CAE 465/526 Building Energy Conservation Technologies

Fall 2023

October 12, 2023

Sensitivity analysis, building energy audits and commissioning

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ANNOUNCEMENTS

Announcements

Announcements

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We're excited to open the 2024 SmithGroup Justice, Equity, Diversity & Inclusion Scholarship program for applications. The scholarship supports students from underrepresented backgrounds who are studying architecture, engineering, interior design, landscape architecture or urban planning.

Each scholarship includes both tuition support and a paid summer internship at one of SmithGroup's locations. Applications are due November 30.

Learn more about eligibility, requirements and the application process:
https://lnkd.in/dJuNTEKt

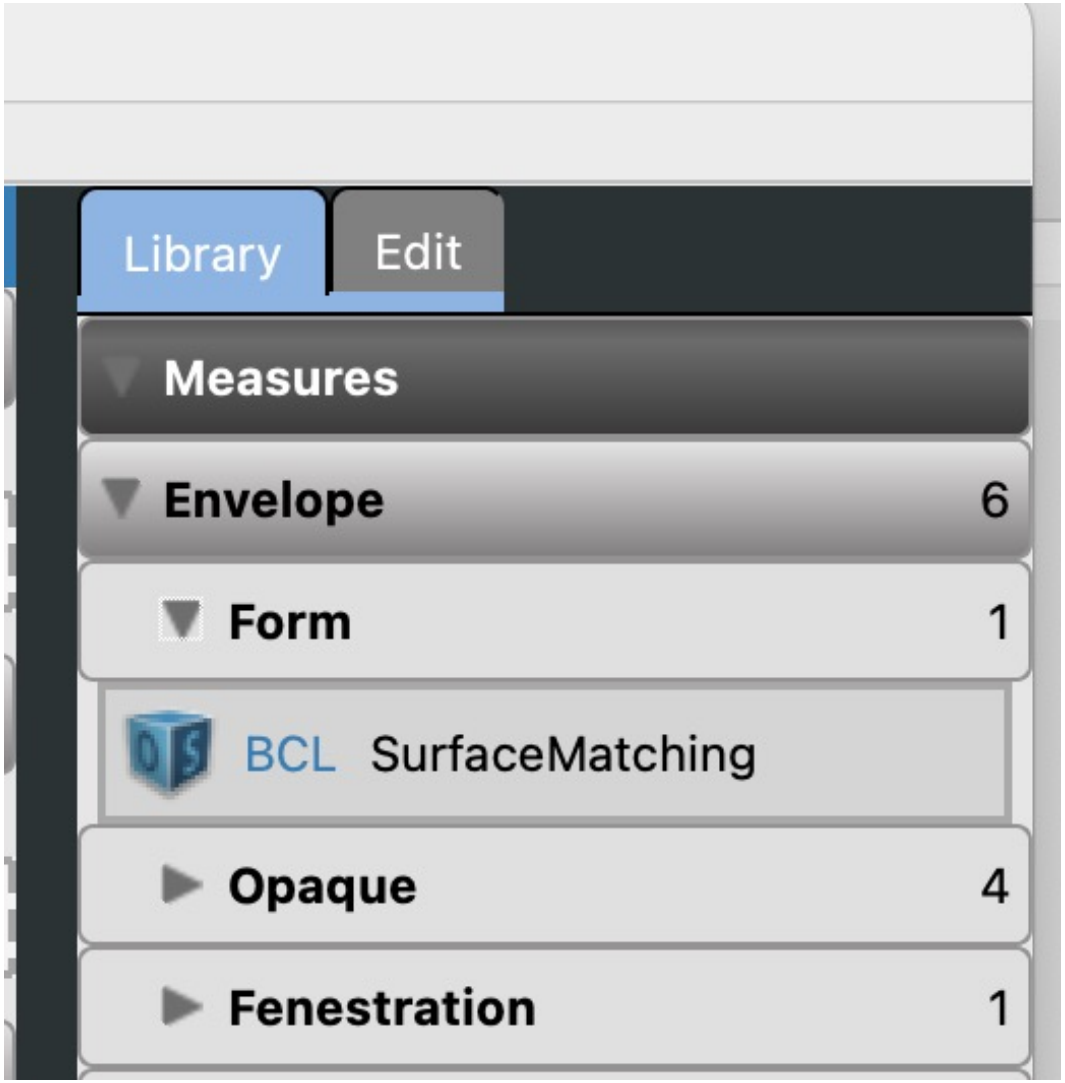
https://www.smithgroup.com/jedi-scholarship

Announcements

- Assignment 5 is posted (no late submission – link will disappear)

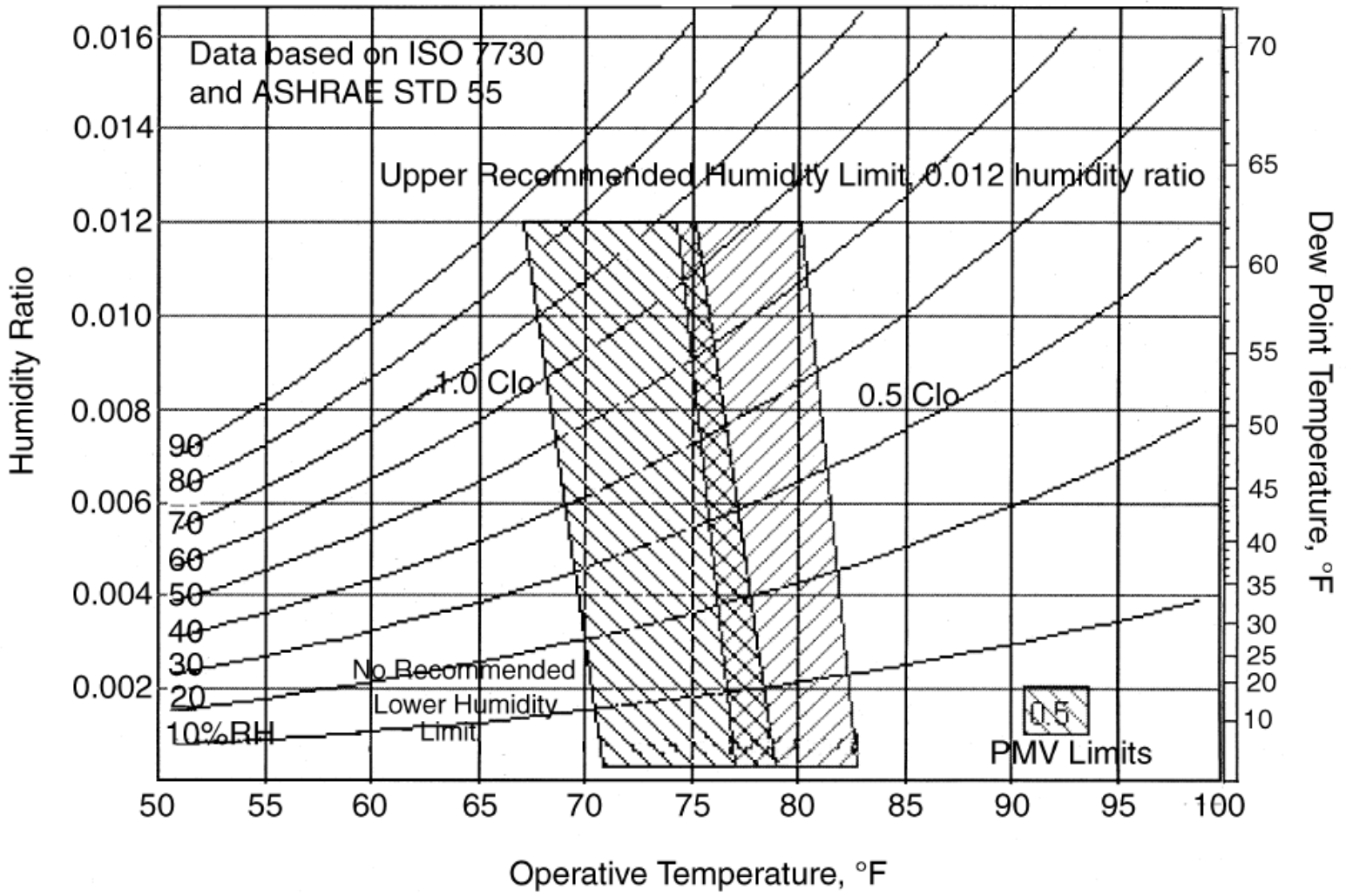
SURFACE MATCHING

Surface Matching



SETPOINTS

Setpoints

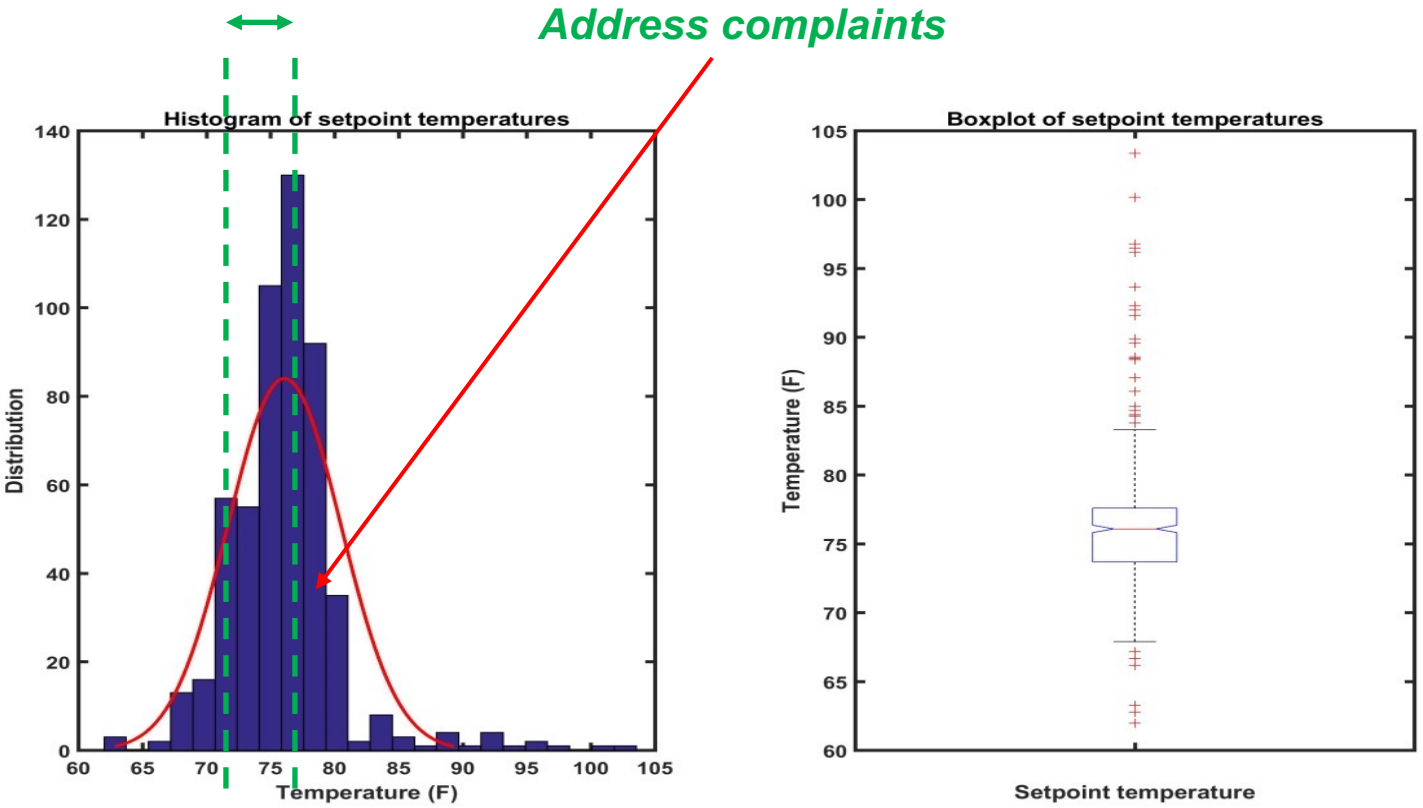


ANSI/ASHRAE Standard 55-2004

Setpoints

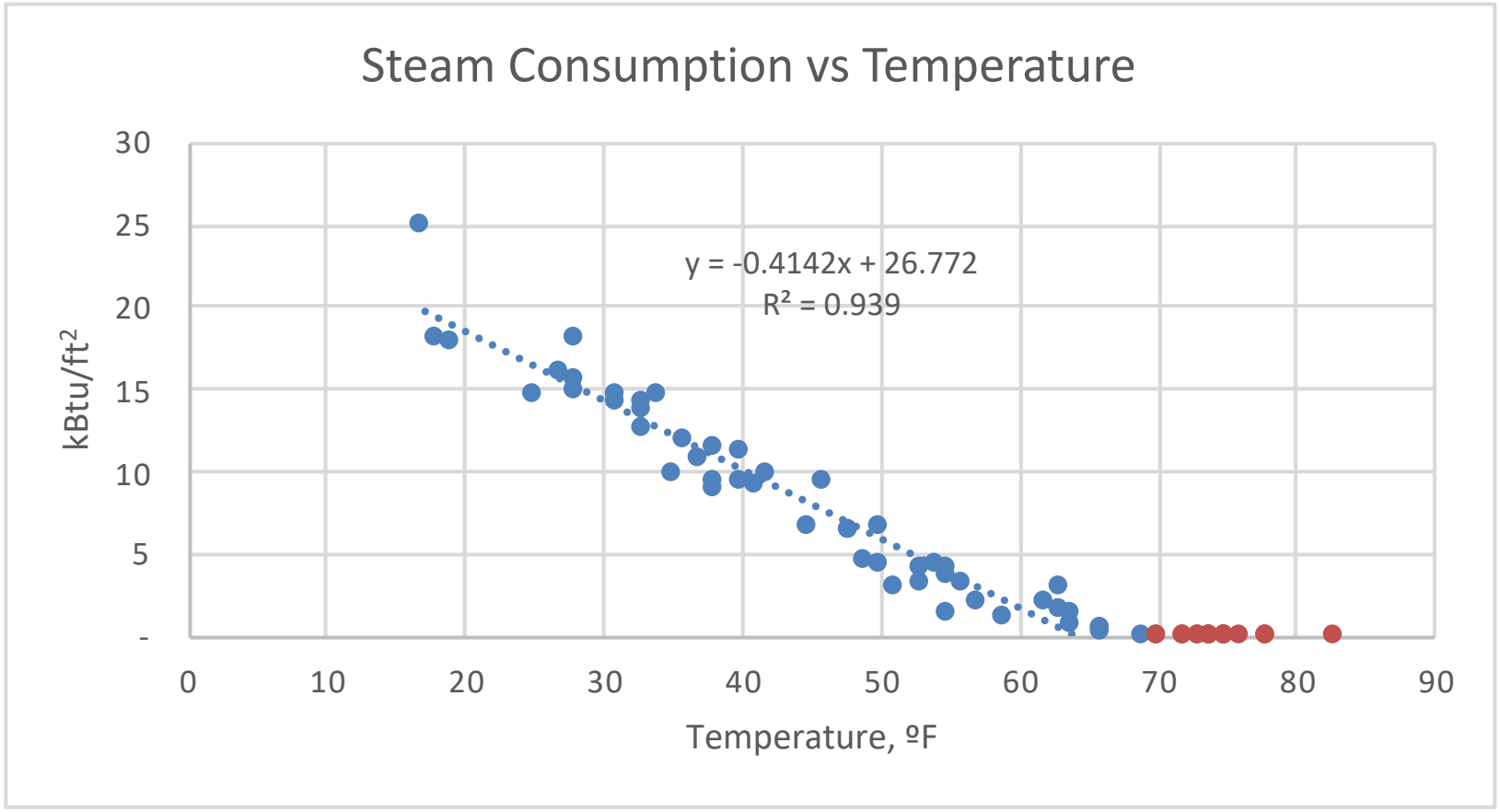
- Poor management of temperature setpoints in the buildings

Thermal comfort range



Setpoints

- Wishnick Hall monthly data:



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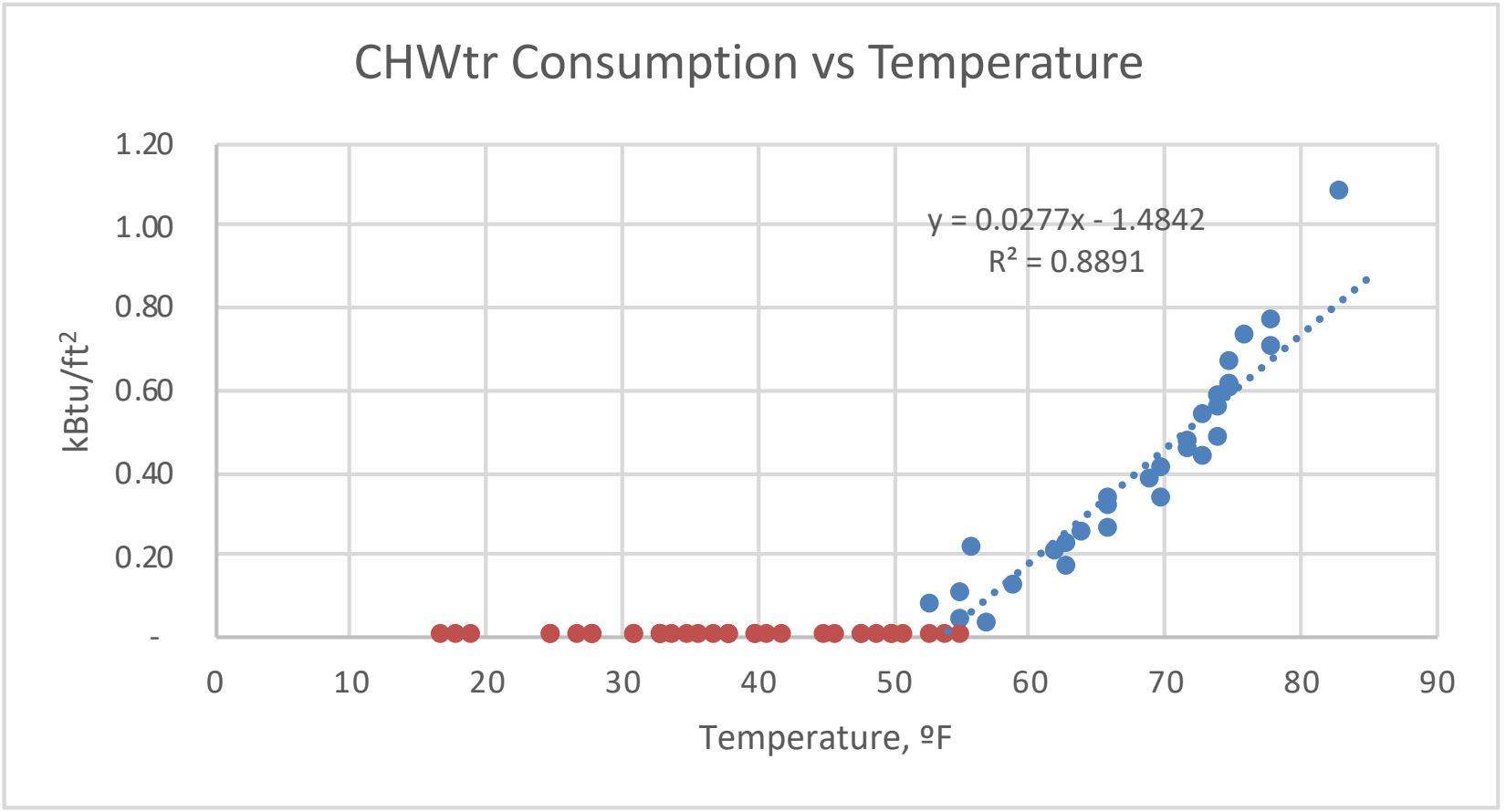


DESIGN VENTILATION

Outdoor Air

- Minimum outdoor air fraction very important

- EnergyPlus options:
  - OA per person (default 20 cfm)
  - OA per floor area
  - OA per zone
  - OA air change per hour
  - Use ~0.1-0.2CFM/ft^2 (or 20% design flow rate)
  - Look at floor plans & ASHRAE 62.1

INFILTRATION

Infiltration

- Infiltration options in E+:
  - Design Flow Rate:

$$Infiltration = \left(I_{Design}\right)\left(F_{Schedule}\right)[A + B[T_{Zone} - T_{Out}] + C(Wind\ Speed) + D(Wind\ Speed)]$$

  - Effective Leakage Area:

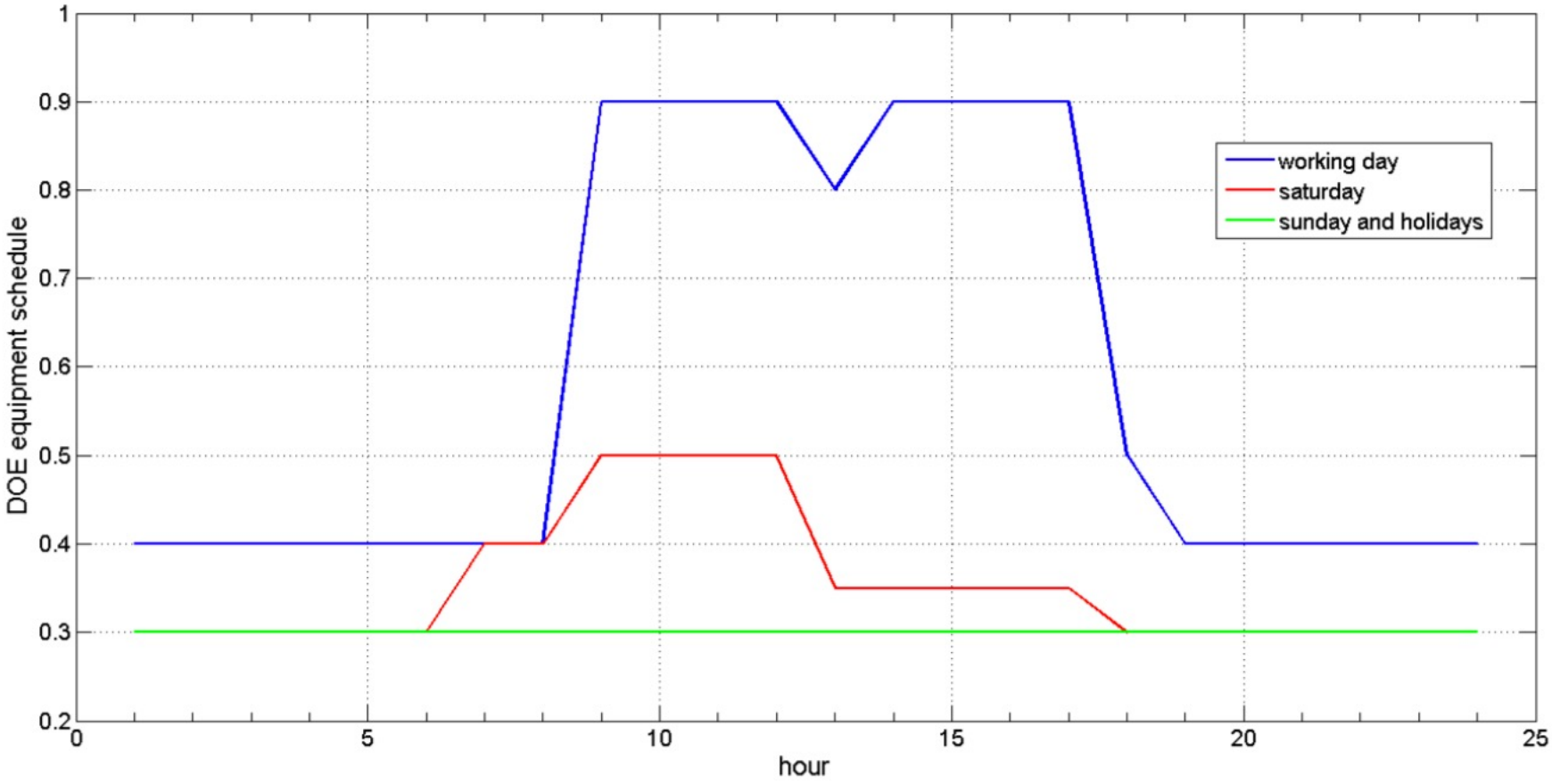
$$Infiltration = \left(F_{Schedule}\right)\frac{A_L}{1000}\sqrt{C_S\Delta T + C_W(Wind\ Speed)^2}$$

  - Flow Coefficient

$$Infiltration = \left(F_{Schedule}\right)\sqrt{(cC_S\Delta T^n)^2 + (cC_W(s \times Wind\ Speed)^{2n})^2}$$

PLUG LOAD

Plug Load Schedule



Is this close to the reality?

Salimifard, P, 2015, Masters Thesis, PSU

Plug Load Schedule

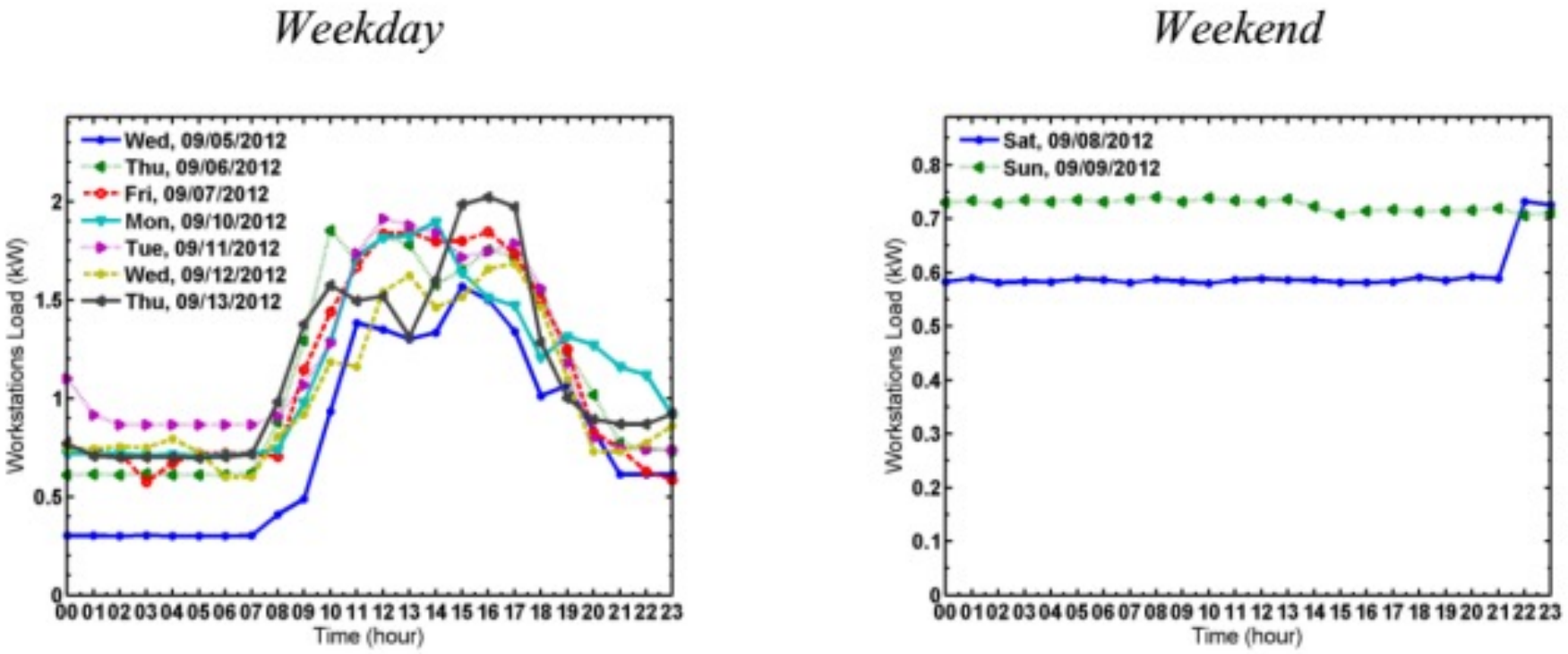


Figure 4. Plug load profiles for workstations.

Delogoshaei et al. (2013) Hourly plug load measurements... AEI 2013

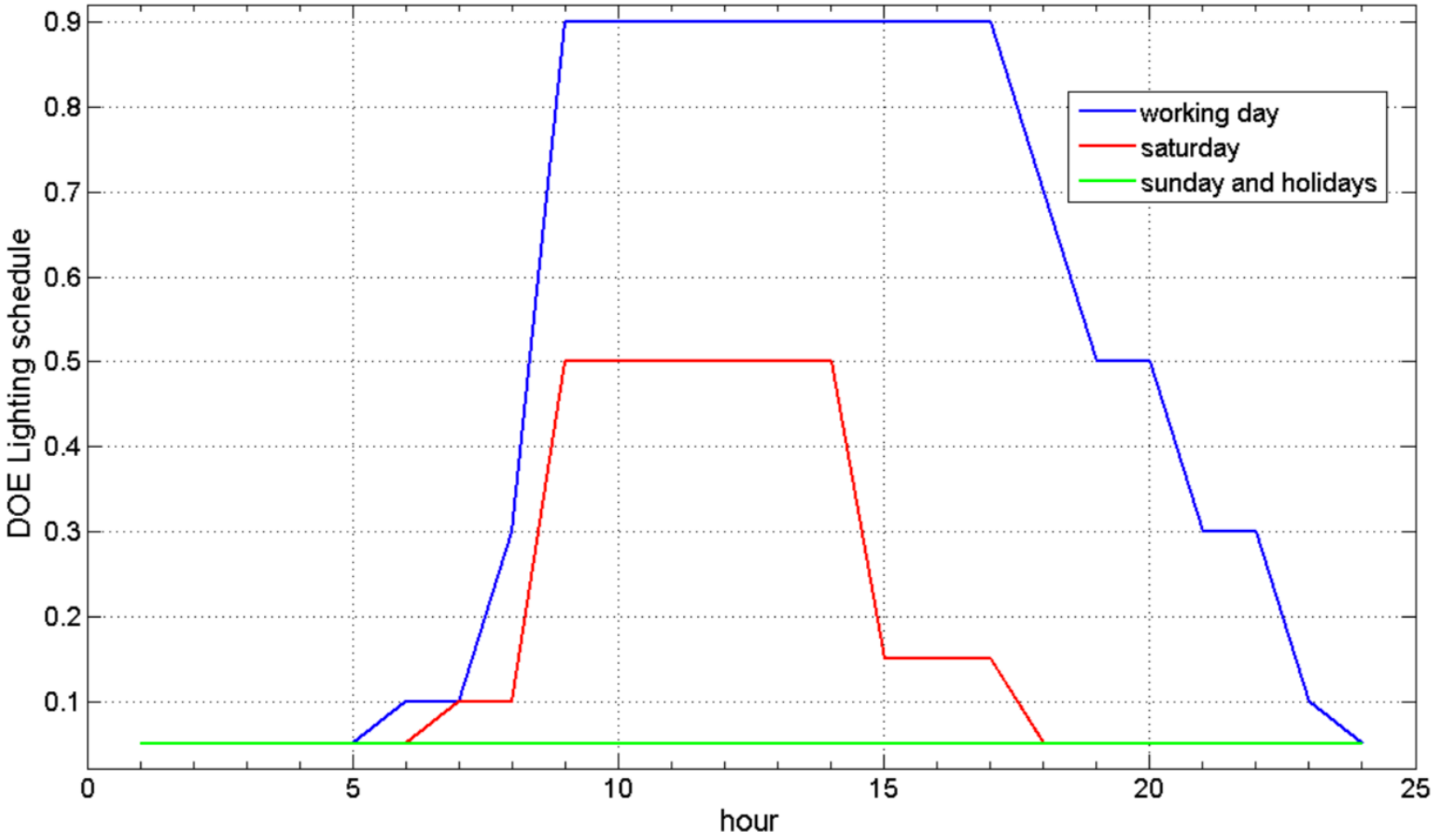
LIGHTING

Lighting Load

$f_{convected}$ = 1.0 – (Fraction Latent + Fraction Radiant + Fraction Lost)

Lighting Schedule

- Suggested DOE Reference building lighting schedule



Is this close to the reality?

Salimifard, P, 2015, Masters Thesis, PSU

Lighting Power Density

- Lighting Power Density (LPD)

TABLE 9.5.1 Lighting Power Densities Using the Building Area Method

Building Area Type[a]	*LPD* (W/ft^2)
Automotive facility	0.82
Convention center	1.08
Courthouse	1.05
Dining: bar lounge/leisure	0.99
Dining: cafeteria/fast food	0.90
Dining: family	0.89
Dormitory	0.61
Exercise center	0.88
Fire station	0.71
Gymnasium	1.00
Health-care clinic	0.87
Hospital	1.21
Hotel	1.00
Library	1.18
Manufacturing facility	1.11
Motel	0.88
Motion picture theater	0.83
Multifamily	0.60
Museum	1.06
Office	0.90
Parking garage	0.25
Penitentiary	0.97
Performing arts theater	1.39
Police station	0.96
Post office	0.87
Religious building	1.05
Retail	1.40
School/university	0.99
Sports arena	0.78
Town hall	0.92
Transportation	0.77
Warehouse	0.66
Workshop	1.20

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

Is this close to the reality?

ASHRAE 90.1-2010

Lighting Power Use

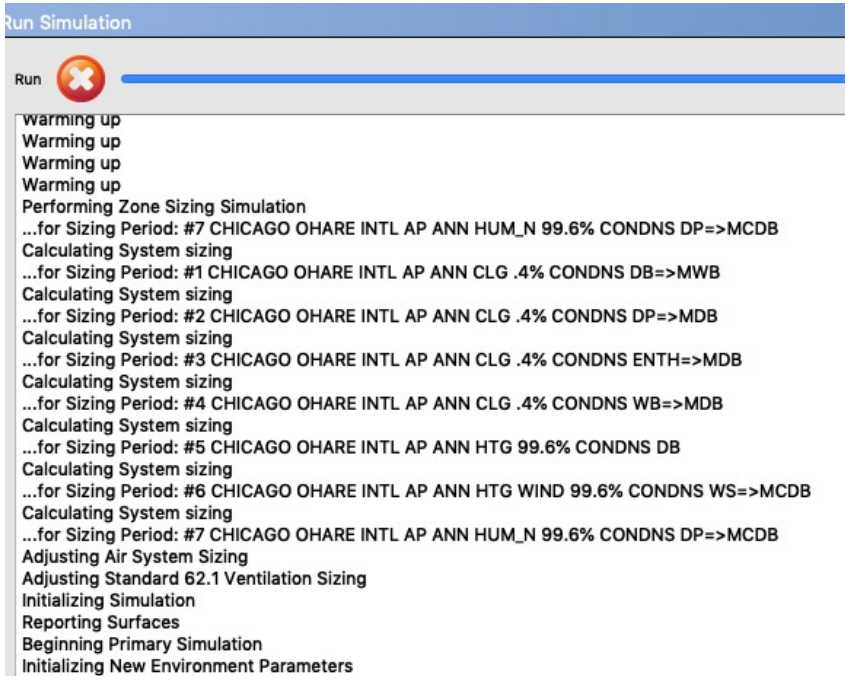
- Lighting power use is equal to =

$$Diversity\ Factor \times LPD \times Area$$

SIMULATION

Convergence Tolerances

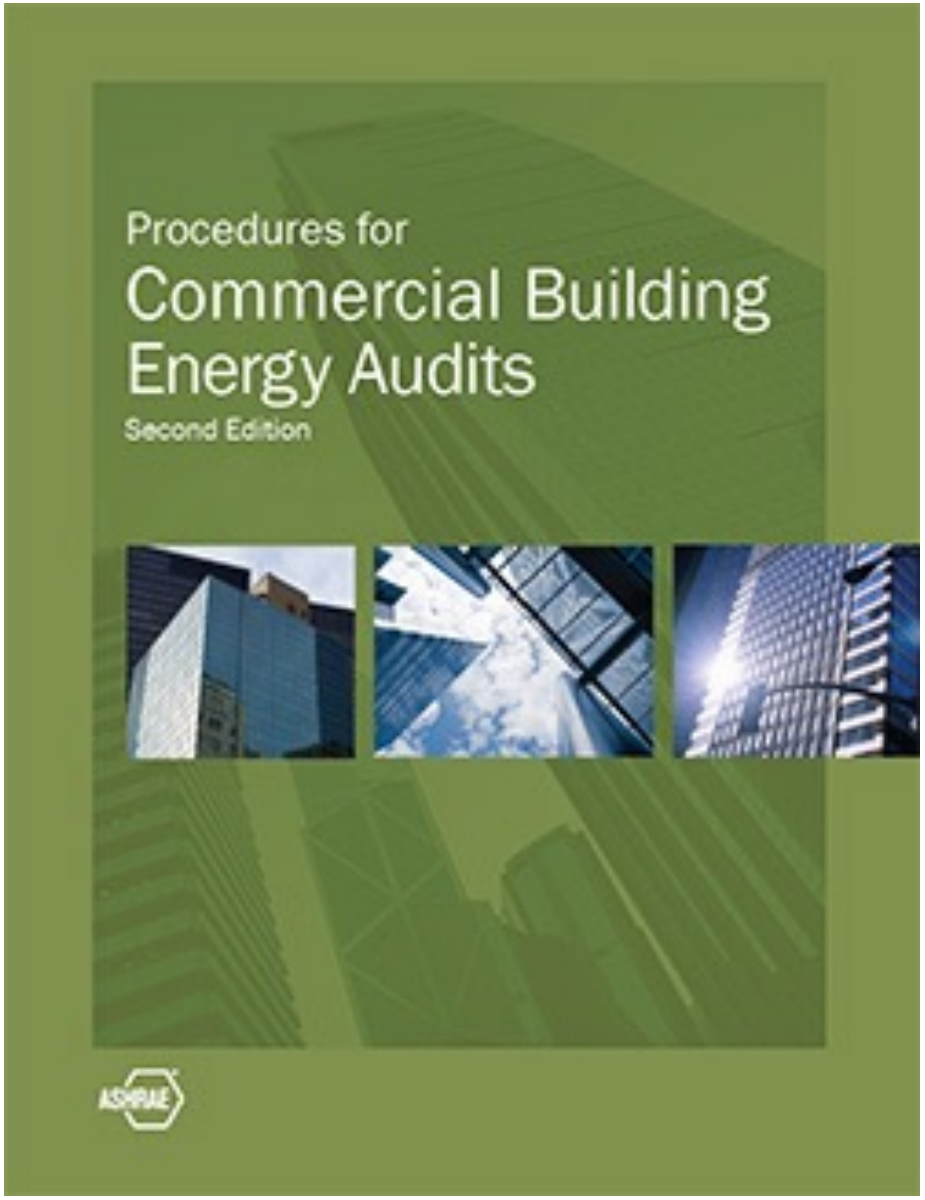
- Convergence tolerances during warm up days:
  - ❑ Design days or run periods repeat until the simulation reaches to the desired convergence tolerances
  - ❑ There will be a warning is the convergence is not met during the load calculations
  - ❑ It is possible to increase the number of warm up days



COMMERCIAL BUILDING ENERGY AUDITS

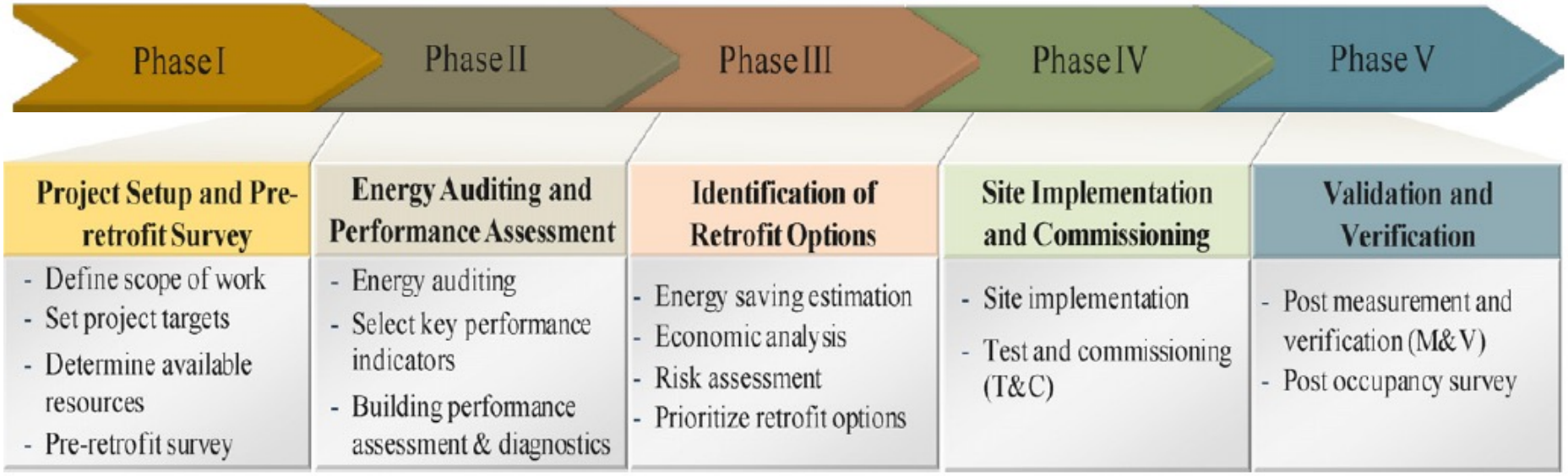
Reference: Procedures for commercial building energy audits, 2nd Edition, ASHRAE

Commercial Building Audits



Commercial Building Audits

- Suggested retrofit phases



Ma, Cooper, Daly, & Ledo, 2012

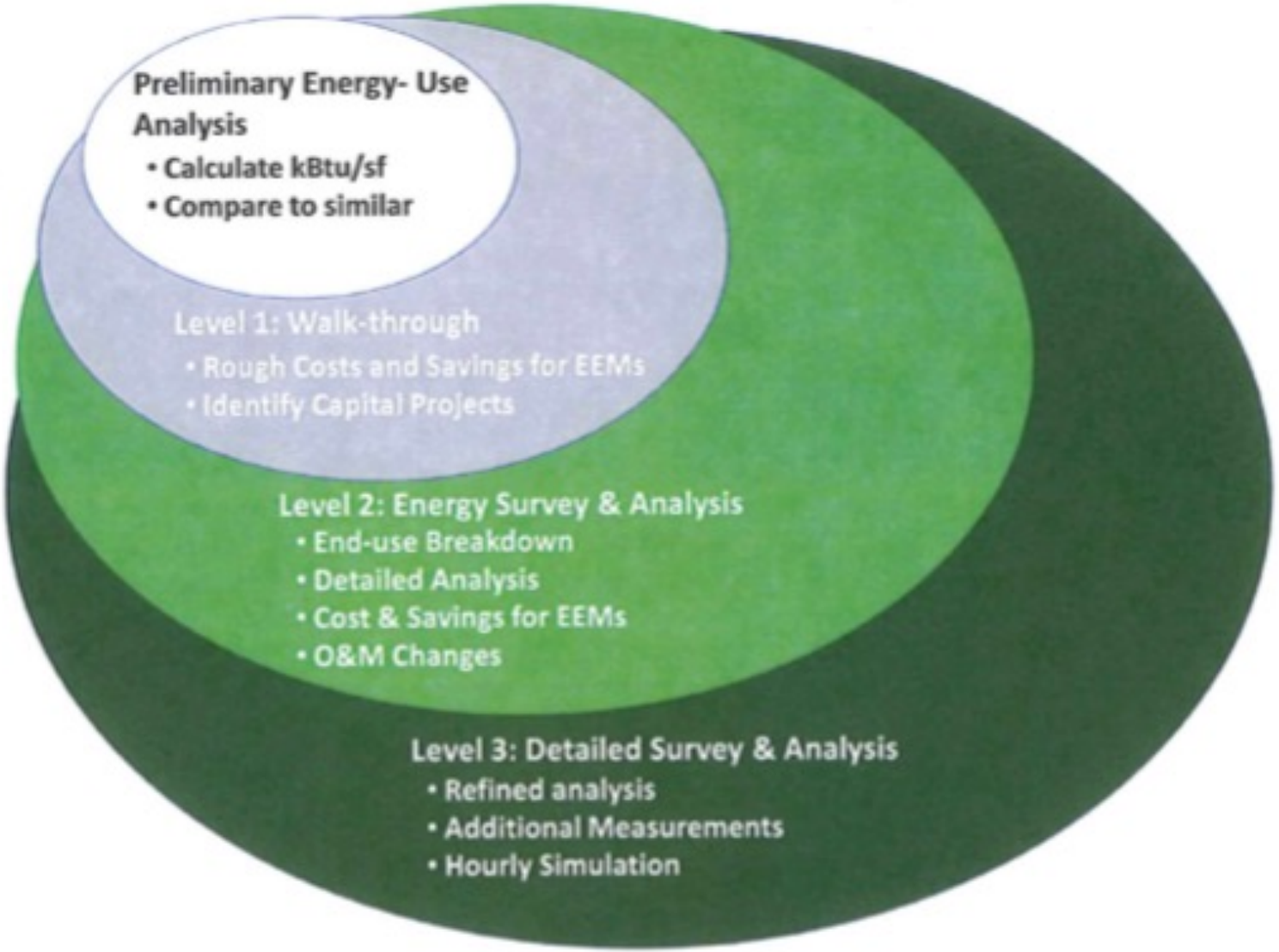
Commercial Building Audits

- A commercial building energy analysis has three levels of:
  - ❑ Level 1: Walkthrough analysis
  - ❑ Level 2: Energy survey analysis
  - ❑ Level 3: Detailed analysis of capital-intensive modifications

- There is a prerequisite for any audit named “Preliminary Energy-Use Analysis (PEA)”

- There are another category named “Targeted audits”

Commercial Building Audits



Procedures for commercial building energy audits, 2nd Edition, ASHRAE

Commercial Building Audits

- Requirements of Preliminary Energy Analysis (PEA) are to:
  - ❑ Analyze historic utility use, peak demand and cost
  - ❑ Develop Energy Cost Index (ECI) of the building in terms of $/ft^2-year
  - ❑ Develop EUI in kBtu/ft^2
  - ❑ Compare the EUI to the similar buildings
  - ❑ Analyze monthly data or interval data

Commercial Building Audits

- Level 1 (walkthrough) requirements are:
  - ❑ Assess energy and cost using data compiled in PEA
  - ❑ Conduct brief survey of the building
  - ❑ Identify low-cost/no-cost energy efficiency measures
  - ❑ Provide a list of capital improvements
  - ❑ Prioritize items for improvements in Level 2 and 3
  - ❑ Remember energy and cost saving calculations in this level are approximate

Commercial Building Audits

- Level 2 audit (energy, survey, analysis) includes:
  - ❑ Involve a more detailed building survey and breakdown of the end-uses
  - ❑ Identify more savings for all practical EEMs to meet the building owner and operator's constraints
  - ❑ Provide additional capital improvements that may require additional data collection

Commercial Building Audits

- Level 3 audits (detailed analysis of capital-intensive) include:
  - ❑ Focus on potential capital-intensive projects identified during Level 2 analysis
  - ❑ Require more field data gathering as well as more rigorous engineering and economic analyses
  - ❑ Often include modeling “simulation”
  - ❑ Go beyond Level 2 economic analysis and use Life-Cycle Cost Analysis (LCCA) for decision-making

Commercial Building Audits

- Targeted audits have different intensions. For example, it could consider:
  - ❑ Single energy-using system
  - ❑ Central plant
  - ❑ Area of the building (e.g., boiler control, lighting retrofit, chiller replacement)

Commercial Building Audits

- Energy audit required tasks comparisons:

Table 1 — Energy Audit Required Tasks

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

Procedures for commercial building energy audits, 2nd Edition, ASHRAE

Commercial Building Audits

- Energy audit required tasks:

Preliminary Energy Use Analysis	• Analysis of two or more years of utility consumption
Site Visit Procedures	• Activities to prepare for the on-site audit
Measurement	• Site visit and audit of building to collect data to quantifying operating parameters and performance
Analysis	• Description and analysis of the energy-using systems of the building • Can include a whole building energy model
Energy Efficiency Measure Types	• Classify and recommended energy efficient measures and bundle together synergistic measures
Economic Evaluation	• Evaluate the capital costs and life cycle cost analysis of efficiency measures and bundles of efficiency measures
Developing an Audit Report	• Provide complete information needed by an owner/operator to decide whether to implement recommended measures
Presentation	• Meet with the owner/operator to review the report, explain results and plan the next step
Implementing Measures	• Implement the chosen efficiency measures • Includes Measures & Verification and continuous commissioning

https://thergroupllc.com/services/energy-consulting/energy-auditing-service/

Commercial Building Audits

- Reporting format:

Report	Level		
	1	2	3
Estimate savings from utility rate change	•	•	•
Compare EUI to EUIs of similar sites	•	•	•
Summarize utility data	•	•	•
Estimate savings if EUI were to meet target	•	•	•
Estimate low-cost/no-cost savings		•	•
Calculate detailed end-use breakdown		•	•
Estimate capital project costs and savings		•	•
Complete building description and equipment inventory		•	•
Document general description of considered measures		•	•
Recommend measurement and verification (M&V) method		•	•
Perform financial analysis of recommended EEMs		•	•
Write detailed description of recommended measures			•
Compile detailed EEM cost estimates			•

Reference: Procedures for commercial building energy audits, 2nd Edition, ASHRAE

Commercial Building Audits

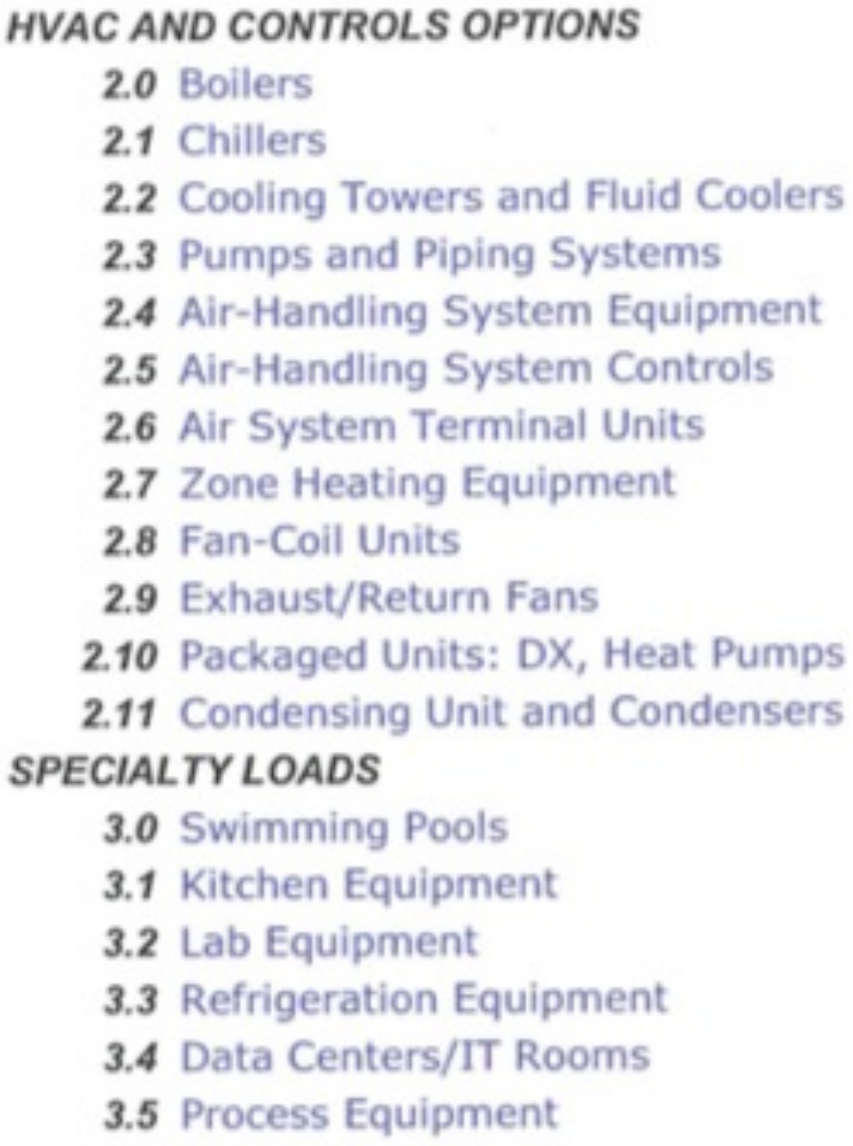
- ASHRAE Audit forms have different categories:

TABLE OF CONTENTS

PCBEA Sample Forms

Commercial Building Audits

- ASHRAE Audit forms have different categories:



HVAC AND CONTROLS OPTIONS

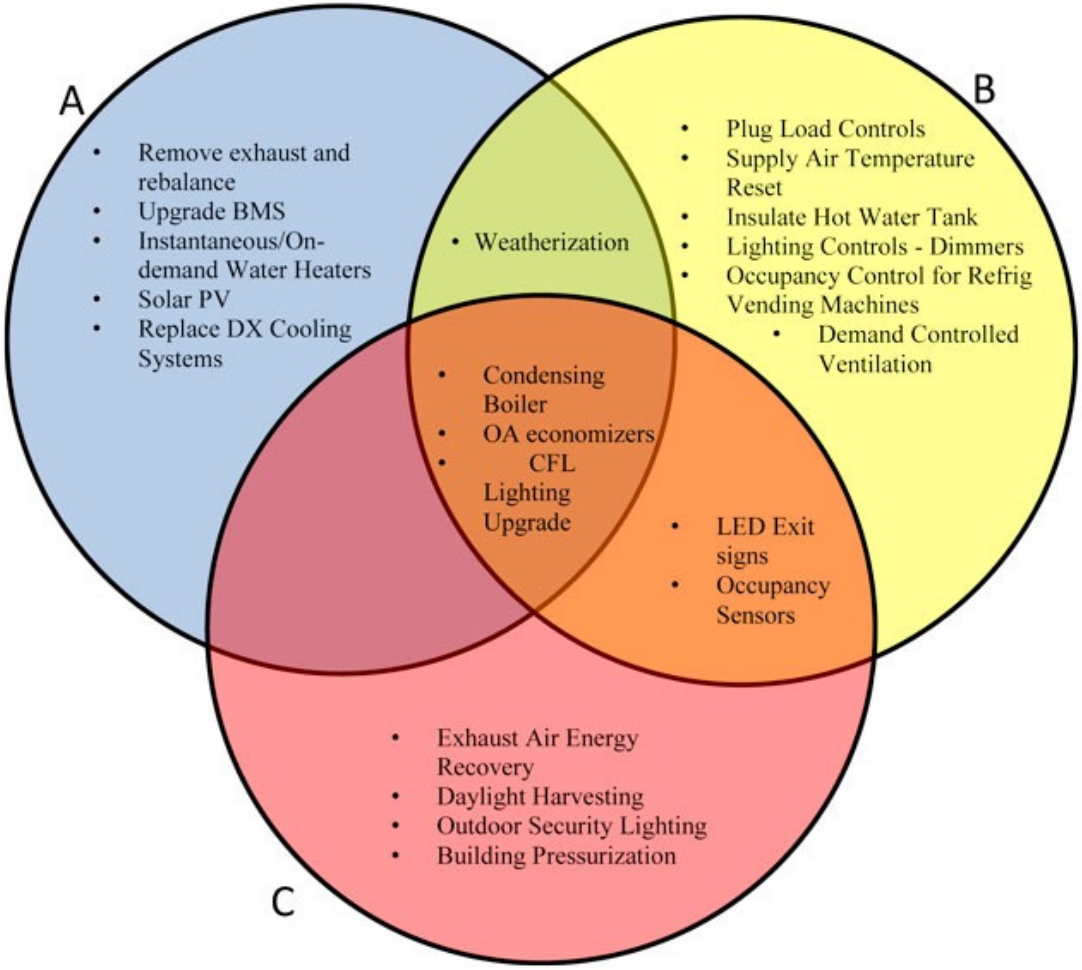
- ***2.0*** Boilers
- ***2.1*** Chillers
- ***2.2*** Cooling Towers and Fluid Coolers
- ***2.3*** Pumps and Piping Systems
- ***2.4*** Air-Handling System Equipment
- ***2.5*** Air-Handling System Controls
- ***2.6*** Air System Terminal Units
- ***2.7*** Zone Heating Equipment
- ***2.8*** Fan-Coil Units
- ***2.9*** Exhaust/Return Fans
- ***2.10*** Packaged Units: DX, Heat Pumps
- ***2.11*** Condensing Unit and Condensers

SPECIALTY LOADS

- ***3.0*** Swimming Pools
- ***3.1*** Kitchen Equipment
- ***3.2*** Lab Equipment
- ***3.3*** Refrigeration Equipment
- ***3.4*** Data Centers/IT Rooms
- ***3.5*** Process Equipment

Commercial Building Audits

- Can we assume all auditors suggest the same retrofit packages?



http://cbei.psu.edu/variation-in-energy-audits/

CLASS ACTIVITY

Class Activity

- Let's look at your project building

- Develop PEA and summarize the results in the file

https://docs.google.com/spreadsheets/d/1eUYbP00uv7EYl3cB5poRmNHMOfJb292LX-gPelbX1Yo/edit#gid=1992687020

RETURN OF INVESTMENT

Return of Investment

- The simple payback period:
  - ❑ Considered as an easy metrics to save if a given energy efficiency retrofit project or technology is viable
  - ❑ It is simple and often allow selecting low-hanging fruits
  - ❑ A payback of 3 years or less is favorable

$$Simple\ Payback\ Period = \frac{(Cost\ of\ Implementation - Rebate)}{Annual\ Savings}$$

https://www.forbes.com/sites/pikeresearch/2016/04/13/energy-efficient-building/#6fd887e748f8

Return of Investment

- Couple easy and important suggestions for using simple payback period
  - ❑ Making the case for funding
  - ❑ Rebates and incentives
  - ❑ Payback criteria
  - ❑ Using low- and no-cost measures
  - ❑ Evaluating performance contracting
  - ❑ The importance of measurement and verification

Simple Payback Period

- Setbacks with the simple payback methods:
  - ❑ Does not assess risk
  - ❑ Does not measure profit
  - ❑ Does not reflect the effects of interest
  - ❑ Does not consider government payback incentives
  - ❑ Does not consider inflation or fluctuation in energy prices
  - ❑ Does not account for budget verses actual performance

Return of Investment

- Anyone recall concepts in CAE 312 for net present value?

Year	Cost of Implementation (or Initial Investment) in $	Energy Savings ($)	Cumulative Cash Flow ($)
0	-150,000	-	-150,000
1	-	15,000	
2			
3			
4			
5			
6			
7			
8			
9			
10			

Beyond Simple Payback Period

- What are the other options beyond simple payback period?
  - ❑ Net Present Value (NPV)
  - ❑ Internal Rate Return (IRR)
  - ❑ Lifecycle Cost Assessment (LCC)

CLASS ACTIVITY

Class Activity

- Form a group of two and three
- Download this building energy audit:
  - http://documents.dps.ny.gov/public/Common/ViewDoc.aspx?DocRefId=%7B58254843-9043-4E02-8FBF-9704E4BEA7EC%7D
- Summarize the similarities and differences

https://docs.google.com/spreadsheets/d/1eUYbP00uv7EYl3cB5poRmNHMOfJb292LX-gPelbX1Yo/edit#gid=1108310639

BUILDING COMMISSIONING

Reference: ASHRAE Guideline 0 - 2019

Building Commissioning

ASHRAE Guideline 0-2019
(Supersedes ASHRAE Guideline 0-2013)
Includes ASHRAE addenda listed in Appendix Q

The Commissioning Process

See Informative Appendix Q for ASHRAE approval dates.

This Guideline is under continuous maintenance by a Standing Guideline Project Committee (SGPC) for which the Standards Committee has established a documented program for regular publication of addenda or revisions, including procedures for timely, documented, consensus action on requests for change to any part of the Guideline. Instructions for how to submit a change can be found on the ASHRAE® website (https://www.ashrae.org/continuous-maintenance).

The latest edition of an ASHRAE Guideline may be purchased from 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.

 ISSN 1049-894X

Building Commissioning

- Building commissioning is the professional practice to ensure buildings operation is according the owner's project requirements

https://www.wbdg.org/building-commissioning

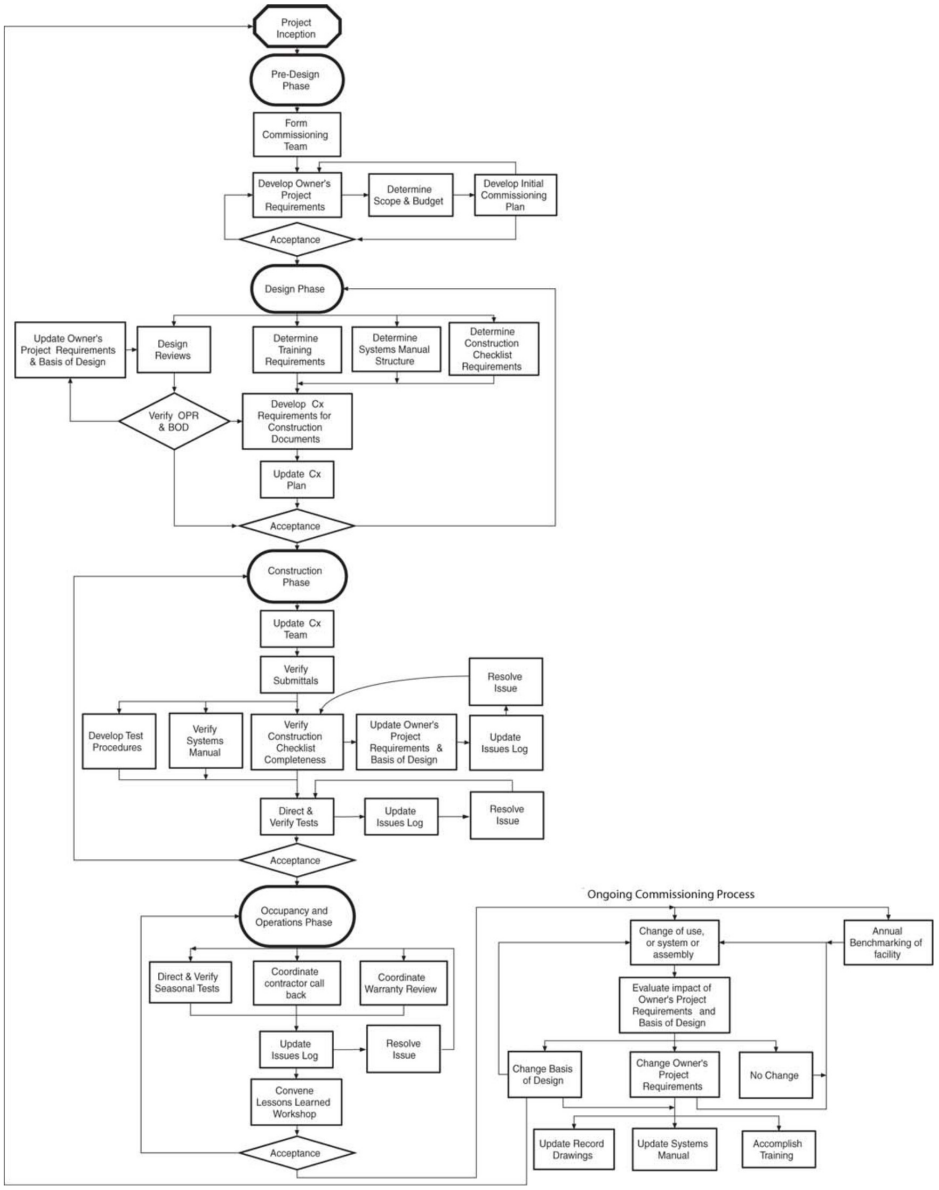
Building Commissioning

- The goals are:
  - ❑ Deliver buildings that meet the owner's project requirements
  - ❑ Prevent/eliminate problems inexpensively through proactive approaches
  - ❑ Verify systems are installed and working correctly
  - ❑ Benchmark that correct operation of the systems
  - ❑ Lower overall first costs and life-cycle costs for the owner
  - ❑ Provide documentation and records on the design, construction, and testing to facilitate operation and maintenance of the facility
  - ❑ Implement trend logs, automated and semi-automated commissioning
  - ❑ Maintain facility performance for the building's entire life cycle

https://www.wbdg.org/building-commissioning

Building Commissioning

- The Cx flowchart:



Building Commissioning

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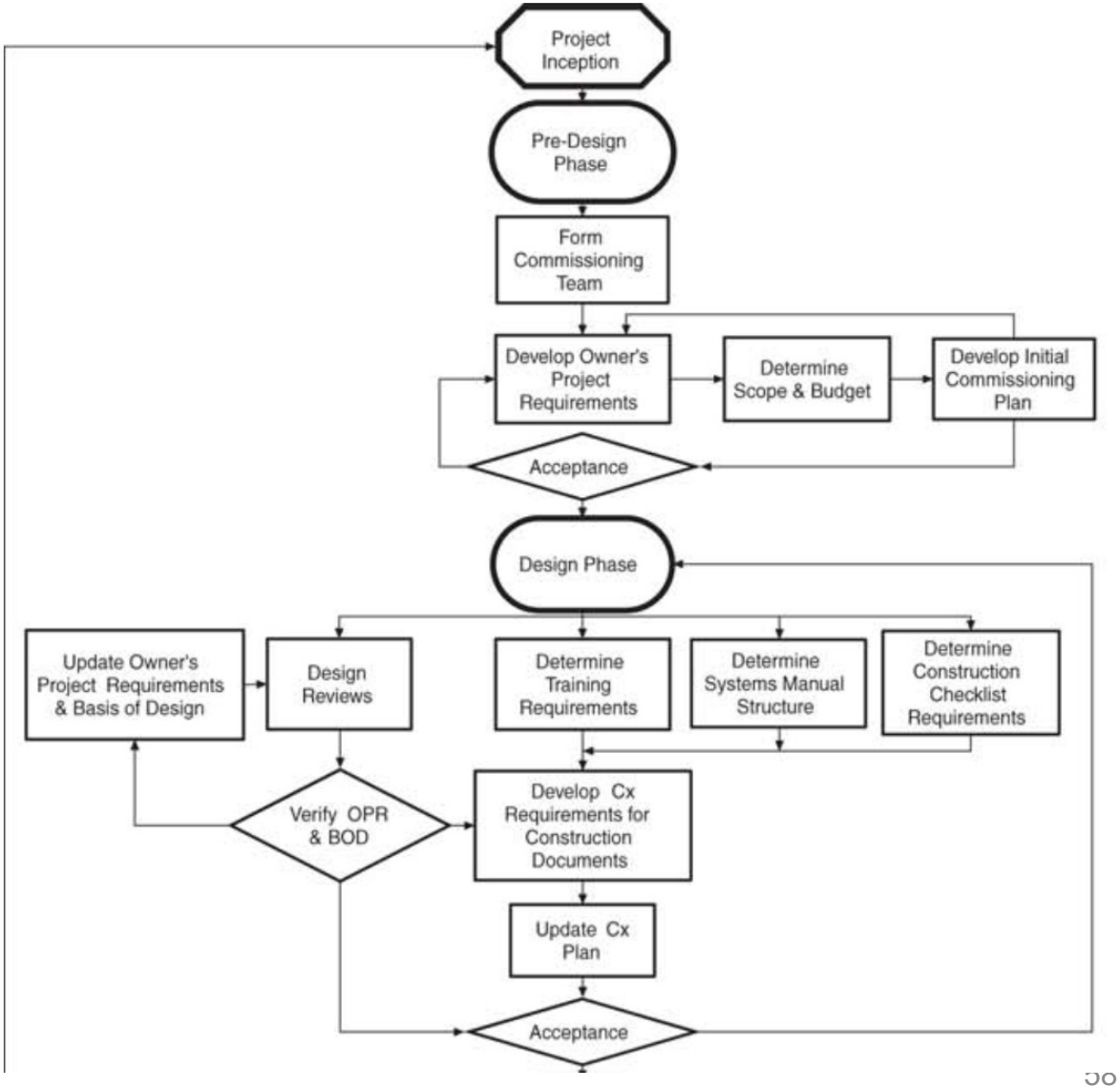

Building Commissioning

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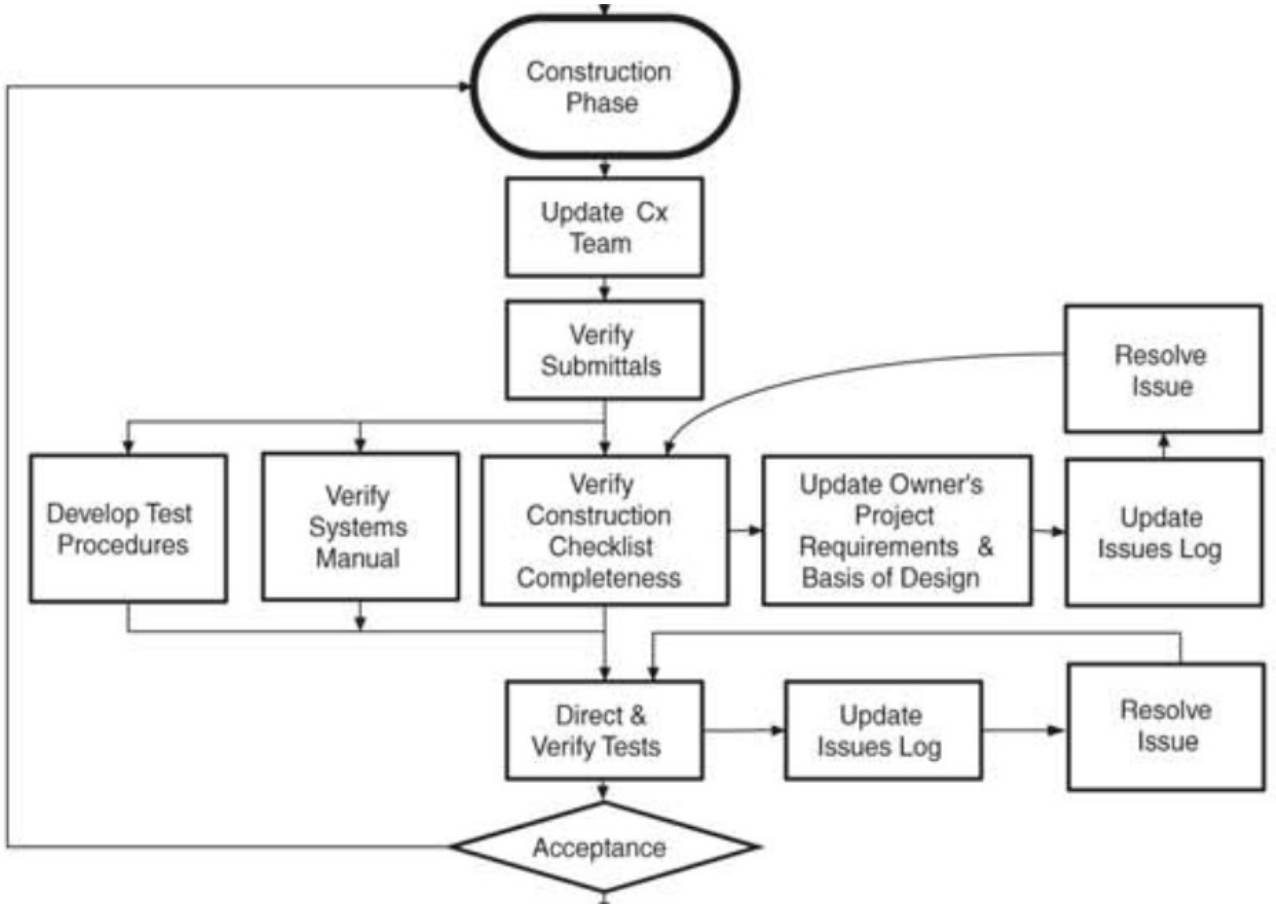

Building Commissioning

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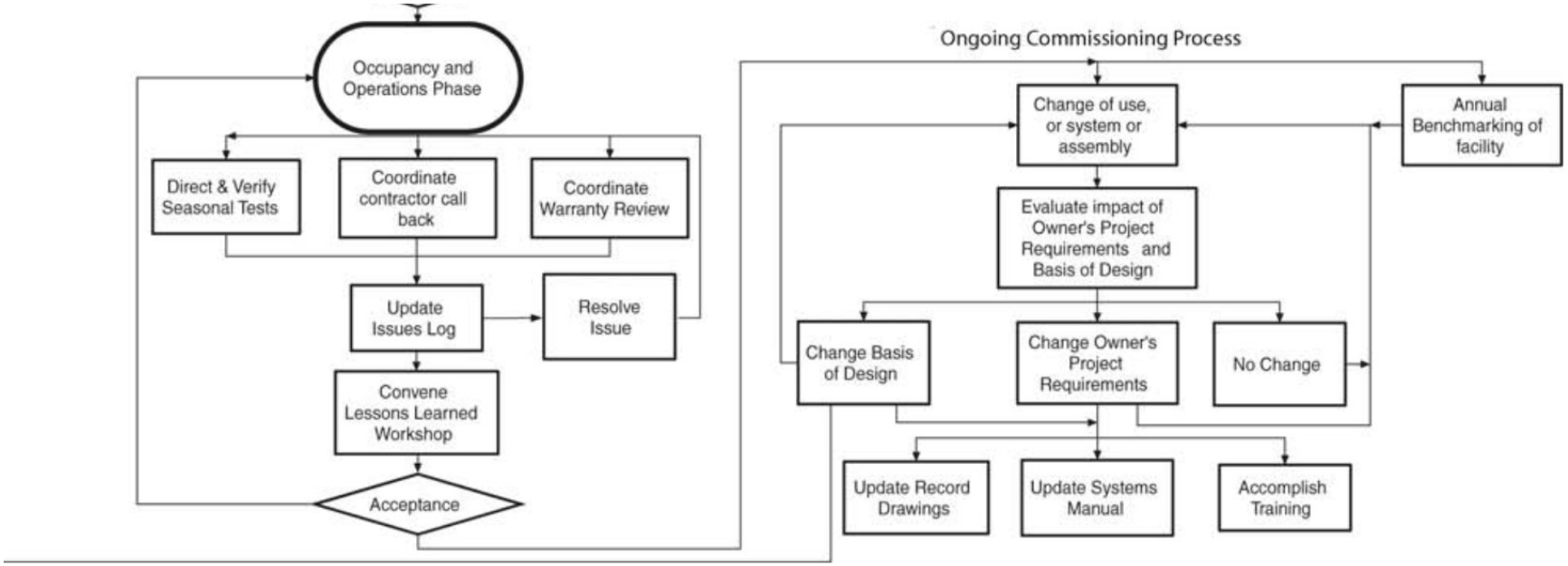


Building Commissioning

- Documentation matrix

Phase	Document	Input By	Provided By	Reviewed/ Approved By	Used By	Notes
Predesign	OPR	O&M, users, capital projects, Design Team (?)	CxP or designer	Owner	CxP, Design Team	Design Team may not be hired yet.
	Cx Plan	Owner, Design Team (?), CxP	CxP	Owner	CxP, Owner, Design Team	Design Team may not be hired yet.
	Systems Manual outline	O&M, CxP	Owner or CxP	Owner	Design Team	May be included in OPR.
	Training Requirements outline	O&M, users, CxP, Design Team	Owner or CxP	Owner	Design Team	May be included in OPR.
	issues and resolution log	CxP	CxP	N/A	CxP, Design Team	May be only format at this phase.
	Issues report	CxP	CxP	Owner	Design Team, Owner	
	Predesign Phase Cx Report	CxP	CxP	Owner	Owner	Close of phase report
Design	OPR update	O&M, users, capital projects, Design Team	CxP or designer	Owner	CxP, Design Team	
	BoD	Design Team	Design Team	Owner, CxP	Design Team, CxP	
	Construction specifications for Cx	Design Team, CxP, Owner	Design Team or CxP	Owner	Contractors, CxP, Design Team	May also be provided by project manager or Owner's rep.
	Systems Manual outline (expanded)	Design Team, CxP, O&M, contractor (?)	Design Team or CxP	Owner, CxP	Design Team, contractor	Contractor may not be hired yet.
	Training requirements in specifications	O&M, users, CxP, Design Team	Owner or CxP	Owner	Design Team	Contractor may not be hired yet.
	Design review comments	CxP	CxP	Owner	Design Team	
	Issues and resolution log	CxP	CxP	N/A	CxP, Design Team	
	Issues report	CxP	CxP	Owner	Design Team, Owner	
	Design Phase Cx Report	CxP	CxP	Owner	Owner	Close of phase report
Construction	OPR update	O&M, users, capital projects, Design Team	CxP or designer	Owner	CxP, Design Team, contractors	
	BoD update	Design Team	Design Team	CxP, Owner	Design Team, CxP	

Notes:

a. The term "contractor" is understood to refer to any of several entities that provide construction services. Depending on the project, this could include, among others, the Owner's representative, construction manager, contractors, and subcontractors.

b. Abbreviations: BoD = Basis of Design; Cx = Commissioning Process; CxP = Cx Provider; O&M = operations and maintenance; OPR = Owner's Project Requirements.

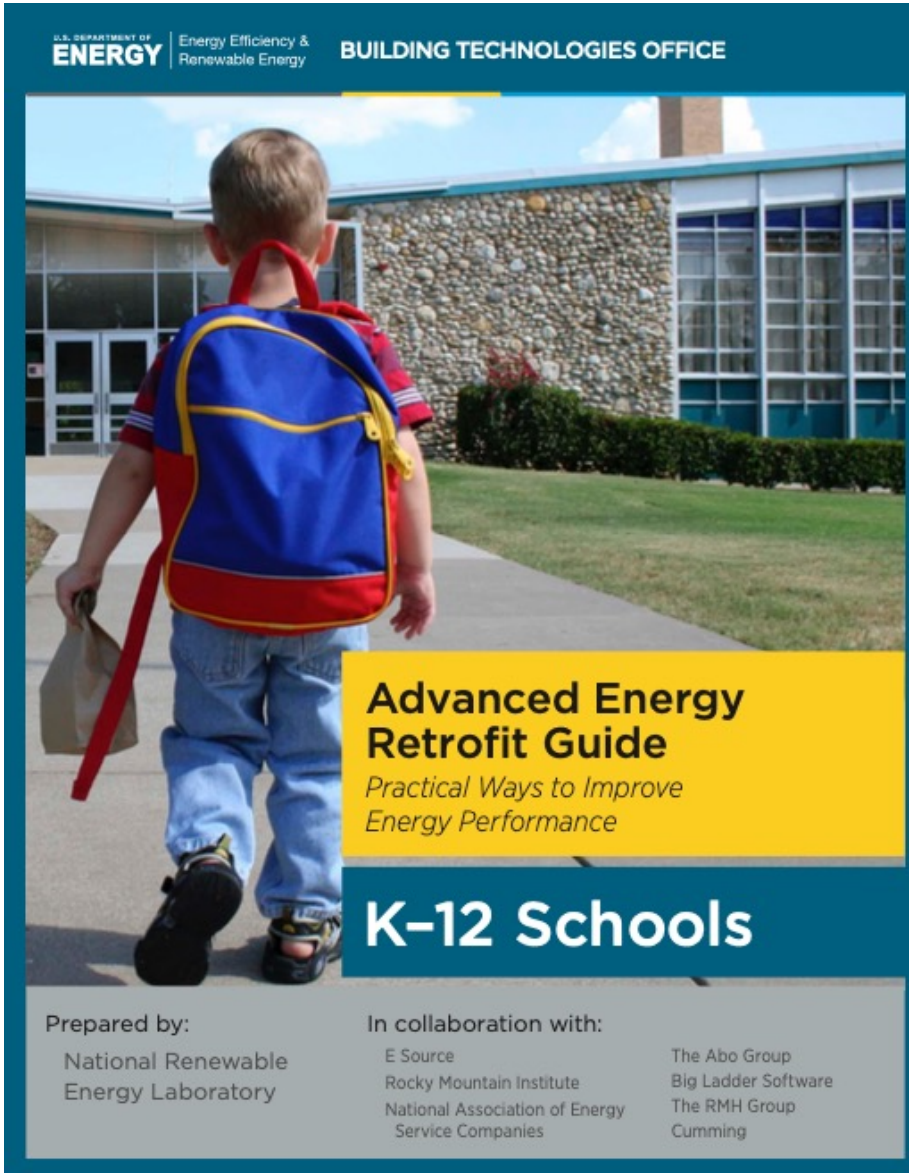
RETROFIT PATH DEVELOPMENT

Retrofit Path Development

- 50% of commercial buildings built before 1980 in the U.S.
  - ❑ Comply with the old building codes
  - ❑ Tend to have limited options for operational changes

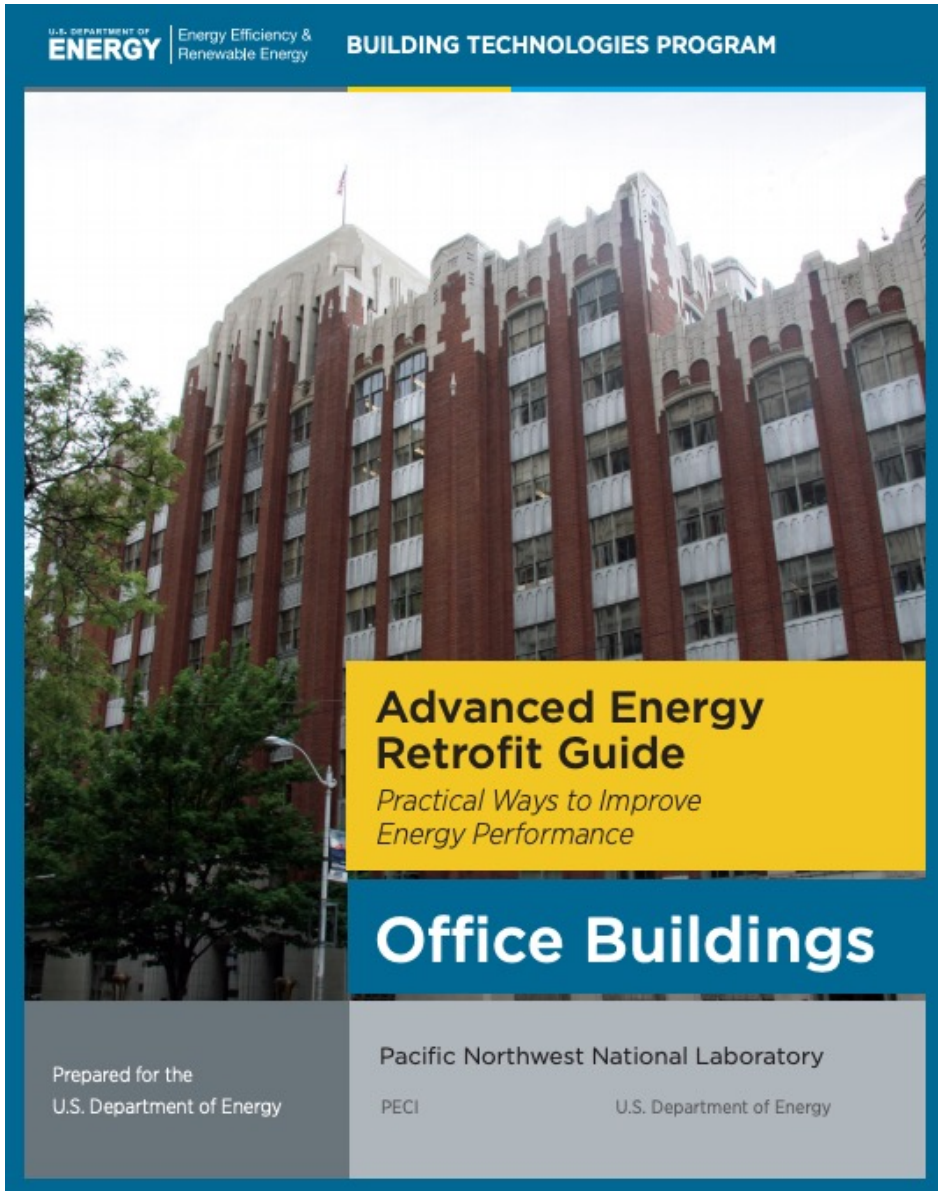
- Retrofitting older buildings is one of the practical paths to reduce energy consumptions

Retrofit Path Development



https://buildingdata.energy.gov/cbrd/resource/17

Retrofit Path Development

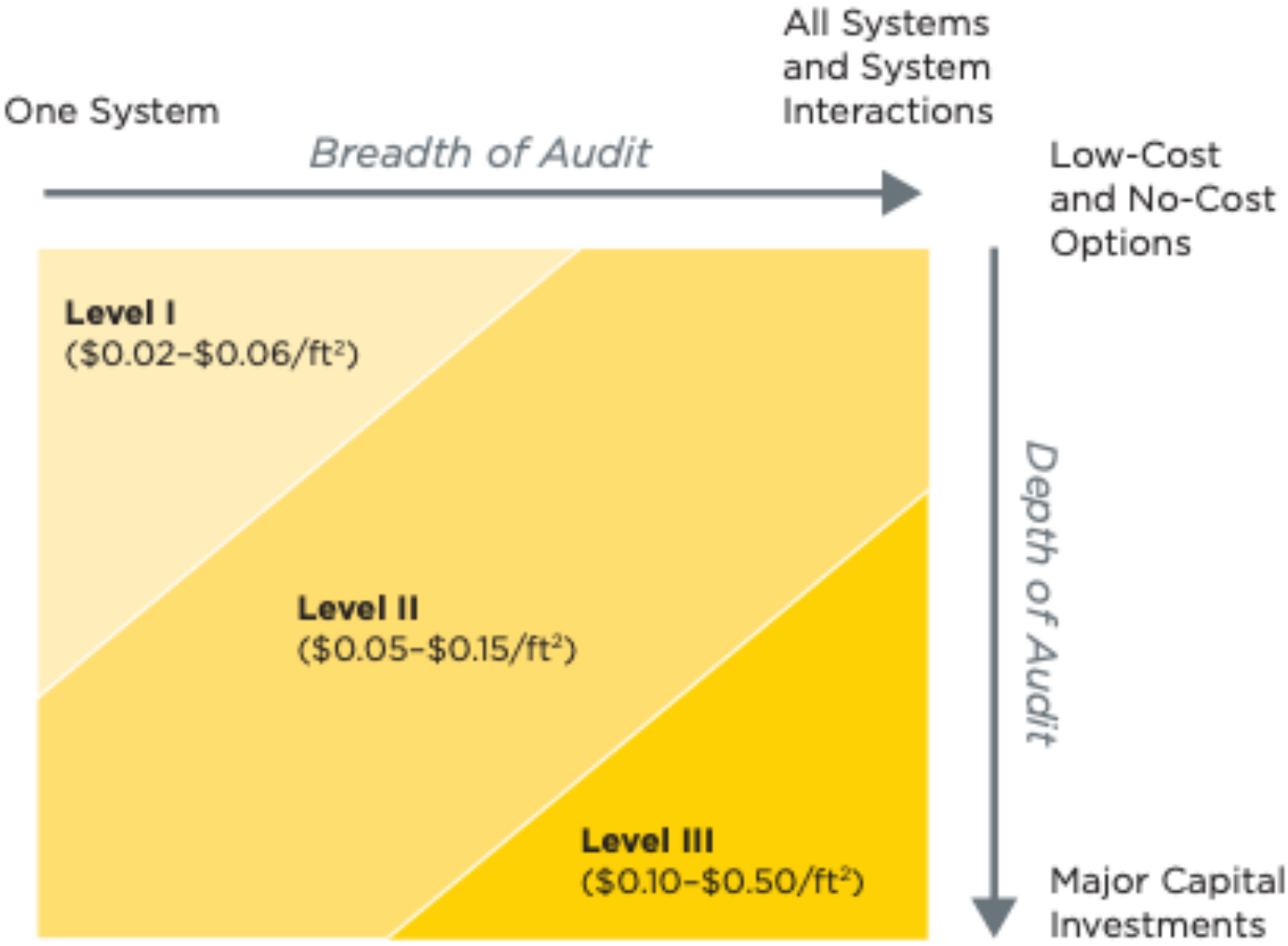


Retrofit Path Development

- Use benchmark plans to set the goals:
  - ❑ Best in class
  - ❑ Performance goal
  - ❑ Baseline
  - ❑ Above average
  - ❑ Commissioned performance level
  - ❑ National ratings

https://www.energystar.gov/sites/default/files/buildings/tools/EPA_BUM_Full.pdf

Retrofit Path Development



What would be the cost of auditing AM Hall building?

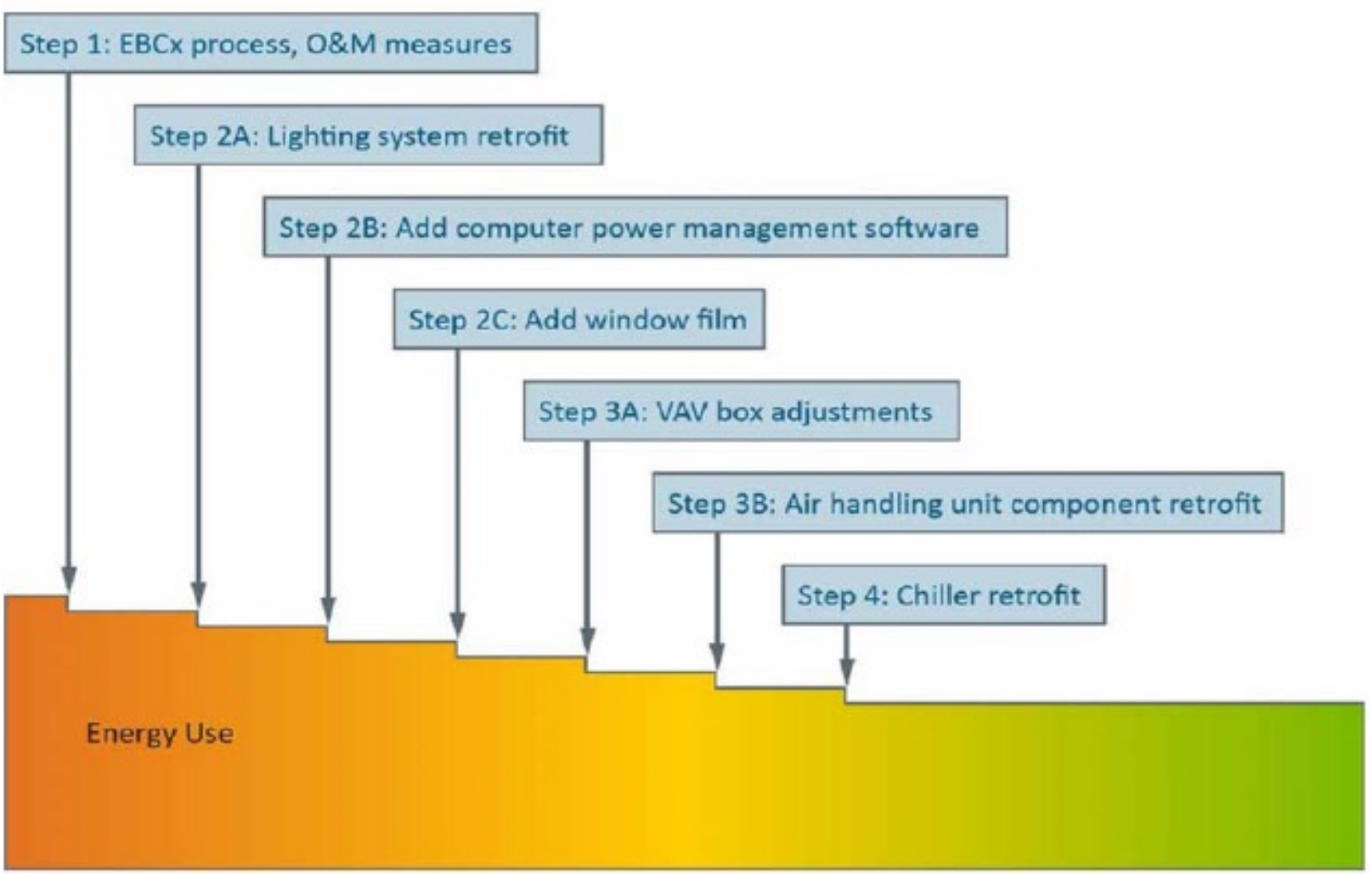
Retrofit Path Development

Table 2–6 Types of Energy Audits

Audit Type	Accounts for Interactions?	Application Notes
Preliminary analysis	No	Indicates overall potential for improvement
Walk-through analysis	No	Identifies no-cost and low-cost EEMs
Single system/targeted audit	No	Considers single systems in detail
Investment-grade audit	Yes	Accounts for interactions between building systems

Retrofit Path Development

- Why do we consider this path?



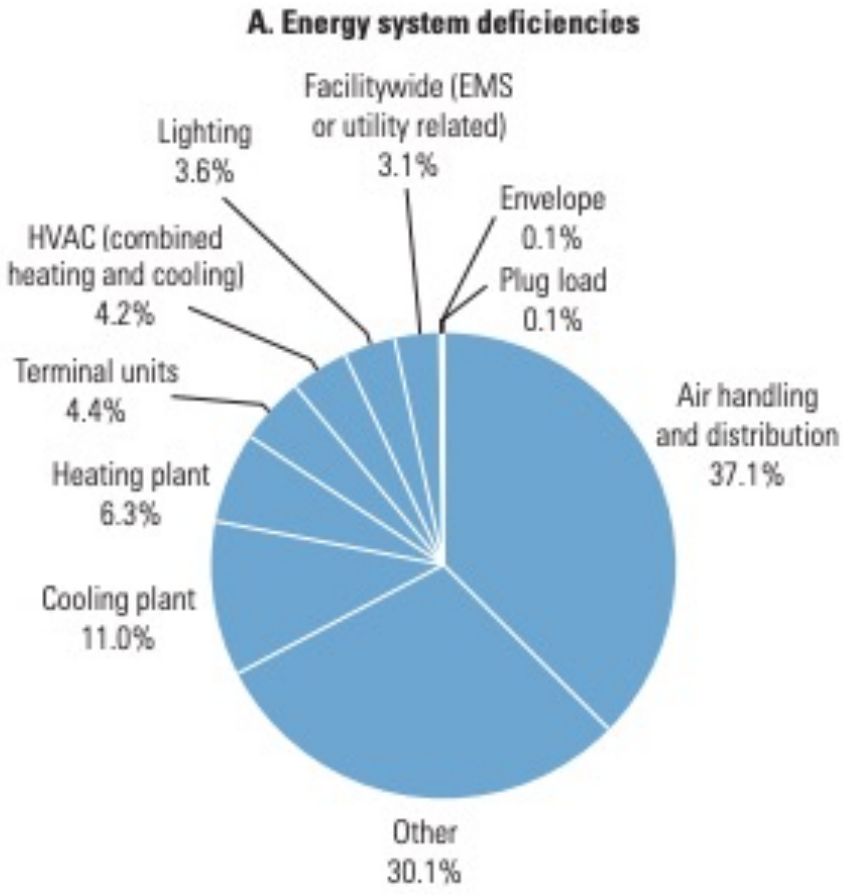
ADEG, PNNL 2011

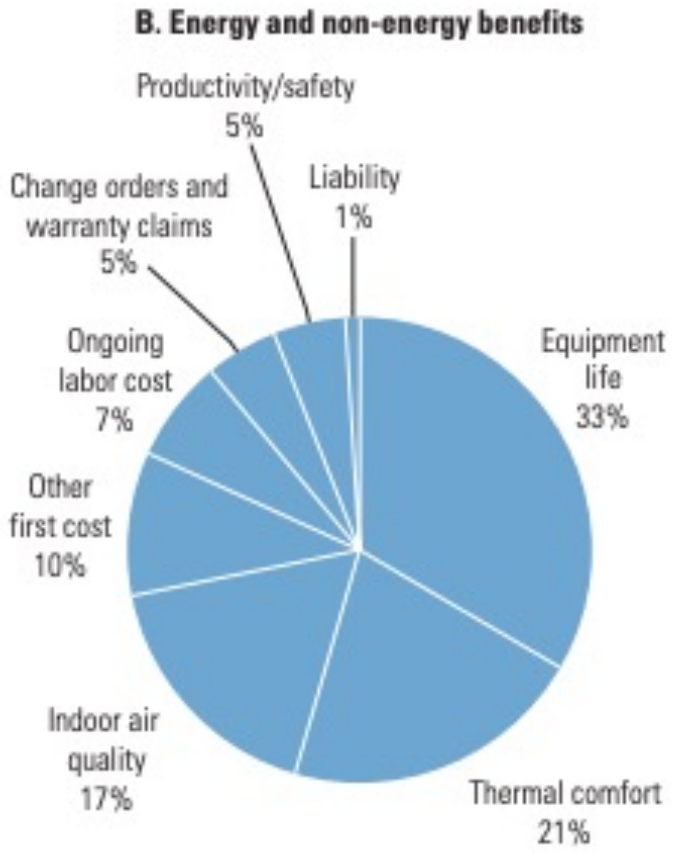
Retrofit Path Development

- Common retrofit path options:
  - ❑ Low-cost and not Existing Building Commissioning (EBCx)
    - Cost effective
    - Options such as targeted tune-ups, comprehensive EBCx, monitoring-base/ongoing commissioning (MBCx)
  - ❑ Whole-building comprehensive retrofits
    - Usually implement in a short span of time
    - Expensive
  - ❑ Staged retrofit
    - Benefit from incremental savings
    - Similar savings are achieved
  - ❑ Targeted retrofit
    - Focused on one or a few objectives

Retrofit Path Development

- A summary of common problems in buildings





https://www.energystar.gov/sites/default/files/buildings/tools/EPA_BUM_Full.pdf

CLASS ACTIVITY

Class Activity

Description	Your Building
Basic site information	
Owner/operator	
Expectation constraints	
Capital improvement ($, budget)	
Operational/energy cost ($)	
Building envelope (wall, window, roof)	
Exterior light (type/wattage)	
Interior light (type/wattage)	
Domestic hot water (fuel, flow rate, capacity)	
HVAC types (Boiler, chiller, …)	
Energy end-use breakdowns (%)	
Suggested EEM (list ten EEMs)	

https://docs.google.com/spreadsheets/d/1eUYbP00uv7EYl3cB5poRmNHMOfJb292LX-gPelbX1Yo/edit#gid=611824012