chilled water ☐ Water-side Economizer ☐ Other (specify) ____________	**Chiller Input***	☐ Electricity ☐ Gas Absorption ☐ Gas ☐ Steam Absorption ☐ Oil (specify grade) ☐ Steam Turbine ☐ Other
		Compressor*	☐ Reciprocating ☐ Scroll/Screw ☐ Centrifugal ☐ Other
		Condenser*	☐ Air ☐ Water ☐ Ground ☐ Indirect Evaporative ☐ Direct Evaporative
Heating Source*	☐ No heating ☐ Central furnace ☐ Heat pump ☐ Central plant ☐ District steam or hot water ☐ Other (specify) ____________	**Heating fuel***	☐ Electricity ☐ Gas ☐ Oil (specify grade)____________ ☐ Other
		Boiler Type*	☐ Steam boiler ☐ Forced draft ☐ Hydronic boiler ☐ Other Draft Type
SHW/DHW Source*	☐ No DHW ☐ Indirect fired ☐ Storage ☐ Instantaneous ☐ Direct fired ☐ Storage ☐ Instantaneous ☐ Heat pump ☐ Other	**SHW/DHW fuel***	☐ Electricity ☐ Gas ☐ Oil (specify grade) ______________ ☐ Other: ________________________

* Cells shown with asterisk are required inputs for the Asset Score tool

Level 2 Audit - Equipment Inventory

Inventory of equipment

The equipment inventory below shall include equipment that represents, in aggregate, 80% or more of the energy use allocated to HVAC & SHW/DHW in the end-use allocation

ID	Description	Location	Area/System Served	Type	Rated efficiency (as applicable)	Output Capacity	Units	Approx Year Installed	Condition (excellent, good, average, poor)

Level 2 Audit - Lighting, Electrical, & Plug Loads

(group by lighting types / fixtures that collectively make up the largest fraction of gross floor area)

Lighting Source Type(s)	Ballast Type(s)	Control(s)	Space Type(s)*	Approx % Area Served

Major Process/Plug Load Type(s)**	Key Operational Details***

* e.g., Office, hallways, mechanical spaces, exterior, etc.
** e.g., Computers, Walk-in freezers, hydraulic press, etc.
***Describe approximate connected load, operating schedule, and other key parameters, where available

Level 2 Audit - QA/QC

user input
calculated

This table is used to check that savings estimates do not exceed end use estimates, as well as ensure that savings interactions are considered.

Projected EEM Savings Levels QA/QC

		Savings by End Use					End Use Savings Backchecks				
		Utility 1	Utility 2	Utility 3	Utility 4	Total Energy	Utility 1	Utility 2	Utility 3	Utility 4	Total Energy
Measure Description	**End Use Category***	Electricity (kWh)	Natural Gas (therms)	#N/A	Oil gallons (Fuel Oil #2)	Total Energy [kBtu]	% Electricity Savings	% Natural Gas Savings	% 0 Savings	% Oil Savings	% Total
Low-Cost and No-Cost Recommendations											
						-	0%	0%	0%	0%	0%
						-	0%	0%	0%	0%	0%
						-	0%	0%	0%	0%	0%
						-	0%	0%	0%	0%	0%
						-	0%	0%	0%	0%	0%
						-	0%	0%	0%	0%	0%
						-	0%	0%	0%	0%	0%
						-	0%	0%	0%	0%	0%
Potential Capital Recommendations											
						-	0%	0%	0%	0%	0%
						-	0%	0%	0%	0%	0%
						-	0%	0%	0%	0%	0%
						-	0%	0%	0%	0%	0%
						-	0%	0%	0%	0%	0%
						-	0%	0%	0%	0%	0%
						-	0%	0%	0%	0%	0%
						-	0%	0%	0%	0%	0%
	Total Savings (QA-QC)	-	-	-	-	-	0%	0%	0%	0%	0%
	Total Savings (EEM Summary)	-	-	-	-	-					
	Total Historical Use	2,321,899	56,800	-	-	13,602,319					

Level 2 QA/QC

Level 2 Audit - QA/QC

user input
calculated

Projected EEM Savings Levels QA/QC

	Savings by End Use				End Use Savir	
	Utility 1	Utility 2	Utility 3	Total Energy	Utility 1	Utility 2
End Use Category*	Electricity (kWh)	Natural Gas (therms)	Purchased Steam (lbs District Steam)	Total Energy [kBtu]	% Electricity Savings	% Natural Gas Savings
Air Distribution (fans)	9,000			30,708	38%	0%
Space Heating	11,000	8,000	40,000	885,292	22%	53%
Lighting	25,000			85,300	50%	0%
Space Heating		(200)		(20,000)	0%	-1%
Air Distribution (fans)	9,000			30,708	38%	0%
Space Heating	11,000		40,000	85,292	22%	0%
Refrigeration	510,000			1,740,120	102%	0%
Space Cooling	20,000			68,240	2%	0%

Replace Roof					-	0%	0%	0%	0%
	Total Savings (QA-QC)	604,000	7,800	80,000	2,936,368	60%	30%	54%	47%
	Total Savings (EEM Summary)	604,000	7,800	80,000	2,936,368				
	Total Historical Use	1,000,000	25,740	148,500	6,191,109				

Level 2 Distributed Energy

Qualitative assessment only

Requires

- One distributed energy resource (e.g., cogen)
- One renewable energy resource (e.g., solar PV)
- Include an estimate of the system size, configuration, savings, cost, and simple payback

Level 3 Elements

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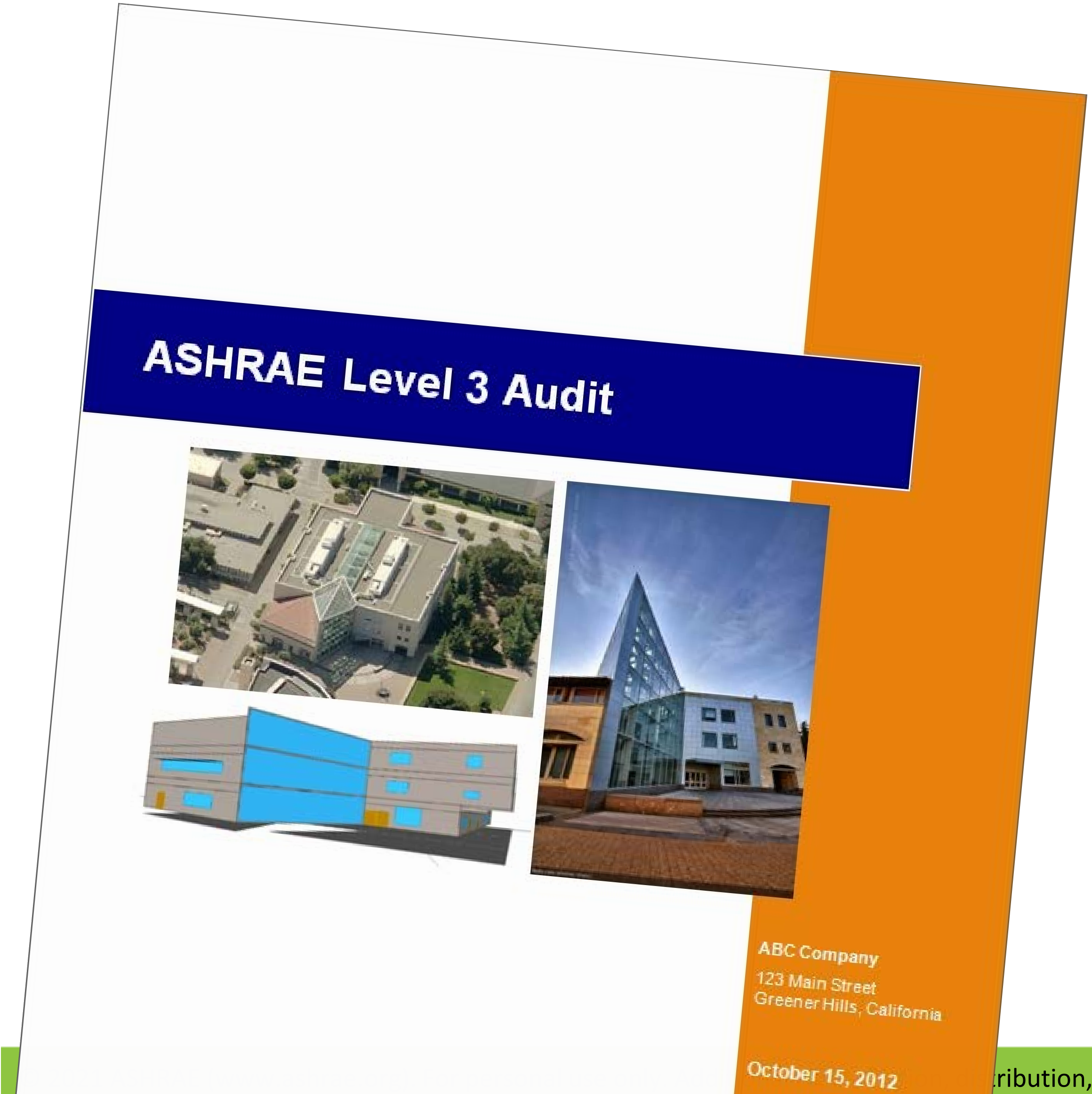
Level 3—A Rare Breed



- Rarely requested
- Seldom formalized as a single Level 3 report
- Typically scope is done as implementation assistance following Level 2

Level 3 Requirements

Reducing risk through project development

- Schematic diagram for the EEMs
- Analyze either
  - measured data or
  - building energy modeling or
  - engineering calculations
- Envelope measures must use building energy modeling
- Costs must be
  - quotes from vendors willing to do the work or
  - based on actual previous project costs for similar projects
- Life-cycle cost analysis is required for all measures
- A simplified risk assessment approach based on the impact of “key assumptions”

Level 3 Requires Detailed Specs

STANFORD UNIVERSITY - PACKARD ELECTRICAL ENGINEERING BUILDNG

SECTION 15910 (23 09 23)

DISTRIBUTED DIGITAL CONTROL (DDC) SYSTEMS

<u>PART 1 -GENERAL</u>

1.1 SUMMARY

A. Stanford University generally uses a hybrid approach for building control. Currently, the campus Energy Management Control System (EMCS) is used in conjunction with a pneumatic control system at the Packard Electrical Engineering Building.

B. This section provides the standards and requirements for a design-build project to convert the existing pneumatic control system at the Packard Electrical Building to a distributed digital control (DDC) system used for zone level temperature control.

C. The following documents are included with this specification:

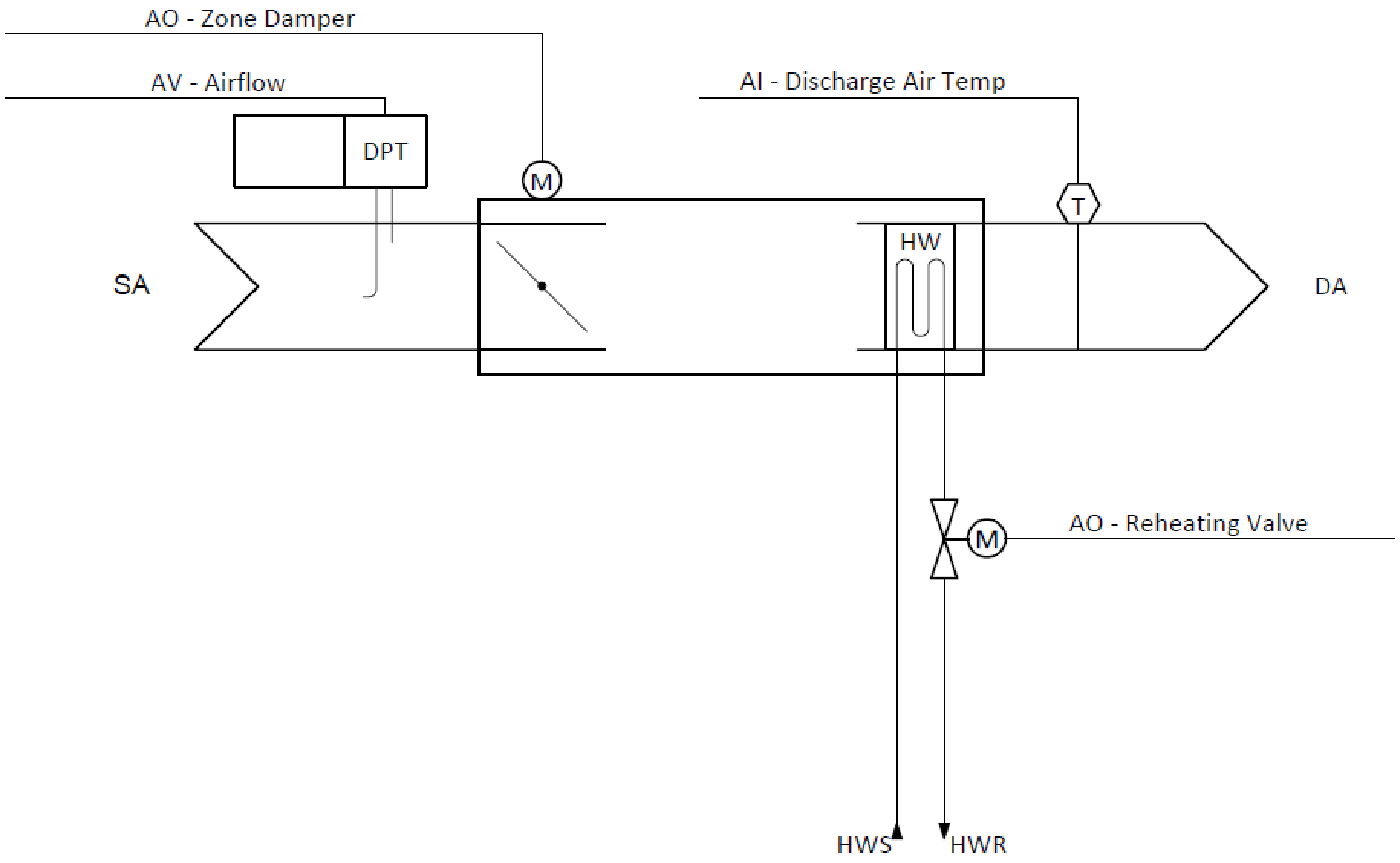
1. Division 01 – General Requirements
2. System architecture schematic
3. Sequence of operations
4. Control schematics for VAV boxes and fan coil units
5. Packard Building Balancing report
6. Packard Building electrical and mechanical drawings

1.2 CONDITIONS AND REQUIREMENTS

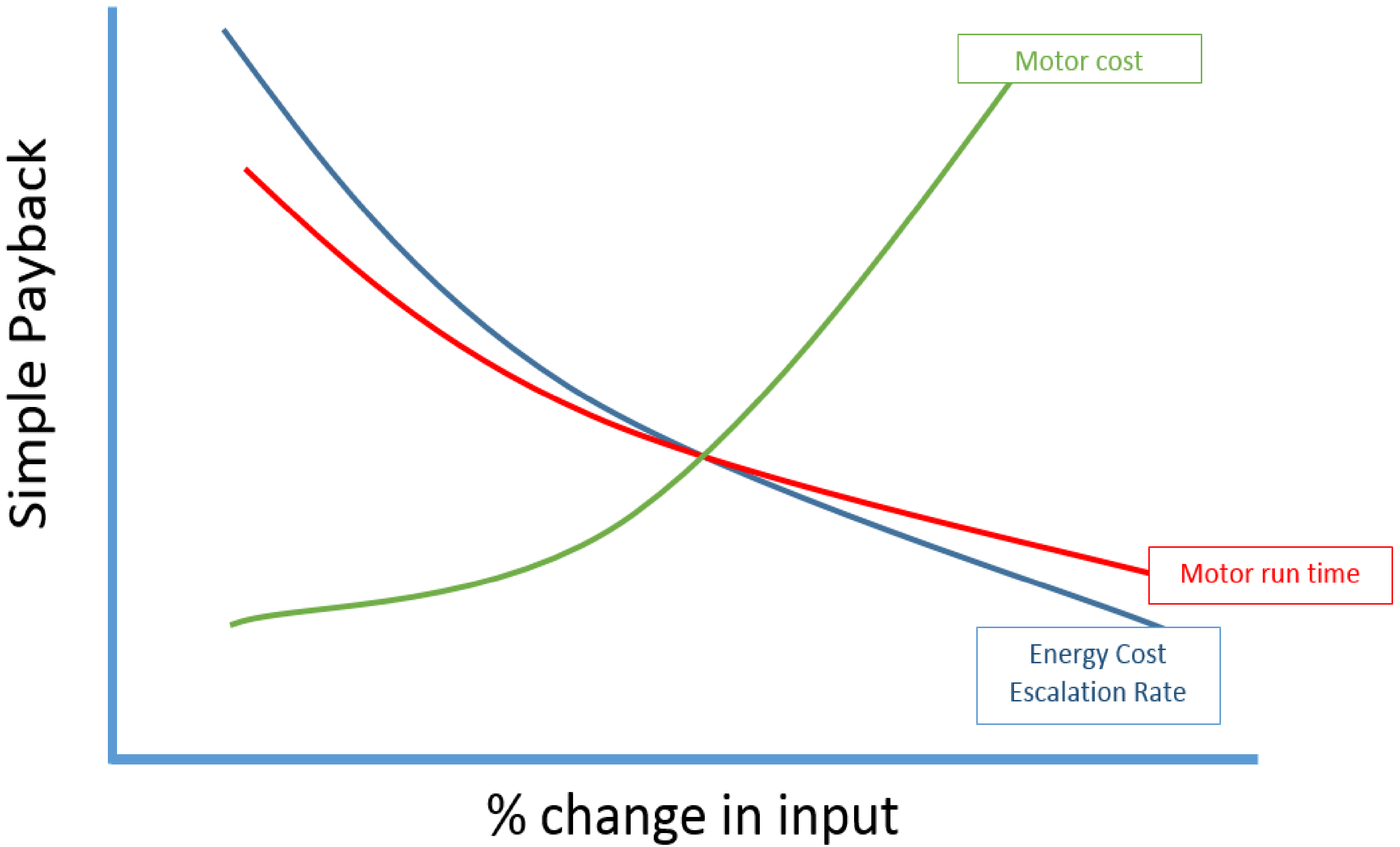
A. Refer to the General Conditions, Supplemental Conditions and Division 01 - General Requirements.

1.3 SCOPE OF WORK

Level 3 Requires Schematics



Sample “Spider Chart”



Targeted Approaches

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“Targeted” Analysis

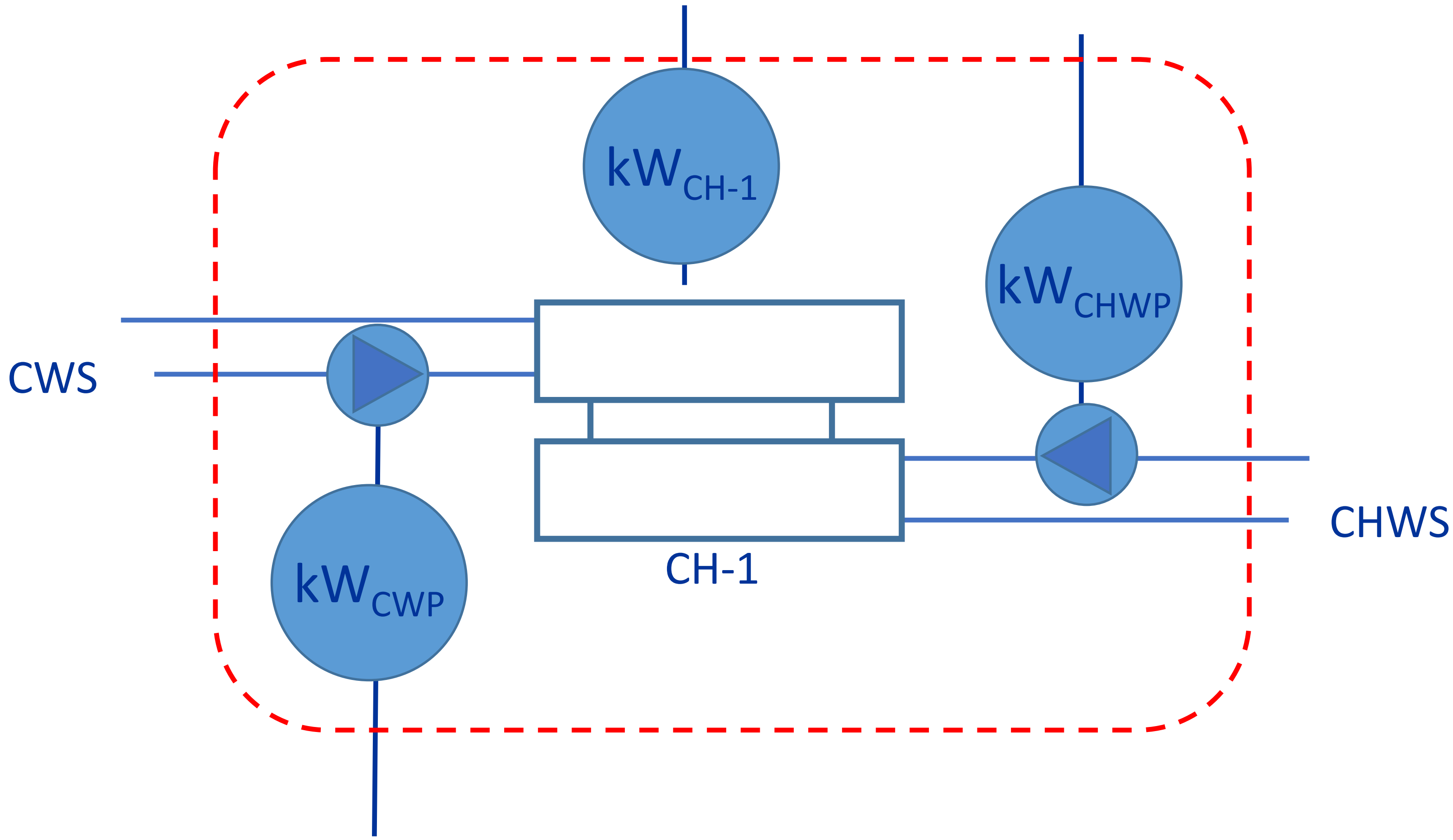
- Some clients may want investigations only into specific systems
- Example: chiller reaching end of useful life
- Comprehensive, whole-building approach may be more than what they want/need
- Advantage: Focus in depth on systems of interest
- Makes whole-building models a difficult or expensive approach

In PCBEA/not ACCA/ASHRAE Standard 211

“Targeted” Analysis Methods

- Clearly define scope
- Draw a “measurement boundary” around the system
- Use spot measurements and/or logging for key variables
- Monitor over time to observe control sequences, system performance, and occupant behavior
- Calibrate to measured data

Establishing Measurement Boundary



Exercise #2: Energy Target

Exercise 2: Energy Target

Given:

- 200,000 ft^2
- All-electric
- 3,000,000 kWh/yr
- $0.20/kWh blended rate (includes demand charges)
- Current ENERGY STAR Score 69
- Target ENERGY STAR Score 75
- Target EUI 47 kBtu/ft^2/yr

Calculate:

1. Annual electricity reduction required to reach target
2. Annual cost saving to reach target
3. Implementation budget available to achieve target savings at a three-year payback

Exercise 2: Portfolio Manager Target

Metric	Dec 2019 (Energy Baseline)	Jun 2020 (Energy Current)	Target*	Median Property*
ENERGY STAR score (1-100)	69	69	75	50
Source EUI (kBtu/ft²)	143.3	143.3	131.5	189.3
Site EUI (kBtu/ft²)	51.2	51.2	47.0	67.6
Source Energy Use (kBtu)	28,660,799.8	28,660,799.2	26,303,359.7	37,867,955.6
Site Energy Use (kBtu)	10,235,999.9	10,235,999.7	9,394,058.2	13,524,271.5
Energy Cost ($)	599,999.98	599,999.99	550,648.19	792,747.59
Total GHG Emissions (Metric Tons CO2e)	2,289.5	2,289.5	2,101.2	3,025.0

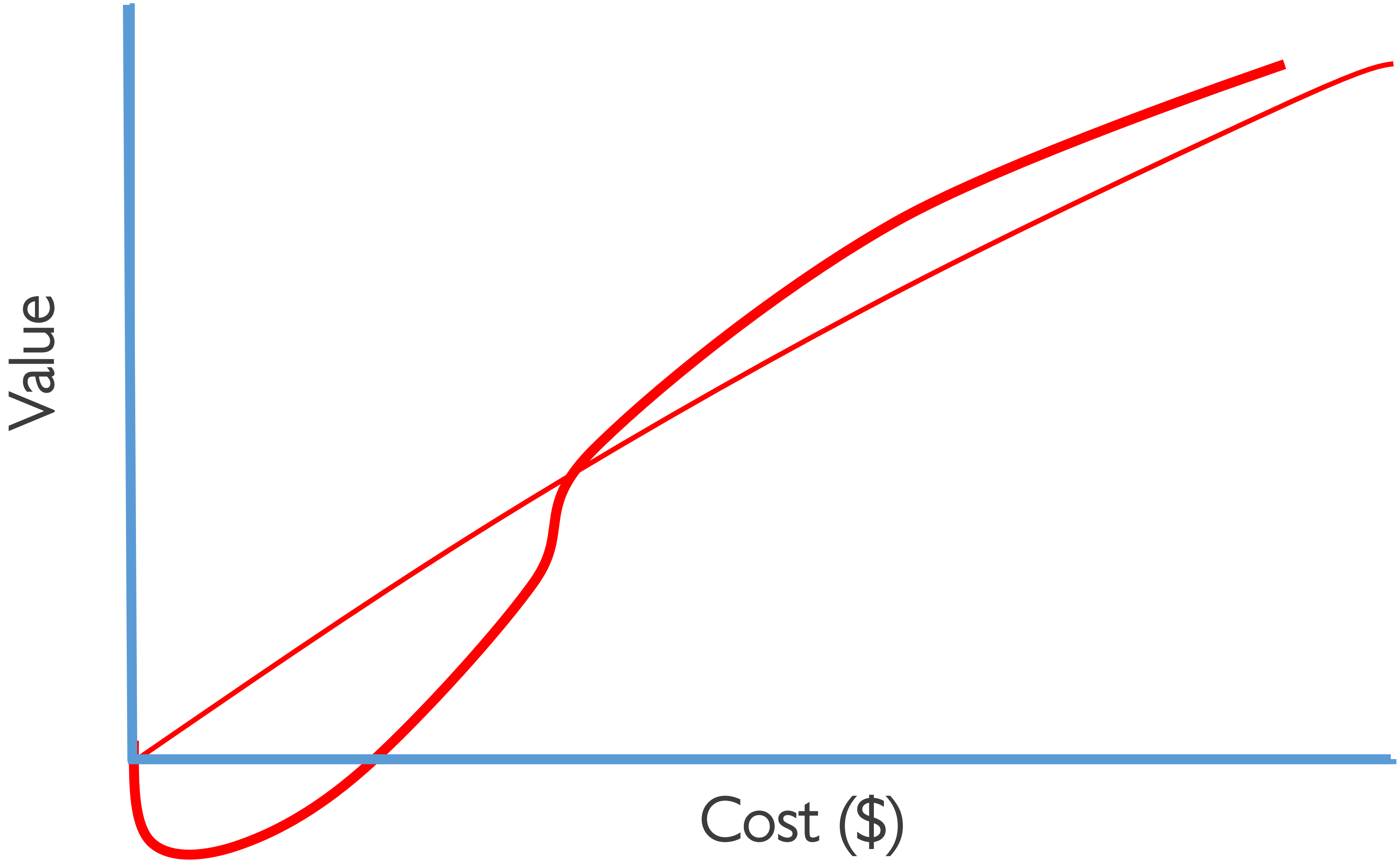
On-Site

Balancing Time and Money

- Detail
- Accuracy
- Rigor
- Confidence
- Risk

- Cost of Service
- Cost of Saved Energy

Value of an Audit: The Kelsey Curve



Mental Prep: General Strategy

kWh = kW * hours

The hard part:
- Retrofits
- Capital improvements

The easier part:
- Turn it off
- Controls
- Scheduling

Mental Prep: Specific Strategies

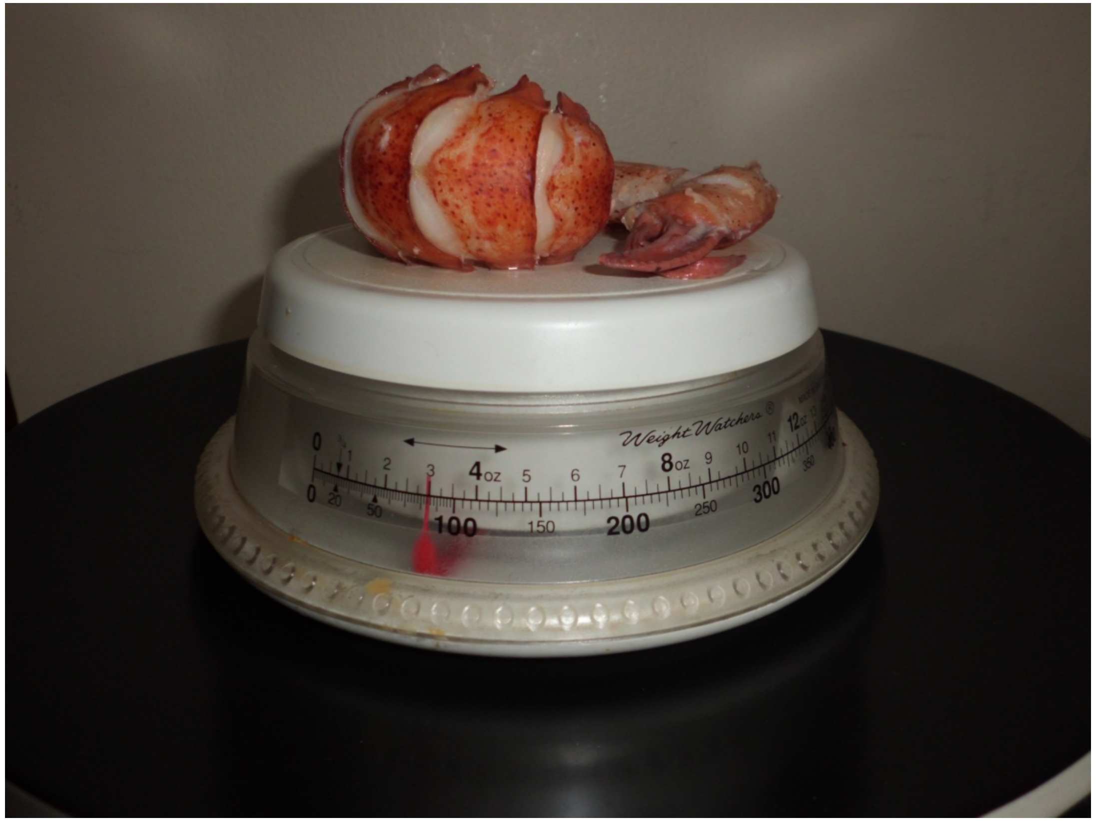
- Tighten scheduling
- Minimize parasitic losses
- Choose most efficient source
- Reduce loads
- Install higher-efficiency equipment

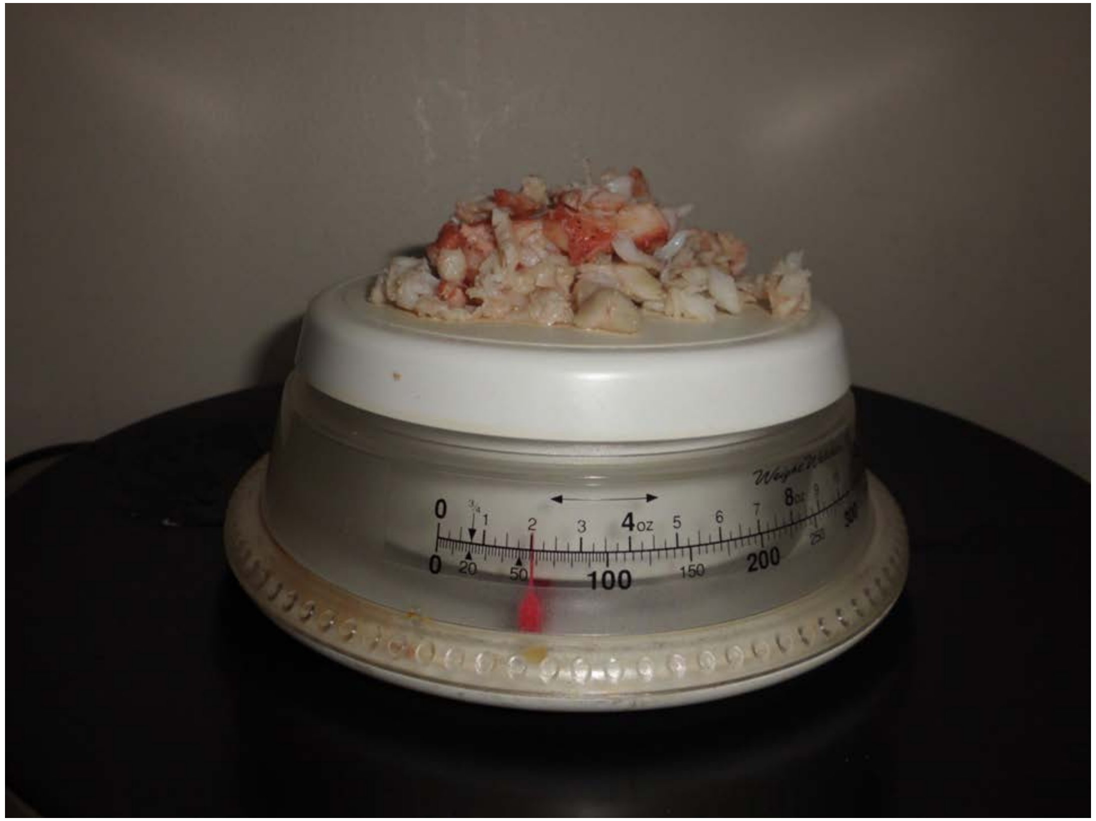
Mental Prep: Lobster Strategy

Saving a lot of energy, or any other resource, at low cost is like eating a lobster. To do it successfully requires both a grasp of system anatomy and attention to detail. There are big, obvious chunks of meat in the tail and the front claws. There's also a roughly equal quantity of tasty morsels hidden in crevices, requiring skill and persistence to extract but worth the effort.

Amory Lovins

Lobster Measurement & Verification





Sources of Data

- Interview staff
- Controls systems
- Drawings/ specifications
- System manuals
- Nameplates
- Spot measurements
- Logged data

Team Building = Listening First

- Key to audit and implementation success
- Be on time or early
- Withhold judgment—seek to understand
- Auditor questions may be threatening

Team Building = Listening First

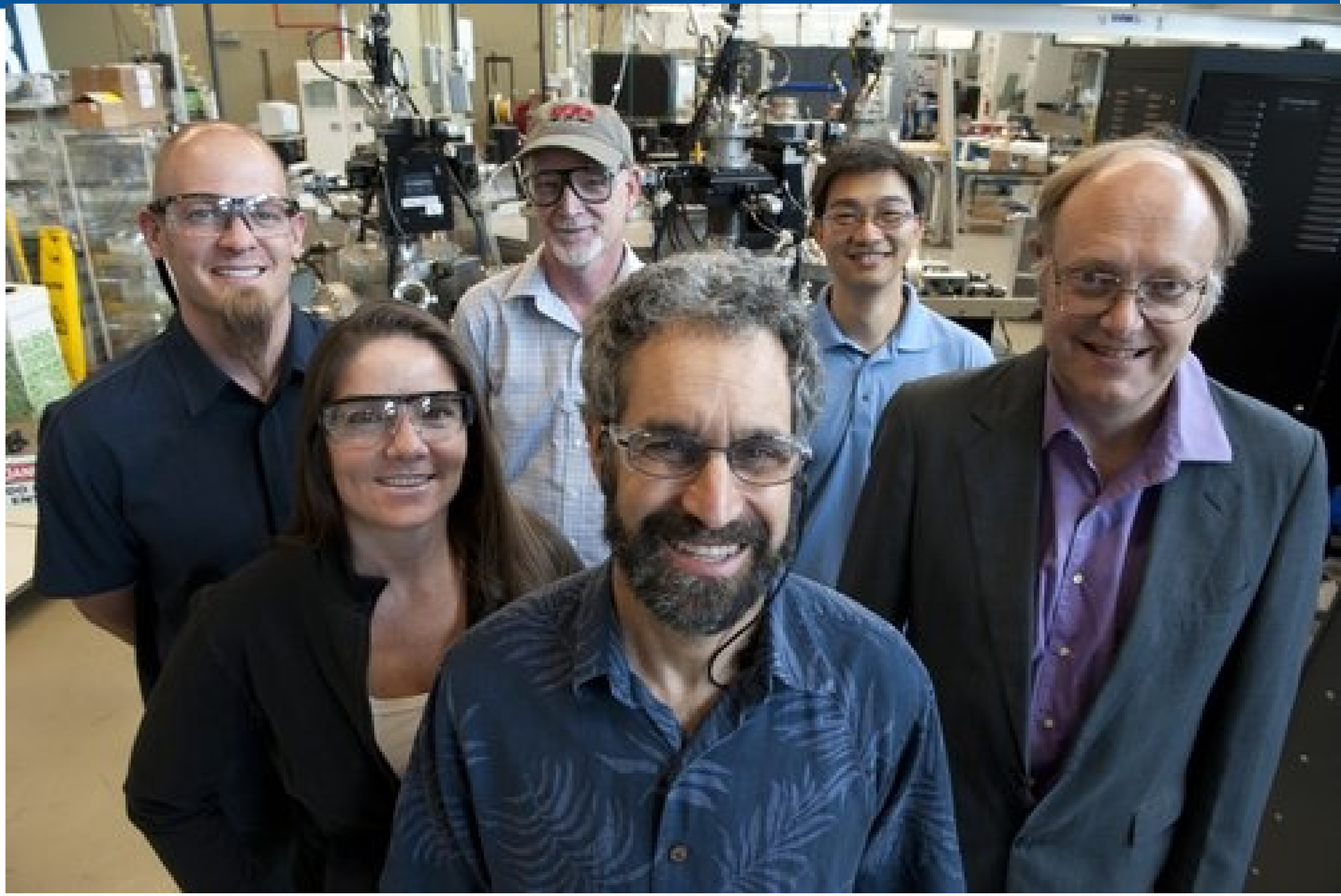
- Seek clarification with open-ended questions
- Seek involvement with key players at site
- Let folks do what they're good at and demonstrate their knowledge of their building

Consider Human Factors

- Don’t believe everything you hear
- Don’t ask leading questions
- Involve staff with solutions
- Leave site staff with the knowledge to follow through
- Follow up with “show me” questions

Build a Balanced Team

- Committed management
- Engaged financial staff who understand risks and rewards
- Trained building engineers
- Trusted contractors and vendors
- Utility account representatives
- Engaged and informed building occupants
- Trained and experienced energy auditor



Incorporate Ideas from Site Staff

Show Me

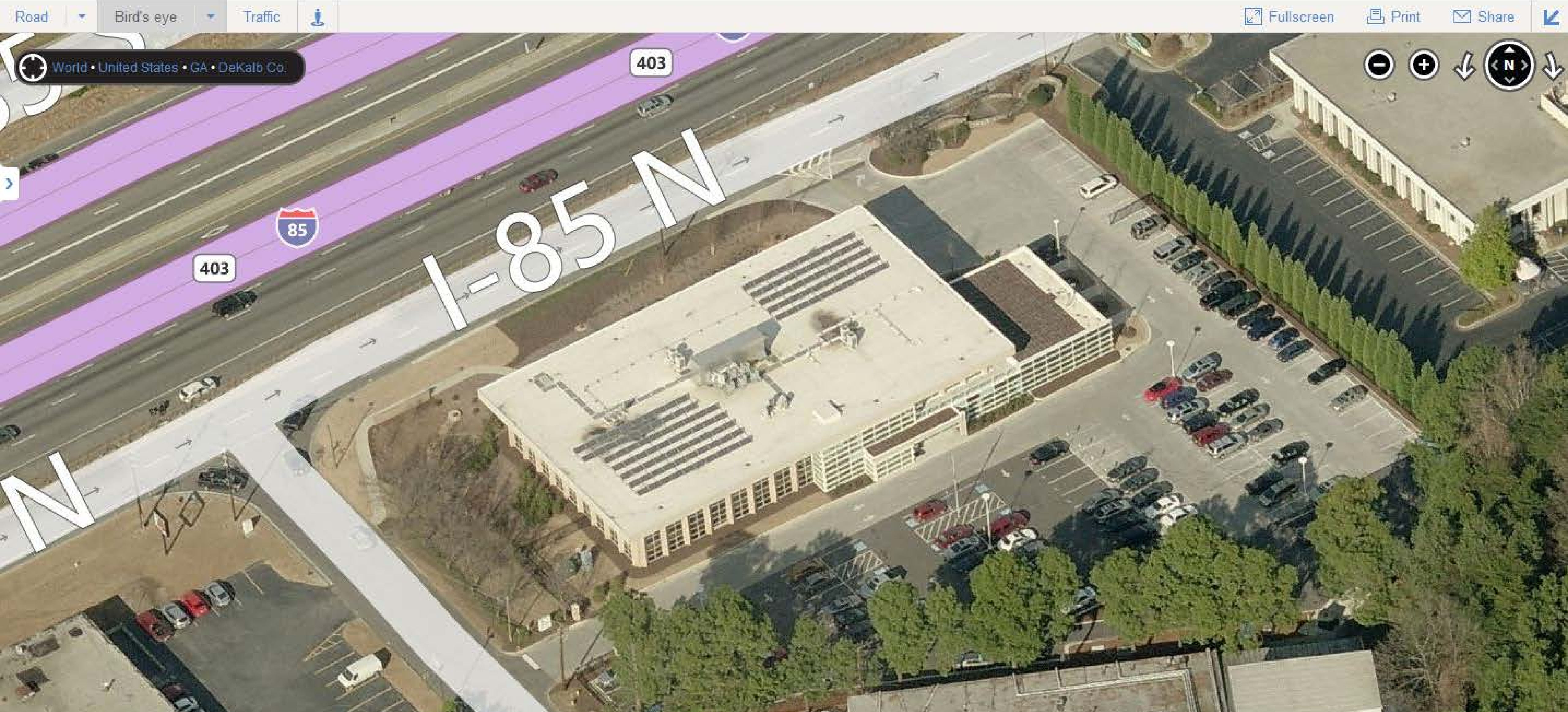
"You mentioned that the boiler is locked out based on an outdoor air temperature sensor. Can you show me the sensor?"

“Oh, there it is. Thanks.”

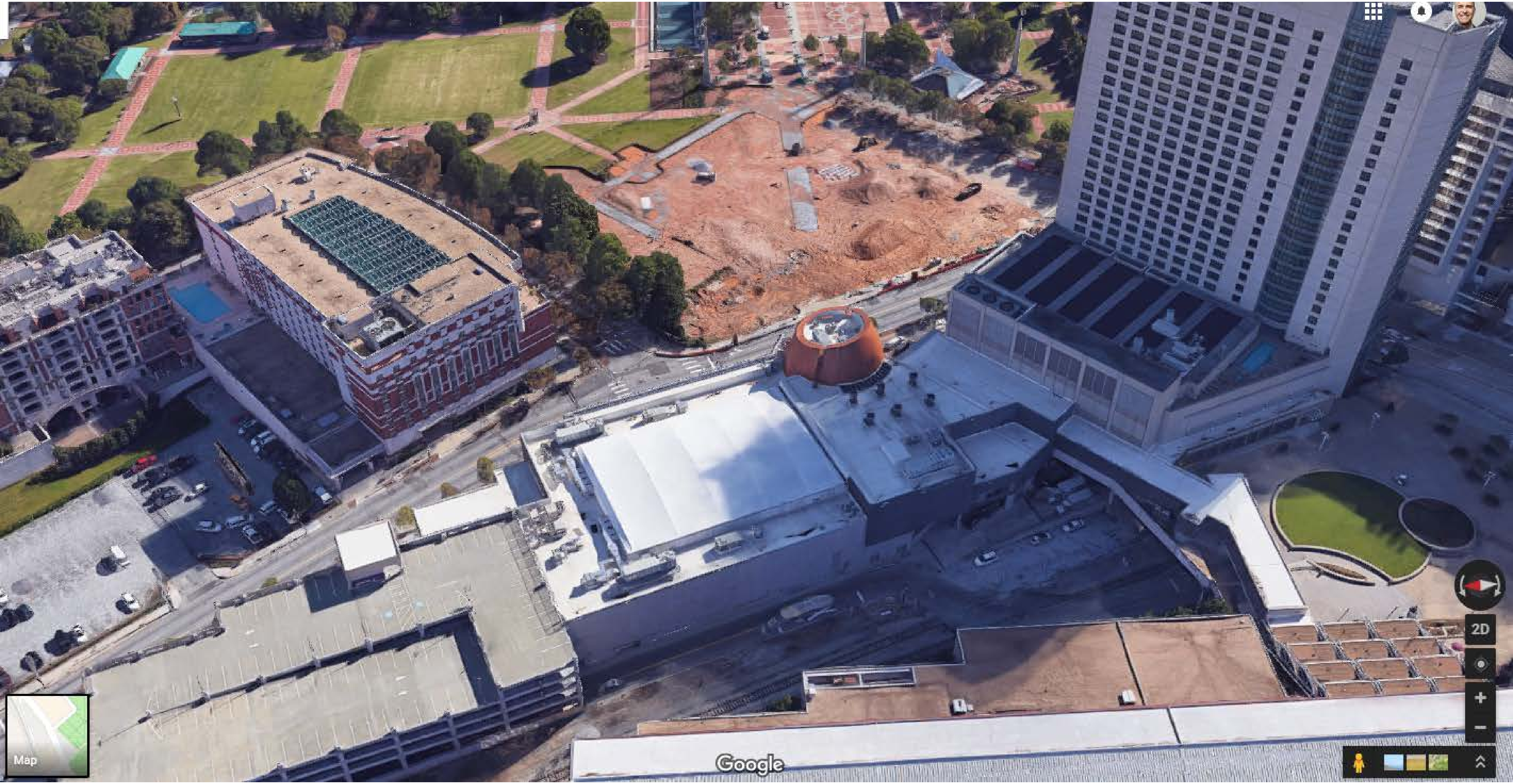
Show Me

… the condensate drain

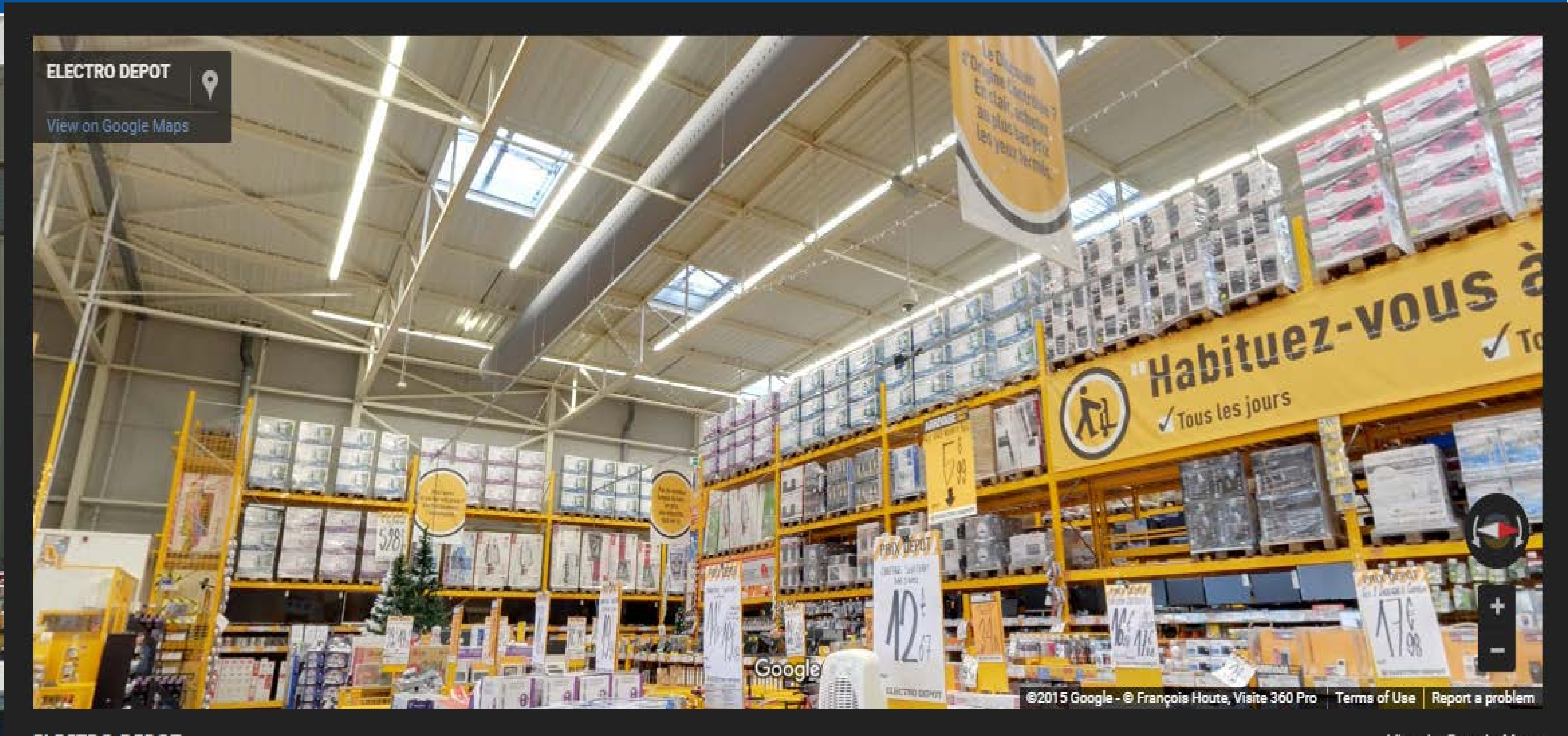
Spy Cams!



Road
Bird's eye
Traffic
Fullscreen
Print
Share
World • United States • GA • DeKalb Co.
403
85
I-85 N
N

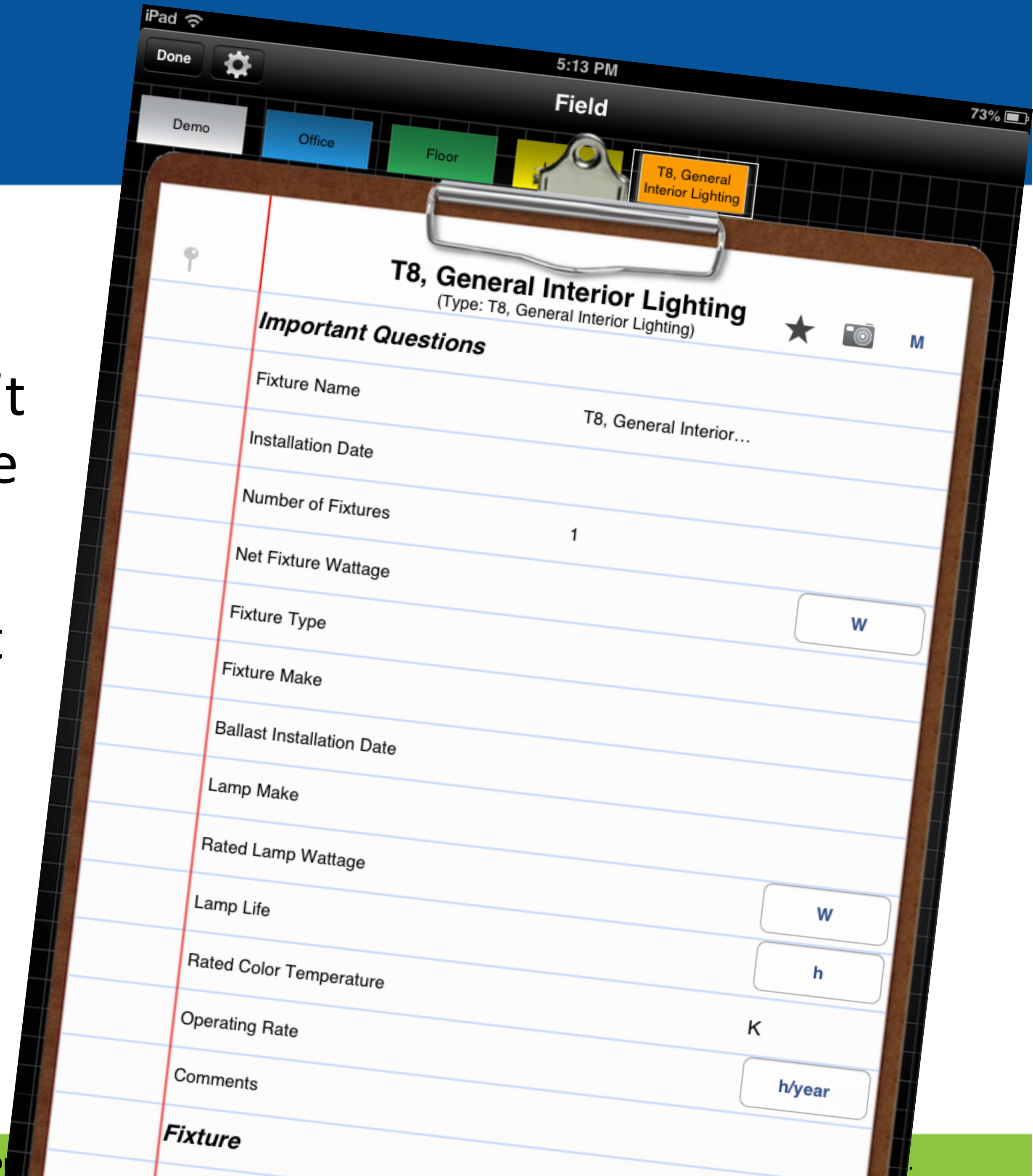

2D
Map
Google

Before You Go…



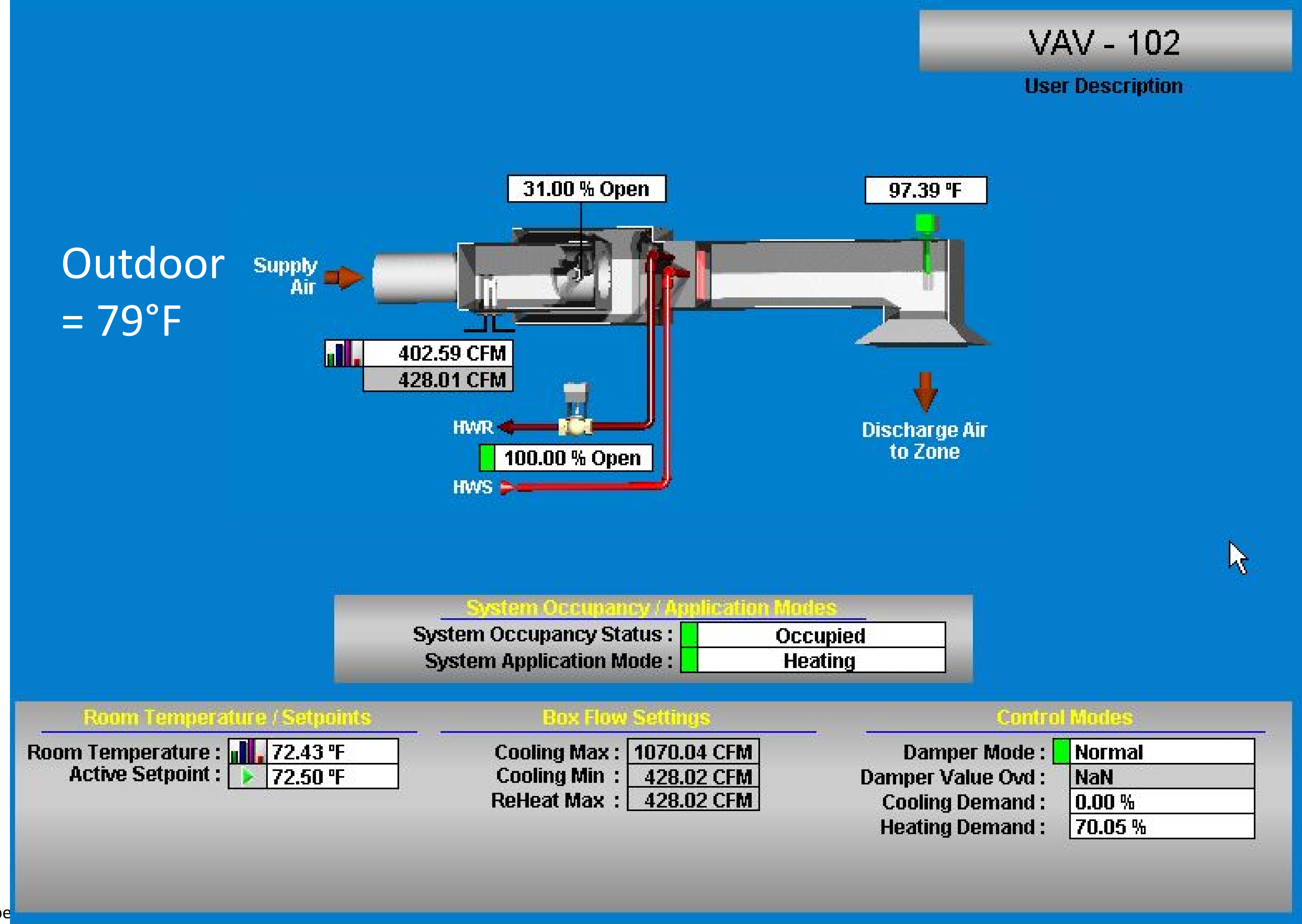
Data Collection

- Photos, photos, photos
- Rule of thumb—if you don't leave the site with it, you're not going to get it
- New tools moving to tablet computer data collection

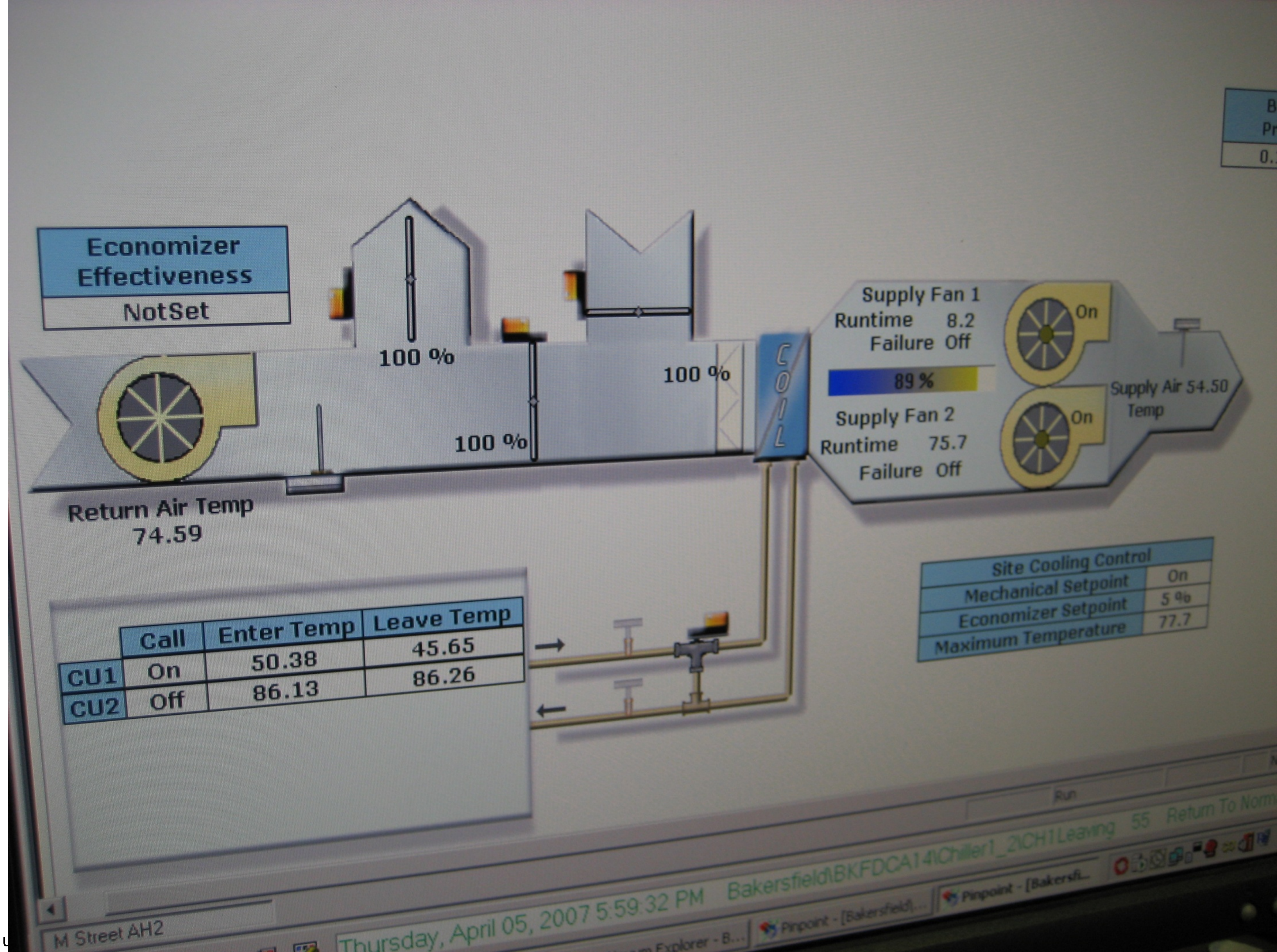


Data Collection (EMS)

Pop Quiz! What's Wrong Here?



Pop Quiz! What's Wrong Here?




EXIT
ACU8
1
system

On a roof? Make sure you have your phone, or else…


KILL A WATT™
METER
583
Watt
Volt
Amp
Watt
VA
Hz
PF
KWH
Hour

Approx surface temp with IR gun


Function
Hold
Power
TYPE K

Pop Quiz: What's Wrong?

OK. Too easy?...

High School—Boiler Room

High School—Boiler Room

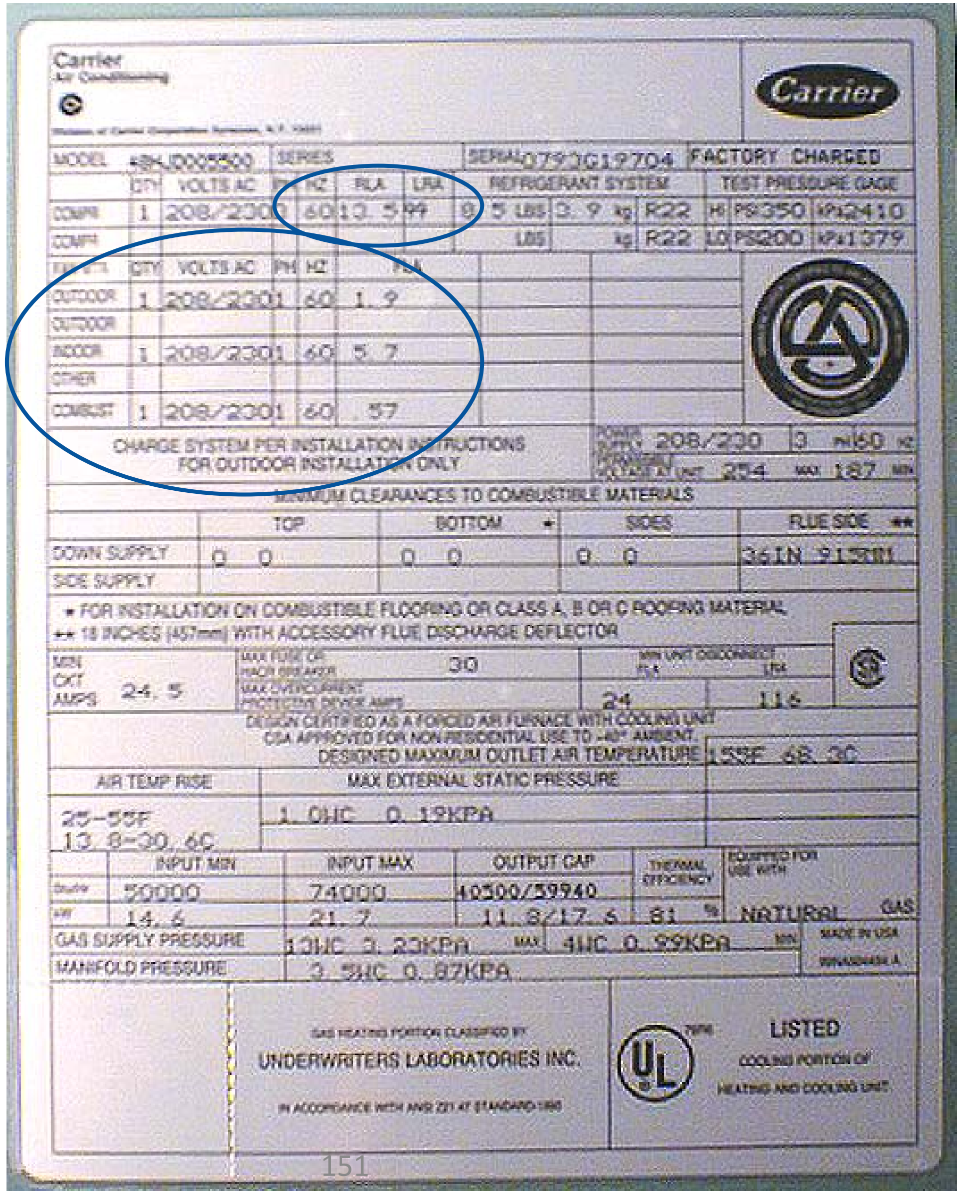
Pop Quiz: What’s Wrong?


DATA HOLD
SPERRY DSA-500
DIGISNAP®
OFF
400A
40A
600V
COM
V/Ω
402
WELDING OUTLET

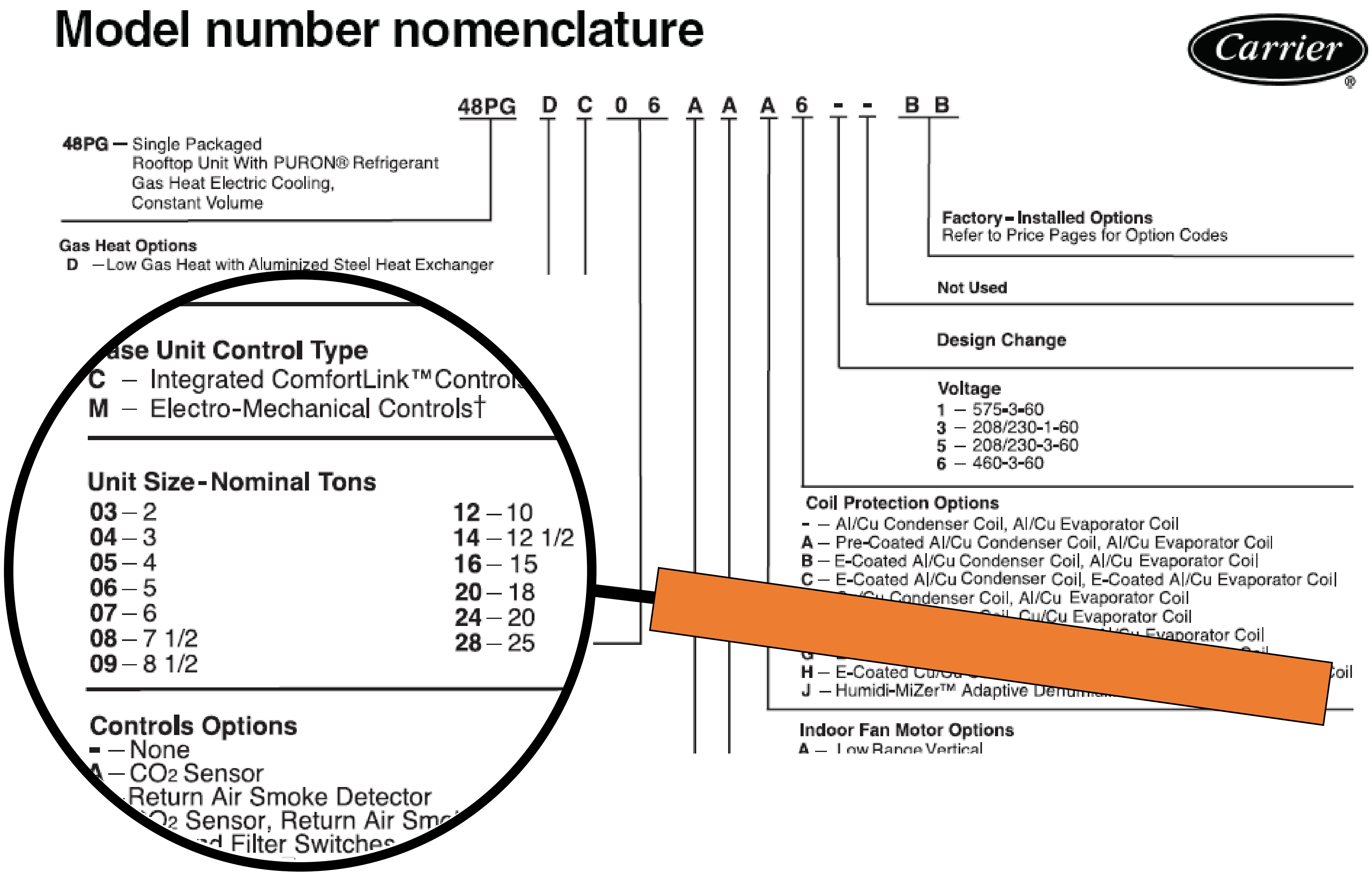

On
1.004
inH2O
testo
testo 506
200hPa/80IWC
+
-

Unitary HVAC Nameplate

- Brand/Model #
- Age
- Voltage/Amperage/kW
- Other information:
  - Rated efficiency?
  - Heating/cooling capacity
  - Airflow rate
  - Liquid flow rate
  - Pressure rise
  - Refrigerant



It’s Not Always Easy to Get the Size



It's Not Always Easy to Get the Size

TRANE

Model Number Description

60 Hz

YC	D	480	A	4	H	A	1	A	4	F	D	1	A	0	0	0	0	0	0	0	0	0	0	0	0*
12	3	456	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29

...ooling, Electric He...
DX Cooling, Natural Gas He...

...git 3 — Unit Airflow Design
... = Downflow Configuration
H = Horizontal Configuration

Digit 4, 5, 6 — Nominal Cooling Capacity
330 = 27½ Tons
360 = 30 Tons
420 = 35 Tons
480 = 40 Tons
600 = 50 Tons

Digit 7 — Major Development Sequence
A = First

...igit 8 — Power Supply (See Note 1)
...08/60/3
...60/3

Digit 13 — Supply Fan Motor, HP
1 = 7.5 Hp Std. Eff.
2 = 10 Hp Std. Eff.
3 = 15 Hp Std. Eff.
4 = 20 Hp Std. Eff.
5 = 7.5 Hp Hi. Eff.
6 = 10 Hp Hi. Eff.
7 = 15 Hp Hi. Eff.
8 = 20 Hp Hi. Eff.

Digit 14 — Supply Air Fan Drive Selections (See Note 3)
A = 550 RPM
B = 600 RPM
C = 650 RPM
D ...
E = ...
F = ...
G = 800 RPM
H = 500 RPM
J = 525 RPM
K = 575 RPM
... = 625 RPM

Digit 15 — Fresh Air Selection
A = No Fresh Air
B = 0-25% Manual Damper
C = 0-100% Economizer, Dry Bulb Control
D = 0-100% Economizer, Reference Enthalpy Control

Digit 16 — System Control
1 = Constant Volume
2 = VAV Supply Air Temperature Control w/o Inlet Guide Vanes
3 = VAV Supply Air Temperature Control w/Inlet Guide Vanes
4 = VAV Supply Air Temperature Control w/Variable Frequency Drive w/o Bypass
5 = VAV Supply Air Temperature Control w/Variable Frequency Drive and Bypass

Note: Zone sensors are not included with option and must be ordered as a separate accessory.

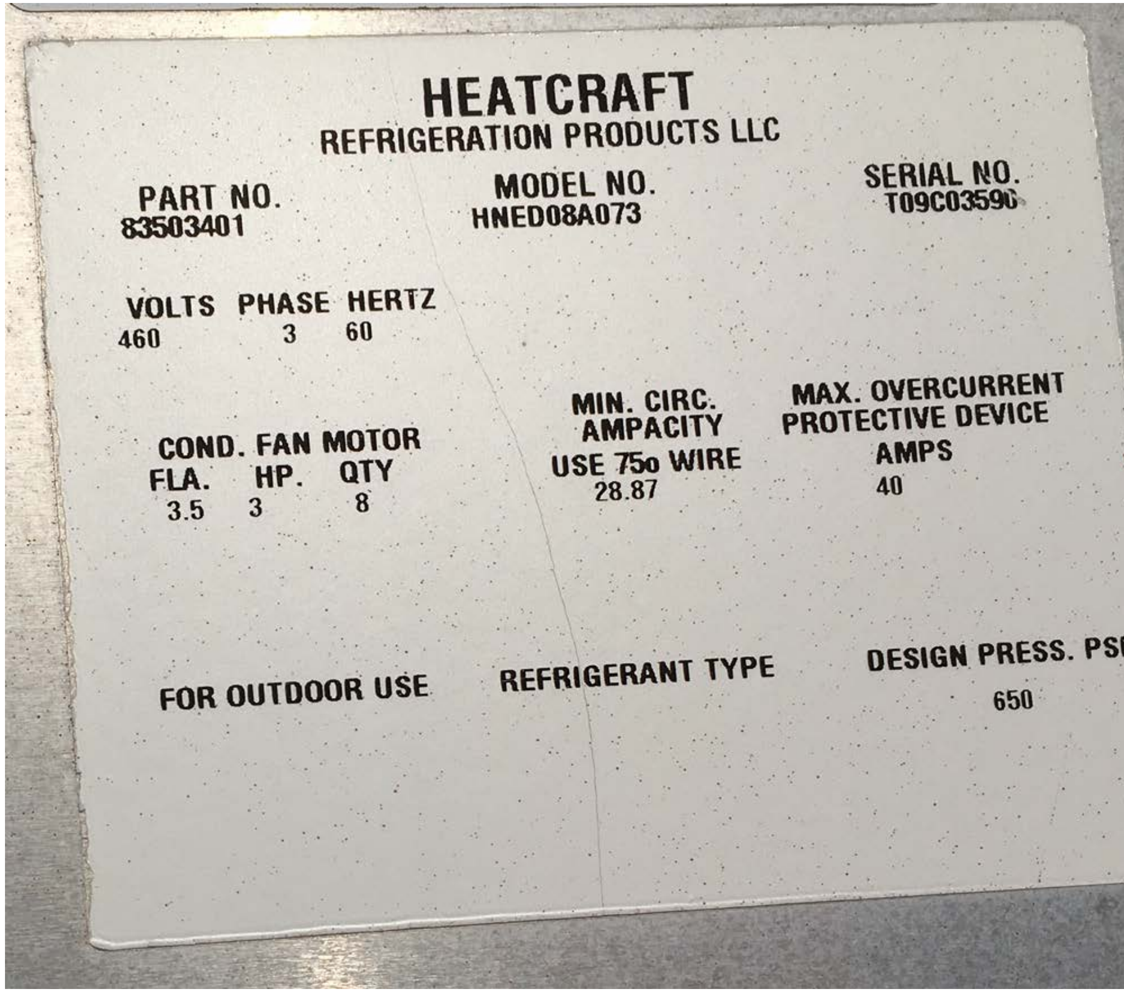
Digit 17 - 29 — Miscellaneous
A = Service Valves (See Note 2)
B = Through the Base Electrical Provision
... Fused Disconnect Switch with
...
Conven...
Disconnect Switch with
External Handle
E = Field-Powered 15A GFI Convenience Outlet

Photographing Nameplates

Don’t lose all the info with a flash

Photographing Nameplates

- Photograph at an angle to avoid flash "white out"
- Use the macro setting for close-ups
- Review after you take it – you can set your camera default to zoomed preview
- Turn off the flash for VDT screens
- Avoid blur by resting on a solid surface

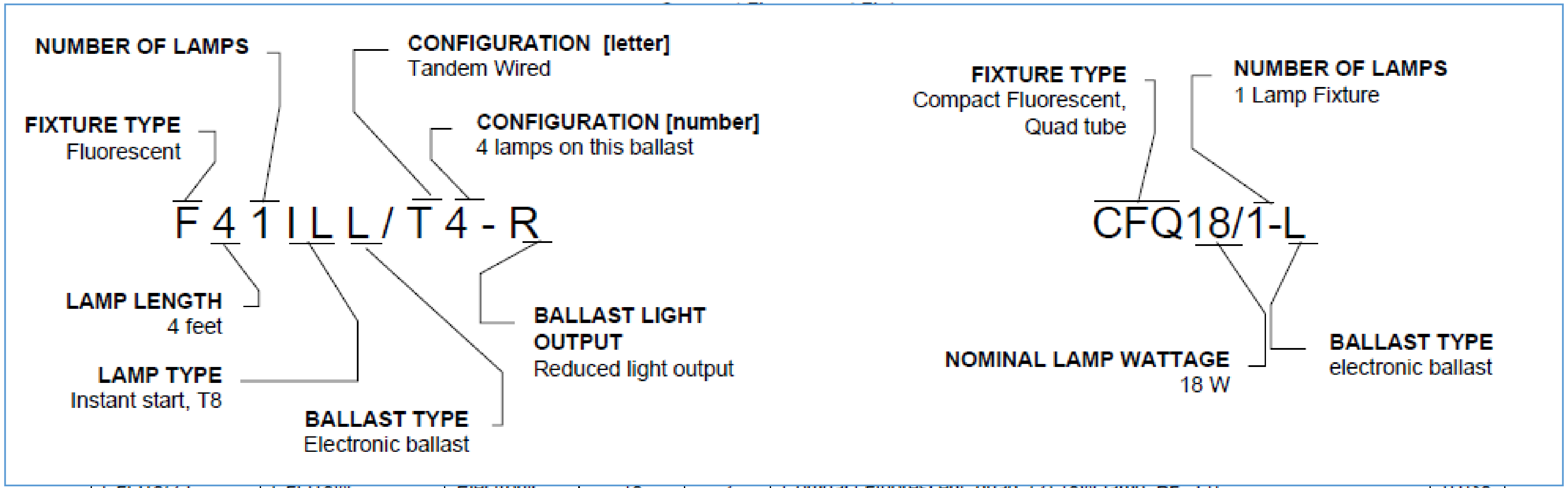


ETL LISTED
CONFORMS TO UL STD 1995
CERTIFIED TO CAN/CSA STD C22.2 NO. 236
19401
26
771855
Carrier
A United Technologies Company
MODEL 50EW-054---600QA
SERIAL 0401F59047
REFRIG/SYSTEM R-22
FACTORY CHARGED
DESIGN/TEST PRESSURE GAGE
COMP 1 460 3 60 43.6 223 50.7 LBS 23.0 kg
COMP 1 460 3 60 30.8 173 46.5 LBS 21.1 kg
HIGH PSI 410 kPa 2827
LOW PSI 150 kPa 1034
FAN MOTORS QTY VOLTS AC PH HZ FLA HP kW OUT
OUTDOOR 4 460 3 60 2.7 1 0.75
INDOOR 1 460 3 60 27.0 20 14.9
OTHER
HEATERS
POWER SUPPLY 460 VOLTS 3 PH 60 HZ
PERMISSIBLE VOLTAGE AT UNIT 508 MAX 414 MIN
ONLY SUITABLE FOR OUTDOOR USE
CKT MIN CIRCUIT AMPS 1 123.1
MAX OVERCURRENT PROTECTION DEVICE AMPS 150
FUSE OR HACR BKR
MIN CLEARANCE TO COMBUSTIBLE MATERIALS ___ INCHES ___ mm. FOR FIRST ___ INCHES ___ mm. OF DUCT WHEN ELECTRIC HEATER IS INSTALLED
TEST WITH EXTERNAL STATIC 0.4 inches H2O 0.10 kPa
MADE IN U.S.A.
TLF
CHARGE SYSTEM PER INSTALLATION INSTRUCTIONS
99NA505293 S
ACCESSORY HEATER | CHK HERE | VOLTS | PH | HZ | HEATER FLA | MIN CKT AMPS | MAX OVERCURRENT PROTECTIVE DEVICE AMPS
CRHEATER132A00-- 460 3 60 65.0 123.1 150 FUSE OR HACR BKR
CRHEATER133A00-- 460 3 60 129.9 163.7 175 FUSE OR HACR BKR

Getting Data on Existing Lighting

Go to the stockpiles first!

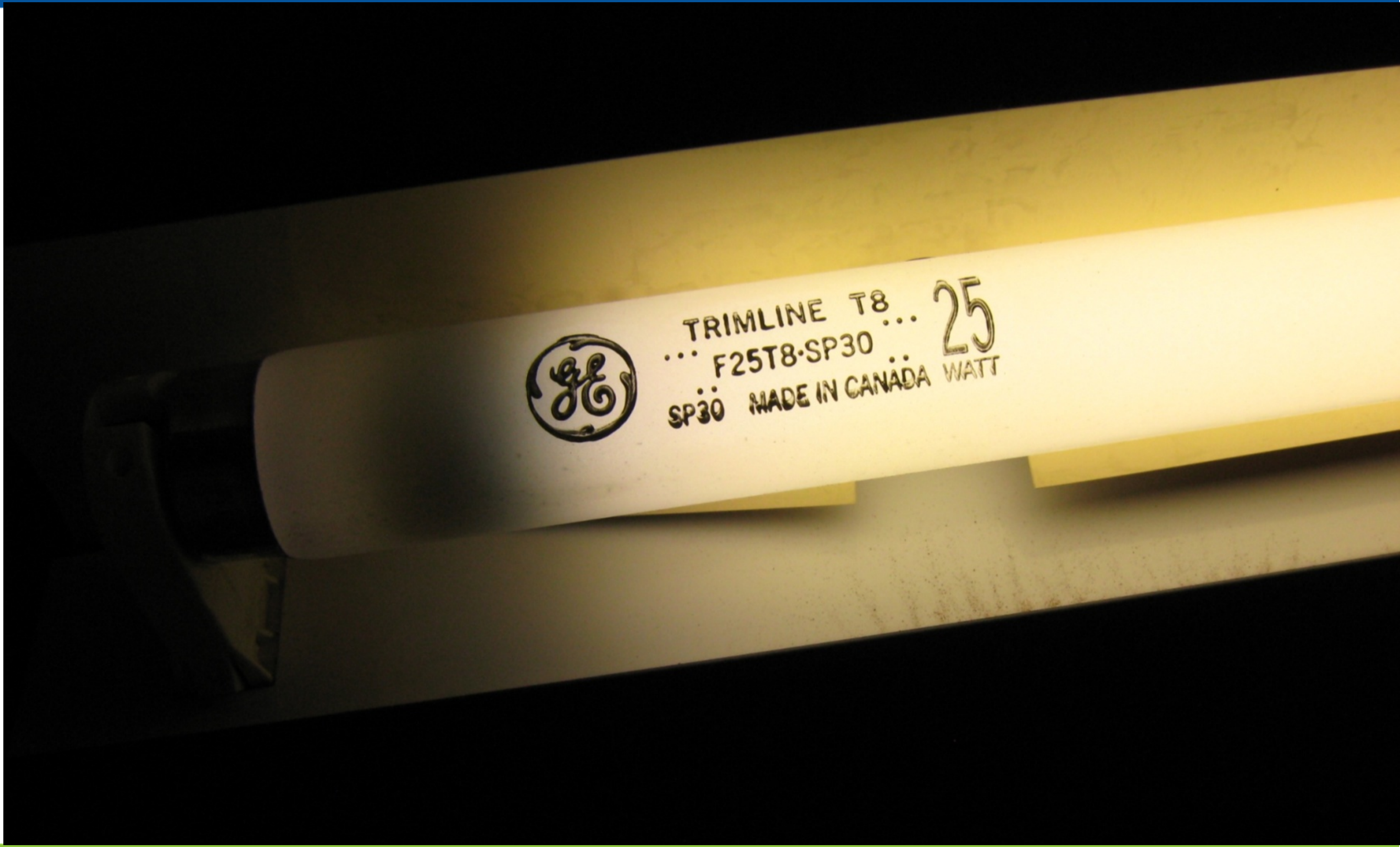
Lighting Wattage Tables



FIXTURE CODE	LAMP CODE	BALLAST TYPE	NOM. W/LAMP	LAMP/ FIXT	DESCRIPTION	kW/ FIXT
CFQ18/2-L	CFQ18W	Electronic	18	2	Compact Fluorescent, quad, (2) 18W lamp, BF=1.0	0.038
CFQ18/4	CFQ18W	Mag-STD	18	2	Compact Fluorescent, quad, (4) 18W lamp	0.090
CFQ20/1	CFQ20W	Mag-STD	20	1	Compact Fluorescent, quad, (1) 20W lamp	0.023
CFQ20/2	CFQ20W	Mag-STD	20	2	Compact Fluorescent, quad, (2) 20W lamp	0.046
CFQ22/1	CFQ22W	Mag-STD	22	1	Compact Fluorescent, Quad, (1) 22W lamp	0.024
CFQ22/2	CFQ22W	Mag-STD	22	2	Compact Fluorescent, Quad, (2) 22W lamp	0.048
CFQ22/3	CFQ22W	Mag-STD	22	3	Compact Fluorescent, Quad, (3) 22W lamp	0.072
CFQ25/1	CFQ25W	Mag-STD	25	1	Compact Fluorescent, Quad, (1) 25W lamp	0.033
CFQ25/2	CFQ25W	Mag-STD	25	2	Compact Fluorescent, Quad, (2) 25W lamp	0.066
CFQ26/1	CFQ26W	Mag-STD	26	1	Compact Fluorescent, quad, (1) 26W lamp	0.033
CFQ26/1-L	CFQ26W	Electronic	26	1	Compact Fluorescent, quad, (1) 26W lamp, BF=0.95	0.027
CFQ26/2	CFQ26W	Mag-STD	26	2	Compact Fluorescent, quad, (2) 26W lamp	0.066
CFQ26/2-L	CFQ26W	Electronic	26	2	Compact Fluorescent, quad, (2) 26W lamp, BF=0.95	0.050
CFQ26/3	CFQ26W	Mag-STD	26	3	Compact Fluorescent, quad, (3) 26W lamp	0.099
CFQ26/6-L	CFQ26W	Electronic	26	6	Compact Fluorescent, quad, (6) 26W lamp, BF=0.95	0.150

Need to Read Specs while the Lights Are on?

You can read these if you have to by waving your hand back and forth over your eye



Expert Tip

- Tenant condenser water loops typically run 24/7
- This can be a savings goldmine—don’t ignore them

Example Site

- 25-story multi-tenant office
- 700,000 gsf
- VAV RH system
- DDC to zone level
- Resetting DSP and SAT
- ENERGY STAR score of 88

Client Ask:
“We’re interested in LEED EBOM only—feel we’ve done the measures on site already”

Condenser Water EEMs (Only)

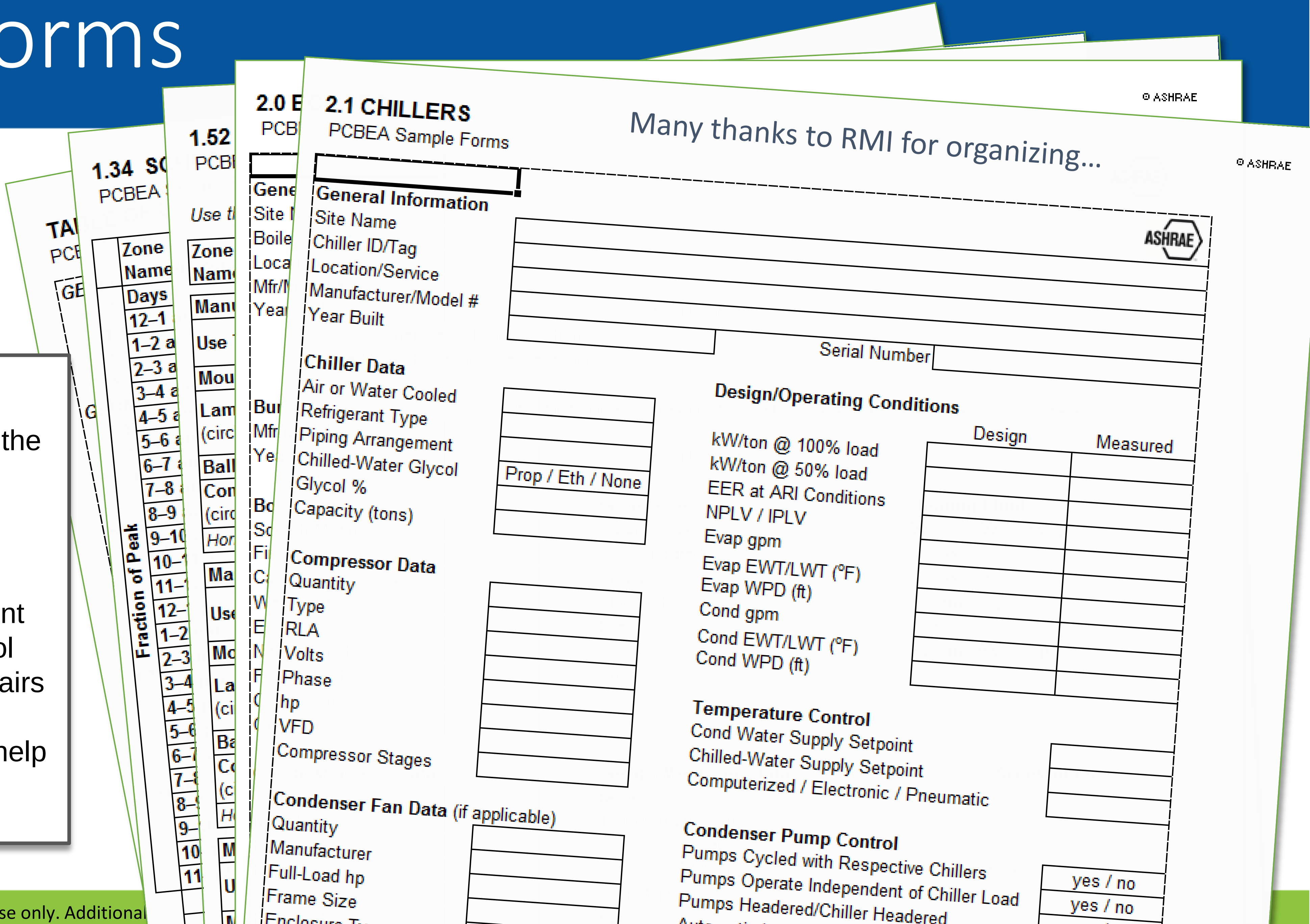
Measure Description	Annual Energy and Cost Savings			Payback		Payback with Incentive	
	Peak Savings (kW)	Electricity Savings (kWh)	Total Cost Savings	Measure Cost	Simple Payback (yr)	Potential Incentive	Simple Payback (yr)
Revise Cooling Tower Fan Control To Stage Both Fans on Sooner	0.0	10,440	$ 1,198	$ 2,500	2.1	$ -	2.1
Install Isolation Valves to Use Only One Cooling Tower Cell When Chillers Are Off	0.0	203,415	$ 23,342	$ 16,080	0.7	$ 8,040	0.3
Install VFD on Tenant Condenser Loop Pump to Reduce Flow	21.3	186,435	$ 22,826	$ 20,818	0.9	$ 10,409	0.5
Install 2-Way Valve to Control Cooling Tower Water Flow to Tenant Loop HX When Chiller Running	0.0	21,387	$ 2,454	$ 16,500	6.7	$ 1,925	5.9
	21.3	**421,677**	**$ 49,820**	**$ 55,898**	**1.1**	**$ 20,374**	**0.7**

Tools for a Level 1 Audit

- Identification
- Notebook/clipboard
- Audit forms appropriate to the site
- Camera
- Phone
- Multi-tool
- Flashlight
- Digital thermometer and/or humidity meter
- Hearing protection

Audit Forms

Many thanks to RMI for organizing…



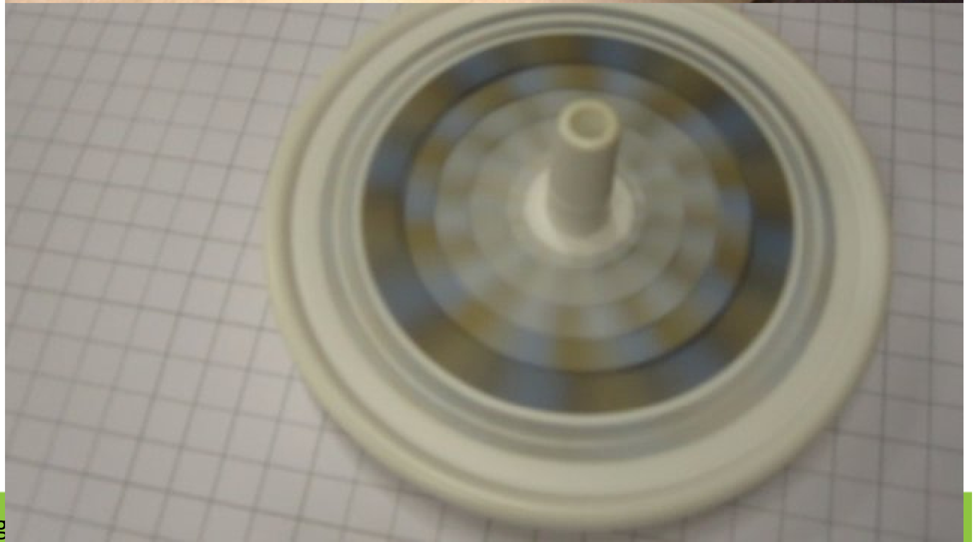
★ **Expert Tip**

When using these forms in the field, put a star next to any energy-efficiency measure opportunity you see.

This could include equipment replacement options, control improvements, or O&M repairs that might lead to an audit recommendation. This will help highlight items for later analysis.

Tools for Level 2 and Level 3

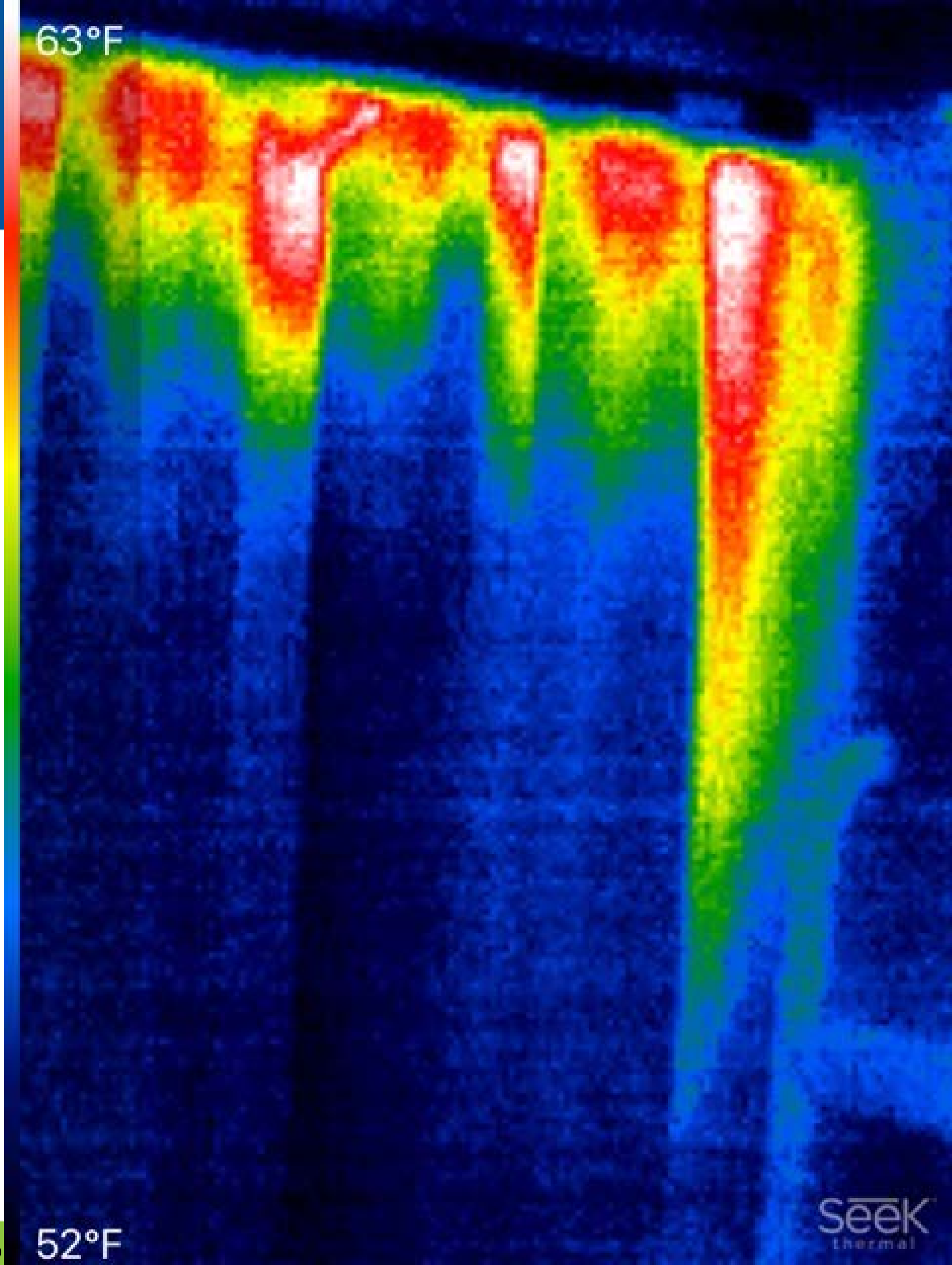
- Energy audit sample forms
- Illuminance meter (light meter)
- Infrared temperature spot meter
- Electronic ballast spinner/detector
- Power meter and/or data loggers
- Temperature loggers
- Light loggers
- Motor runtime status loggers
- Tape measure



Specialized Equipment

- Boiler stack gas analyzer (for combustion tests)
- Ultrasonic flow meters (for monitoring chilled-water, condenser-water, or heating-water flows)
- Infrared camera
- Pipe caliper
- Centralized data-logging systems
- Personal protection equipment (PPE) per OSHA (may include construction hard hat, safety glasses, gloves)

Check for local resources like tool lending libraries, for example: www.pge.com/pec/tll/



Audit Report = Valuable Resource

- Many times this is the best documentation of existing equipment and controls
- Inventory of equipment
  - Number
  - Tag ID
  - Capacity/nameplate specs
- Intended control strategies

Cooling

Most spaces at XXXXXXX are cooled by the main chiller plant, which consists of:

- One 550-ton centrifugal chiller with two compressors (lead chiller):
  - water-cooled by one 1,650-gpm centrifugal fan cooling tower, with a 40-hp motor and on/off controls
  - served by one 880-gpm centrifugal CHW pump and one 1,200-gpm centrifugal CW pump, both with on/off controls
- Two 1,350-ton centrifugal chillers (lag chillers):
  - water-cooled by a three-cell axial fan cooling tower; each cell is rated at 1,800 gpm and contains a 40-hp two-speed motor
  - served by two 2,025-gpm centrifugal CHW pumps and two 2,700-gpm condenser water pumps, all with on/off controls

How to Hire an Auditor

How to Hire an Auditor

- Determine your initial scope
- What role might auditor play beyond audit (project design, implementation, Cx)?
- Sole source or competitive bids
- Look for:
  - ❑References
  - ❑Sample work
  - ❑Qualified staff
  - ❑Vendor neutrality
  - ❑Certifications (BEAP, CEM, CEA)

1. Call References

What to ask references (p.1):

1. Results: *Did the audit report lead to implementation of projects saving energy?*
2. Expertise: *Did the auditor know building systems in and out? Current technologies?*
3. Partnering: *Did the auditor:*
   - ❑ *Collaborate well with you and your team?*
   - ❑ *Understand and respond to your needs?*
4. Action oriented: *Did the audit report guide you on what to do and when?*

1. Call References

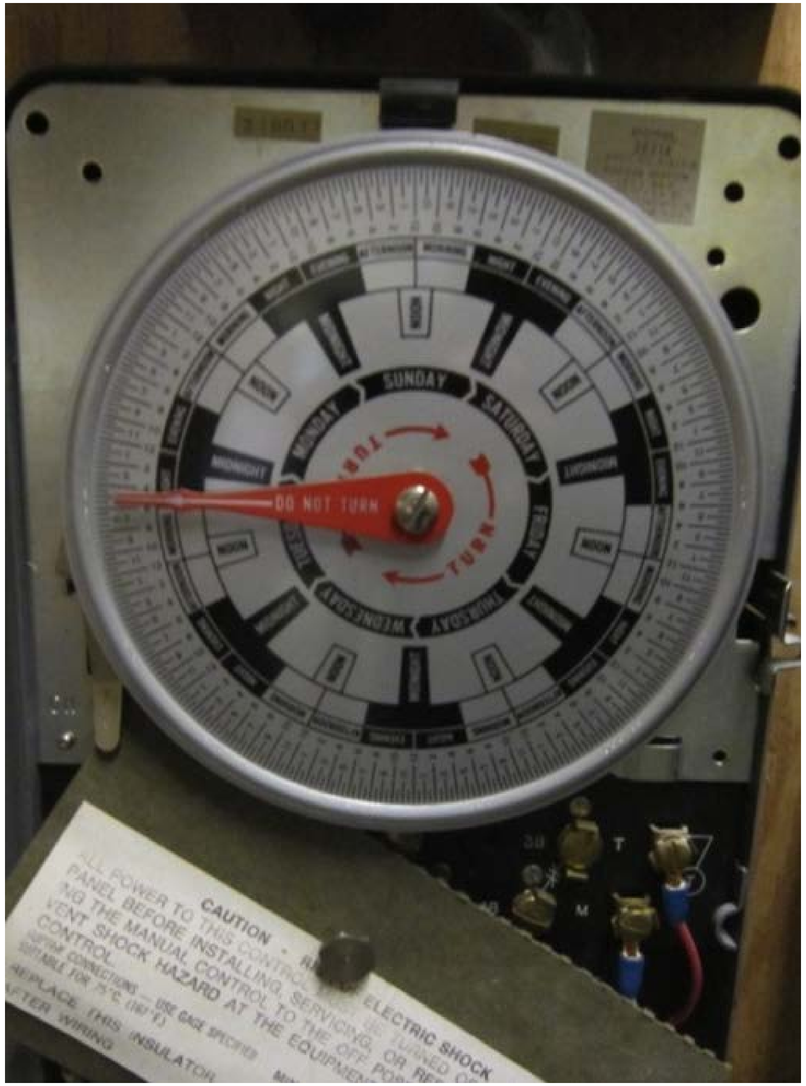
What to ask references (p.2):

5. Accuracy and transparency: *Did you have confidence in the report numbers (project savings, costs, returns)?*
6. Independence: *Was the auditor unbiased and objective?*
7. Use of Data: *Did the auditor take measurements and obtain data for <u>your</u> building?*
8. Guidance: *Did the audit provide guidance to more resources and next steps?*

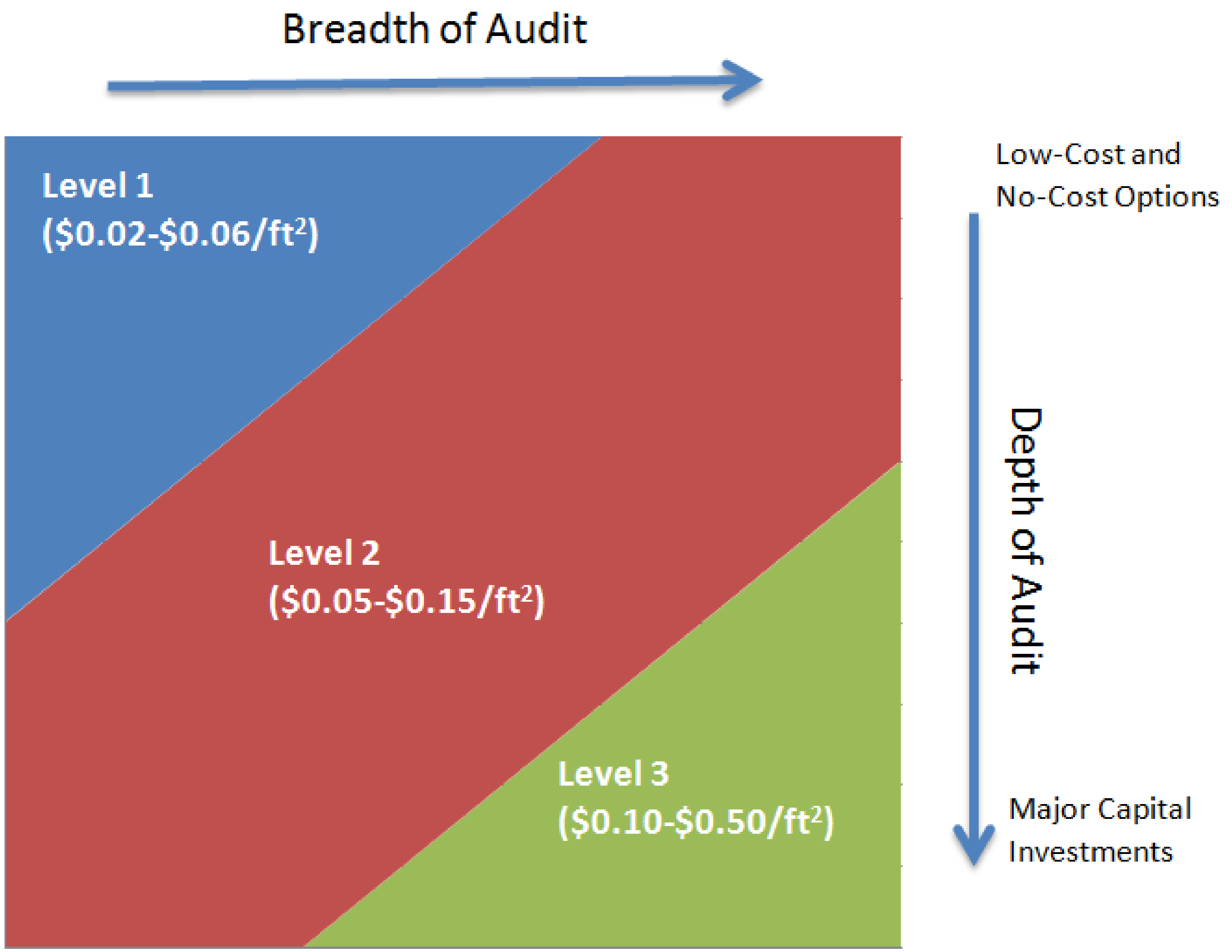
2. Evaluate Sample Audits

Detailed measure recommendations

- Observations
- Recommendations
- Implementation notes
  - Specific equipment changes
  - Specific control set points or algorithms
- Basis of savings
- Costs and incentives
- Methodology and assumptions
- Photos



What's an Audit Cost?



Source: U.S. DOE. 2011. *Advanced Energy Retrofit Guide; Practical Ways to Improve Energy Performance: Office Buildings*. U.S. Department of Energy, Building Technologies Program, Pacific Northwest National Laboratory.

Who's Qualified?

- ❑Engineers?
- ❑PEs?
- ❑Contractors?

Most people reply, in effect, *"me."*

Who’s Qualified?

- ***qualified energy auditor:*** an energy solutions professional who assesses building systems and site conditions; analyzes and evaluates equipment and energy use; and recommends strategies to optimize building resource use. Experience must include completion of five commercial (nonresidential) building energy audits within the past three years or a cumulative completion of ten or more commercial building energy audits. The auditor must be one of the following:
    - A person who holds a certification from a credentialing program approved by the U.S. Department of Energy Better Buildings Workforce Guidelines for Building Energy Auditors or Energy Managers
    - A licensed professional engineer or a licensed contractor specifically approved by the AHJ to conduct energy audits
    - A person approved as qualified by the authority having jurisdiction (AHJ)
- **Informative Note:** For a current listing of certifications that meet the requirements of the DOE’s Better Building Workforce Guidelines, see the website referenced in Informative Annex H. Only credentialing programs that specifically certify building energy auditors or energy managers are applicable.

Who’s Qualified?

Top 5 characteristics of an energy auditor:

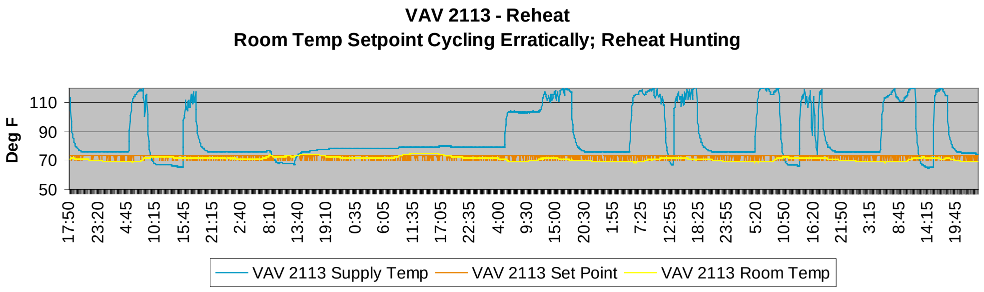
- ❑
- ❑
- ❑
- ❑
- ❑

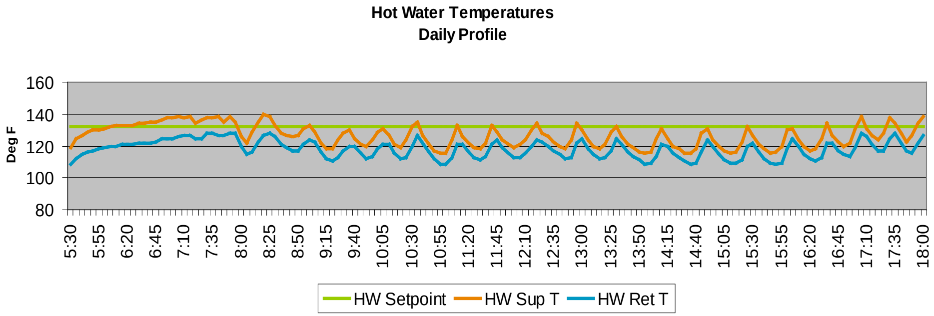
Number 5

- Doesn’t like “cookie-cutter” approach

Number 4

- ❑ Is addicted to trend data - in massive doses



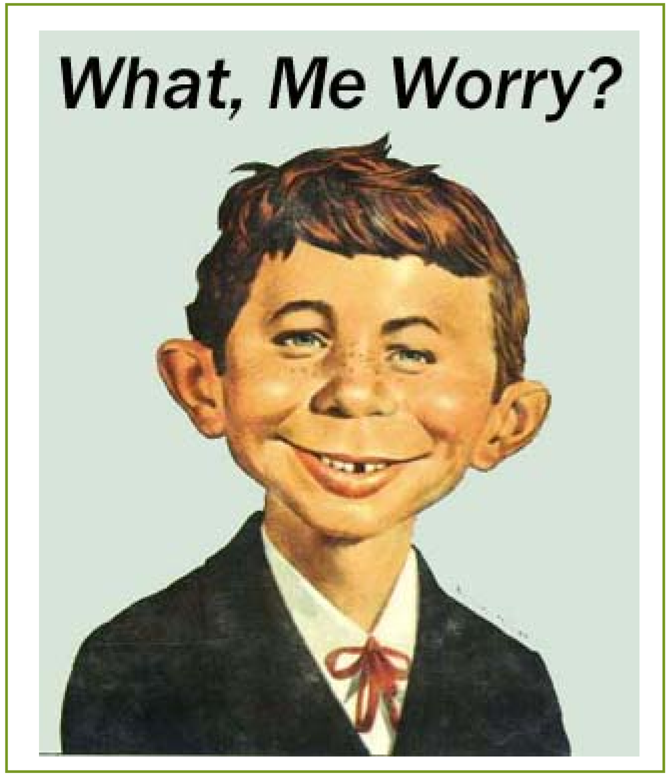


Number 3

- ❑ Has multiple personalities
  - ❑Engineer
  - ❑Controls technician
  - ❑Psychologist/Therapist

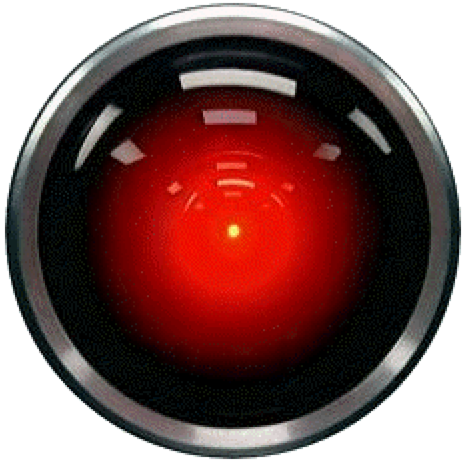
Number 2

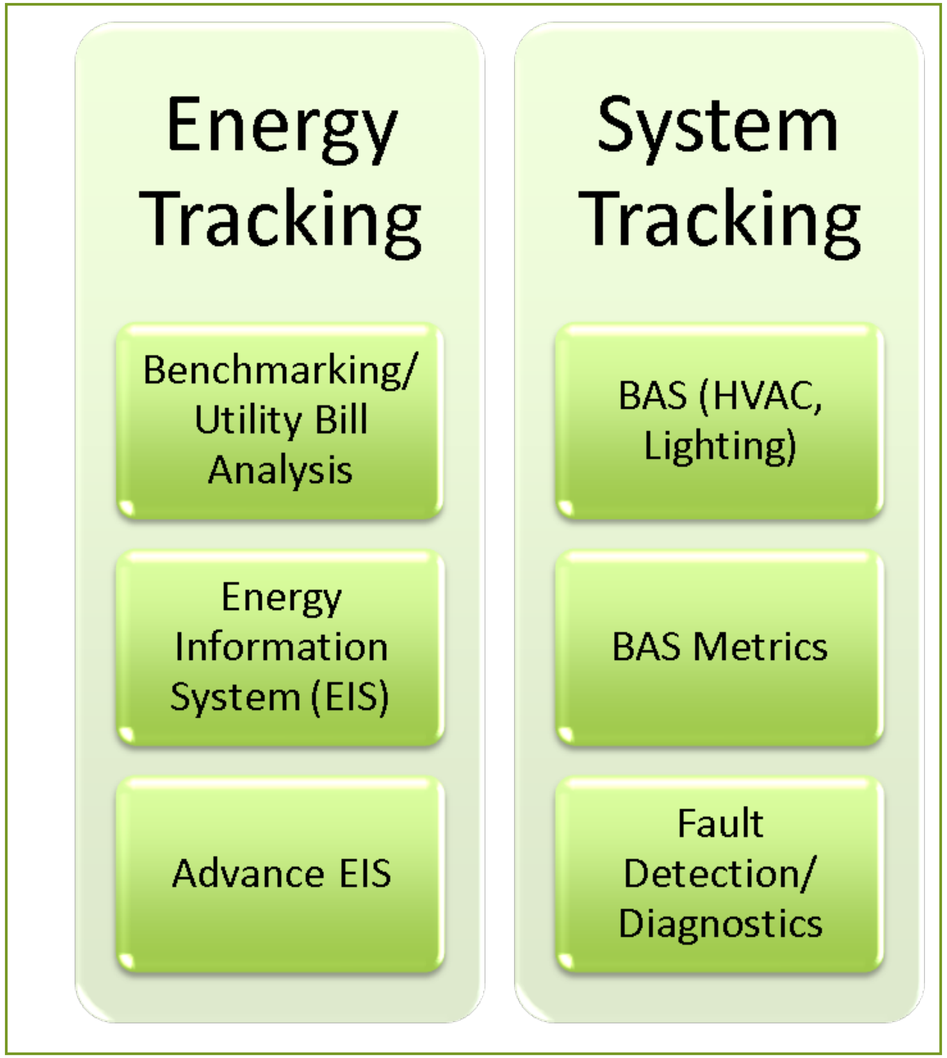
- Feels a sense of accomplishment at the completion of a project, but always worries about the future



Number 1

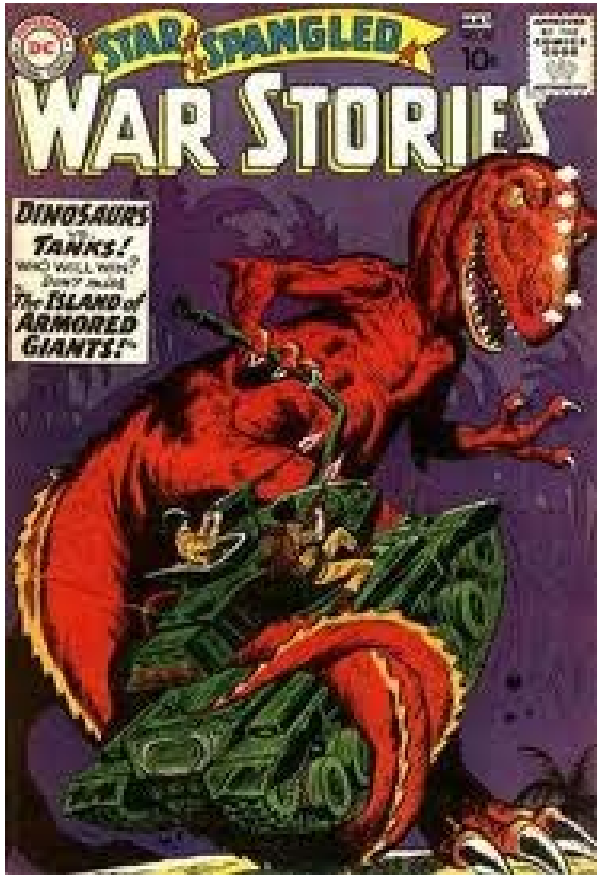
- Has a healthy skepticism about technology





Bonus

- ❑ Loves to tell war stories



Part 2

What We’ll Cover—Part 2

- ❑Economics
- ❑Calculations
- ❑EEMs
- ❑Selling your ideas
- ❑Celebrating success
- ❑What's next
- ❑Wrap up

Economics

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Simple Payback

$$\text{Simple Payback} = \frac{\text{Measure Cost}}{\text{Annual Cost Savings}}$$

- Simple
- Does not indicate magnitude of savings or investment
- Poor frame for investment decision
- Omits time value of money, O&M, tax implications, utility cost escalation, etc.

LCCA

Life-cycle cost analysis must include:

- Time value of money
- Measure lifetime
- Equipment life

Federal References

- NIST Handbook 135
- BLCC software

Can include:

- Energy cost escalation
- O&M (regular and one-time)

LCCA

- NPV
  Net present value
- SIR
  Savings-to-investment ratio
- IRR
  Internal rate of return
- MIRR or IRR*
  Modified IRR

$$\text{NPV} = \sum_{t=1}^{n} \frac{CF_t}{(1+d)^t} - CF_o$$

where

CF = cash flow,

t = current time period, and

n = number of cash flows

$$\text{SIR} = \frac{\text{NPV}_{savings}}{\text{NPV}_{costs}}$$

$$0 = \left(\sum_{t=1}^{n}\right) \frac{CF_t}{(1+\text{IRR})^t} - CF_o$$

MIRR or Adjusted IRR

- Modified internal rate of return *or* adjusted internal rate of return
- IRR assumes reinvestment at same rate
- For example, if you have a two-year payback, assumes reinvestment at ~ 50% rate of return
- MIRR takes into account reinvestment of interim returns at realistic rate
- MIRR = fn (CF, life, reinvestment rate)
- Or download BLCC from DOE/FEMP

Resources

Search for "BLCC"

https://www.energy.gov/eere/femp/building-life-cycle-cost-programs

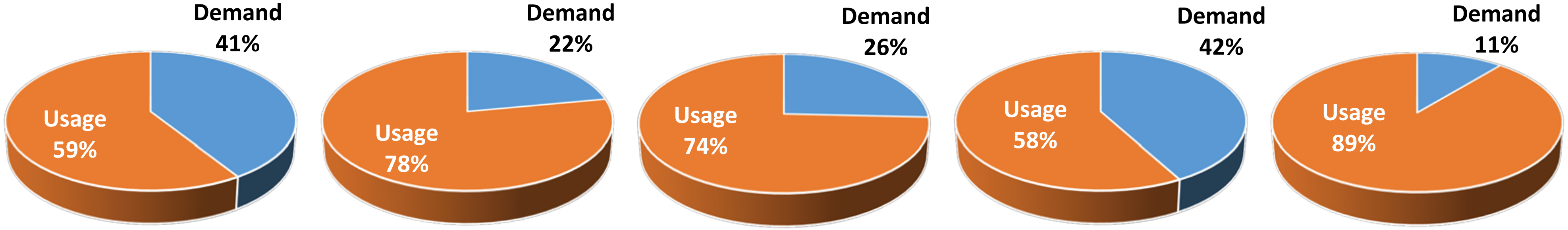
https://sustainable.stanford.edu/sites/default/files/Guidelines_for_Life_Cycle_Cost_Analysis.pdf

Marginal Energy Price

For each metered or delivered energy source, a marginal unit energy price shall be calculated. Energy cost savings shall be based on the marginal costs and demand charges. **Use of average unit cost (blended rates) is prohibited.**

Blended Rate Breakdown

	SoCal	NYC	Chicago	Atlanta	Orlando
Average $/kWh	$0.15	$0.18	$0.11	$0.08	$0.11
% Demand	41%	22%	26%	42%	11%
% Consumption	59%	78%	74%	58%	89%



Marginal Electric Price – Examples

Measure Type	$/kWh
Average	$0.15
24-hour Load	$0.11
Night Load	$0.07
Cooling Load	$0.21

Exercise #3: Marginal Energy Prices

Exercise 3: Marginal Energy Prices

Given:

- Annual usage: 3,000,000 kWh
- Annual bill: $600,000
- Marginal demand rate: $25/kW/Month
- Marginal usage rate: $0.10/kWh
- Interior lighting LED retrofit:
  - 100 kW load reduction
  - 2,500 hrs/yr
- Exterior night lighting LED retrofit:
  - 100 kW load reduction
  - 4,000 hrs/yr

Calculate:

1. Annual average (blended) electric rate $/kWh
2. Annual cost saving for interior LED retrofit using blended rate
3. Annual cost saving for interior LED retrofit using marginal rate
4. Annual cost saving for exterior LED retrofit using blended rate
5. Annual cost saving for exterior LED retrofit using marginal rate

Calculations

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One-Line Calc

- Follow a system
- Identify inputs/outputs
- Document your approach

Base Case

CFM	36,040	
SP	1.75	
Fan Eff	70%	
Fan BHP	14.2	
Motor Eff	85.5%	
Fan kW	12.4	
hours	3,128	
Annual use	38,705	kWh

Proposed Case

Fan kW	12.4	
hours	2,607	
Annual use	32,255	kWh

Savings

Base Annual use	38,705	kWh
Proposed Annual use	32,255	kWh
Annual Savings	6,451	kWh

Simplified Example

Basis of “energy balance”

Base Case	
100	fixtures
90	W each
9	kW
2,000	hrs
18,000	kWh

Proposed Case	
100	fixtures
60	W each
6	kW
1,500	hrs
9,000	kWh

Savings	
3	kW
9,000	kWh

Bin Sims

Sample simple bin sim.xlsx - Microsoft Excel non-commercial use

P12 | Observed Conditions on-site

Simulated Units:	Typical, non-VFD Controlled AHU on Floors 4, 6-12
Operating Schedule:	6:00 AM - 6:00 PM

Note: This bin sim models a typical air handler with Discharge Dampers at the site. The economizer inputs were modified based on the observed air handler operations during the site visit. These inputs were adjusted until the temperatures observed in the mixed air plenum aligned with our observed temperature data.

	Fan kW	Voltage	Phase	Amps	PF	OAT
Observed	10.7	220	3	33	0.85	60
	Fan kw	hp	Efficiency	Load Factor		
Max	18.7	20	91.00%	0.85		

VAV Reheat Simulation

	Fan kW	Supply Air Flow rate (CFM)	Minimum OSA	Minimum OSA	Maximum OSA	Minimum Supply Air Flow	Design SAT	Est Min SAT (F)	Estimated Max Zone Load	Fan Control	Average Space Temp (F)	Avg RAT (F)	Balance Temp (F)
Supply Air	18.7	13,700	1,370	10%	60%	58%	55	55	100%	FC OD	72.0	72.0	60

	kW/ton	OSA LO (F)
Cooling	0.80	65

	Efficiency	OSA LO (F)	Reset OAT	Reset SAT Reset
Heating	80%	60	50	55
			70	55

Econ	Design Htg Temp (F)	Design Clg Temp (F)
Y	38.8	83

Fan Curve Coefficients (a,b,c, min): 0.190667 | 0.31 | 0.5 | 22%

Observed Conditions on-site

	OSA Temp (F)	Hrs/yr	% OSA	MAT (F)	CV Zone SAT (F)	Zone Load (kBtuh)	% CFM	CCoil Setpoint (F)	CCoil DAT (F)	SAT (F)	Coil Load (kBtuh)	Perimeter Zone Load	Heating (kBtu/yr)	Cooling (kBtu/yr)	Cooling kW/ton	Cooling kW	Cooling kWh	Fan kW	Fan kWh
Annual Energy Use	92	1	10%	74.0	55.0	252	100%	55.0	55.0	55.0	281	-	-	201	0.80	18.2	13	18.7	13
	90	1	10%	73.8	55.0	252	100%	55.0	55.0	55.0	278	-	-	397	0.80	18.2	26	18.7	27
	88	-	10%	73.6	55.0	252	100%	55.0	55.0	55.0	275	-	-	-	0.80	-	-	-	-
	86	2	10%	73.4	55.0	252	100%	55.0	55.0	55.0	272	-	-	583	0.80	18.2	39	18.7	40
	84	6	10%	73.2	55.0	252	100%	55.0	55.0	55.0	269	-	-	1,731	0.80	17.9	115	18.7	120
	82	16	10%	73.0	55.7	241	96%	55.0	55.0	55.0	255	-	-	4,013	0.80	17.1	268	17.7	278
	80	19	10%	72.8	57.2	219	87%	55.0	55.0	55.0	229	-	-	4,422	0.80	15.3	295	15.7	302
	78	24	10%	72.6	58.7	197	78%	55.0	55.0	55.0	204	-	-	4,802	0.80	13.6	320	13.8	326
	76	24	10%	72.4	60.2	175	69%	55.0	55.0	55.0	179	-	-	4,212	0.80	11.9	281	12.1	285
	74	53	60%	73.2	61.7	152	61%	55.0	55.0	55.0	163	-	-	8,624	0.80	10.9	575	10.5	555
	72	83	60%	72.0	63.1	132	58%	55.0	55.0	56.7	146	15	-	12,088	0.80	9.7	806	10.1	834
	70	130	60%	70.8	64.6	110	58%	55.0	55.0	59.2	136	36	-	17,627	0.80	9.0	1,175	10.1	1,308
	68	106	60%	69.6	66.1	87	58%	55.0	55.0	61.8	125	58	-	13,335	0.80	8.4	889	10.1	1,071
	66	216	60%	68.4	67.6	65	58%	55.0	55.0	64.4	115	81	-	24,806	0.80	7.7	1,654	10.1	2,171
	64	393	60%	67.2	69.0	44	63%	55.0	67.2	67.2	-	-	-	-	0.80	-	-	10.8	4,255
	62	337	60%	66.0	70.5	22	58%	55.0	66.0	69.4	-	29	-	-	0.80	-	-	10.1	3,393
	60	**366**	60%	**64.8**	**72.0**	**0**	**58%**	**55.0**	**64.8**	**72.0**	-	62	-	-	**0.80**	-	-	**10.1**	**3,680**
	58	382	10%	70.6	73.5	-22	58%	55.0	70.6	74.6	-	34	13,118	-	0.80	-	-	10.1	3,846
	56	353	10%	70.4	75.0	-44	58%	55.0	70.4	77.2	-	58	20,591	-	0.80	-	-	10.1	3,551
	54	272	10%	70.2	76.4	-65	58%	55.0	70.2	79.6	-	81	21,953	-	0.80	-	-	10.1	2,739
	52	199	10%	70.0	77.9	-87	58%	55.0	70.0	82.2	-	105	20,790	-	0.80	-	-	10.1	1,998
	50	98	10%	69.8	79.4	-109	58%	55.0	69.8	84.8	-	129	12,597	-	0.80	-	-	10.1	985
	48	127	10%	69.6	80.9	-132	58%	55.0	69.6	87.3	-	152	19,312	-	0.80	-	-	10.1	1,279
	46	104	10%	69.4	82.3	-152	58%	55.0	69.4	89.8	-	175	18,132	-	0.80	-	-	10.1	1,042
	44	39	10%	69.2	83.8	-175	58%	55.0	69.2	92.3	-	198	7,646	-	0.80	-	-	10.1	388
	42	20	10%	69.0	85.3	-197	58%	55.0	69.0	94.9	-	222	4,445	-	0.80	-	-	10.1	201
	40	15	10%	68.8	86.8	-219	58%	55.0	68.8	97.5	-	246	3,694	-	0.80	-	-	10.1	151
	38	4	10%	68.6	88.3	-241	58%	55.0	68.6	100.1	-	270	1,159	-	0.80	-	-	10.1	43
	36	1	10%	68.4	89.7	-262	58%	55.0	68.4	102.5	-	293	209	-	0.80	-	-	10.1	7
DEER Peak	81	7/17/2000	10%	73	56.5	229	91%	55	55	55	241	-	0	241	0.80	16.0		16.6	
	80	7/17/2000	10%	73	57.2	219	87%	55	55	55	229	-	0	229	0.80	15.0		15.7	
	79	7/17/2000	10%	73	58	207	82%	55	55	55	216	-	0	216	0.80	14.0		14.7	
	87	7/18/2000	10%	74	55	252	100%	55	55	55	274	-	0	274	0.80	18.0		18.7	
	84	7/18/2000	10%	73	55	252	100%	55	55	55	269	-	0	269	0.80	18.0		18.7	
	82	7/18/2000	10%	73	55.7	241	96%	55	55	55	255	-	0	255	0.80	17.0		17.7	
	79	7/19/2000	10%	73	58	207	82%	55	55	55	216	-	0	216	0.80	14.0		14.7	
	78	7/19/2000	10%	73	58.7	197	78%	55	55	55	204	-	0	204	0.80	14.0		13.8	
	78	7/19/2000	10%	73	58.7	197	78%	55	55	55	204	-	0	204	0.80	14.0		13.8	
	Total	**3,389**											**143,646**	**96,842**		**15.6**	**6,456**	**16.0**	**34,888**

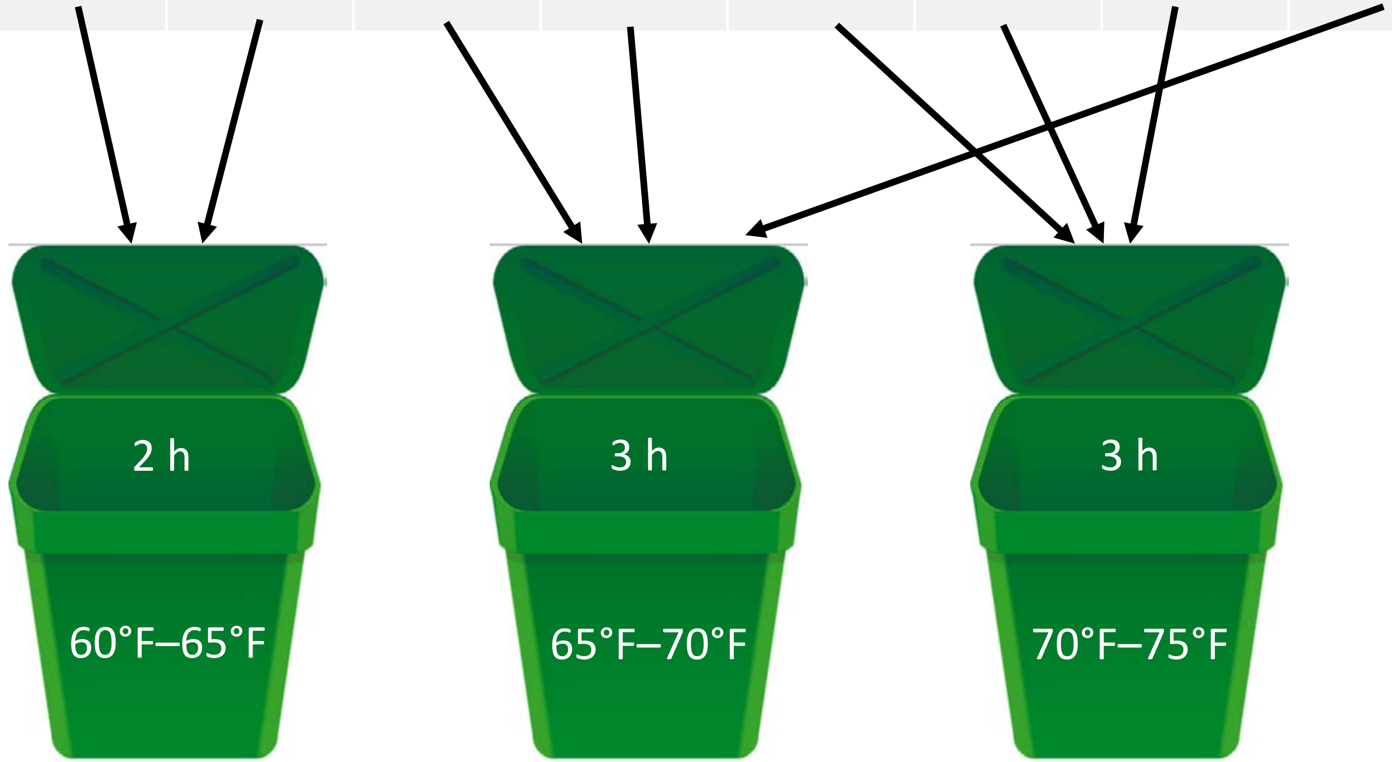
COOLING	6,456	kWh
HEATING	172	1000's lb Steam
VENTILATION	34,888	kWh
PEAK COOLING kW	15.6	kW
PEAK VENT kW	16.0	kW

Basecase

Ready

"Bin" Weather Data

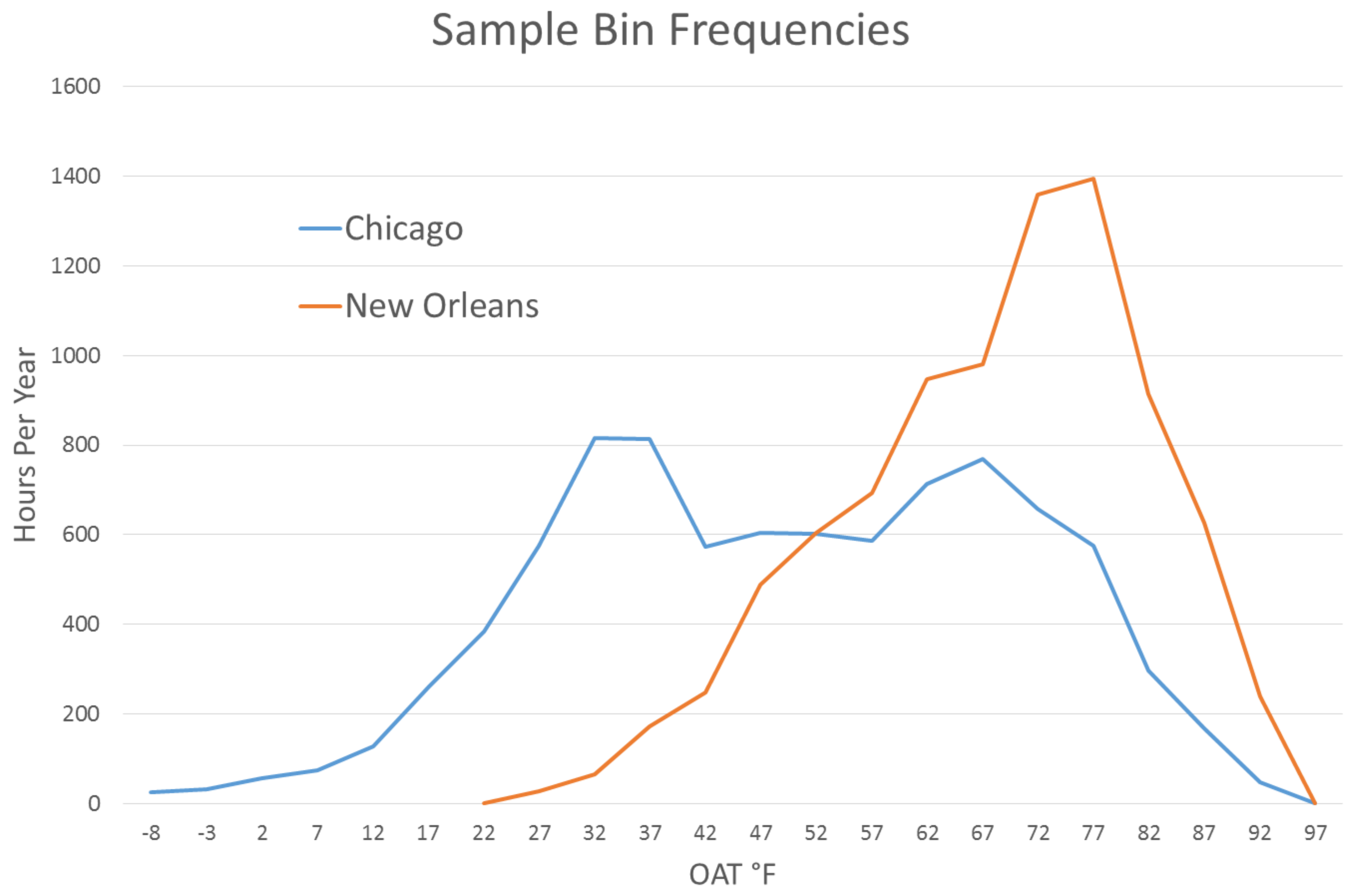
Hour	1	2	3	4	5	6	7	8
OAT [°F]	60	62	65	69	73	75	72	69



Bin Sim: Climate/Schedule

- Temperature bins
  - Top/bottom bins must include design temperatures
  - Bin end points are inclusive and exclusive Example: 75 < bin $\leq$ 80, mid point = 77.5
- Schedule
  - Reflect hours that equipment is **available**
  - Account for nights, weekends, and holidays
- Data
  - Typical (TMY3, e.g.)
  - Actual (DWR, monitored)

Bin Mid-point	Hours/yr
107.5	4
102.5	10
97.5	38
92.5	74
87.5	114
82.5	163
77.5	219
72.5	263
67.5	318
62.5	436
57.5	558
52.5	483
47.5	330
42.5	226
37.5	105
32.5	38
27.5	8
22.5	1
TOTAL	3,388


Sample Bin Frequencies
1600
1400
1200
1000
800
600
400
200
0
Hours Per Year
Chicago
New Orleans
-8
-3
2
7
12
17
22
27
32
37
42
47
52
57
62
67
72
77
82
87
92
97
OAT °F

Bin Sim: Fixed Assumptions

- Design conditions
  - Heating peak temp
  - Cooling peak temp
- Building
  - Balance point
- Equipment
  - Capacities (heating, cooling)
  - Efficiencies (EER, thermal)
  - Fan power
  - Airflow rate
  - Amount of outdoor air
  - Supply air temperatures
  - Economizer operation

Single Zone Simulation (Constant Volume)

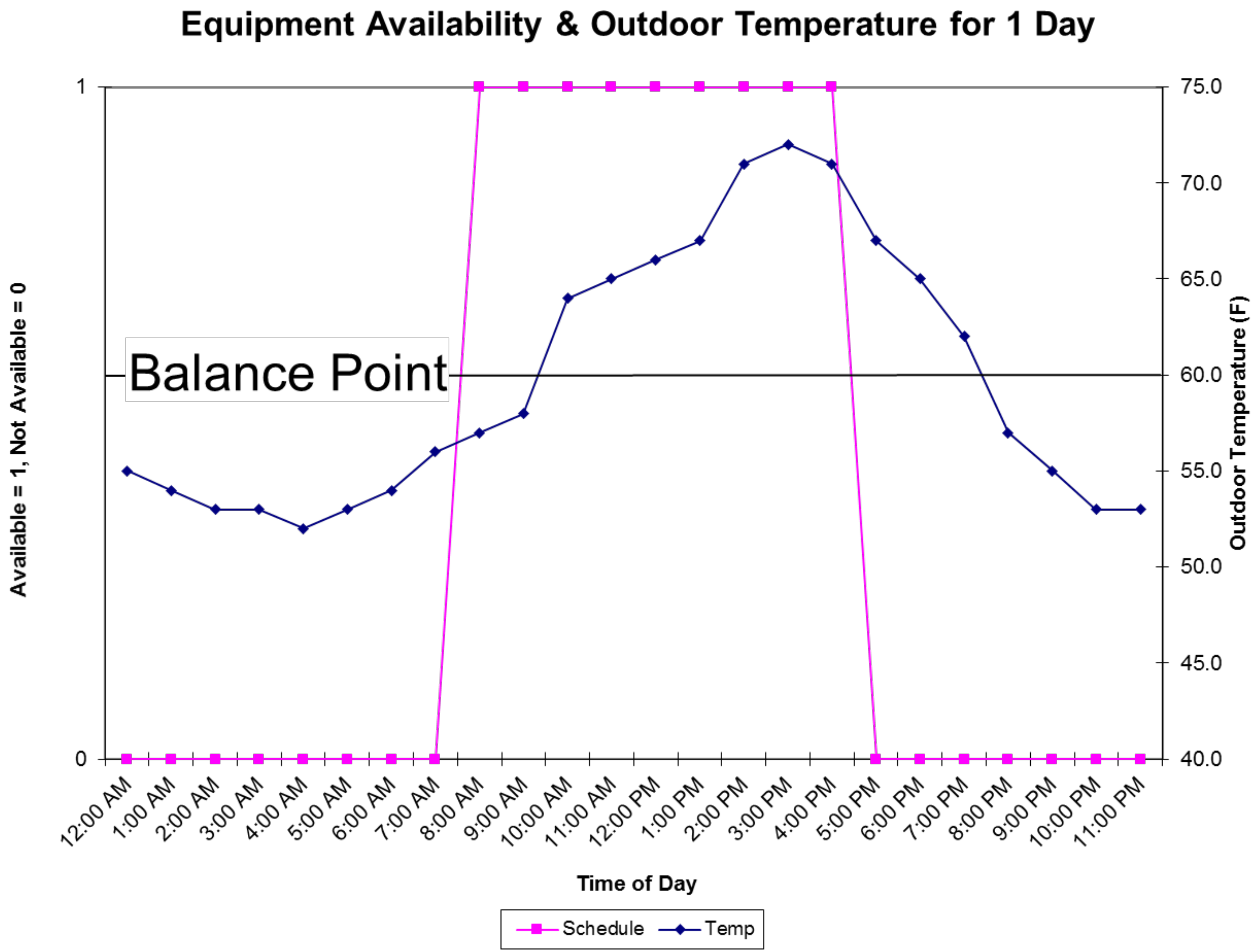
	Fan kW	Supply Air Flow rate (CFM)	Minimum OSA	Minimum OSA	Minimum Supply Air Flow	Design SAT	Est Min SAT (F)	Estimated Max Zone Load
Supply Air	3	3,000	450	15%	100%	55	55	100%

Average Space Temp (F)	Avg RAT (F)	Balance Temp (F)
72	74	60

Econ	Design Htg Temp (F)	Design Clg Temp (F)
N	32	102

	EER	OSA LO (F)
Cooling	10.00	0

	Efficiency	OSA LO (F)
Heating	80%	120



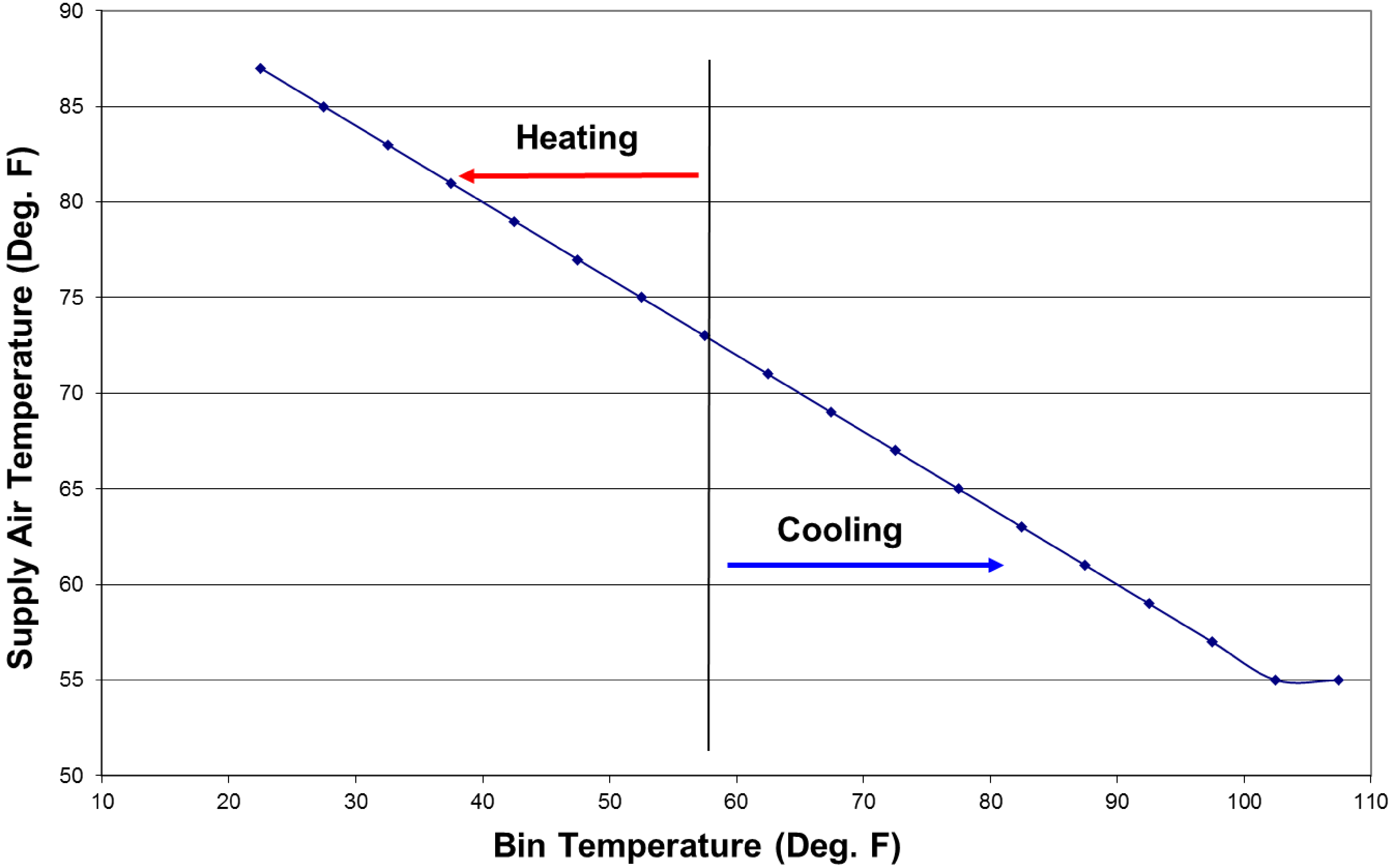
For this day, there are 2 hours of heating and 7 hours of cooling

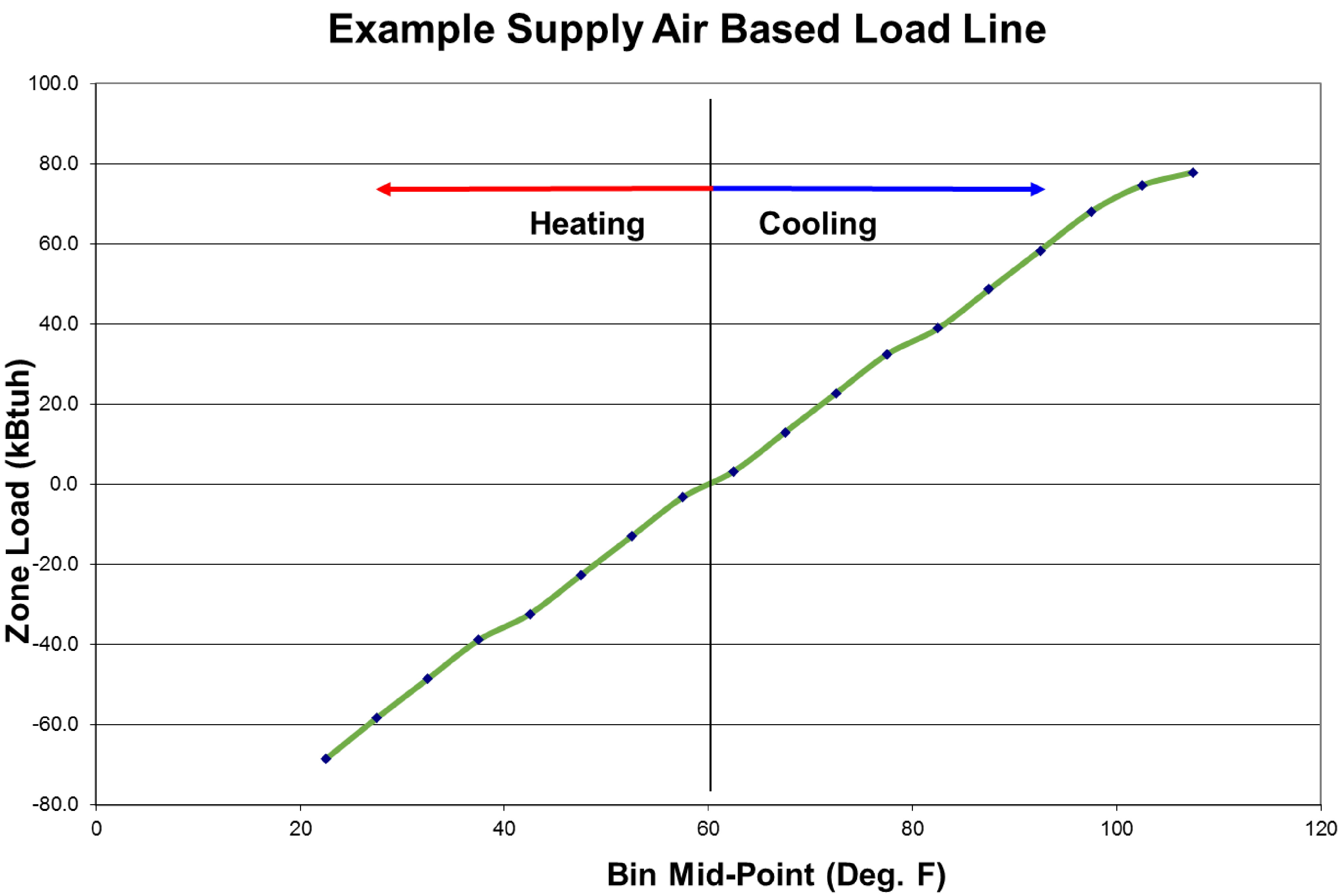
Bin Sim: Load Line

- The load line specifies the hourly heating or cooling load for the zone
- This configuration uses the average supply air temperature as the load line
  - Minimum temperature is design cooling supply temperature (typically 55°F)
  - Maximum temperature is defined by slope of load line and minimum bin temperature or design heating supply temperature
  - Slope of the load line is calculated with the minimum expected cooling supply temperature and the balance point

Bin Mid-point	SAT (F)
107.5	55
102.5	55
97.5	57
92.5	59
87.5	61
82.5	63
77.5	65
72.5	67
67.5	69
62.5	71
57.5	73
52.5	75
47.5	77
42.5	79
37.5	81
32.5	83
27.5	85
22.5	87

Supply Air Temperature Versus Bin Temperature




Example Supply Air Based Load Line
Heating
Cooling
Zone Load (kBtuh)
100.0
80.0
60.0
40.0
20.0
0.0
-20.0
-40.0
-60.0
-80.0
0
20
40
60
80
100
120
Bin Mid-Point (Deg. F)

Bin Sim: Outdoor/Mixed Air

- Outdoor air temperature is simply the bin mid-point temperature

- Mixed air temperature is calculated as the result of mixing the return air with the outdoor air

- For this example:

  MAT = 15% Bin Temp + 85% Return Air Temp

% OSA	MAT (F)
15%	79
15%	78
15%	78
15%	77
15%	76
15%	75
15%	75
15%	74
15%	73
15%	72
15%	72
15%	71
15%	70
15%	69
15%	69
15%	68
15%	67
15%	66

Bin Sim: Calcs and Results

- Hourly sensible loads for each bin are calculated as:
  - Bin Load = 1.08 × cfm × (Mixed AirT – Supply AirT)
  - Note that heating will be negative
- Annual bin loads = [bin loads] × [annual hours for that bin]
- Total annual loads are the sum of all annual bin loads
- Annual consumption is computed by applying equipment efficiencies to the total annual loads

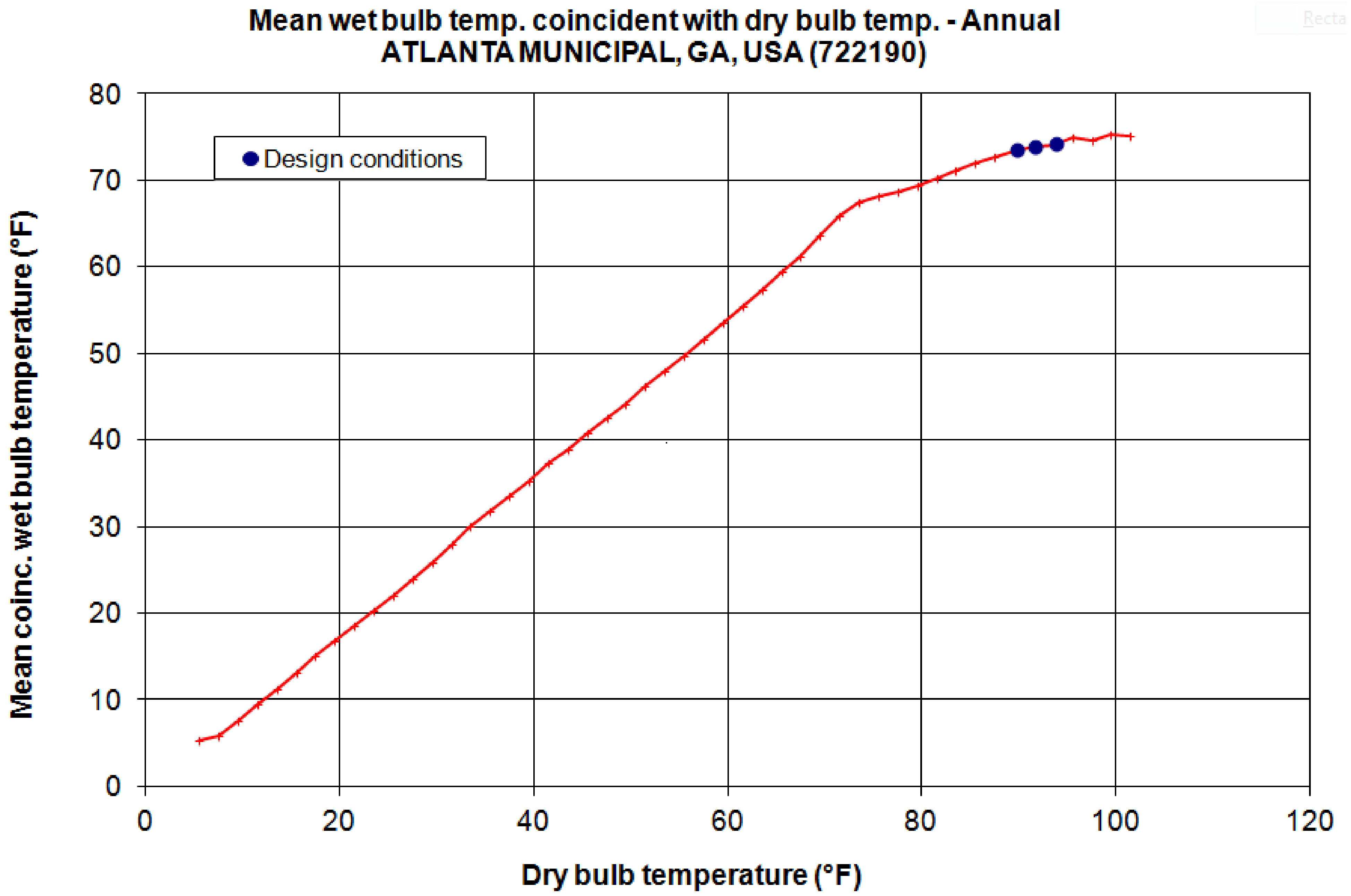
Heating (kBtu/yr)	Cooling (kBtu/yr)
0	278
0	759
0	2,576
0	4,338
0	5,546
0	6,353
0	7,093
0	5,976
0	4,125
0	1,412
1,807	0
6,264	0
7,478	0
7,310	0
4,082	0
1,836	0
469	0
49	0
29,295	**38,456**

COOLING	3,846 kWh
HEATING	366 Therms
VENTILATION	10,163 kWh

Bin Sim: Other Options

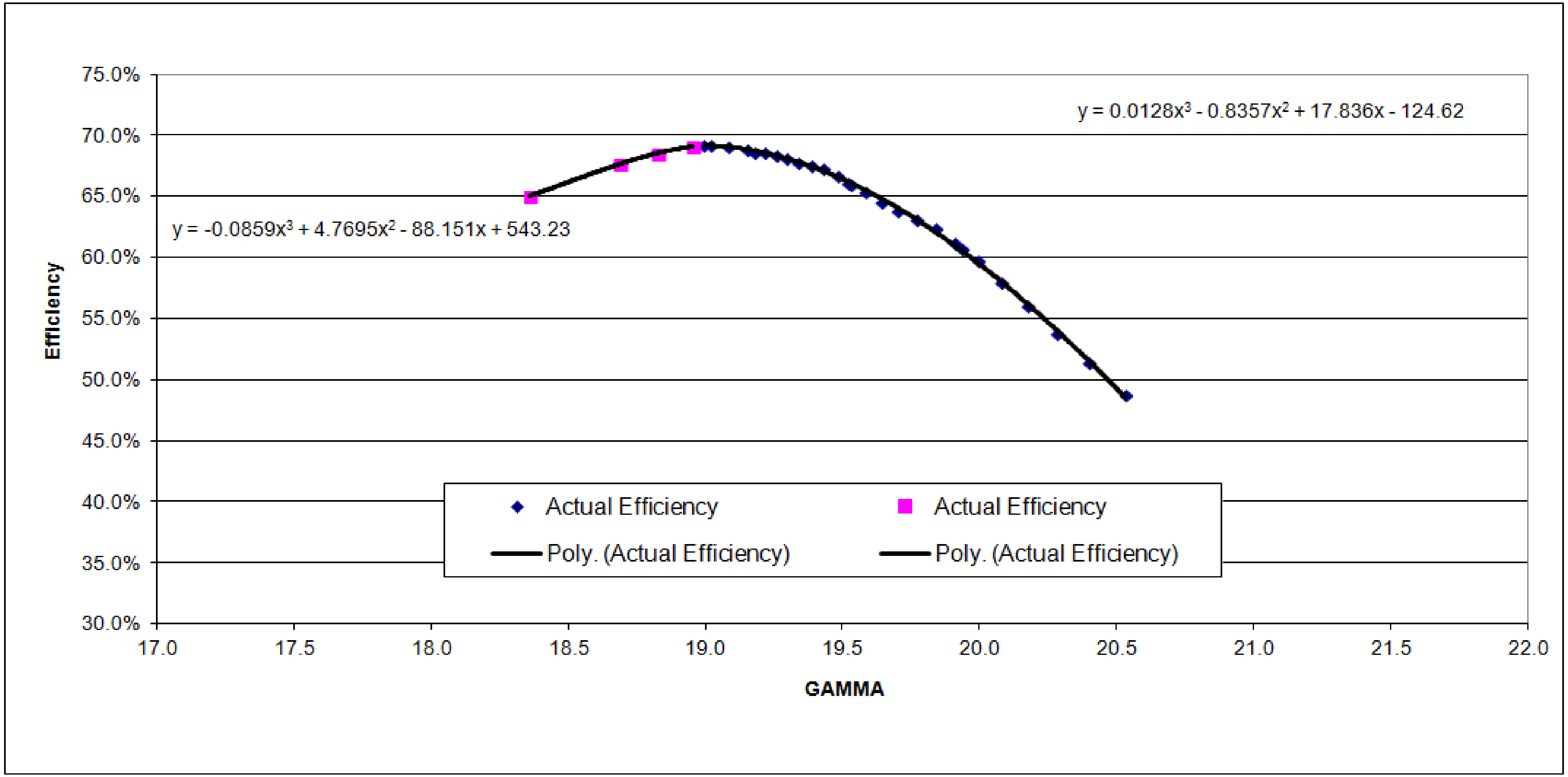
- The load line can be specified as a function of cooling capacity
  - Assume a cooling load at design conditions
  - Cooling (and heating) load is zero at the balance point
  - Output for both heating and cooling is limited to the capacity of the unit
- The load line can be calculated using metered data
  - Must have enough data to cover a range of operation

Bin Mid-point	Load (kBtuh)
107.5	77.8
102.5	74.6
97.5	68.0
92.5	58.3
87.5	48.6
82.5	38.9
77.5	32.4
72.5	22.7
67.5	13.0
62.5	3.2
57.5	-3.2
52.5	-13.0
47.5	-22.7
42.5	-32.4
37.5	-38.9
32.5	-48.6
27.5	-58.4
22.5	-68.6



from ASHRAE's Weather Data Viewer Tool WD 5.0

CFM	Flow (cubic feet per minute) from manufacturers performance data.
SP	Static pressure from manufacturers performance data.
BHP	Brake horsepower from manufacturers performance data.
SCC	System curve coefficient = SP / CFM^2
GAMMA	= -LN(SCC)
Efficiency	= CFM * SP / (6350 * BHP)



Stein, Jeff, and Mark M. Hydeman. 2004. ASHRAE AN-04-3-1, Development and Testing of the Characteristic Curve Fan Model. *Proceedings of the 2004 Winter Conference*. 347–356. CA: Anaheim.

OSA Temp (F)	Hours/yr	% OSA	MAT (F)	SAT (F)	Heating (kBtu/yr)	Cooling (kBtu/yr)	Cooling kW/ton	Cooling kW	Cooling kWh	Zone Load (kBtu/h)	Coil Load (%)	Fan Runtime (%)	Fan kW	Fan kWh
112	-	15%	78.0	47.2	-	-	0.96	-	-	54	0%	100%	1.2	-
107	-	15%	77.3	47.2	-	-	0.96	-	-	54	0%	100%	1.2	-
102	33	15%	76.5	47.2	-	2,089	0.96	5.1	167	54	106%	100%	1.2	40
97	87	15%	75.8	47.2	-	5,375	0.96	4.9	430	54	103%	100%	1.2	107
92	178	15%	75.0	47.2	-	10,689	0.96	4.8	855	54	100%	100%	1.2	218
87	277	15%	74.3	51.0	-	13,941	0.96	4.0	1,115	46	84%	100%	1.2	339
82	393	15%	73.5	54.0	-	16,553	0.96	3.4	1,324	39	70%	100%	1.2	481
77	421	15%	72.8	57.0	-	14,368	0.96	2.7	1,149	33	57%	100%	1.2	516
72	575	100%	72.0	61.0	-	13,662	0.96	1.9	1,093	24	40%	100%	1.2	704
67	747	100%	67.0	64.0	-	4,841	0.96	0.5	387	17	11%	100%	1.2	915
62	1,032	50%	67.0	67.0	-	-	0.96	-	-	11	0%	100%	1.2	1,264
57	1,452	15%	69.8	71.0	3,764	-	0.96	-	-	2	1%	100%	1.2	1,779
52	1,300	15%	69.0	74.0	14,040	-	0.96	-	-	(4)	6%	100%	1.2	1,592
47	1,110	15%	68.3	77.0	20,859	-	0.96	-	-	(11)	10%	100%	1.2	1,360
42	759	15%	67.5	81.0	22,132	-	0.96	-	-	(20)	16%	100%	1.2	930
37	288	15%	66.8	84.0	10,700	-	0.96	-	-	(26)	20%	100%	1.2	353
32	97	15%	66.0	87.0	4,400	-	0.96	-	-	(33)	25%	100%	1.2	119
27	11	15%	65.3	91.0	611	-	0.96	-	-	(41)	30%	100%	1.2	13
22	-	15%	64.5	94.0	-	-	0.96	-	-	(48)	0%	100%	1.2	-
17	-	15%	63.8	97.0	-	-	0.96	-	-	(54)	0%	100%	1.2	-
12	-	15%	63.0	101.0	-	-	0.96	-	-	(63)	0%	100%	1.2	-
7	-	15%	62.3	104.0	-	-	0.96	-	-	(69)	0%	100%	1.2	-
2	-	15%	61.5	108.0	-	-	0.96	-	-	(78)	0%	100%	1.2	-
TOTAL	**8,760**				**76,506**	**81,518**		**5.1**	**6,520**				**1.2**	**10,730**

Bin Sim Example

Bin Sim: Pros and Cons

Pros

- Spreadsheets are transparent
- Customizable to real systems
- Can incorporate measured data

Cons

- Poor regarding transient effects/envelopes
- May be hard to debug

Great Resource

DegreeDays.net

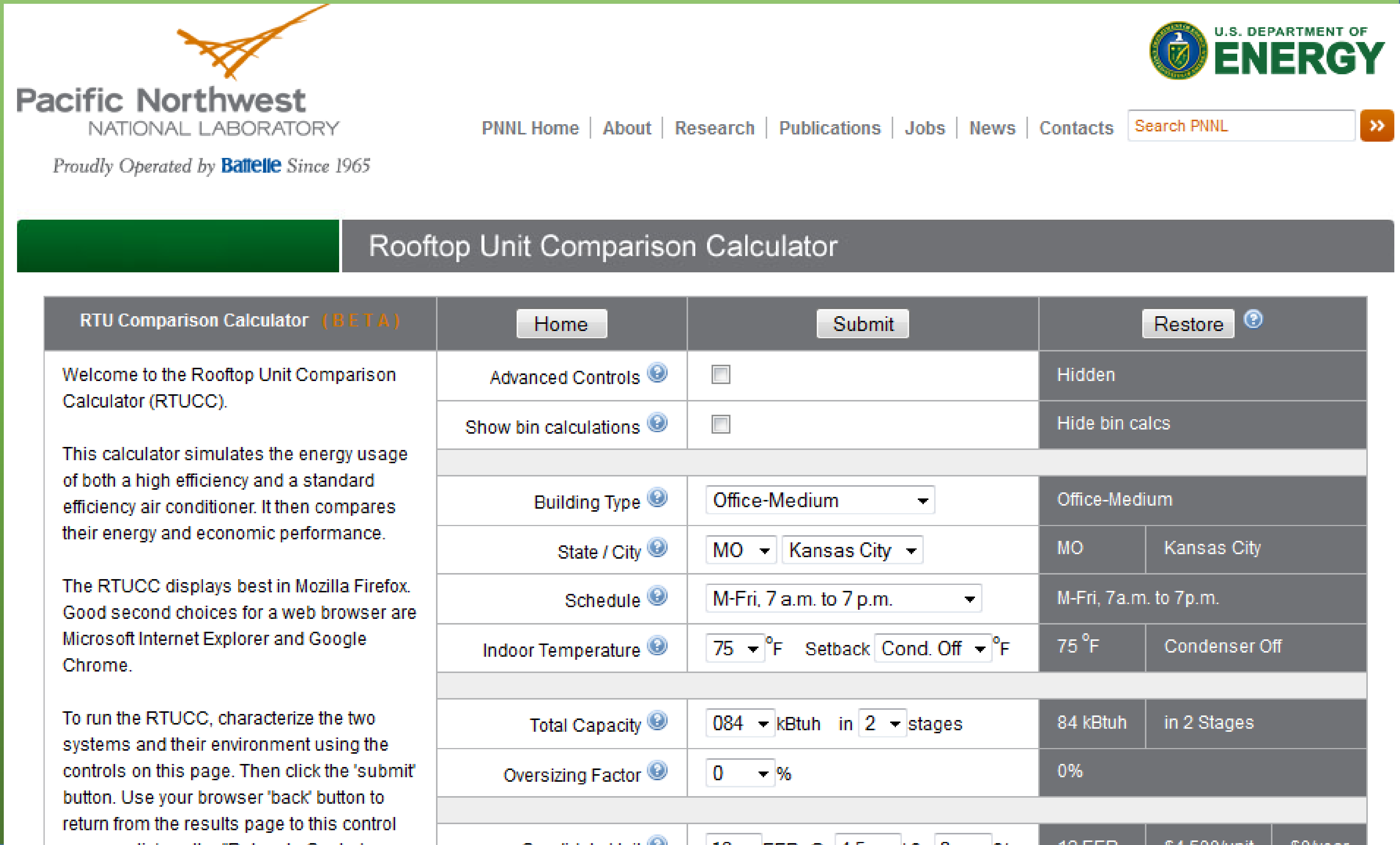
Description:	Fahrenheit-based heating degree days for a base temperature of 65F
Source:	www.degreedays.net (using temperature data from www.wunderground.com)
Accuracy:	Estimates were made to account for missing data: the "% Estimated" column shows how much each figure was affected (0% is best, 100% is worst)
Station:	ATLANTA FULTON COUNTY AIRPORT, GA, US (84.52W,33.78N)
Station ID:	KFTY

Month starting	HDD	% Estimated
6/1/2014	0	0.07
7/1/2014	3	0.03
8/1/2014	2	0.1
9/1/2014	9	0.03
10/1/2014	165	0.1
11/1/2014	571	0
12/1/2014	539	0
1/1/2015	732	0
2/1/2015	739	0
3/1/2015	324	0
4/1/2015	108	0
5/1/2015	47	0

Great Resource

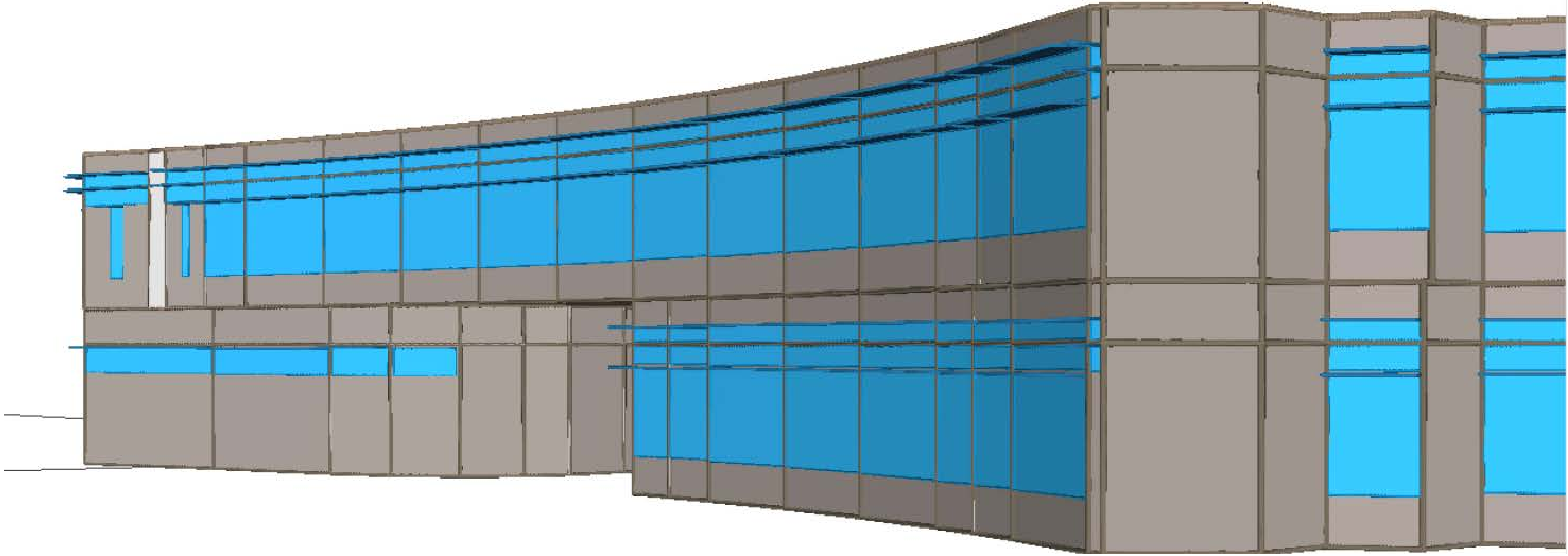
www.pnnl.gov/uac

PNNL RTU Comparison Calculator (RTUCC)



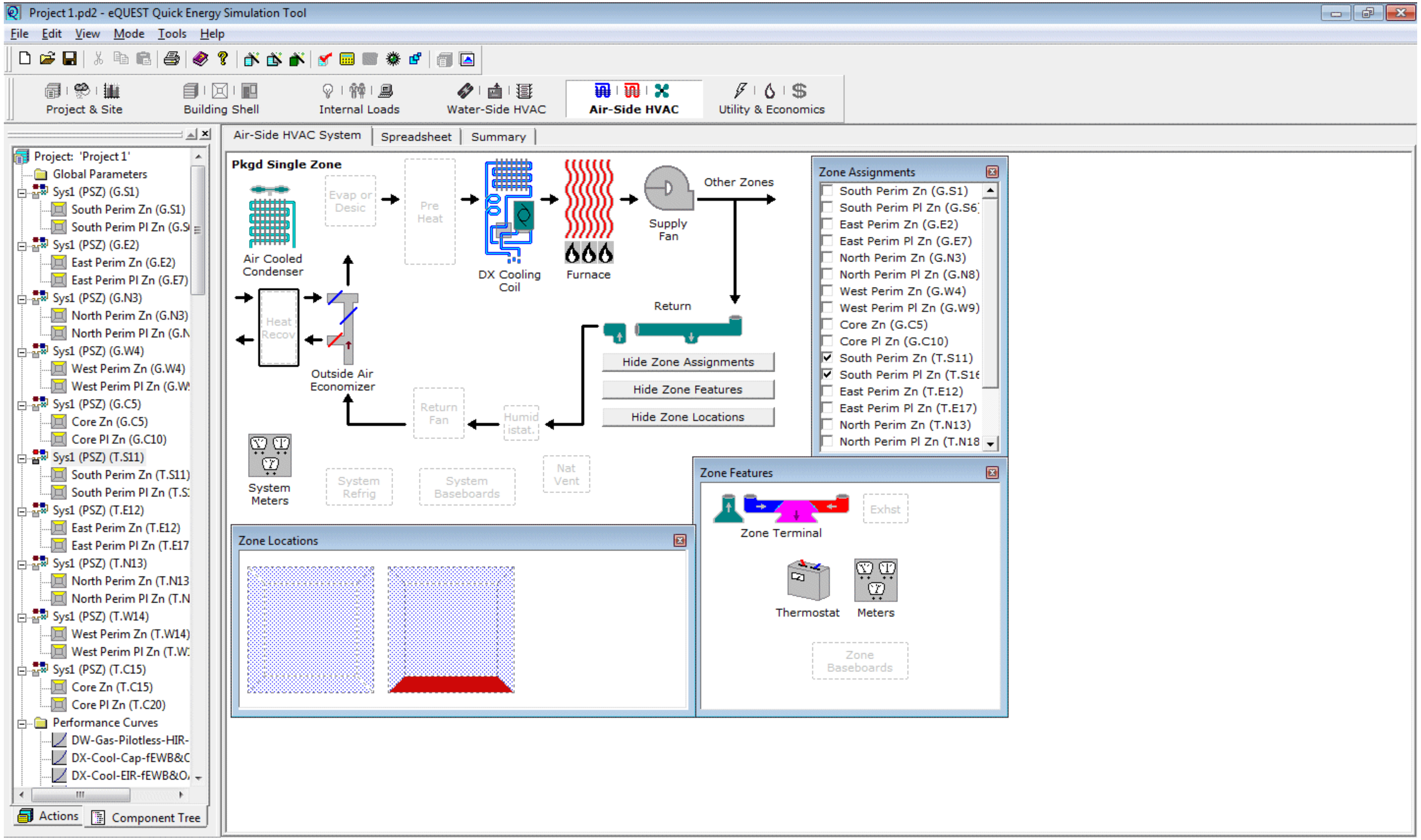
Hourly Simulations

Hourly Simulations

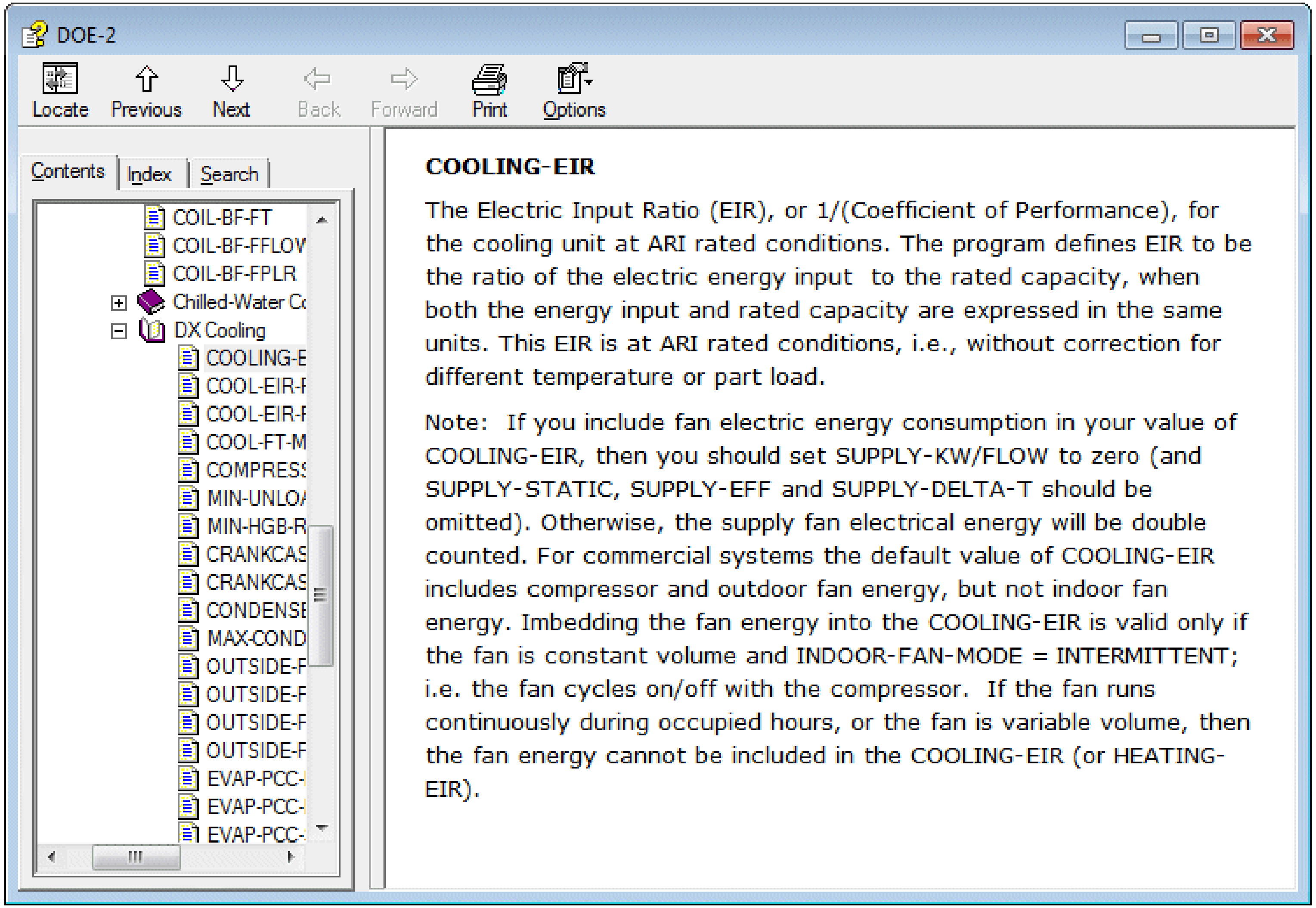


Model shared by RMI

Hourly Simulations—Details



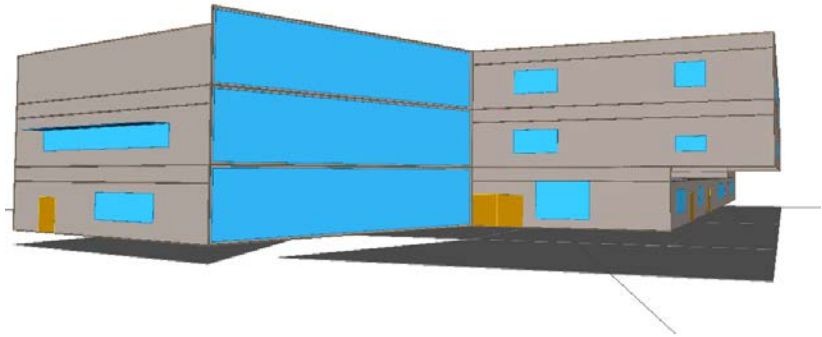
Hourly Simulations—Details



Hourly Sims: Pros and Cons

Pros

- Transient behavior
- Hourly analysis
- Sophisticated rate analysis
- "Credibility"
- IRS, for example



Cons

- Complicated/powerful/ sensitive
- Steep learning curve
- Large number of inputs
- Most systems limited to pre-existing system types
- For example, no multiple systems/zones
- No multiple exhausts

Saving Calculation Tools

Level 1

- One-line calculations
- Rules of thumb
- Advanced Energy Retrofit Guides

Level 2&3

- Modified bin simulations
- RTUCC
- Hourly simulations (EnergyPlus, eQUEST)
- 3E Plus

Calculating Energy Use

Basic/approximate method:

$$\text{Energy Use (kWh)} = \frac{\text{Load} * \text{time}}{\text{EER}}$$

$$\text{Energy Use (kWh)} = \frac{\text{(kBtu/h)} * \text{hrs}}{\text{(kBtu/kWh)}}$$

Improve by correcting for actual conditions, varying loads, monitored data

Calculating Energy Use

Basic/approximate method (alternate)

Energy Use (kWh) = (tons) × (kW/ton) × h

Where: $\text{kW/ton} = \dfrac{12}{\text{EER}}$

Adding Interactive Effects

- Shortcut for cooling impact of load reduction
- Multiplier = 1 + 1/COP
- Interactive Savings = Load Savings × Multiplier
- COP = EER/3.412
- Doesn't work unless steady state
- For example, lighting savings in refrigerated spaces or air-conditioned space

Exercise #4: Interaction

Exercise 4a: LED Retrofit Savings

Given:

- 400,000 ft^2 building
- Two lamp, T-8 fixtures
- 72 Watts/fixture
- 1 fixture per 100 ft^2
- On M–F, 7 AM–7 PM

Calculate LED Retrofit Savings:

- Two lamp, LED fixtures
- 36 Watts/fixture

Exercise 4b: Occupancy Sensor Savings

Given:

- 400,000 ft^2 building
- Two lamp, T-8 fixtures
- 72 Watts/fixture
- 1 fixture per 100 ft^2
- On M–F, 7 AM–7 PM

Calculate Occupancy Sensor Savings:

- Reduce operating hours by 4 hrs/day

Exercise 4a/b: Interaction

Given:

- 400,000 ft^2 building
- Two lamp, T-8 fixtures
- 72 Watts/fixture
- 1 fixture per 100 ft^2
- On M–F, 7 AM–7 PM

Calculate Bundled Savings:

- Two lamp, LED fixtures
- 36 Watts/fixture
- Reduced operating hours by 4 hrs/day

EEM Recommendations

Well, a Few Anyway…

Comprehensive List of Measures

STANDARD

ANSI/ASHRAE/IES Standard 90.1-2019
(Supersedes ANSI/ASHRAE/IES Standard 90.1-2016)
Includes ANSI/ASHRAE/IES addenda listed in Appendix I

Energy Standard for Buildings Except Low-Rise Residential Buildings (I-P Edition)

ISSN 1041-2336

STANDARD

ANSI/ASHRAE/IES Standard 100-2015
(Supersedes ANSI/ASHRAE/IESNA Standard 100-2006)

Energy Efficiency in Existing Buildings

ISSN 1041-2336

CONTENTS

ANSI/ASHRAE/IES Standard 100-2018
Energy Efficiency in Existing Buildings

NOTE

Approved addenda, errata, or interpretations for this standard can be downloaded free of charge from the ASHRAE Web site at www.ashrae.org/technology.

Comprehensive List of Measures

(This annex is not part of this standard. It is merely informative and does not contain requirements necessary for conformance to the standard. It has not been processed according to the ANSI requirements for a standard and may contain material that has not been subject to public review or a consensus process. Unresolved objectors on informative material are not offered the right to appeal at ASHRAE or ANSI.)

INFORMATIVE ANNEX E
ENERGY EFFICIENCY MEASURES

This informative annex provided categorized listings of typical *energy efficiency measures* (*EEMs*) that can be applied to enable *buildings* to meet the set *energy targets*. It identifies commonly applied elements that can improve *building* performance but is not intended to suggest specific requirements, nor does it comprehensively covered all of the options available to an owner.

Measures included in these listings are intended to improve energy efficiency and reduce overall energy use. They are not intended to encourage fuel switching unless such actions as installation of cogeneration, trigeneration, or combined heating and cooling plants would result in overall reduction in total energy used.

Some measures, such as demand response/control, may also save energy as an incidental side benefit. Other measures may result in extension of the capacity of given infrastructure systems and/or the ability for energy efficiency to defer or eliminate the need for plant expansions. Such results can be factored into the resulting return on investment or life-cycle cost analysis.

E1. BUILDING ENVELOPE

E1.1 Walls

E1.1.1 Insulate Walls. Retrofit insulation can be external and internal.

E1.1.1.1 External post insulation makes large savings possible, as this type of insulation contributes not only to a reduction of the heat loss through large wall surfaces but also eliminates the traditional thermal bridges where floor and internal wall are anchored in the exterior wall.

E1.1.1.2 Internal insulation is typically used when external insulation is not allowed, such as for historical *buildings*.

E1.1.2 Insulate cavity walls using spray-in insulation.

E1.1.3 Consider converting internal courtyard into an atrium to reduce external wall surface.

E1.2 Roofs

E1.2.1 Use cool roof (high-reflectance roofing material) with reroofing projects.

E1.2.2 Determine roof insulation values and recommend roof insulation as appropriate.

E1.2.3 Insulate ceilings and roofs using spray-on insulation.

E1.2.4 Where appropriate, exhaust hot air from attics.

E1.3 Floors

E1.3.1 Insulate floors.

E1.3.2 Insulate floors using spray-on insulation.

E1.3.3 Insulate basement wall with a slab over unheated basement.

E1.4 Windows

E1.4.1 Replace single-pane and leaky windows with thermal/operable windows to minimize cooling and heating loss.

E1.4.2 Install exterior shading, such as blinds or awnings, to cut down on heat loss and to reduce heat gain.

E1.4.3 Install storm windows and multiple glazed windows.

E1.4.4 Use tinted or reflective glazing or energy control/solar window films.

E1.4.5 Replace existing fenestration (toplighting and/or sidelighting) with dual-glazed low-e glass wherever possible to reduce thermal gain.

E1.4.6 Adopt weatherization/fenestration improvements.

E1.4.7 Consider replacing exterior windows with insulated glass block when visibility is not required but light is required.

E1.4.8 Landscape/plant trees to create shade and reduce air-conditioning loads.

E1.5 Doors

E1.5.1 Prevent heat loss through doors by draft sealing and using thermal insulation.

E1.5.2 Install automatic doors, air curtains, or strip doors at high-traffic passages between conditioned and unconditioned spaces.

E1.5.3 Use self-closing or revolving doors and vestibules if possible.

E1.5.4 Install high-speed doors between heated/cooled *building* space and unconditioned space in the areas with high-traffic passages.

E1.6 Install separate smaller doors for people near the area of large vehicle doors air leakage.

E1.6.1 Seal top and bottom of *building*.

E1.6.2 Seal vertical shafts, stairways, outside walls, and openings.

E1.6.3 Compartmentalize garage doors and mechanical and vented internal and special-purpose rooms.

E1.7 Moisture Penetration

E1.8 Reduce air leakage.

E1.9 Install vapor barriers in walls, ceilings, and roofs.

E2. HVAC SYSTEMS

E2.1 Ventilation

E2.1.1 Reduce *HVAC system* outdoor airflow rates when possible. Minimum outdoor airflow rates should comply with ASHRAE Standard 62.1[9] or local code requirements.

E2.1.2 Reduce minimum flow settings in single-duct and dual-duct variable-air-volume (VAV) terminals as low as is practical to meet ventilation requirements.

E2.1.3 Minimize exhaust and makeup (ventilation) rates when possible by complying with the most stringent federal, state, and/or local code requirements.

E2.1.4 When available, use operable windows for ventilation during mild weather (natural ventilation) when outdoor

E2.2 HVAC Distribution Systems

E2.2.1 Convert a constant-air-volume system (CAV) (including dual duct, multizone, and constant-volume reheat systems) into a VAV system with variable-speed drives (VFDs) on fan motors. A VAV system is designed to deliver only the volume of air needed for conditioning the actual load.

E2.2.2 Control VAV system VFD speed based on the static pressure needs in the system. Reset the static pressure set point dynamically as low as is practical to meet the *zone* set points.

E2.2.3 Reset VAV system supply air temperature set point when system is at minimum speed to provide adequate ventilation.

E2.2.4 If conversion to VAV from CAV systems is impractical, reset supply air temperatures in response to load. Dynamically control heating duct temperatures as low as possible, and cooling duct temperatures as high as possible, while meeting the load.

E2.2.5 Use high-efficiency fans and pumps; replace or trim impellers of existing fans if they have excessive capacity relative to peak demand.

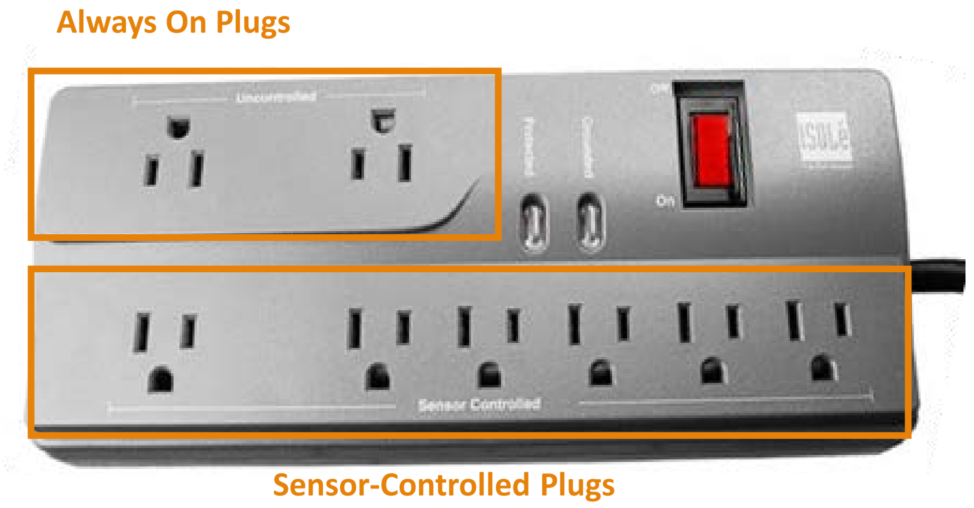
Low- and No-Cost Measures

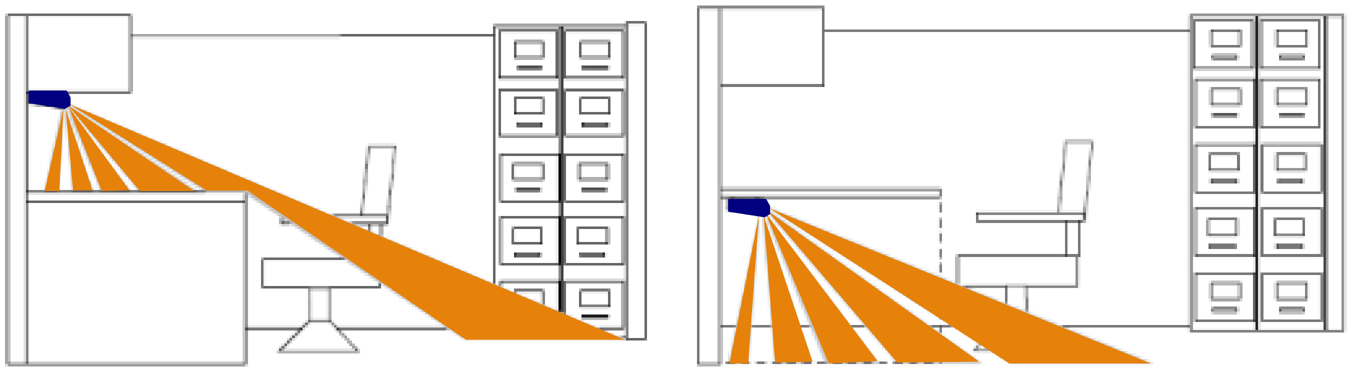
Corridor Lighting Controls

- Most corridors have variable occupancy
- Corridor lighting often 24/7
- Reduce operating hours
  - Occupancy sensors
  - Time clock or panel controls
- With time clock control, minimum egress FC needed

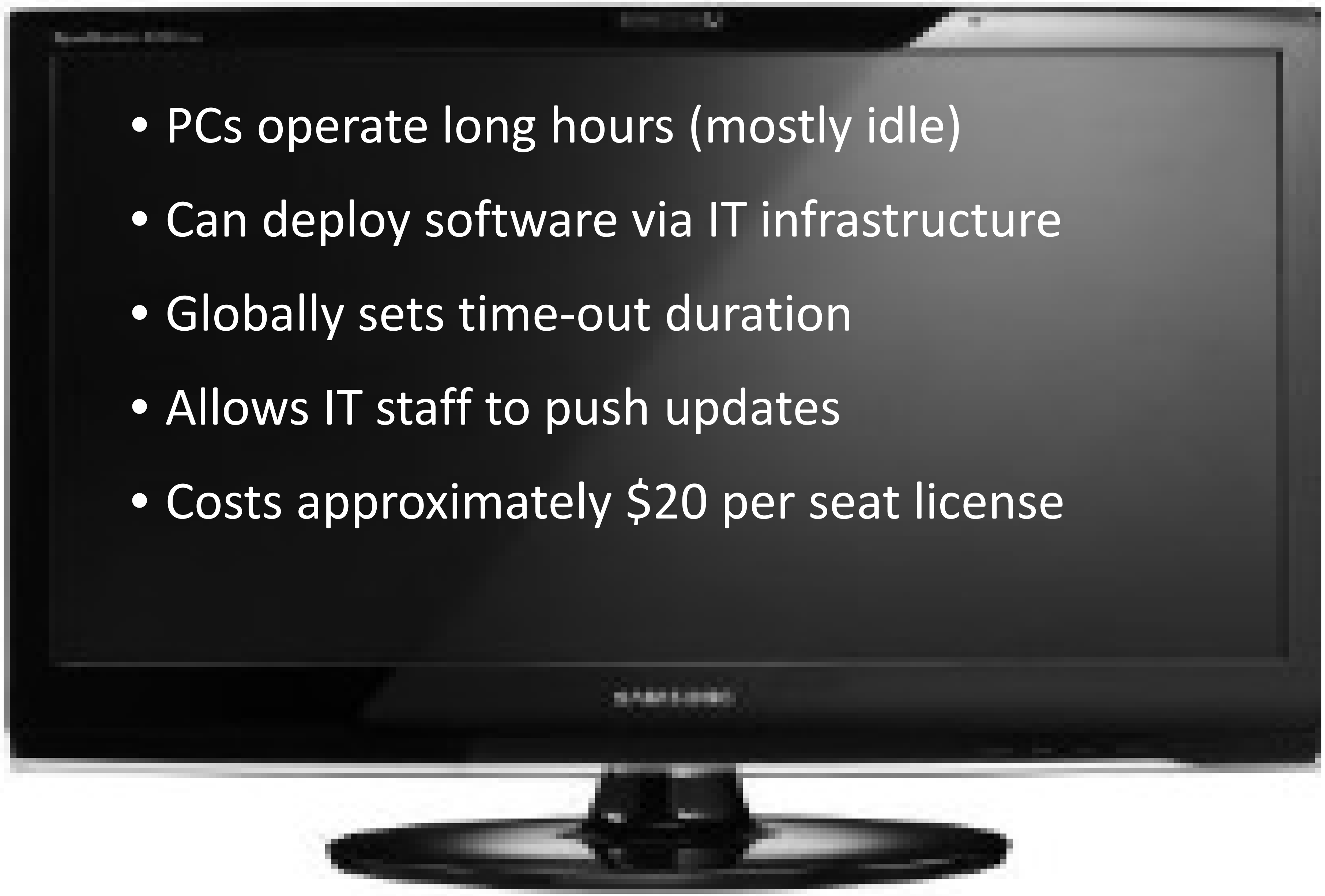
Power Strip Occupancy Sensors

- Plug loads are a big energy consumer on college campuses
- Reduce operating hours
  - Occupancy sensors
  - Slave plugs to PC
- Costs are approximately $100/unit





PC Power Management Software



- PCs operate long hours (mostly idle)
- Can deploy software via IT infrastructure
- Globally sets time-out duration
- Allows IT staff to push updates
- Costs approximately $20 per seat license

Daylighting Controls

- Daylighting controls reduce operating hours
- Easily identified during the day
- Typical PB around 1-year if 300W or more controlled

Web-Enabled Thermostats

About $170 to $300 each

Include ability to monitor remotely

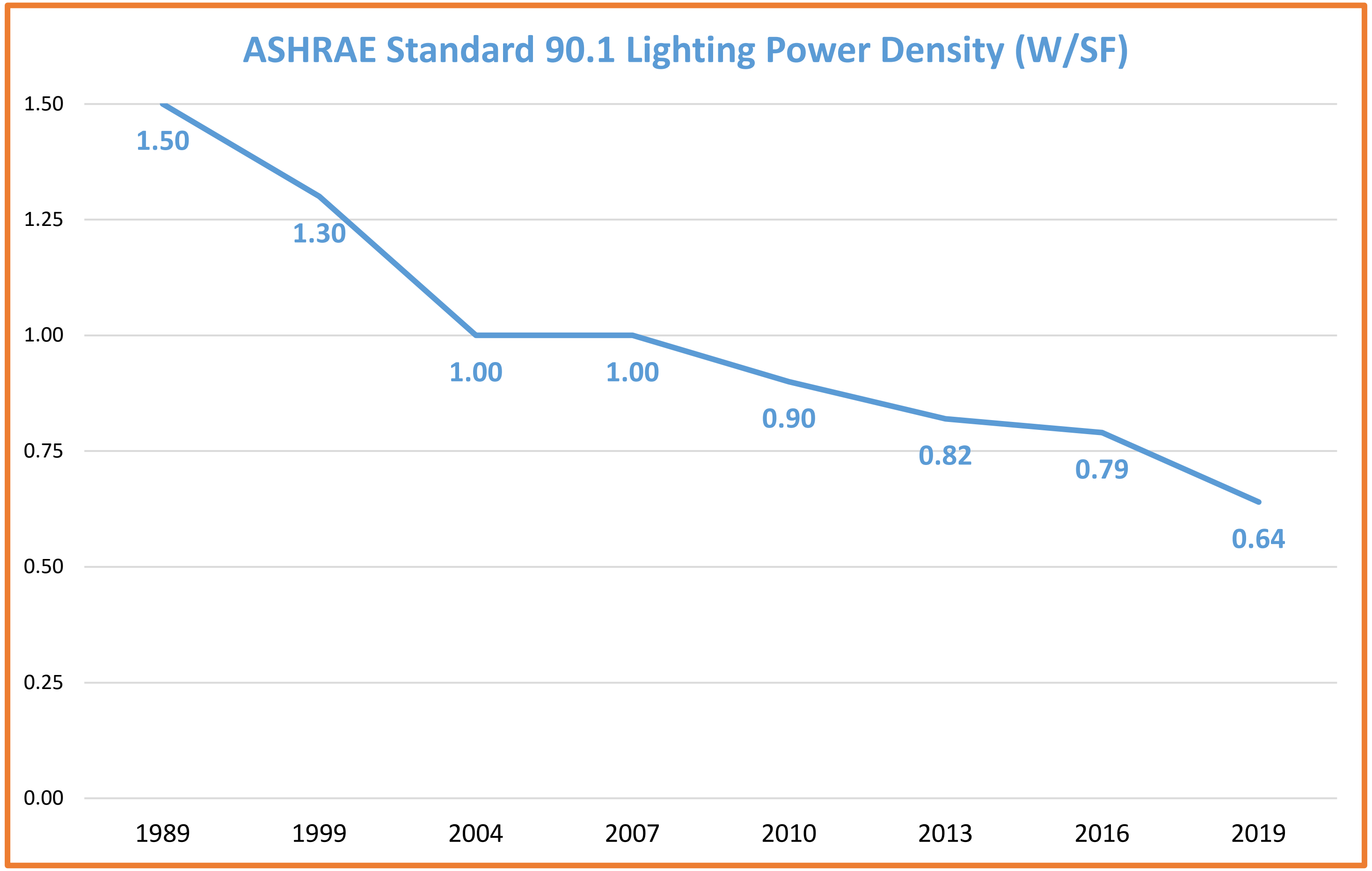
Wi-Fi, Ethernet, Mesh

www.ecobee.com

Capital Measures

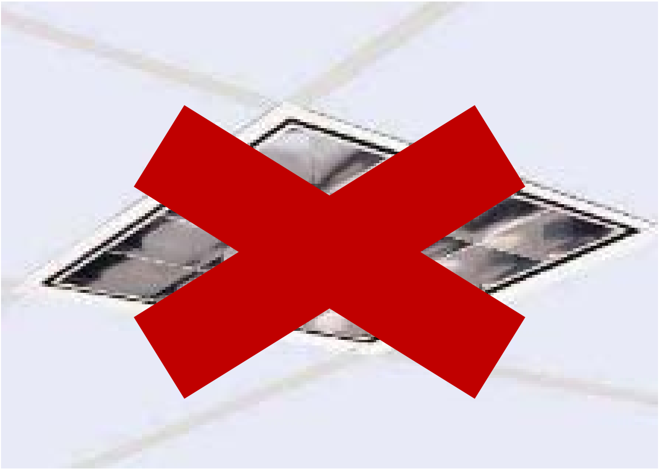
239

Lighting Power Density - Offices



Interior Lighting Upgrades

- Easily one of the most noticeable energy upgrades!
- Avoid parabolic louvers and perforated metal baskets (reduces efficiency)
- Perform LCCA to account for changes in lamp life (reduced maintenance)

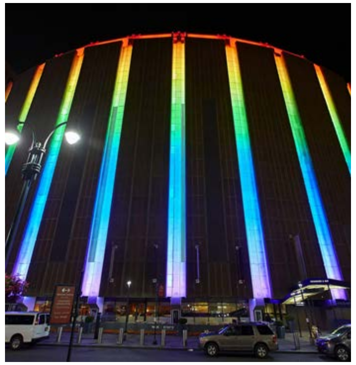


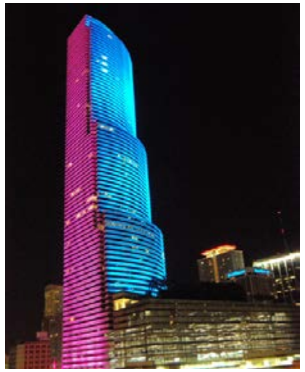
Light Emitting Diodes (LED)

- LED sources are near parity with linear fluorescent (T8/T5) lamps in new construction
- In retrofit applications, keep an eye out for:
  - Bi-level lighting opportunities (exterior)
  - Difficult-to-access fixtures (maintenance benefit)
  - Three- or four-lamp, existing linear fluorescent fixtures with parabolic louvers
- Try to specify fixtures listed by the DesignLights Consortium to receive incentives and select good products

DESIGNLIGHTS CONSORTIUM

LED Lighting Applications





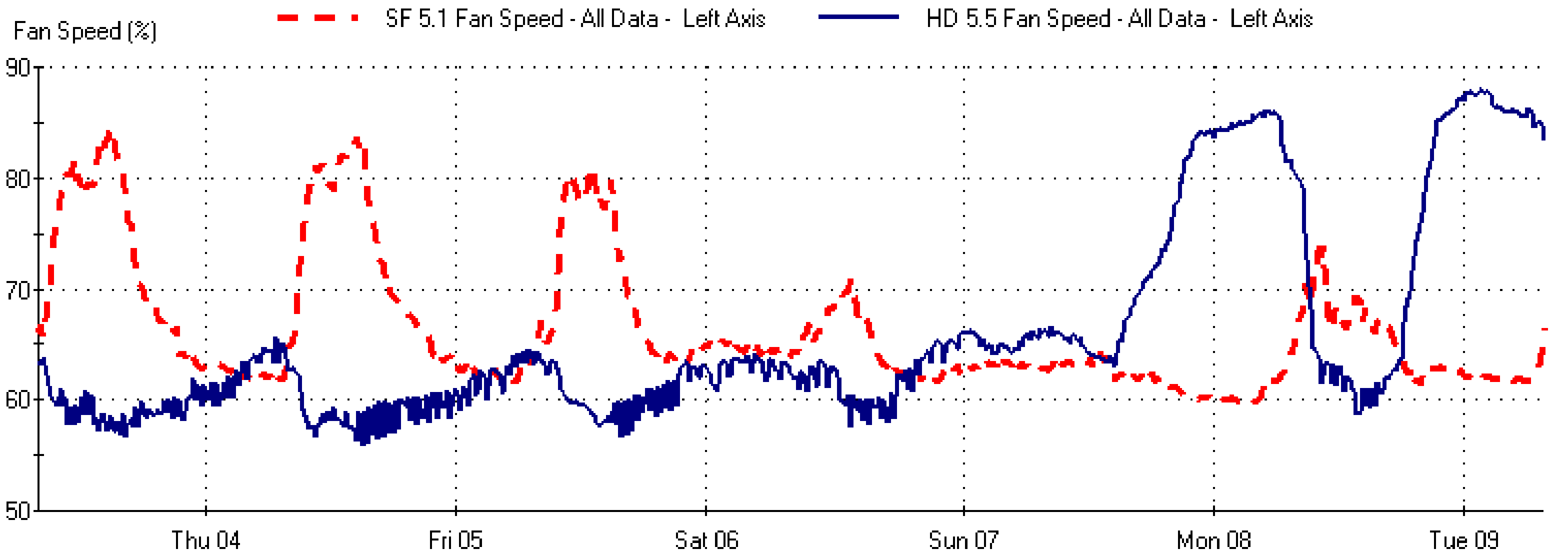
- Downlights
- Fluorescent Fixtures
- Decorative
- Stairwells
- Exterior
- Parking Lots

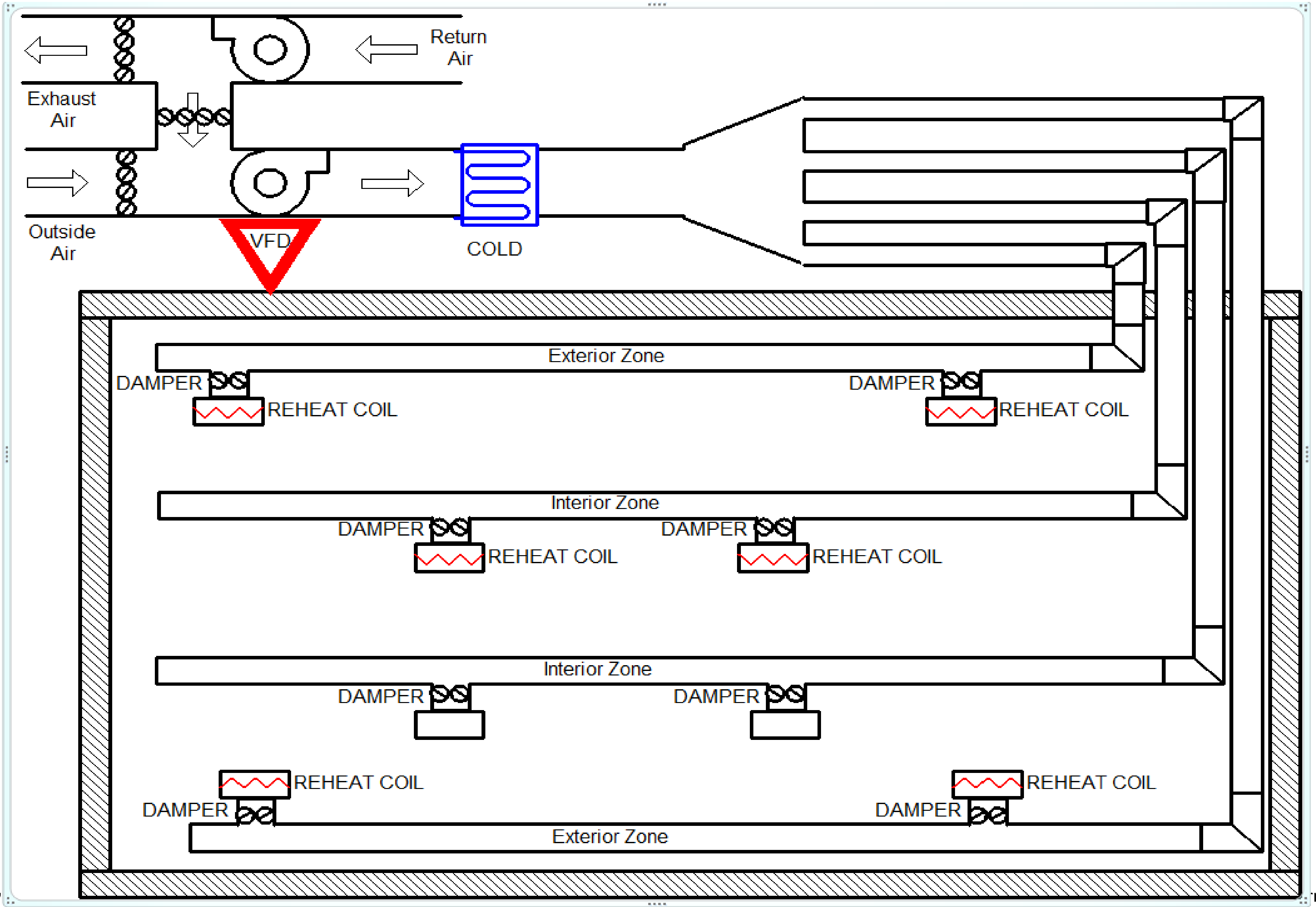
Exterior Bi-Level Lighting

- Exterior lighting is necessary for safety, but of limited use when no one is present
- Bi-level light fixtures and retrofits reduce light output and energy consumption when no one is present
- Networked lighting controls can provide additional benefits to campus security

Building Control Upgrades

- Pneumatic zone-controls don’t provide feedback
- DDC controls at the zone provide more information to the BAS
- Feedback provides better info for resets that save energy and preserve occupant comfort




Return
Air
Exhaust
Air
Outside
Air
VFD
COLD
Exterior Zone
DAMPER
REHEAT COIL
DAMPER
REHEAT COIL
Interior Zone
DAMPER
REHEAT COIL
DAMPER
REHEAT COIL
Interior Zone
DAMPER
DAMPER
REHEAT COIL
DAMPER
REHEAT COIL
DAMPER
Exterior Zone

Building Control Upgrades *(cont.)*

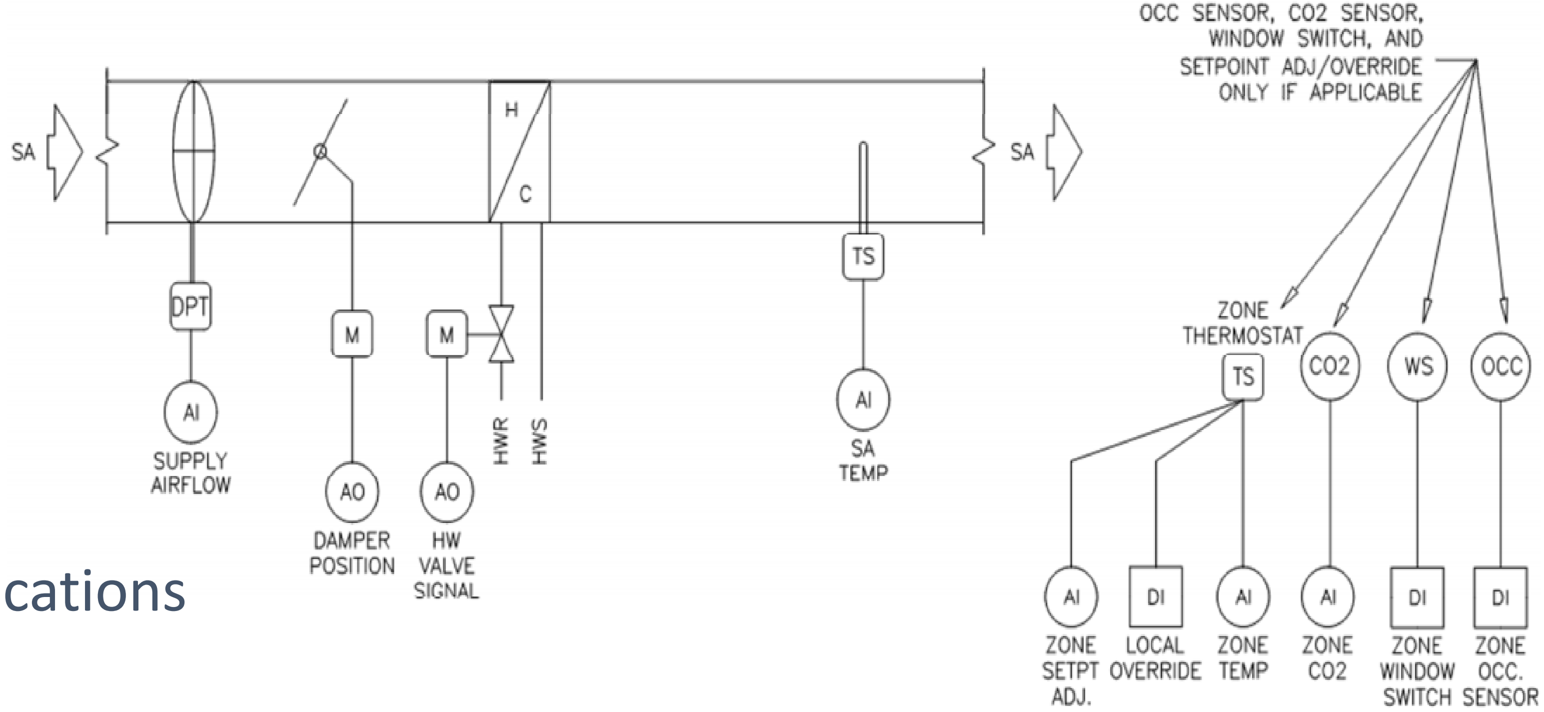
- Provides the following control opportunities
  - Zone scheduling and setbacks while unoccupied
  - Trim and respond controls
    - Duct static pressure reset (VAV damper)
    - Chilled-water temperature reset (AHU CHW valve)
    - Heating hot-water temperature reset (VAV RH valve)
    - Supply air temperature reset (VAV cooling request)
  - DR global temperature adjustment

ASHRAE RP-1455/Guideline 36

ASHRAE RP-1455: Advanced Control Sequences for HVAC Systems
Phase I, Air Distribution and Terminal Systems

2 Control Diagrams

A. VAV Terminal Unit with Reheat



Advanced Control Sequences for HVAC Systems

www.taylor-engineering.com/publications
(and choose design guides)

DCV Controls

- Ideal for classrooms, theaters, and rooms that have highly variable occupancy
- Installing an occupancy sensor reduces ventilation loads when occupancy is low
- Possible to tie into classroom lighting for additional energy savings to reset VAV minimum flow

Wireless Pneumatic Thermostats (WPTs)

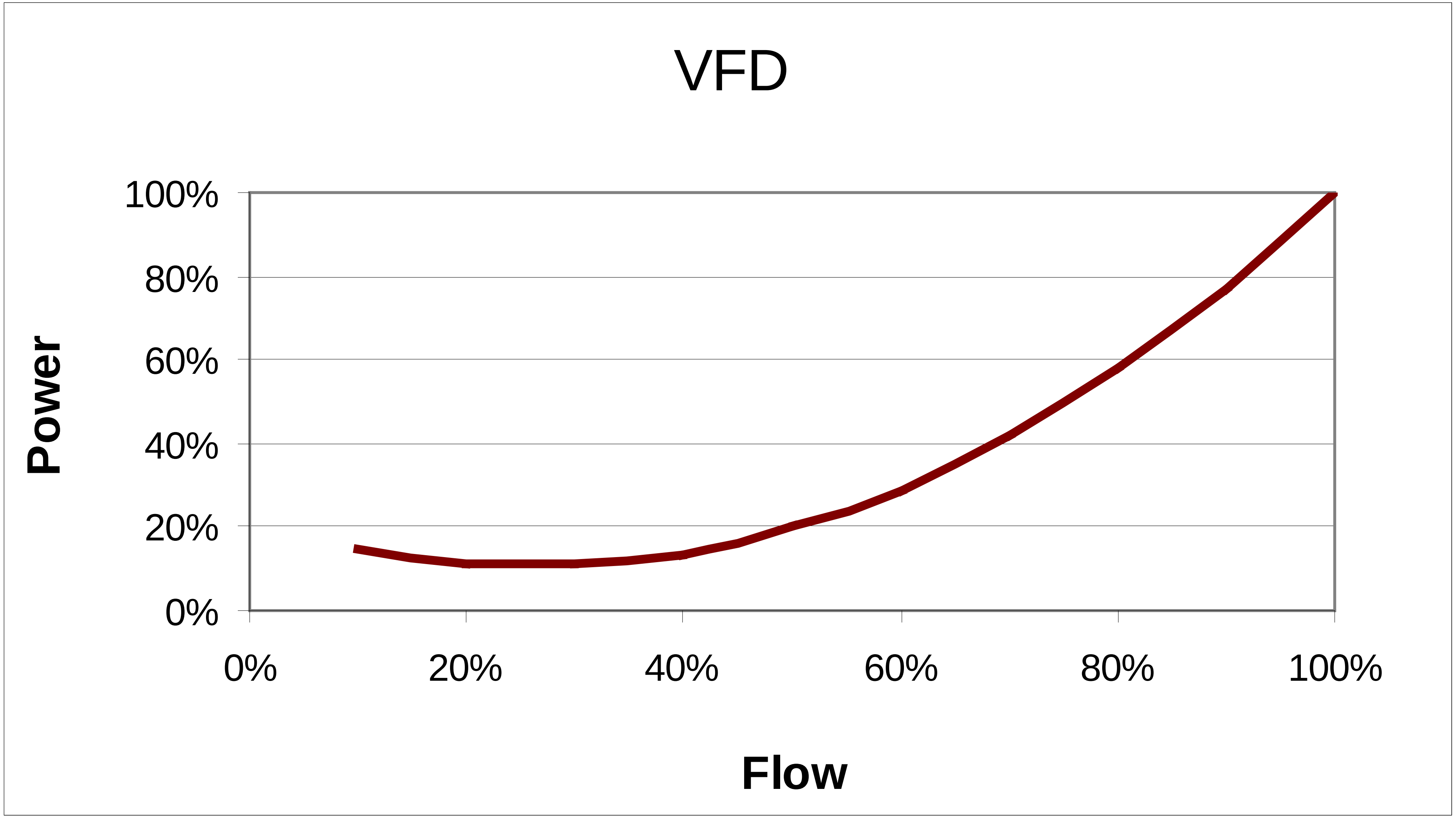
- WPTs are a direct replacement for existing pneumatic thermostats
- Electronic components translate pneumatic signals to digital signals
- Digital signals pass to the BAS via a wireless network
- Better data for resets as described previously but reduces retrofit costs
  - Requires battery replacement (every three to five years)
  - Instantaneous data retrieval accelerates battery wear

VFDs for Fans

- Many systems use variable flow air distribution
- Fan power laws dictate that power is roughly proportional to the ***flow rate cubed***
- VFD quality/reliability have improved greatly over time
- VFD costs have dropped significantly with wider adoption
- Now required by code for many applications in new construction

www.abb.com

Why Fans with VFDs Save Energy



These relationships between fan energy and fan flow are taken from the California Energy Commission Guide to Preparing Feasibility Studies and the 1998 Nonresidential ACM Approval Manual. Note that a typical system curve, DOE2 default, is assumed and these relationships are not applicable to all systems.

VFDs for Pumps

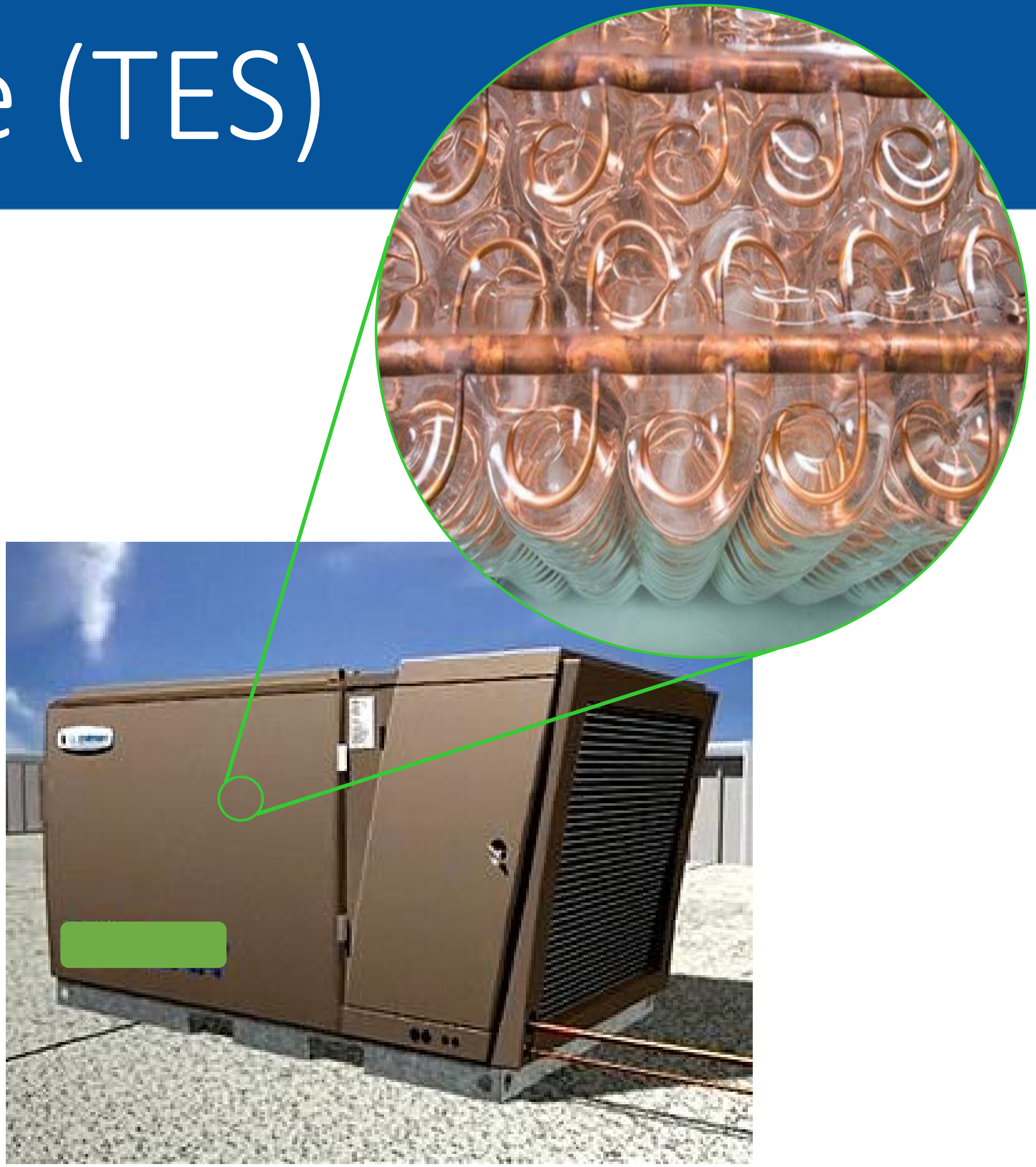
- VFDs save energy when allowed to slow pump motors down
- Controlled to differential pressure sensor located at most hydraulically distant point
  - Incorrect sensor placement can reduce energy savings
- Identify any throttling valves on the loop and use VFD to regulate flow

Kitchen Hood Exhaust Controls

- Kitchens hoods remove steam and other cooking fumes from the kitchen
- Hoods require MUA units to provide fresh, conditioned air to kitchen staff
- Hood controls slow down fans based on sensors detecting steam/fumes
- Saves fan energy and conditioning energy

Thermal Energy Storage (TES)

TES is available in large,
building-scale storage and modular units…



… or inside an auxiliary,
rooftop packaged unit

Battery Storage

Battery Storage

Heat Pump Water Heaters

Heat Pump Water Heater

1. A fan pulls air through the top air filter.
2. Heat in the air is absorbed by eco-friendly refrigerant inside the evaporator coil and cool (dehumidified air) is exhausted.
3. Refrigerant is pumped through a compressor,which increases the temperature.
4. Simultaneously the cooler water from the bottom of the tank is pumped to the top of the appliance, where it circulates.
5. Hot refrigerant transfers its heat to the water inside the condensor coil.
6. Heated water is returned back to the top of the tank.
7. Condensate drain connection.
8. Backup electric heating elements.

- Res sizes (40 to 80 gallons) $1600 to $2000
- Commercial sizes can be $10k
- Cost effective versus propane

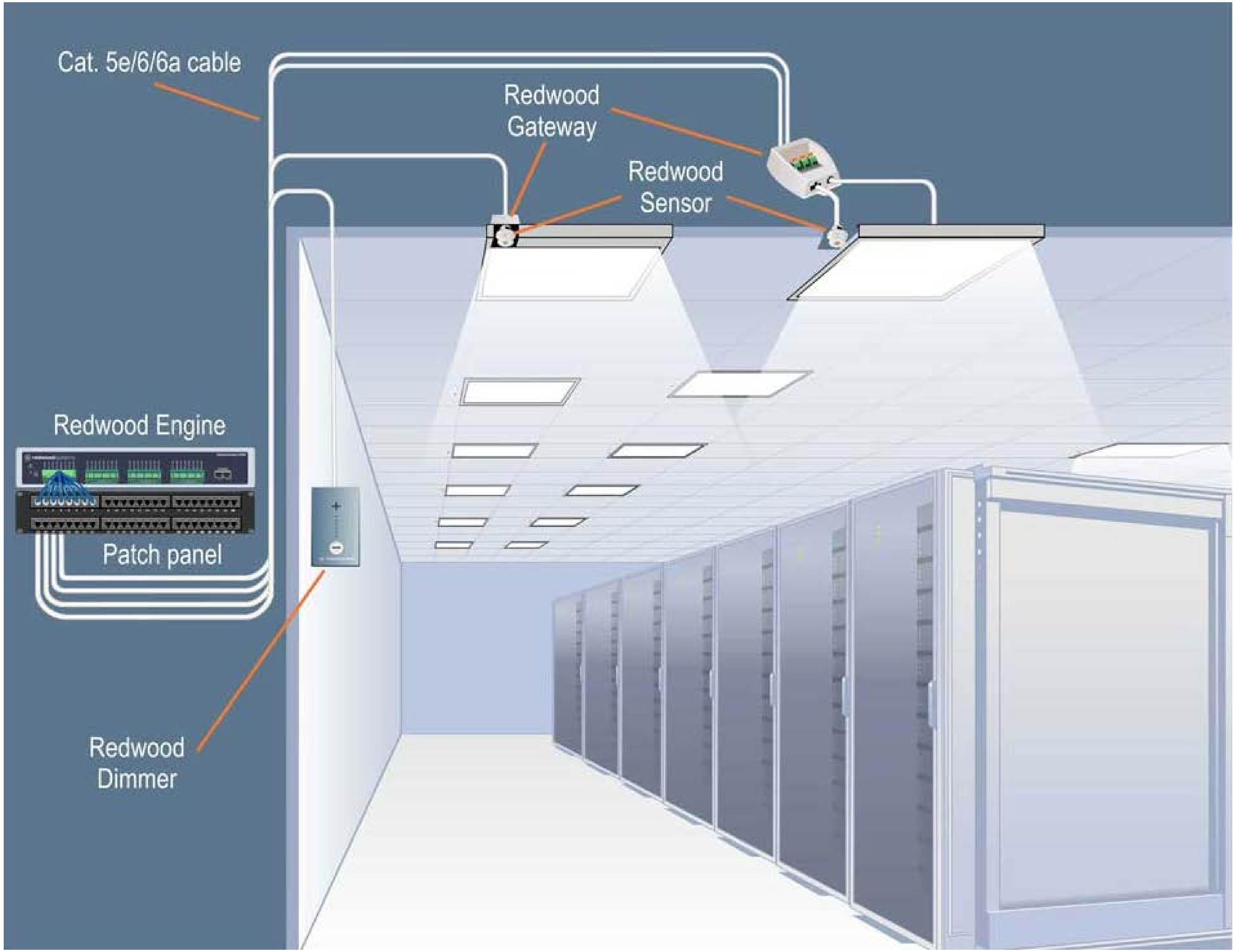
Source: www.ahrinet.org.

Advanced Lighting Controls (ALC)

- ALC systems integrate light fixtures and lighting sensors into a network
- Controls lighting with dimming, task-tuning, occupancy, scheduling, etc.
- Option to tie into HVAC system
  - Convey occupancy data
  - Capture remote new HVAC points wirelessly
- Demand response compatible
- Multiple vendors available

Source: www.enlightedinc.com

Advanced Lighting Controls



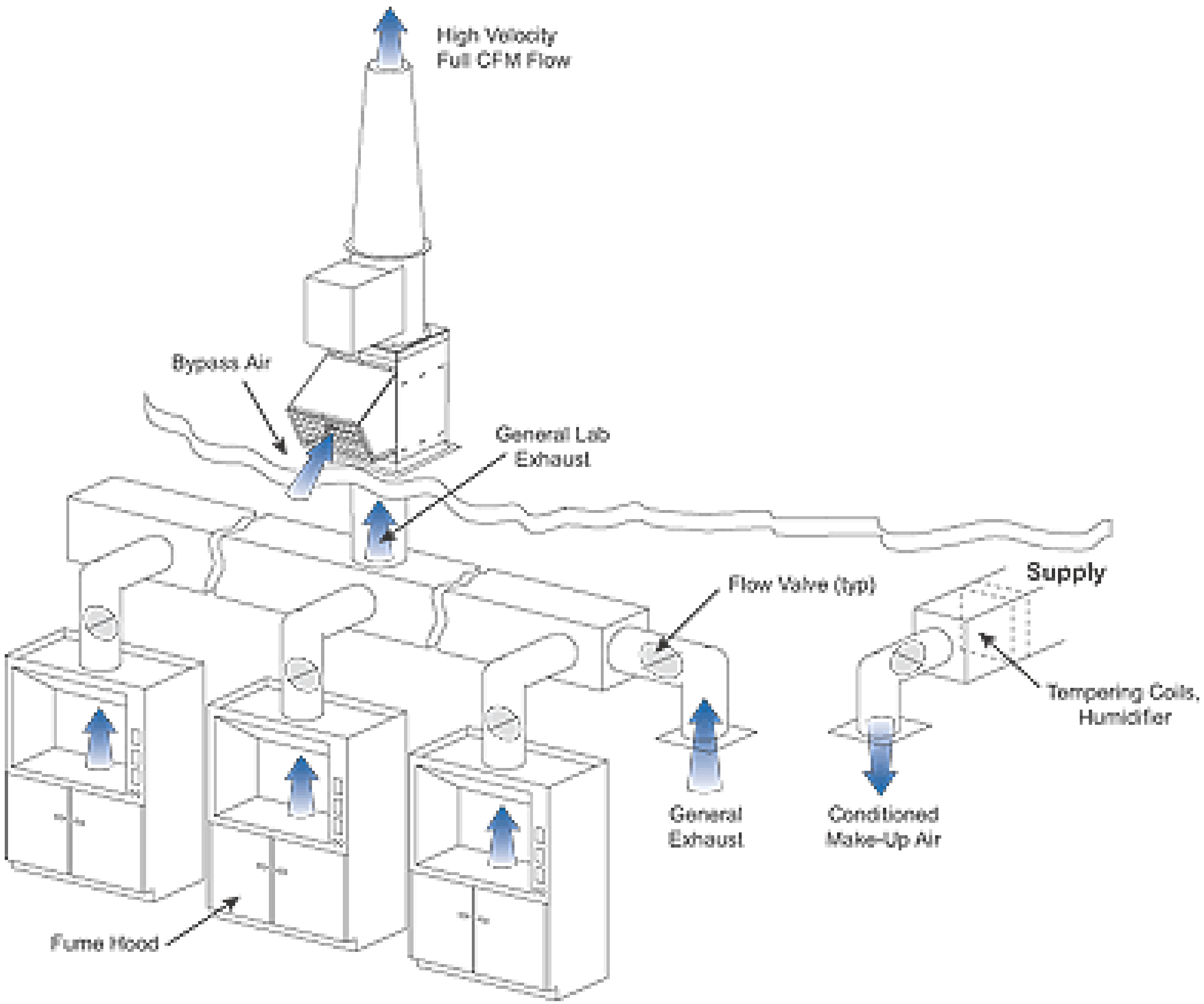
See aceee.org/files/proceedings/2014/data/papers/11-1204.pdf

www.redwoodsystems.com

Automated Steam Trap Management (ASTM)

- Steam traps can break, leading to steam leaks
- ASTM systems watch traps via wired or wireless sensors
- Alarms when steam trap fails, saves $$
  - Lost steam (utility cost)
  - Time necessary to inspect all traps (labor cost)
  - Prevents damage to equipment (material cost)

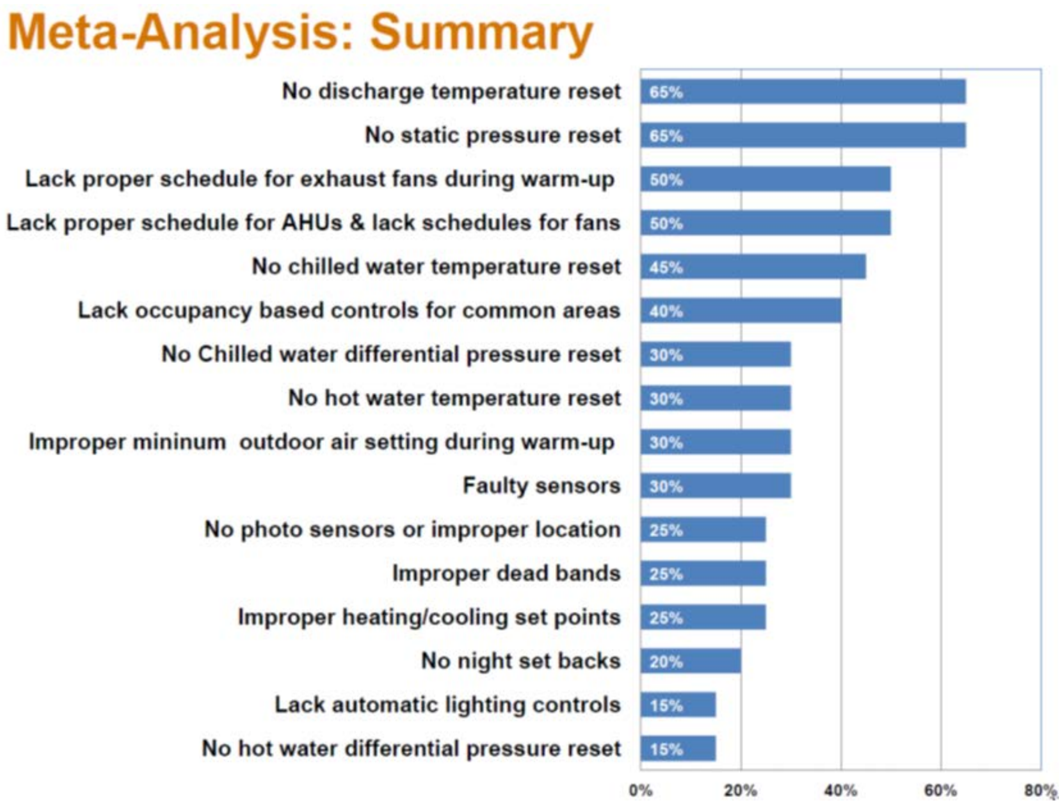
Manifold Laboratory Exhaust



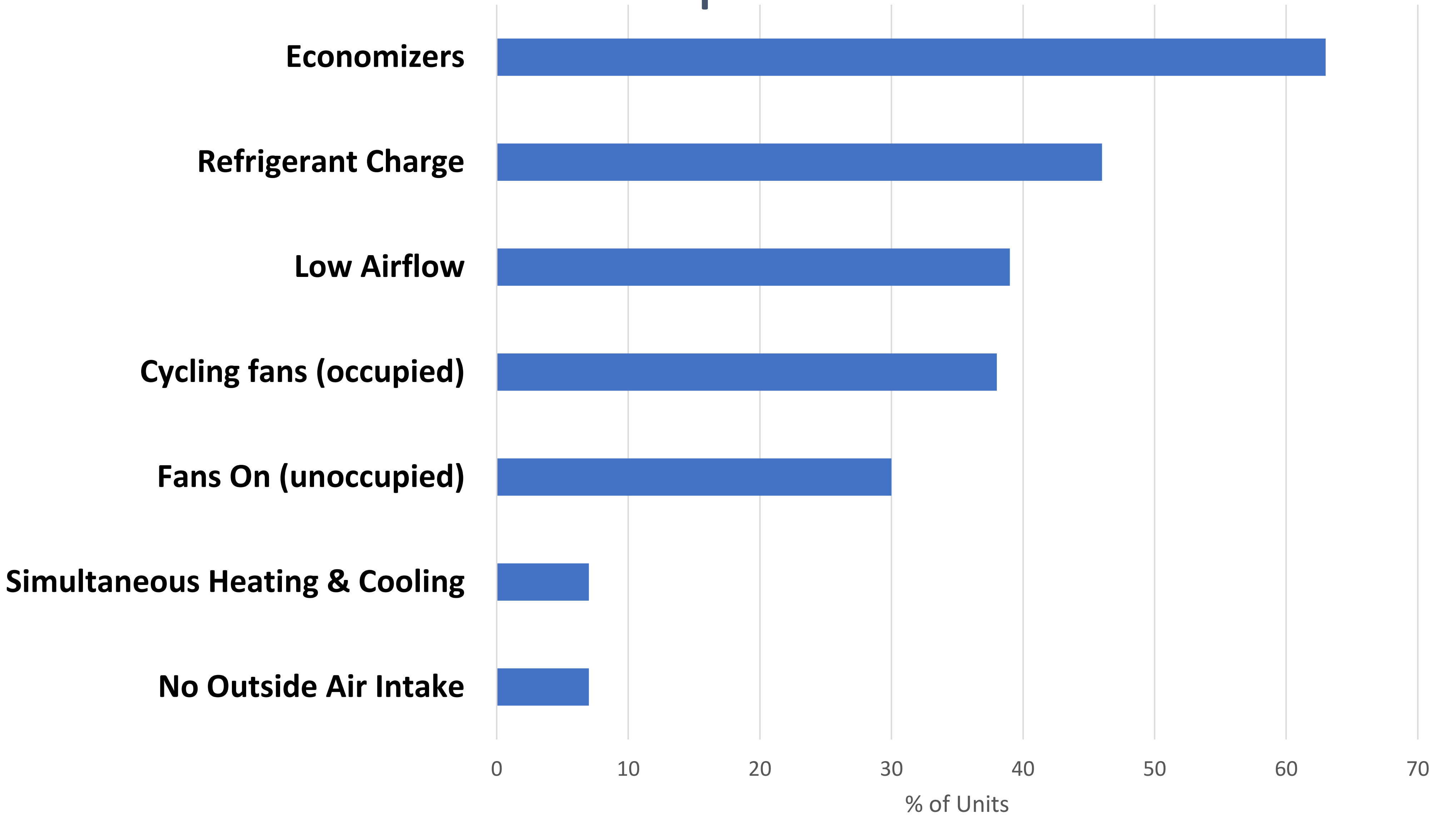
RCx/MBCx

RCx Savings

- **PNNL Study:**
  - **99 buildings nationwide**
  - **Savings ranged from 2% to 26%**
  - **Median savings 15%**



Small HVAC: Frequent Issues



https://www.energy.ca.gov/2005publications/CEC-500-2005-046/CEC-500-2005-046-FS.PDF

PIER Buildings Program Design Guide: Big Savings on Small HVAC Systems

Economizer Repairs and Alarms

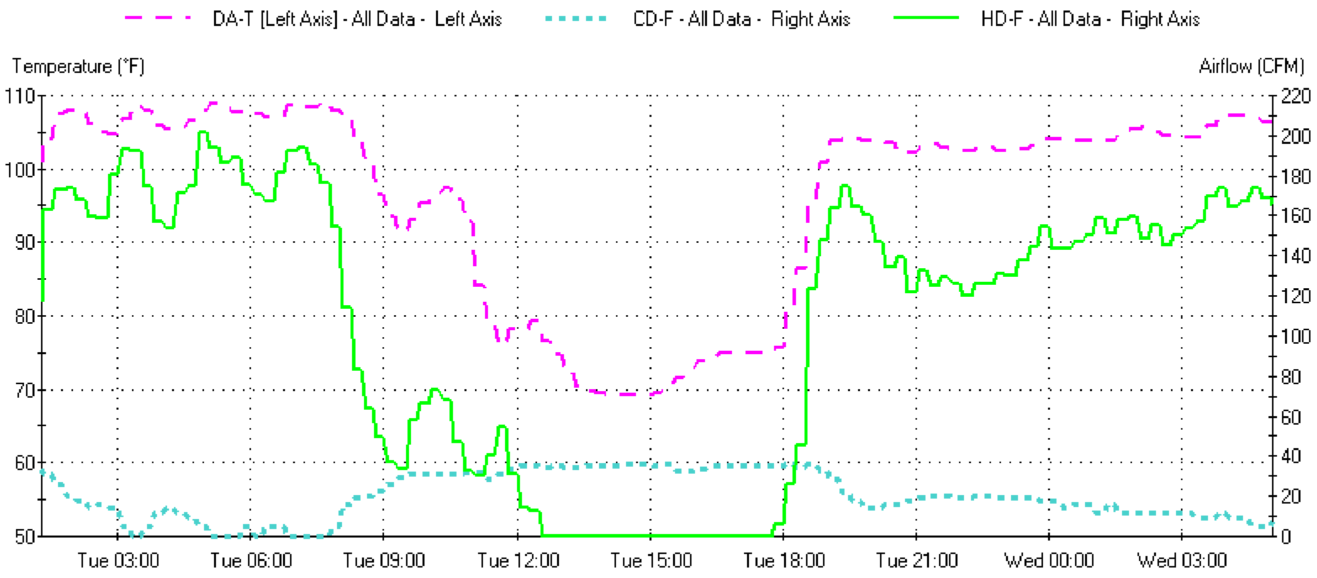
- Economizers save energy during moderate weather
- Prone to failure
- Economizer repair frequency mitigated with maintenance and alarms
- Spot-check observations may indicate good operation but trends necessary

Economizer “Brains”

- Economizer controls
- FDD
- CO_2/occupancy controls/DCV
- Trending

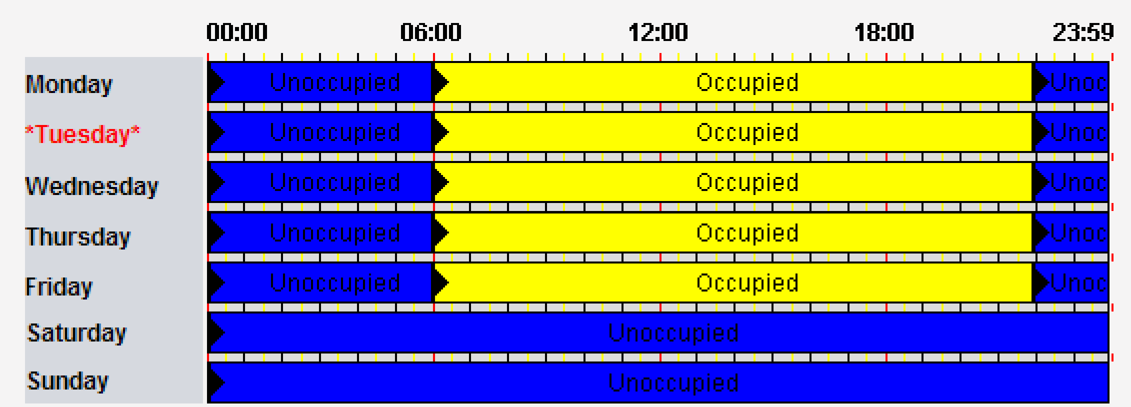
Add/Improve Reset Strategies

- Not all resets are created equal
  - OAT reset versus RAT reset versus zone-based reset
- The closer the reset moves to monitoring the control or limiting variable, the better the energy savings
- Requires review
  - Reset sequences
  - Sensor locations
  - Trend data

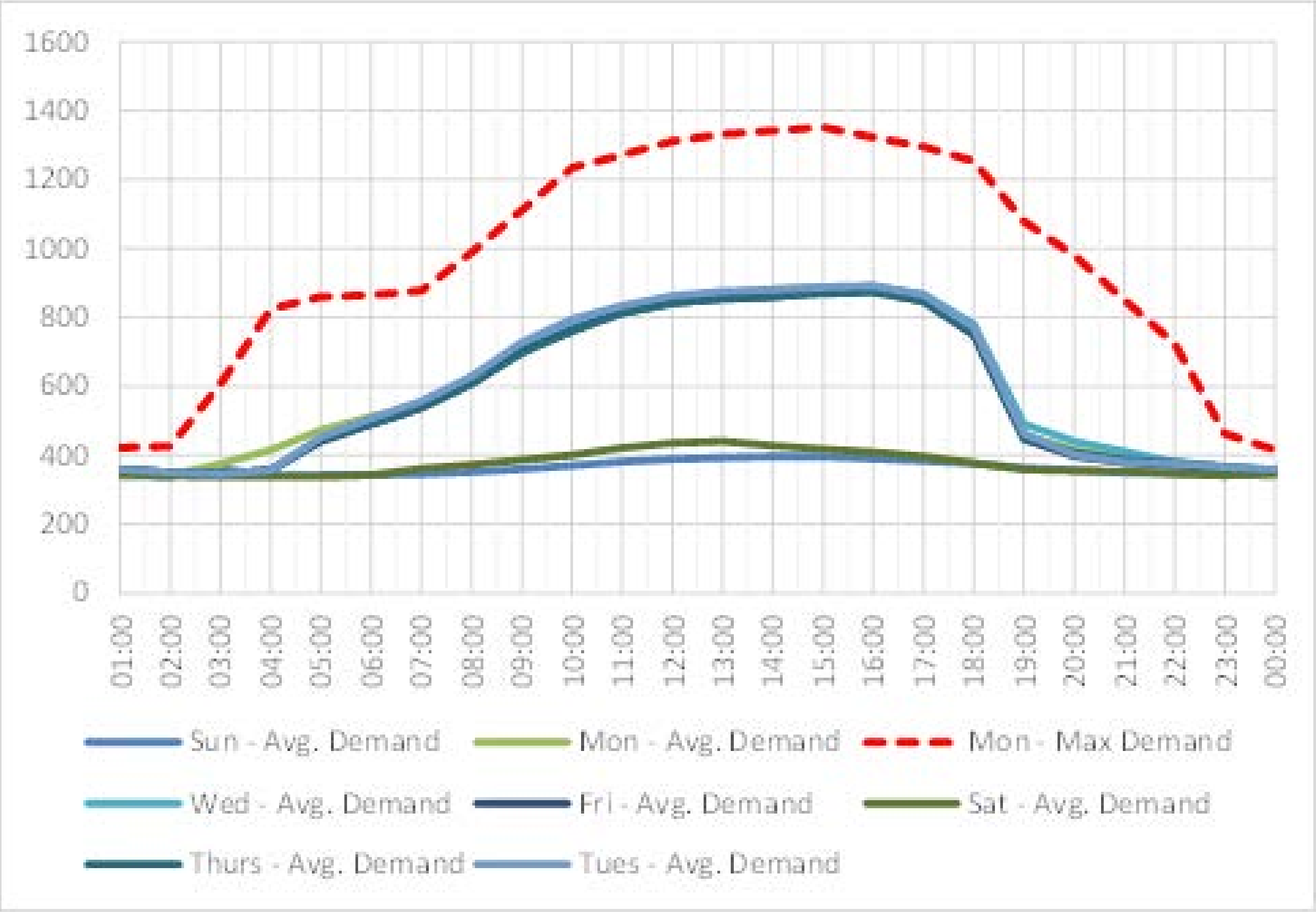


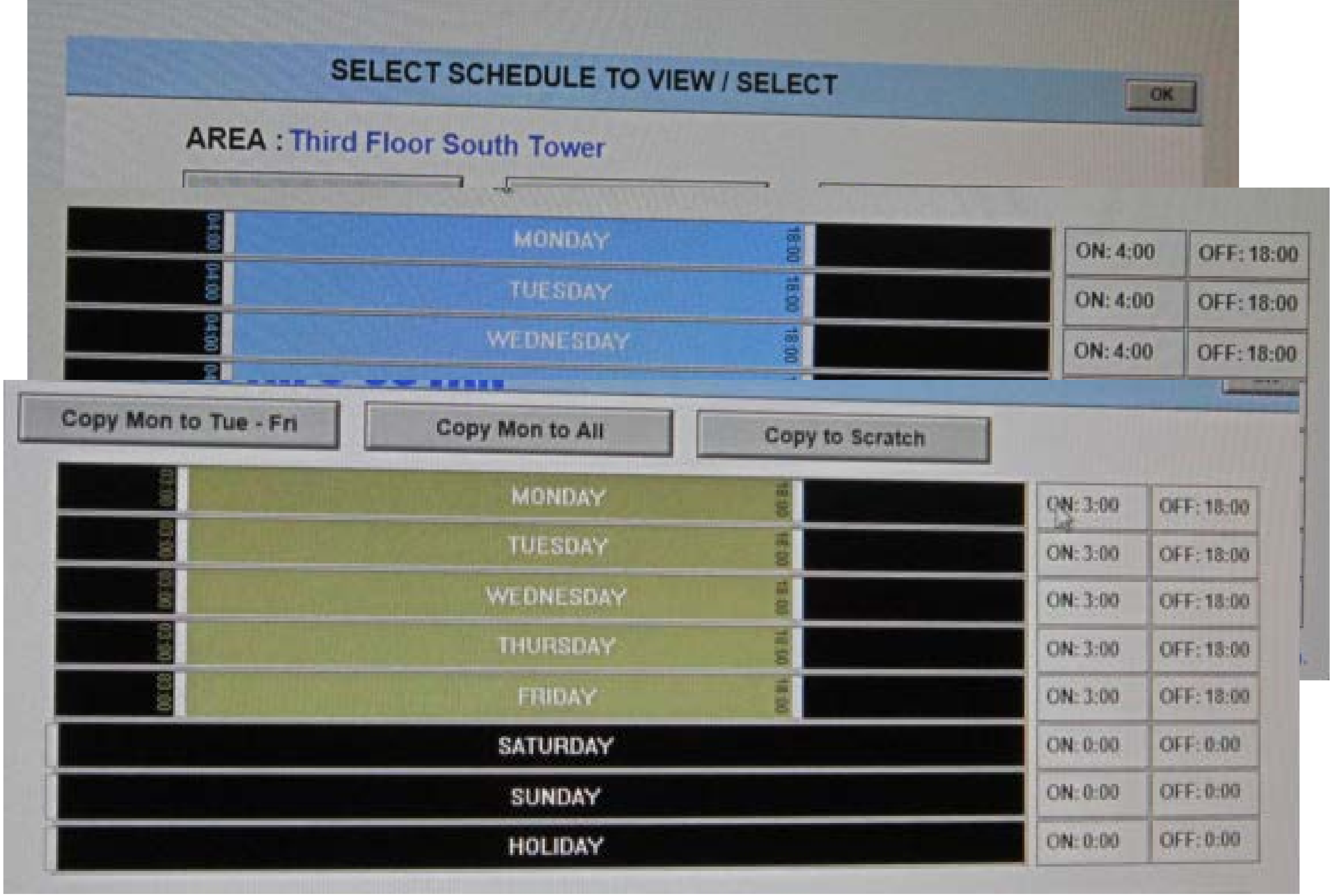
Add/Revise Scheduling Controls

- Turning equipment off when not in use provides straightforward energy savings
- Important to identify changes in schedules
- Avoid excessive override periods
- Program in holidays and breaks



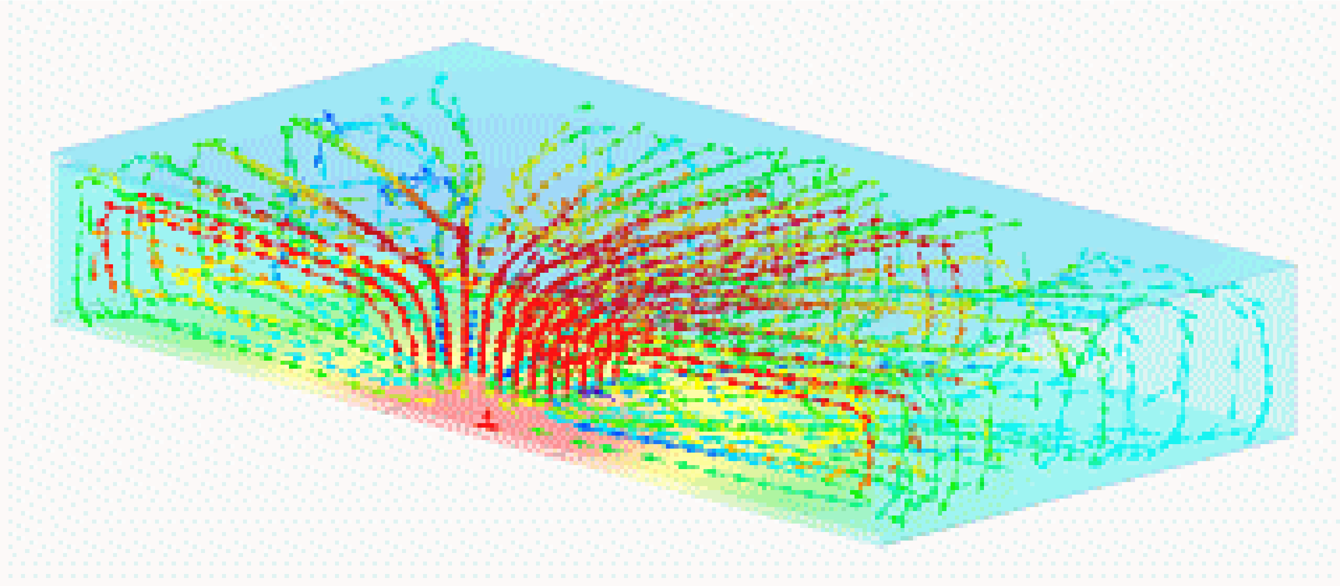
Scheduling Example




SELECT SCHEDULE TO VIEW / SELECT
OK
AREA : Third Floor South Tower
MONDAY
TUESDAY
WEDNESDAY
ON: 4:00
OFF: 18:00
ON: 4:00
OFF: 18:00
ON: 4:00
OFF: 18:00
Copy Mon to Tue - Fri
Copy Mon to All
Copy to Scratch
MONDAY
TUESDAY
WEDNESDAY
THURSDAY
FRIDAY
SATURDAY
SUNDAY
HOLIDAY
ON: 3:00
OFF: 18:00
ON: 3:00
OFF: 18:00
ON: 3:00
OFF: 18:00
ON: 3:00
OFF: 18:00
ON: 3:00
OFF: 18:00
ON: 0:00
OFF: 0:00
ON: 0:00
OFF: 0:00
ON: 0:00
OFF: 0:00

Schedule Laboratory Air Changes

- Labs have unique air change requirements
- Unoccupied labs are more flexible
- Investigate with your EH&S department
- Old rule of thumb =
  8 to 12 ach
  Now moving towards
  4 to 6 ach



EEM Recommended Sources

- ASHRAE Standard 100
- ASHRAE *Procedures for Commercial Building Energy Audits*, 2nd Edition/ online resources "EEMs to Consider" (in your resources)
- ASHRAE Advanced Energy Design Guidelines
- *Energy Efficiency Manual*, Donald R. Wulfinghoff, Energy Institute Press, ISBN 0-9657926-7-6

http://energybooks.com/wp-content/uploads/2015/06/list_of_measures.pdf.
(21 pages of measures!)

Exercise #5:

Rule-of-Thumb Roundup

Exercise 5: Rules of Thumb

Design by rule of thumb is poor practice. But using rules to estimate energy impacts is good way for getting a first-order idea of savings potential.

Exercise:

List as many rules as you can that might be applicable for first-order savings estimates.

Example: Plug load density in commercial office buildings is about 1 W/ft^2.

Selling Your Ideas

Selling Efficiency

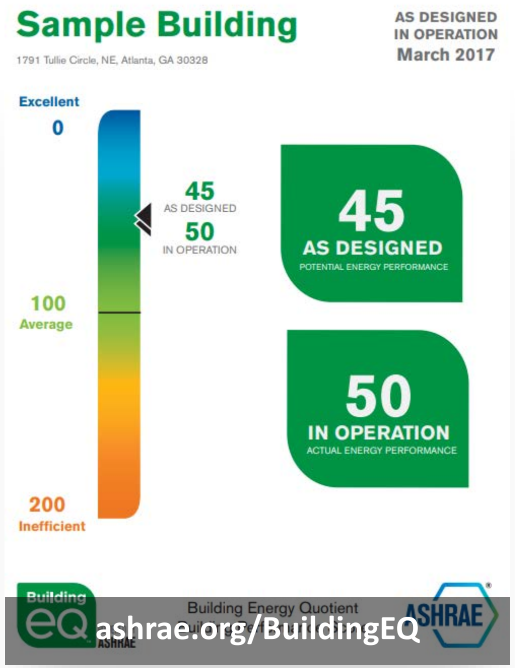
- Emphasize other benefits
- Comfort, reliability
- Incentives
- Tax deductions
- Water savings
- Productivity/sales
- Property value impacts

Realizing Property Value Impacts

The results suggest that an otherwise identical commercial building with an ENERGY STAR certification will rent for about 3% more per square foot; ***the difference in effective rent is estimated to be about 7%. The increment to the selling price may be as much as 16%.***

Piet Eichholtz, Nils Kok, and John M. Quigley. 2010. Doing Well by Doing Good? Green Office Buildings. *American Economic Review* 24922–2509.

Celebrating Success



Energy Rating Programs

Building Energy Quotient Dashboard

Building eQ

EXAMPLE BUILDING
000 MAIN STREET
ANYTOWN, ST 00000

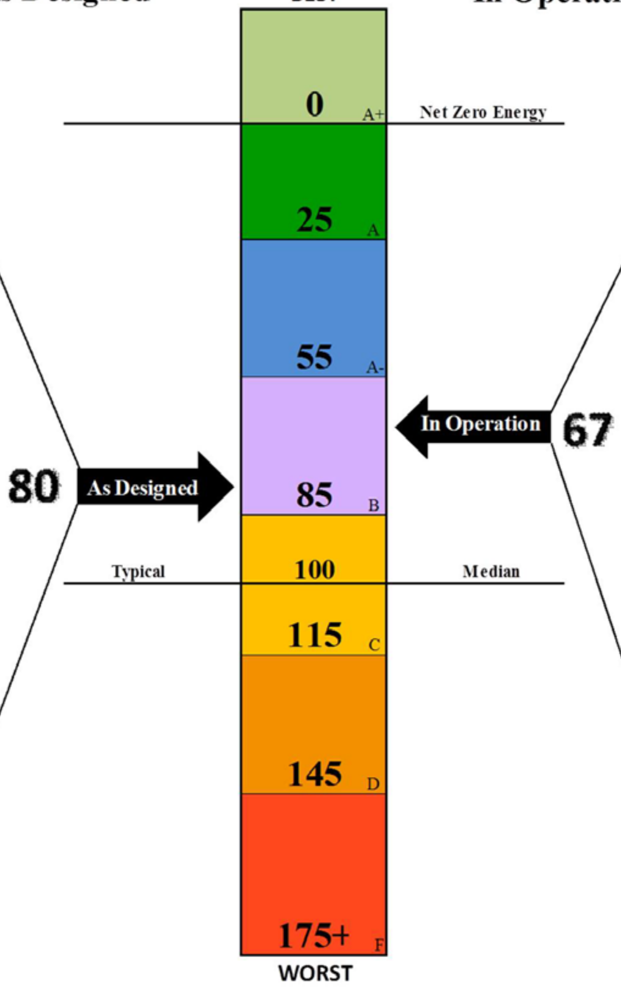
RATED BUILDING TYPE:
BUILDING GROSS SQUARE FOOTAGE:
ORIGINAL CONSTRUCTION DATE:
LATEST MAJOR RENOVATION DATE:

As Designed

As Designed Rating Date:	
Previous Rating Scores/Dates	
Total Modeled Bldg Energy Use (kBtu)	
Modeled Renewable Energy kBtu and %	
Total Modeled Net Bldg Energy Use (kBtu)	
Modeled Site EUI (kBtu/ft^2-yr)	
Modeled Source EUI (kBtu/ft^2-yr)	
ENERGY STAR Target Finder	
Other Ratings Awarded	

In Operation

In Operation Rating Date:	
Previous Rating Scores/Dates	
Total Measured Bldg Energy Use (kBtu)	
Measured Renewable Energy kBtu and %	
Total Measured Net Bldg Energy Use (kBtu)	
Measured Site EUI (kBtu/ft^2-yr)	
Measured Source EUI (kBtu/ft^2-yr)	
Measured ECI ($/ft^2-yr)	
ENERGY STAR Portfolio Manager	
Other Ratings Awarded	



ENERGY STAR®
PortfolioManager®
The most-used energy measurement and tracking tool for commercial buildings.

LEED Certification

LEED v4.1 for Operations & Maintenance: Existing Buildings
Scorecard

Y	?	N			
0	0	0	**Location and Transportation**		**14**
6			Prereq	Transportation Performance	14
0	0	0	**Sustainable Sites**		**4**
			Credit	Rainwater Management	1
			Credit	Heat Island Reduction	1
			Credit	Light Pollution Reduction	1
			Credit	Site Management	1
0	0	0	**Water Efficiency**		**15**
6			Prereq	Water Performance	15
0	0	0	**Energy and Atmosphere**		**35**
Y			Prereq	Energy Efficiency Best Management Practices	Required
Y			Prereq	Fundamental Refrigerant Management	Required
13			Prereq	Energy Performance	33
			Credit	Enhanced Refrigerant Management	1
			Credit	Grid Harmonization	1
0	0	0	**Materials and Resources**		**9**
Y			Prereq	Purchasing Policy	Required
Y			Prereq	Facility Maintenance and Renovations Policy	Required
3			Prereq	Waste Performance	8
			Credit	Purchasing	1

EA

0	0	0	**Indoor Environmental Quality**		**22**
Y			Prereq	Minimum Indoor Air Quality	Required
Y			Prereq	Environmental Tobacco Smoke Control	Required
Y			Prereq	Green Cleaning Policy	Required
8			Prereq	Indoor Environmental Quality Performance	20
			Credit	Green Cleaning	1
			Credit	Integrated Pest Management	1
0	0	0	**Innovation**		**1**
			Credit	Innovation	1
0	0	0	**TOTALS**	Possible Points:	**100**

Certified: 40-49 points, **Silver:** 50-59 points, **Gold:** 60-79 points, **Platinum:** 80+ points

- Energy efficiency can get you ~half way to LEED certification
- Energy credits also have a payback!

LEED Certification

- Prerequisite: Level 1 Audit
- Up to 33 points for energy efficiency and greenhouse gas emissions reductions

0	**0**	**0**	**Energy and Atmosphere**		**35**
Y			Prereq	Energy Efficiency Best Management Practices	Required
Y			Prereq	Fundamental Refrigerant Management	Required
13			Prereq	Energy Performance	33
			Credit	Enhanced Refrigerant Management	1
			Credit	Grid Harmonization	1

What's Next?

286

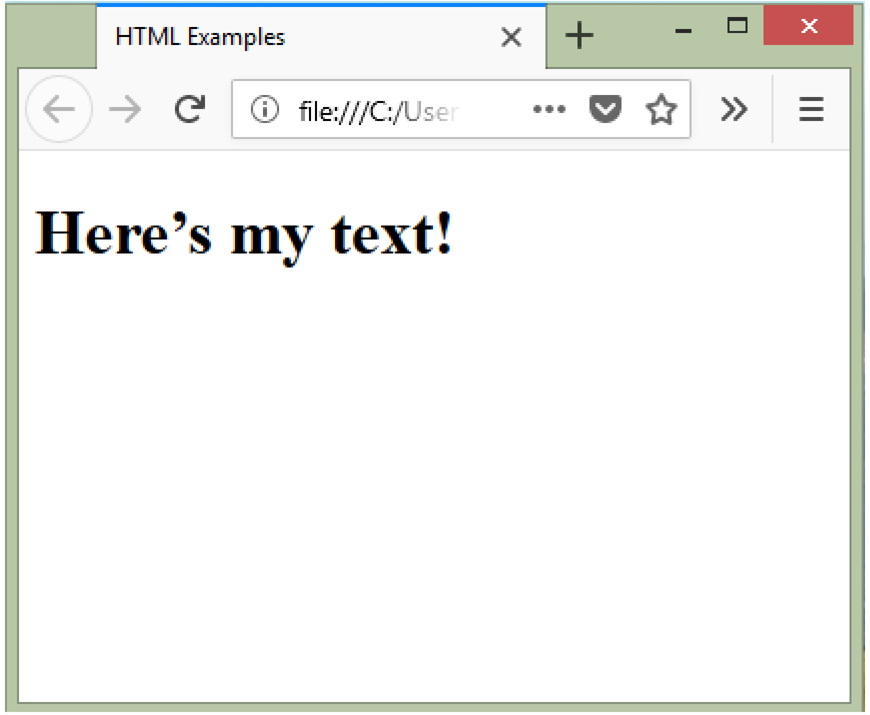
BuildingSync Schema: What Is It?

"A standard language for commercial building energy audit data that software developers can use to exchange data between audit tools."

∴ It's language, not a tool

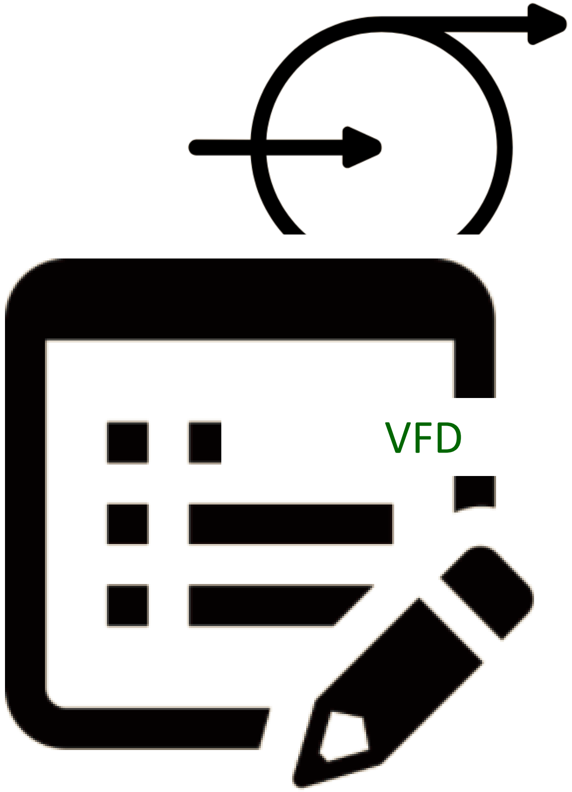
It’s Kind of Like HTML…

```
<!DOCTYPE html>
<html lang="en-US">
<head>
<title>HTML Examples</title>
<body>
<H1>Here’s my text!</H1>
</body>
</html>
```



BuildingSync: How is It Used

```
<xs:element name="PumpControlType"
minOccurs="0">
<xs:annotation>
<xs:documentation>
        Type of pump speed control
</xs:documentation>
</xs:annotation>
<xs:simpleType>
<xs:restriction base="xs:string">
<xs:enumeration value="Constant Volume"/>
<xs:enumeration value="Variable Volume"/>
<xs:enumeration value="VFD"/>
<xs:enumeration value="Multi-Speed"/>
<xs:enumeration value="Other"/>
<xs:enumeration value="Unknown"/>
</xs:restriction>
</xs:simpleType>
</xs:element>
```



First App: Asset Score

Asset Score Inputs

Building Geometry

Floor to Floor Height	
Floor to Ceiling Height	
Orientation	

Building Footprint Dimensions

Option 1

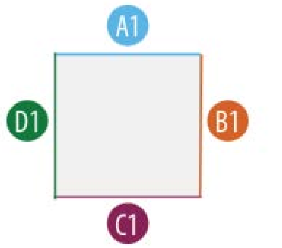
Glazing area, approx % of exposed wall area [10, 25, 50, 75, 90, 100]*

North	
South	
East	
West	

Option 2

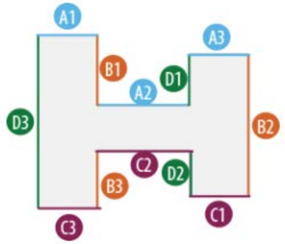
Provide building footprint dimernsions and approximate window to wall ratio for each side.

Rectangular Shape



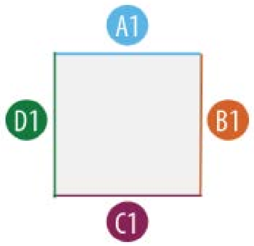
Surface ID	Length (ft)
A1	
B1	
C1	
D1	

H-Shape



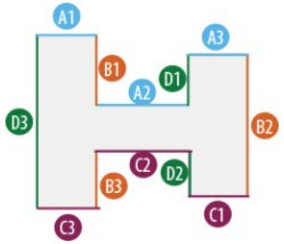
Surface ID	Length (ft)
A1	
A2	
A3	
B1	
B2	
B3	
C1	
C2	
C3	
D1	
D2	
D3	

Rectangular Shape



Surface ID	Length (ft)	Glazing Area %
A1		
B1		
C1		
D1		

H-Shape



Surface ID	Length (ft)	Glazing Area %
A1		
A2		
A3		
B1		
B2		
B3		
C1		
C2		
C3		
D1		
D2		
D3		

Asset Score

Now used to report energy audit results in NYC, San Francisco, and ?...

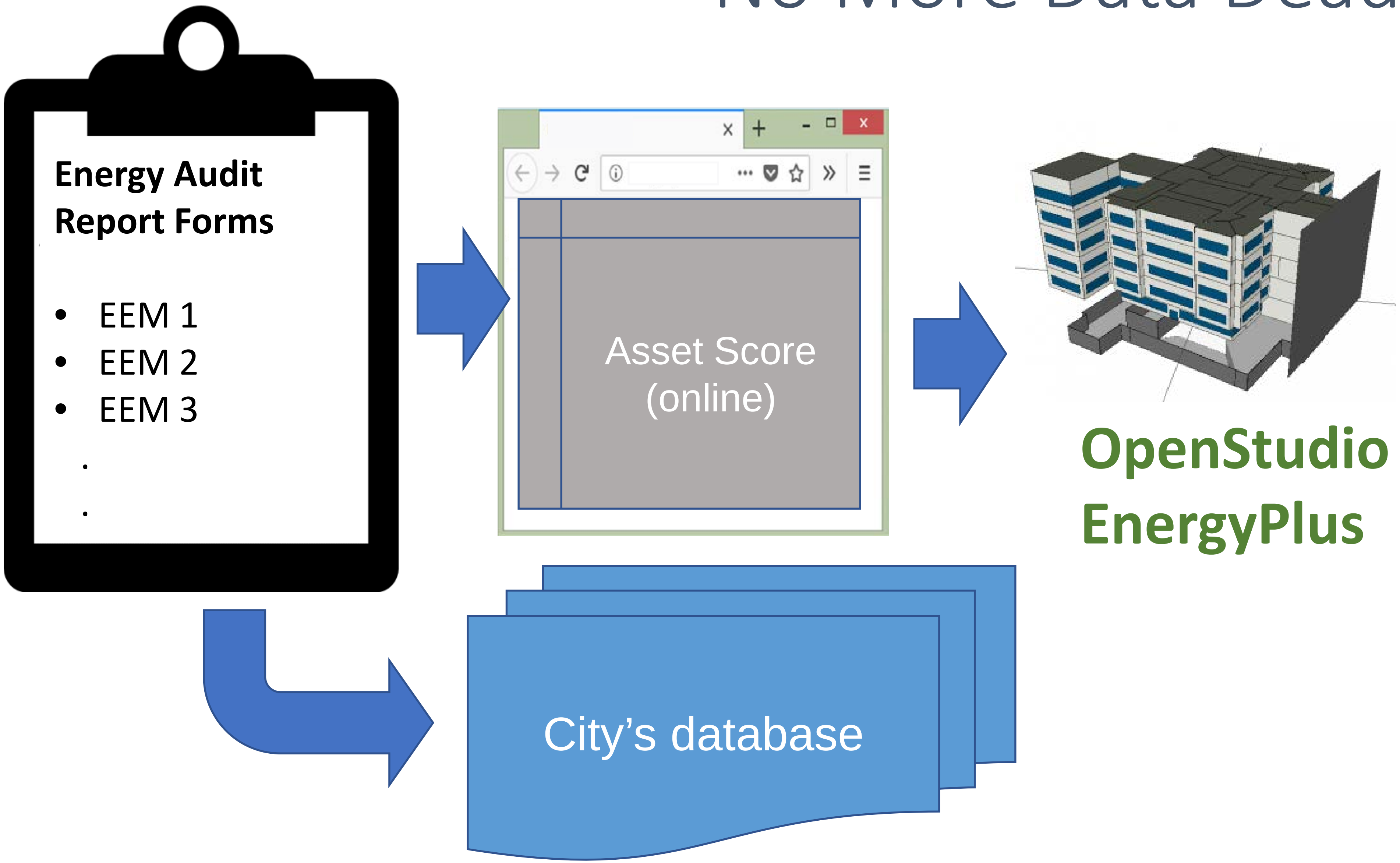
Annual Energy & Cost Savings

Package Name Measure; Status (^) *	Measure Description	Total Cost Savings	Peak Demand Savings (kW)	Electricity Savings (kWh)	Natural Gas Savings (therms)
Low Cost and No Cost Recommendations					
HVAC Controls RCx Upgrade operating protocols, calibration, and/or sequencing; ^5	Contro Sequence Optimization	2996.0	5.0	9000.0	800.0
Light Level Reduction Upgrade operating protocols, calibration, and/or sequencing; ^5	Adjust Lighti Level Setpoints on Lightin BAS	1323.0	2.4	6000.0	0.0
Cx of AAON Cooling Unit Upgrade operating protocols, calibration, and/or sequencing; ^4	Enable Variable Speed Compressor Staging	1807.0	5.0	8200.0	0.0
Potential Capital Recommendations					
Zone DDC Upgrade - 4th and 7th Floors Convert pneumatic controls to DDC; ^5	Convert 4th and 7th Floor Zones to DDC	815.0	0.0	1400.0	400.0
Totals (recomm. measures)		***6941.0***	***12.4***	***24600.0***	***1200.0***

Payback with Incentives

Package Name Measure; Status (^) *	Measure cost	Rebates available?	Potential incentives	Portion affected	Measure life (years)	*Net measure cost*	*Simple ROI (%)*	*Simple Payback (w/o incentives - years)*	*Simple Payback (w/ incentives - years)*
Low Cost and No Cost Recommendations									
HVAC Controls RCx Upgrade operating protocols, calibration, and/or sequencing; ^5	1800.0	No	0.0	Entire Building	4.0	*1800*	*166%*	*0.6*	*0.6*
Light Level Reduction Upgrade operating protocols, calibration, and/or sequencing; ^5	0.0	No	0.0	Entire Building	4.0	*0*	*0%*	*0.0*	*0.0*
Cx of AAON Cooling Unit Upgrade operating protocols, calibration, and/or sequencing; ^4	1000.0	No	0.0	Entire Building	12.0	*1000*	*181%*	*0.6*	*0.6*
Potential Capital Recommendations									
Zone DDC Upgrade - 4th and 7th Floors Convert pneumatic controls to DDC; ^5	45000.0	No	0.0	Tenant Spaces	20.0	*45000*	*2%*	*55.2*	*55.2*

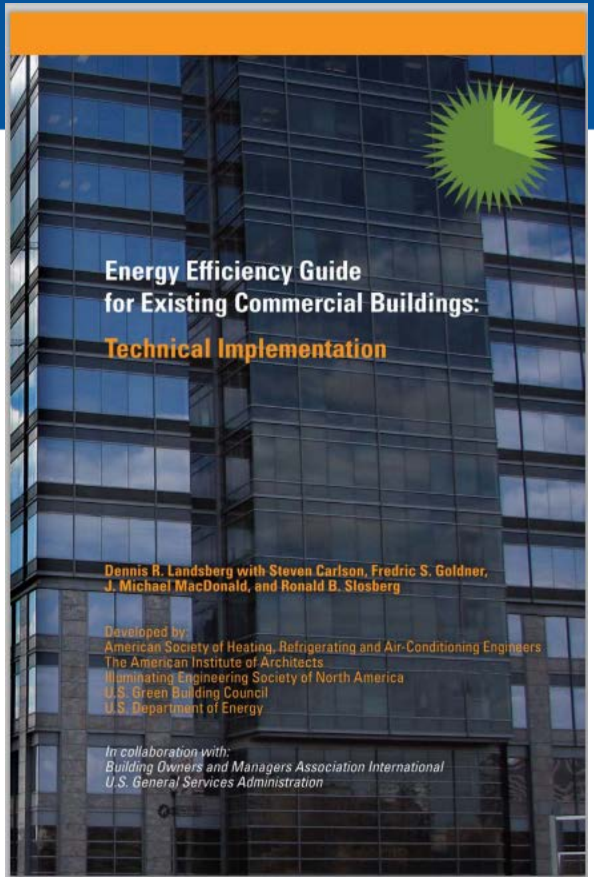
No More Data Dead Ends!



Resources

Energy Efficiency Guides for Existing Commercial Buildings

In the ASHRAE bookstore:
http://www.techstreet.com/ashrae/products/1834658



Additional Resources

- CEC Guide to Preparing Feasibility Studies for Energy Efficiency Projects
  www.energy.ca.gov/efficiency/
- Consortium for Energy Efficiency
  (guidelines for specifying EERs and rough costs/savings)
  www.cee1.org
- Energy Design Resources
  www.energydesignresources.com

Additional Resources

- ASHRAE Advanced Energy Design Guidelines
  - www.ashrae.org
  - Small Office, Small Retail, Small Warehouses and Self-Storage Buildings, and Schools K-12 are Free
- Energy cost calculators for:
  - Commercial unitary air conditioner (rooftops)
  - Lighting, appliances, food service equip, etc.
  - https://www.energy.gov/eere/femp/federal-energy-management-tools

Additional Resources

- Green Building Studio—Online Quick Simulation
  - https://gbs.autodesk.com/GBS/
- Weather Data
  - TMY3 (https://rredc.nrel.gov/solar/old_data/nsrdb/1991-2005/tmy3/)
  - www.whiteboxtechnologies.com/weather_data.html
  - www.wunderground.com

Additional Resources

- California Commercial End-Use Survey (CEUS) www.energy.ca.gov/ceus
- Commercial Building Energy Consumption Survey (CBECS) www.eia.gov/consumption/commercial
- California Commissioning Collaborative ECAM and BOA www.cacx.org

Questions?

Thanks!

Questions?

Jim Kelsey, P.E., BEAP, LEED® AP
E-mail: kelsey@kw-engineering.com

Evaluation and Certificate

- ASHRAE values your comments about this course. All course registrants will receive a separate email from ALI-Education (edu@ashrae.org) allowing access to the Course Survey and Certificate of Attendance. Once the Course Survey is complete, you will be directed to the Certificate of Attendance. Questions should be sent to edu@ashrae.org.

- A copy of the presentation is available at:

  https://www.ashrae.org/2021SCORSEnergyOfficeapr28

- 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 Tiffany Cox, Course Administrator, at **tcox@ashrae.org**.

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- Standards and Guidelines
- CoV-2 Mitigation

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  - Embedded metadata uniquely linked to you
  - Shareable in electronic media, including LinkedIn and email
  - Instant recognition, with real-time, third-part verification

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