Building Commissioning and Energy Efficiency

AEE Georgia Chapter Meeting
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Agenda

- What is Commissioning?
  - Definitions &Goals
  - Guidelines &Certifications
- Commissioning and Energy Efficiency
  - Review of comprehensive study on building commissioning and energy efficiency and ghg reductions
  - "Building commissioning: a golden opportunity for reducing energy costs and greenhouse gas emissions in the United States"
- Sample Deficiencies from Recent Projects

An Overview of Building Systems Commissioning

Commissioning- ASHRAE

"A quality-focused process for enhancing the delivery of a project. The process focuses upon verifying and documenting that all of the commissioned systems and assemblies are planned, designed, installed, tested, operated, and maintained to meet the Owner's Project Requirements."

- Guideline 0-2019, *The Commissioning Process*
- ASHRAE/IES Standard 202-2018, *Commissioning Process for Buildings and Systems*

Definition – WBDG*

"Building Commissioning is the professional practice that ensures buildings are delivered according to the Owner's Project Requirements (OPR)."

- Buildings that are properly commissioned typically have fewer change orders, tend to be more energy efficient, and have lower operation and maintenance cost.
- The documentation of the commissioning process provides the foundation for correctly benchmarking the baseline energy consumption of the facility.

Whole Building Design Guide: The WBDG Workgroup consists of representatives from over 15 agencies including the Department of Defense (NAVFAC Engineering Innovation and Criteria Office, Army Corps of Engineers, Air Force Civil Engineer Center), Department of Veterans Affairs, Department of Energy, General Services Administration (GSA), Department of Homeland Security and Department of State Bureau of Overseas Buildings Operations (OBO).

Commissioning Goals

- The primary goal of commissioning any project is to ensure that success for the project is clearly defined in the OPR* and that the building performs as intended to fulfill that mission. The definition accurately depicts commissioning as a holistic process that spans from **pre-design planning to occupancy and operations** at a minimum and should also include ongoing commissioning. Accordingly, the goals of commissioning are to:

Commissioning Goals

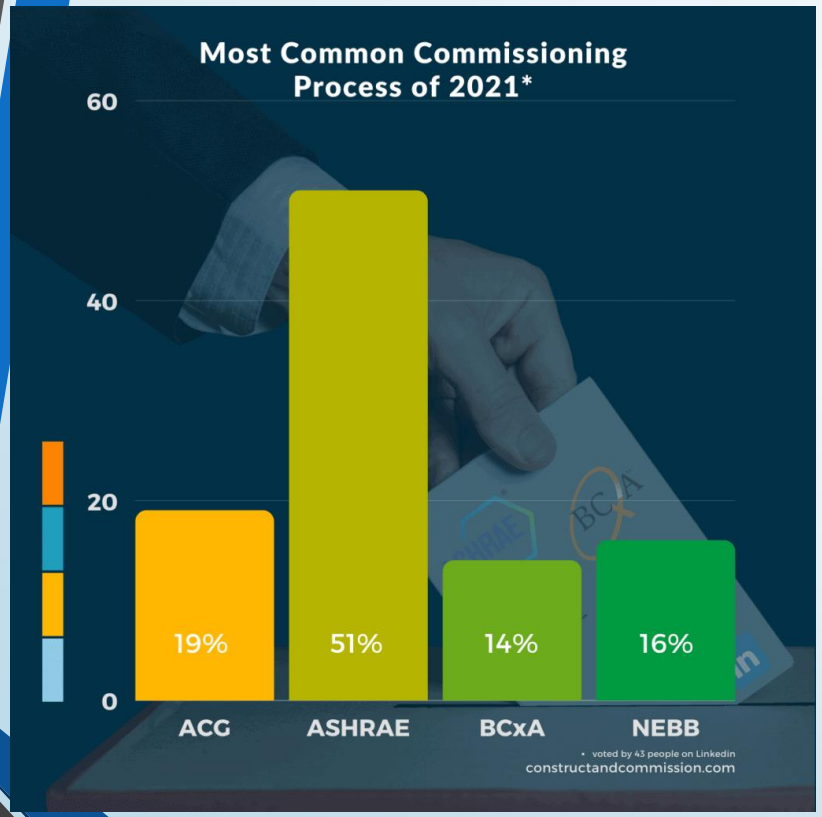
- Deliver buildings and construction projects that meet the owner's project requirements.
- Prevent or eliminate problems inexpensively through proactive quality techniques.
- Verify systems are installed and working correctly and benchmark that correct operation.
- Lower overall first costs and life-cycle 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 Cu tools to enable O&M staff ongoing Cu.
- Maintain facility performance for the building's entire life cycle

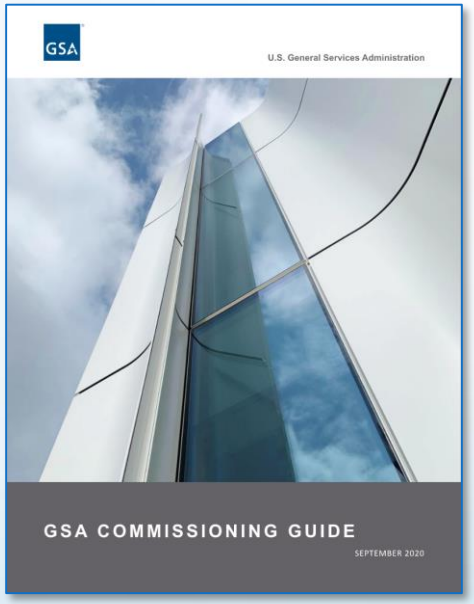
Commissioning Certifications*

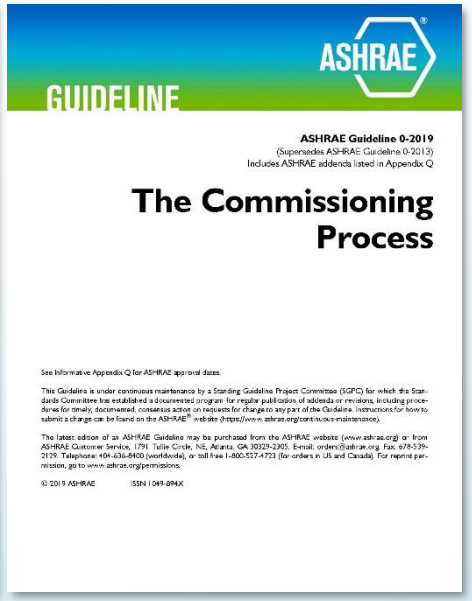
Title	Acronym	Organization
Certified Commissioning Authority	**CxA**	ACG - AABC Commissioning Group
Certified Building Commissioning Professional	**CBCP**	AEE - The Association of Energy Engineers
Building Commissioning Professional Certification	**BCXP**	ASHRAE -The American Society of Heating, Refrigerating and Air-Conditioning Engineers
Certified Commissioning Professional	**CCP**	Bae - Building Commissioning Association
Building System Commissioning Certified Professional	**CxCP**	NEBB - National Environmental Balancing Bureau
Qualified Commissioning Process Provider	**QCxP**	University of Wisconsin–Madison

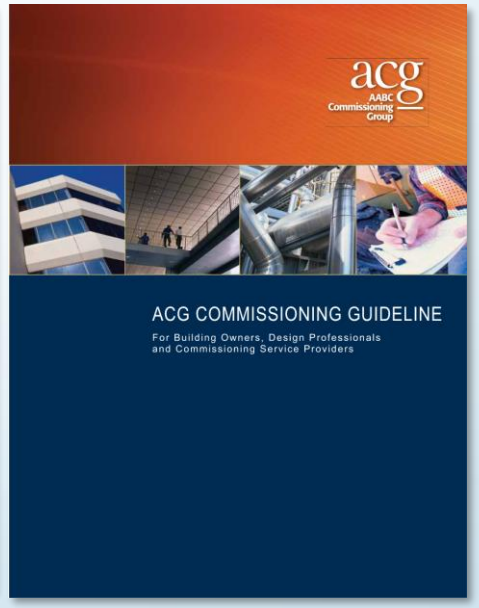
*This is not an exhaustive list

Various Commissioning Guidelines Exist



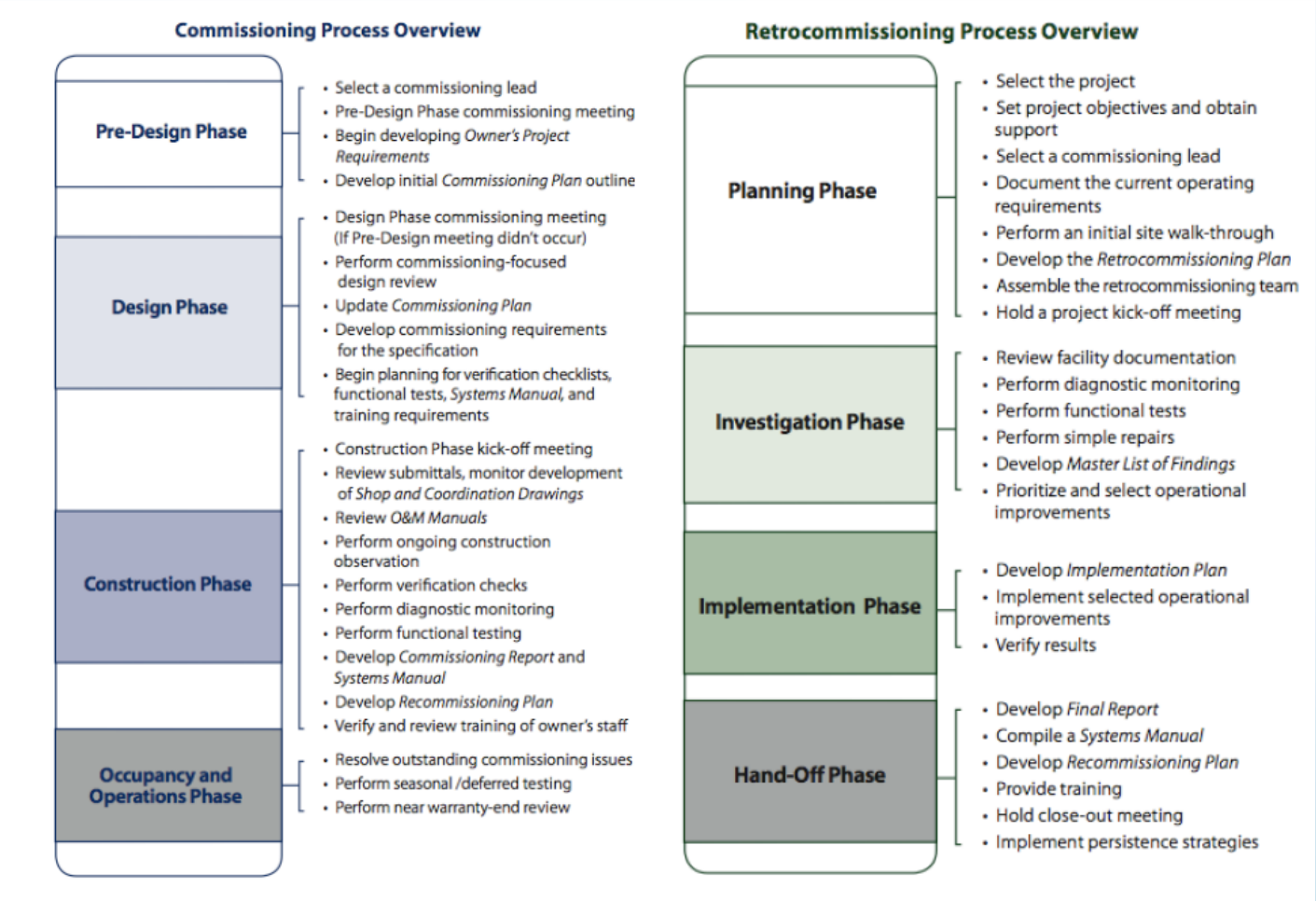






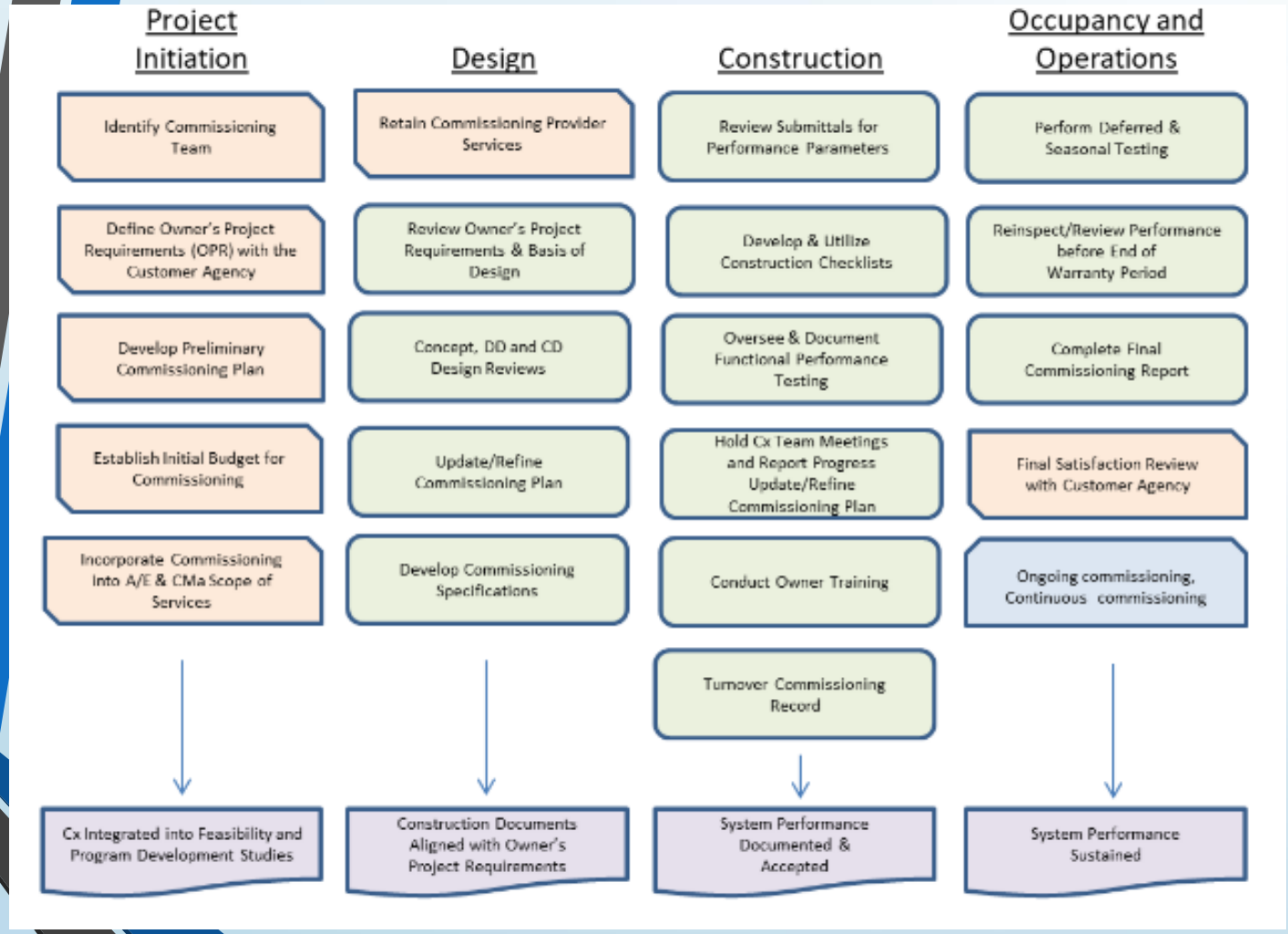
Data Source:
constructandcommission.com
LinkedIn Survey N=43

Commissioning Process Overviews



Mills, E. Building commissioning: a golden opportunity for reducing energy costs and greenhouse gas emissions in the United States. Energy Efficiency 4, 145–173 (2011). https://doi.org/10.1007/s12053-011-9116-8S

The Building Commissioning Process - GSA



This process is often abbreviated or truncated with several of these steps being omitted

Sample SVC and FPT Checklists – ACG Guideline

HVAC COMMISSIONING
SYSTEM VERIFICATION/START-UP CHECKLIST
ROOF TOP UNIT - GAS HEAT/DX COOLING

PROJECT:_____

Equipment Name/Tag:_____ Location:_____

System/Area Served:_____ Related Equipment:_____

ITEM	√	COMMENTS
PRE-START-UP INSPECTION		
Commissioning lock-out procedures reviewed		
Operation and maintenance information		
Mounting/support system and vibration isolation		
Seismic restraints		
Equipment guards		
Alignment & V-belt tension		
Freedom of rotation		
Lubrication		
Plenums clean and free of loose material		
Temporary start-up filters		
Fire & balance dampers positioned		
Access doors, Insulation and interior lights		
Filter bank, DP switch gauge and photohelics		
Local valving/piping (gas, condensate, pans, drains)		
Motorized dampers		
D/X expansion (cooling) coil and compressor		
D/X condensing coil and fans		
Gas piping and valving complete		
Gas inspection certificate		
Regulatory authority approved installation and burner control (certificate available)		
Building cleanliness		
Electrical wiring complete		
Overload protection (sized correctly)		
Disconnect switch (tested)		
Local control module with DDC interface		
Control system - point to point checks complete		
START-UP		
Start-up by manufacturer's representative with report and certificate or log provided		
Direction of rotation		
Electrical interlocks - stop/start		
Local air leakage acceptable		
Vibration & noise level acceptable		
Motor Amps - Rated :__Actual :_____		
Motor Volts - Rated :__Actual :_____		
Final operating filters installed		

Pre-start checks by:_____ _____ Date:_____

Start-up checks by:_____ _____ Date:_____

print name signature

HVAC COMMISSIONING
FUNCTIONAL PERFORMANCE TEST CHECKLIST
PACKAGED ROOFTOP GAS HEAT/DX COOL SYSTEM

PROJECT:_____

System:_____ Location:_____

Area Served:_____ Equipment:_____

SEQUENCE OF OPERATION:	PASS FAIL	NOTE
Occupied mode:		
– Confirm that SF is ON		
When heating is required, confirm that:		
– MAD is positioned to minimum OA setpoint (value set by TAB agency).		
– DX cooling if OFF		
– GB cycles ON/OFF to maintain space heating temp. setpoint.		
Record the following data:		
– OA temp. ____ °F		
– Max. space temp., when GB stops ____ °F; Min. space temp., when GB starts ____ °F		
– Max. supply air temp. (SAT) ____ °F; Min. SAT ____ °F		
When heating is not required, and free cooling can maintain space temp below cooling setpoint, confirm that:		
– GB and DX cooling are both OFF.		
– MAD modulates from min. OA position to 100% open to OA, to maintain space cooling setpoint ____ °F		
When cooling is required, confirm that:		
– MAD is positioned to minimum OA setpoint (value set by TAB agency).		
– DX cooling cycles ON/OFF to maintain space cooling temp. setpoint.		
Record the following data:		
– OA temp. ____ °F		
– Max. space temp., when DX starts ____ °F; Min. space temp., when DX stops ____ °F		
– Max. supply air temp. (SAT) ____ °F; Min. SAT ____ °F		
NOTES:		
1.		
2.		
Continued on next page:		

Checks performed by:_____ _____ Date:_____

print name signature

HVAC COMMISSIONING
FUNCTIONAL PERFORMANCE TEST CHECKLIST
PACKAGED ROOFTOP GAS HEAT/DX COOL SYSTEM

PROJECT:_____

System:_____ Location:_____

Area Served:_____ Equipment:_____

SEQUENCE OF OPERATION:	PASS FAIL	NOTE
Unoccupied mode:		
When space temp. > night setback heating setpoint, confirm that:		
– MAD is tightly closed to OA.		
– Heating and cooling are both OFF		
– Supply fan (SF) is OFF.		
When space temp. < night setback heating, confirm that:		
– MAD stays tightly closed to OA and cooling stays OFF.		
– SF is started		
– Gas heating (GB) fires		
– When space temp. rises to > night setback heating setpoint, confirm GB and SF turn OFF.		
NOTES:		
1.		
2.		

Checks performed by:_____ _____ Date:_____

print name signature

Reducing energy costs and greenhouse gas

Mills, E. Building commissioning: a golden opportunity for reducing energy costs and greenhouse gas emissions in the United States. *Energy Efficiency* **4,** 145–173 (2011). https://doi.org/10.1007/s12053-011-9116-8

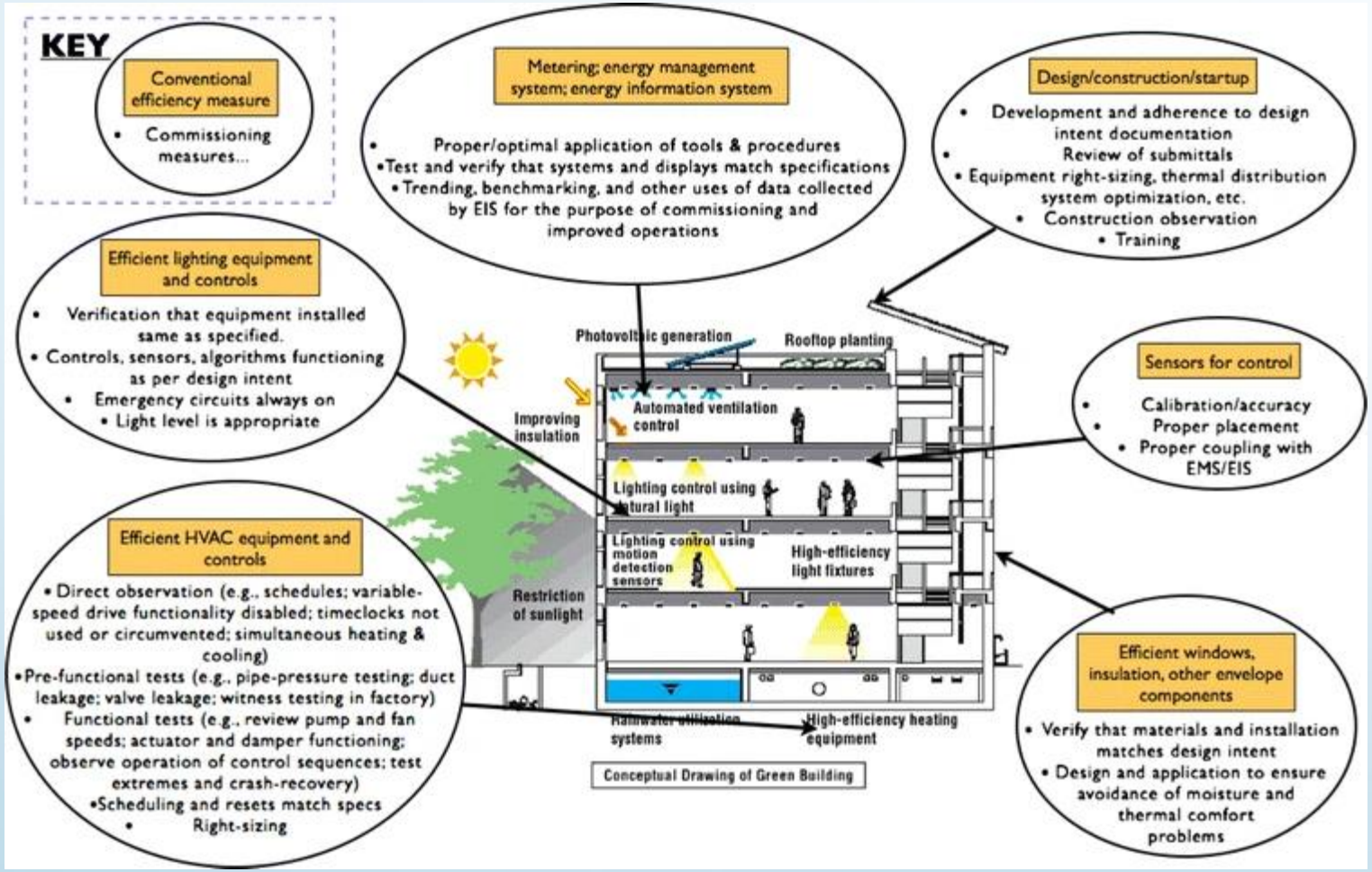
Key points

- "World's largest compilation and meta-analysis of commissioning experience…" (as of 2011)
- Analysis of 673 non-residential buildings,
- 99M SF of floors space
- $43M in commissioning expenditures
- Median Cu cost (in 2009 dollars)
  - $1.16/SF – new construction (0.4% of construction cost)
  - $0.30/SF – existing buildings

	Total	Existing	New construction
Education			
K-12	3,123,754	2,467,661	656,093
Higher education	12,029,520	11,401,833	627,687
Food sales	983,402	848,039	135,363
Food service	187,724	187,724	–
Health care			
Outpatient healthcare	4,525,424	4,319,124	206,300
High-tech Facilities	–	–	–
Cleanrooms	301,000	–	301,000
Data center	12,888	12,888	–
Laboratory	6,526,658	4,561,593	1,965,065
Inpatient	7,478,988	6,791,029	687,959
Lodging	10,037,291	9,880,307	156,984
Mercantile			
Retail	2,926,038	2,926,038	–
Service	227,000	227,000	–
Office	40,867,062	39,972,765	894,296
Public assembly	3,166,611	2,476,985	689,626
Public order and safety	4,756,949	2,485,277	2,271,672
Religious worship	12,500	12,500	–
Warehouse and storage	175,379	13,500	161,879
Industrial	475,000	475,000	–
Other	1,411,622	1,351,622	60,000
Vacant	–	–	–

Source: [Miller 2011]

Relationships: Commissioning and Energy Savings



Source: [Miller 2011]

Top faults causing energy inefficiencies in commercial buildings (top 13 of 100+)

	National Energy Waste (Quads, primary/year)	Electricity equivalent (BkWh/year)	Cost ($billion/year)
Duct leakage	0.3	28.6	2.9
HVAC left on when space unoccupied	0.2	19.0	1.9
Lights left on when space unoccupied	0.18	17.1	1.7
Airflow not balanced	0.07	6.7	0.7
Improper refrigerant charge	0.07	6.7	0.7
Dampers not working properly	0.055	5.2	0.5
Insufficient evaporator airflow	0.035	3.3	0.3
Improper controls setup / commissioning	0.023	2.2	0.2
Control component failure or degradation	0.023	2.2	0.2
Software programming errors	0.012	1.1	0.1
Improper controls hardware installation	0.01	1.0	0.1
Air-cooled condenser fouling	0.008	0.8	0.1
Valve leakage	0.007	0.7	0.1
Total (central estimate)	1.0	94.6	9.6
Total (range)	0.34-1.8	32.4-171.4	3.3-17.3

Adapted from Roth et al. (2005) assuming 10,500 BTU/kWh, and $0.10/kWh

Source: Roth, K.W. D. Westphaler, M.Y. Feng, Patricia Llana, and L. Quartararo. 2005. "Energy Impact of Commercial Building Controls and Performance Diagnostics: Market Characterization, Energy Impact of Building Faults and Energy Savings Potential: Final Report." Prepared by TAIX LLC for the U.S. Department of Energy. November. 412 pp (Table 2-1).

Deficiency Photos

Hot water valve motion impeded by piping layout [EMC no date (a)]

Building envelope moisture entry [Aldous 2008]

Source: [Miller 2011]

Deficiency Photos

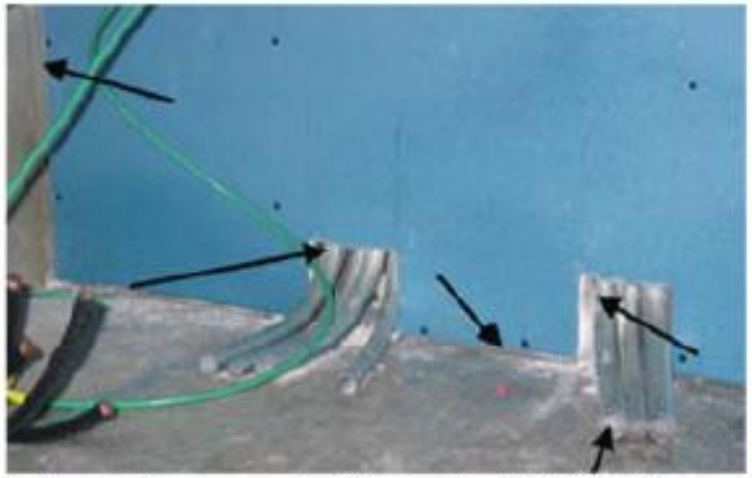
Rust indicates poor anti-condensation heating control setpoints in supermarket refrigeration cabinet [Sellers and Zazzara 2004]

Photosensor (for daylight harvesting) shaded by duct [Deringer 2008]

Source: [Miller 2011]

Deficiency Photos

Plugged filter causing condensation on bottom of fan coil unit and damage to insulation coil resulting in poor air flow [Martha Hewett, MNCEE]



Air leakage in an underfloor air-distribution system [Stum 2008]

Source: [Miller 2011]

Deficiency Photos

Exhaust fan hardwired in an "always on" position
[Mittal and Hammond 2008]

Failed window film treatment

Source: [Miller 2011]

Study Data

10,000 energy-related deficiencies (available for ~one third of projects reviewed) when corrected resulted in:

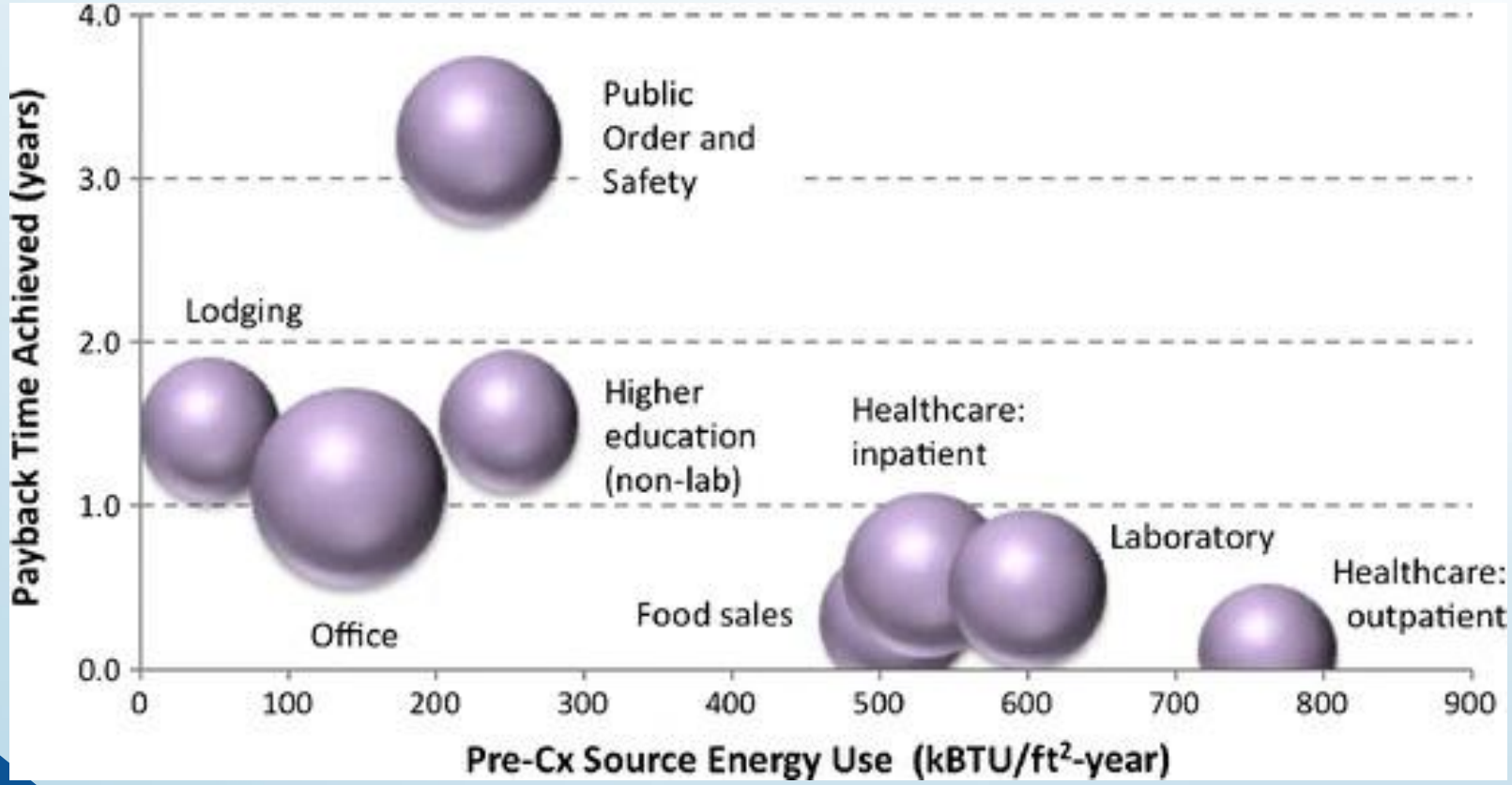
- Existing buildings
  - 16% whole building energy savings
  - 1.1 year payback
  - (-$110/ton CO2e) GHG reduction cost*
- New Construction
  - 13% whole building energy savings
  - 4.2 year payback
  - (-$25/ton CO2e) GHG reduction cost*

*Per author - negative cost for GHG reductions because energy savings exceed commissioning cost

Source: [Miller 2011]

	Total	Existing	New
Characteristics			
Number of projects	409	332	77
Number of buildings	643	561	82
Number of states	26	21	15
Identified commissioning providers[a]	37	28	15
Commissioned floor area			
Total (square feet)	99,224,809	90,410,884	8,813,925
Per building (median ksf)		190,907	67,987
Ownership (by % of floor area)			
Public	71%	69%	85%
Private	29%	31%	15%
Investment			
Commissioning investment (US$2009)[b]			
Total project cost (US$2009)	43,484,002	28,562,970	14,921,031
US$2009/project		49,075	86,546
US$2009/ft^2		0.30	1.16
Cost as % of construction cost			0.4%
Outcomes			
Number of deficiencies identified[c]	10,180	6,652	3,528
Number of measures[c]	5,795	4,104	1,691
Energy savings			
Total primary energy		16%	13%
Electricity		9%	–
Peak electrical demand		5%	–
Fuel		16%	–
Combined central thermal		31%	–
Central hot water		12%	–
Central chilled water		16%	–
Cental steam		19%	–
Payback time (years)[d]		1.1	4.2
Cost–benefit ratio[d]		4.5	1.1
Cash-on-cash return[d]		91%	23%
Cost of conserved carbon ($/tonne)[d]		−110	−25

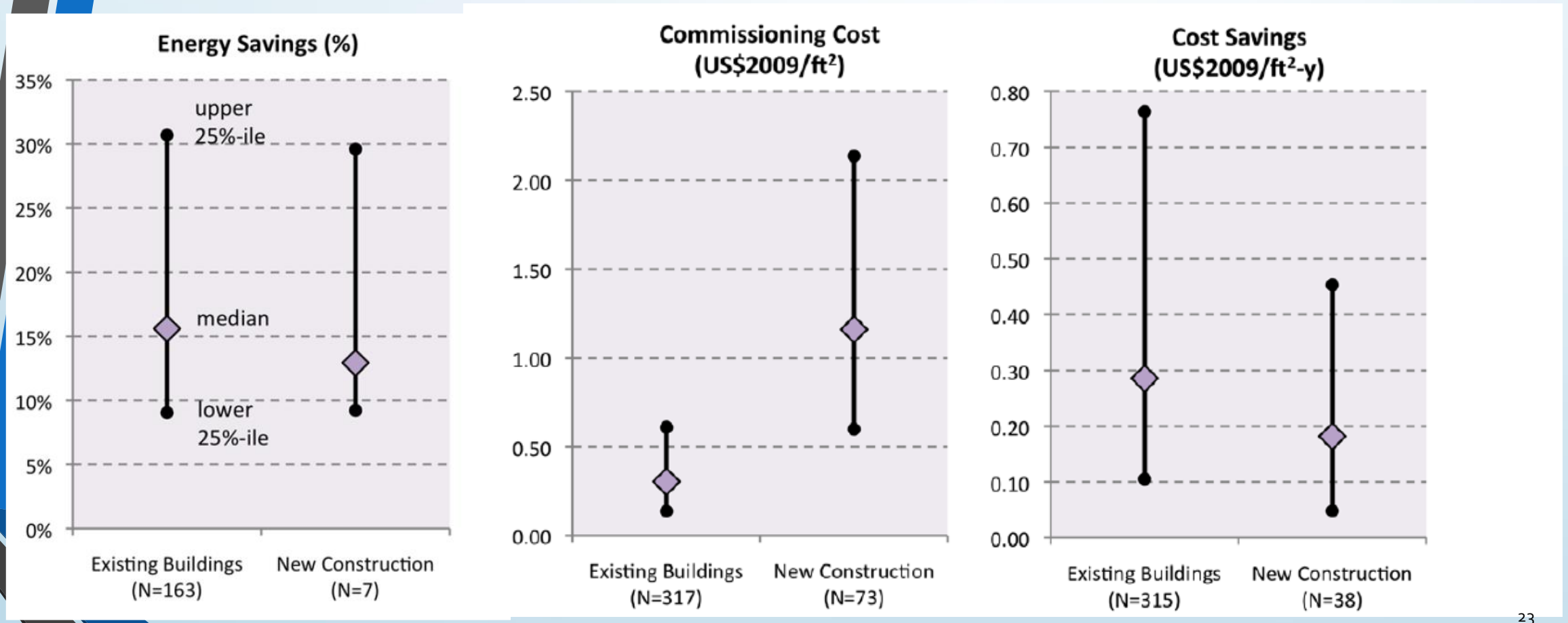
Results by building type



Circle diameter is proportional to percent energy cost savings (e.g., "Office" = 22%). Public order and safety includes prisons

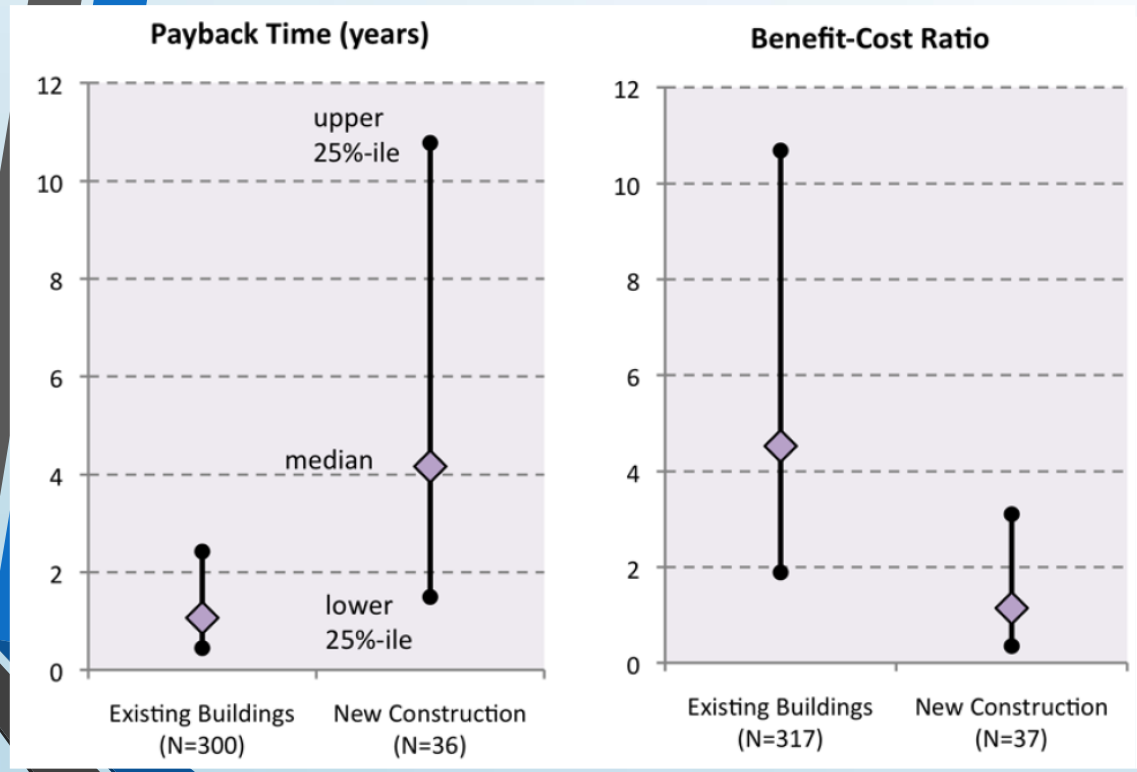
Source: [Miller 2011]

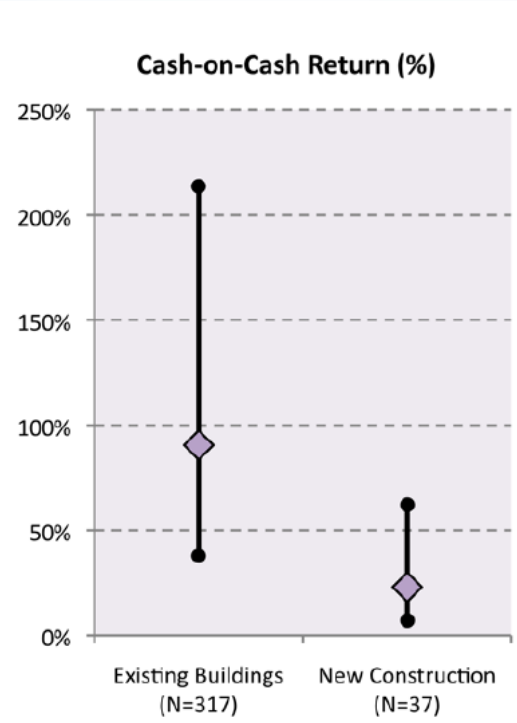
Central Tendencies and Data Spread

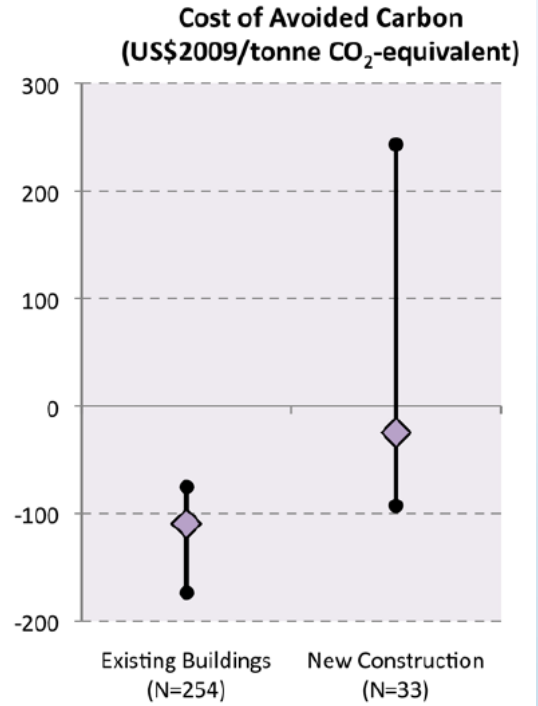


Source: [Miller 2011]

Central Tendencies and Data Spread







Source: [Miller 2011]

Findings

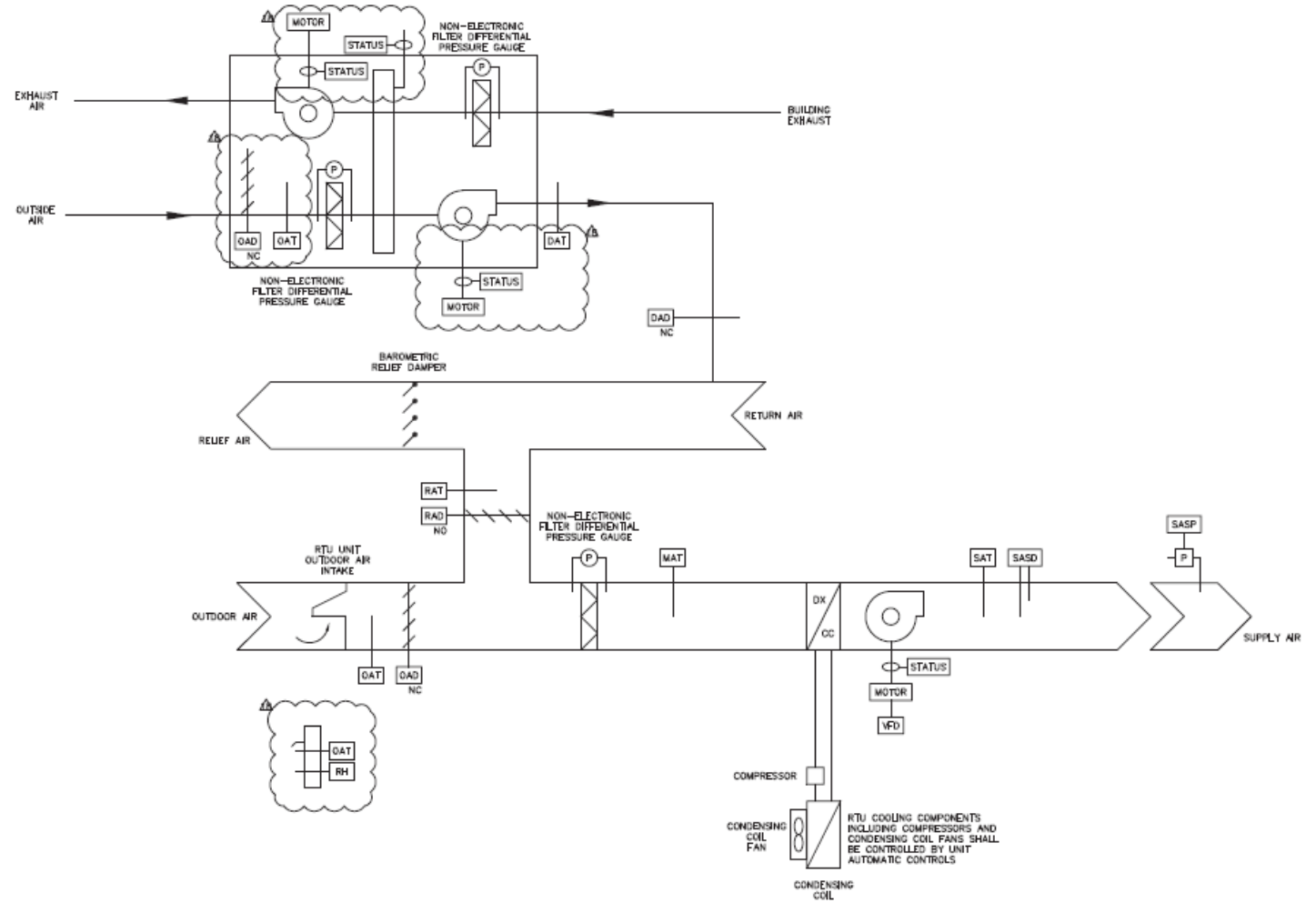
- "Commissioning is arguably the single most cost-effective strategy for reducing energy costs and greenhouse gas emission in building today"
- Cases with comprehensive commissioning attained nearly twice the overall median level of savings and five times the savings of the least-thorough projects.
- Significant non-energy benefits such as improved indoor air quality are also achieved.
- Applying the median whole-building energy saving values to the US non-residential buildings stock corresponds to an annual energy-saving potential of $30 billion (and 340 Mt of CO_2) by the year 2030.

Source: [Miller 2011]

Sample Deficiencies from Recent Projects

1	AHU-3 & AHU-6: The supply fan in these units are setup to run all the time. This appears to be an energy discrepancy since the unit does not appear to be able to cycle off during unoccupied periods. The fan runs at 50% during unoccupied periods and 100 % during occupied periods.
2	AHU-6: Room sensor on this unit is reading 10 OF warmer that actual room temperature. This was resulting in building occupants' complaints due to overcooling of the space.
3	The hot water system currently produces 90 OF water during summertime (when there is a call for heat) and 180 OF water during wintertime because it has very unsophisticated controls. Due to proper working OAT Sensor and no BAS control, the potential energy savings available through temperature reset, and occupancy optimizations are not realized on the Hot Water System.
4	During Unoccupied and Optimal Start modes the outside air damper is supposed to go to 0% (closed) however the damper on this unit does not close all the way. It remains open about 20%. Recommend having someone adjust the linkages on this damper so that at 0% open there is a good seal providing no outside air intake.
5	Lighting Controls Study Rooms C & D: The occupancy sensors in these two rooms have their sensitivity set so that they get triggered from outside the room. This is resulting in the lights are always on due to folks oassing outside
6	Lighting Controls Exterior Lights: Zone 10 of the Lighting Controls Schedule require that the exterior canopies and site parking lights are controlled via photocell. The exterior canopy lights did not appear to turn off throughout our time during this test, even with lots of sunlight.
7	Hot Water Reset Not Implemented: Currently the energy saving Hot Water Reset sequence is not operational on the boiler. The sequences call for the BAS to communicate the boiler setpoint via BACnet communication. Based on conversations with Craig Ragone with BAS Systems, writing to the boiler setpoint is problematic and not recommended. The boiler is therfore operating without a setpoint, ie. it just fires without a targeted supply temperature.

8	BAS Screens do not include critical points that are needed to allow the HVAC system to function correctly. Missing points include OA Relative Humidity, OA Temperature, DA Static Pressure, Filter DP, Mixed Air Temp, Among Others.
9	There is a mismatch between the supply fan VFD speed as displayed on the drive and what is displayed on the BAS screen (e.g. 58% on BAS vs 78% on VFD).
10	Outside air for this unit is not filtered. The Design documents (M502) shows that this unit should have a filter rack on the outside air entering the unit, upstream of the the enthalpy wheel, and one on the return side before it crosses the enthalpy wheel. At the time of this test only the filter on the Return Air side of the unit was present.
11	The design documents show that the supply air from the Energy Recovery Unit is to be be fed into the return air duct of the RTU. This in an unconventional way to do energy recovery and this negates the energy savings advantage of using such a device. The normal application of these two units is to have the supply air from the ERU feed directly into the OA intake of the RTU.
12	The Sequence of operation for Economizer Mode will not operate with the unit's configuration. The sequence requires that the OA damper and RA damper modulate to maintain 55degF Supply temp but the OA damper is not being used. The RTU's OA damper is mechanically fixed shut.
13	Controls contractor has implemented a DAT temperature reset routine on the RTU. This routine looks at the RA temp and if it is below 70deg F there is an assumption that the building is overcooling, and resets the DAT setpoint to 60degF. This routine will not work because the RA senor reads MA instead of true RA because of the configuration of the unit.



1 RTU-1 AND ERU-1 CONTROL DIAGRAM
SCALE: NTS

PAT SAT ZAT

SEQUENCE OF OPERATION

18 ECONOMIZER MODE: THE SYSTEM SHALL ENTER THE ECONOMIZER BASED ON FIXED ENTHALPY 28 BTU/LB (ADJ.) AND FIXED DRY BULB 75°F (ADJ.). ERU-1 SUPPLY FAN SHALL BE OFF AND ERU-1 OA DAMPER CLOSED. ERU-1 EXHAUST FAN SHALL CONTINUE TO RUN. RTU-1 SUPPLY FAN SHALL RUN AND THE OUTDOOR AIR DAMPER AND RETURN AIR DAMPER SHALL MODULATE TO MAINTAIN A 55°F (ADJ.) SUPPLY AIR TEMPERATURE.