

Building Commissioning:

A Golden Opportunity for Reducing Energy Costs and Greenhouse Gas Emissions

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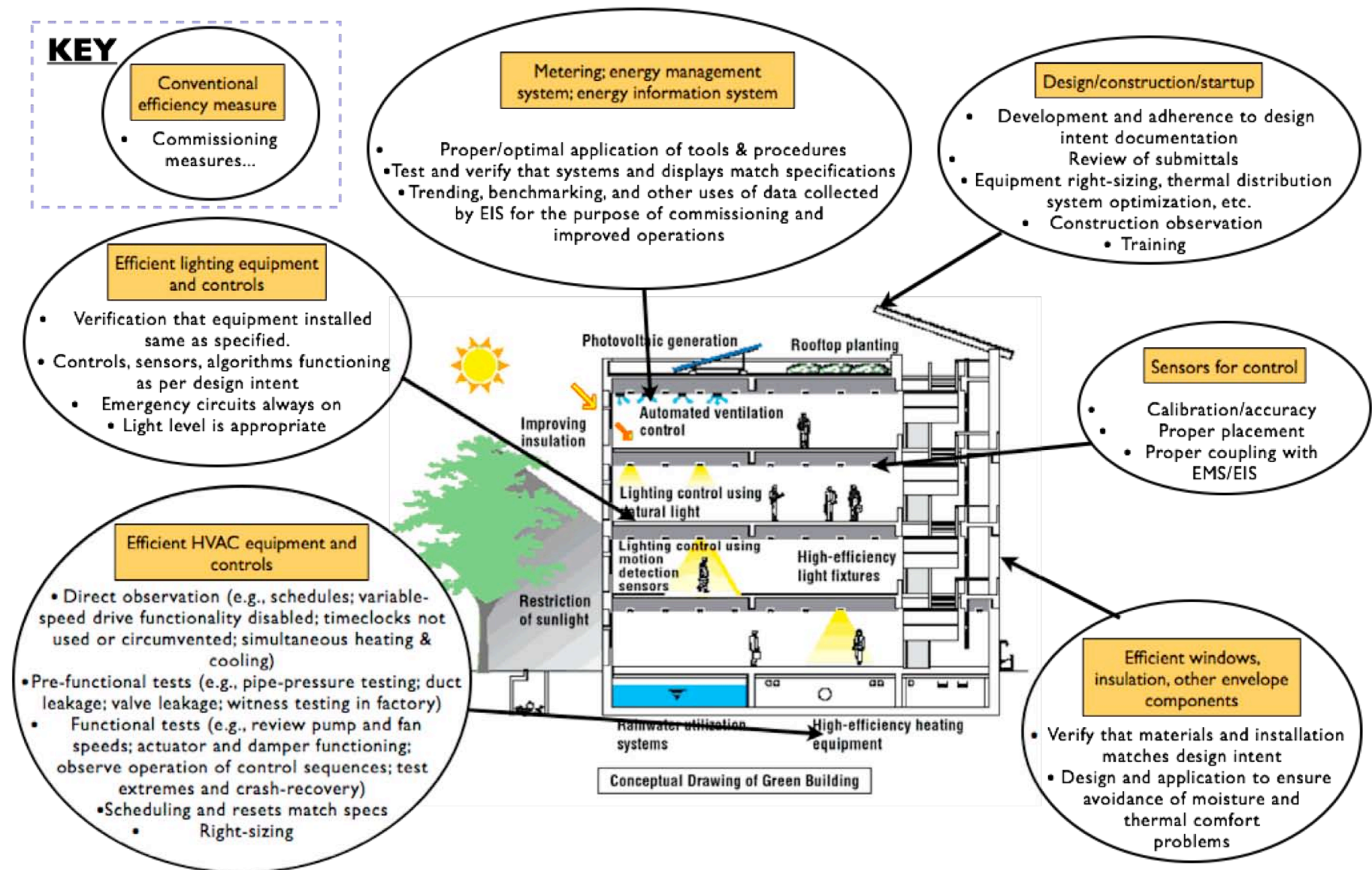
Report Prepared for:
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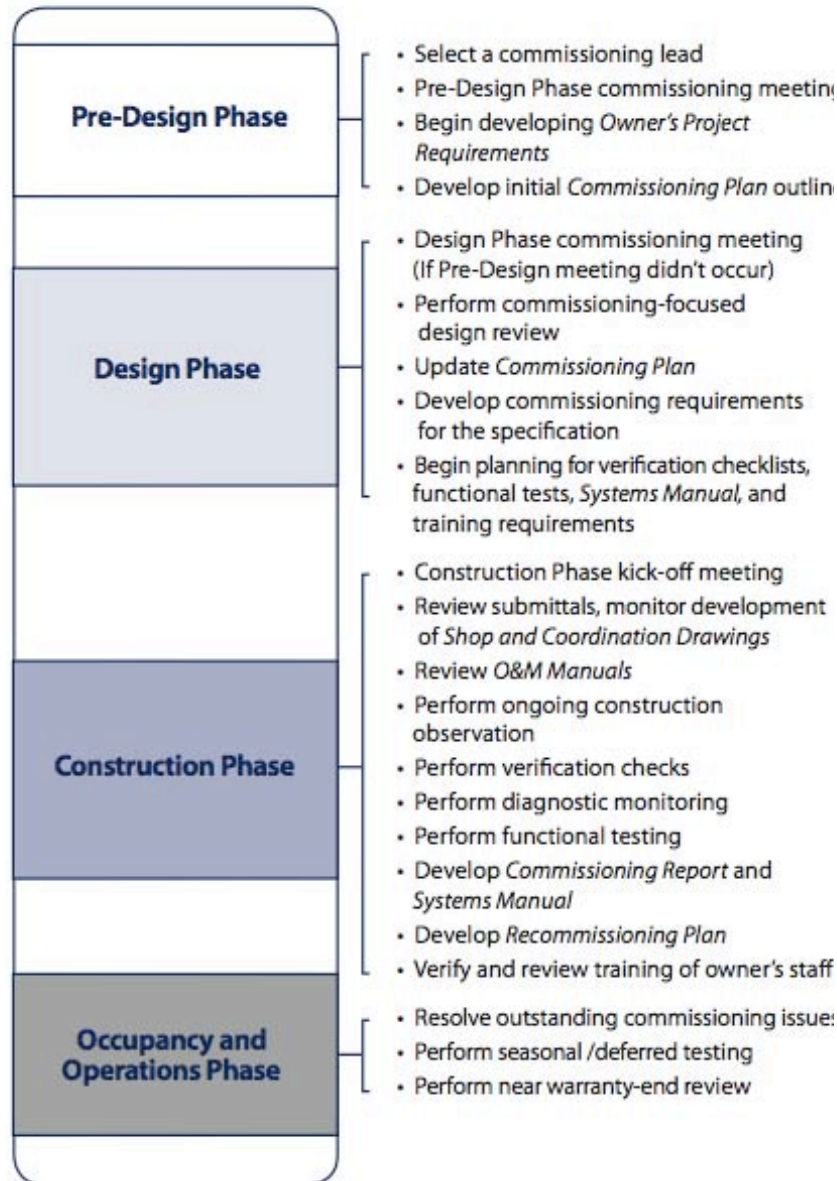
OBJECTIVES

- Remove uncertainties regarding the savings and cost-effectiveness of commissioning new and existing commercial buildings
- Gather data on actual commissioning projects in new and existing buildings
- Document patterns of issues identified and addressed in the commissioning process
- Perform a standardized analysis of energy savings, carbon reductions, and cost-effectiveness
- Estimate the national (U.S.) savings potential and required job creation

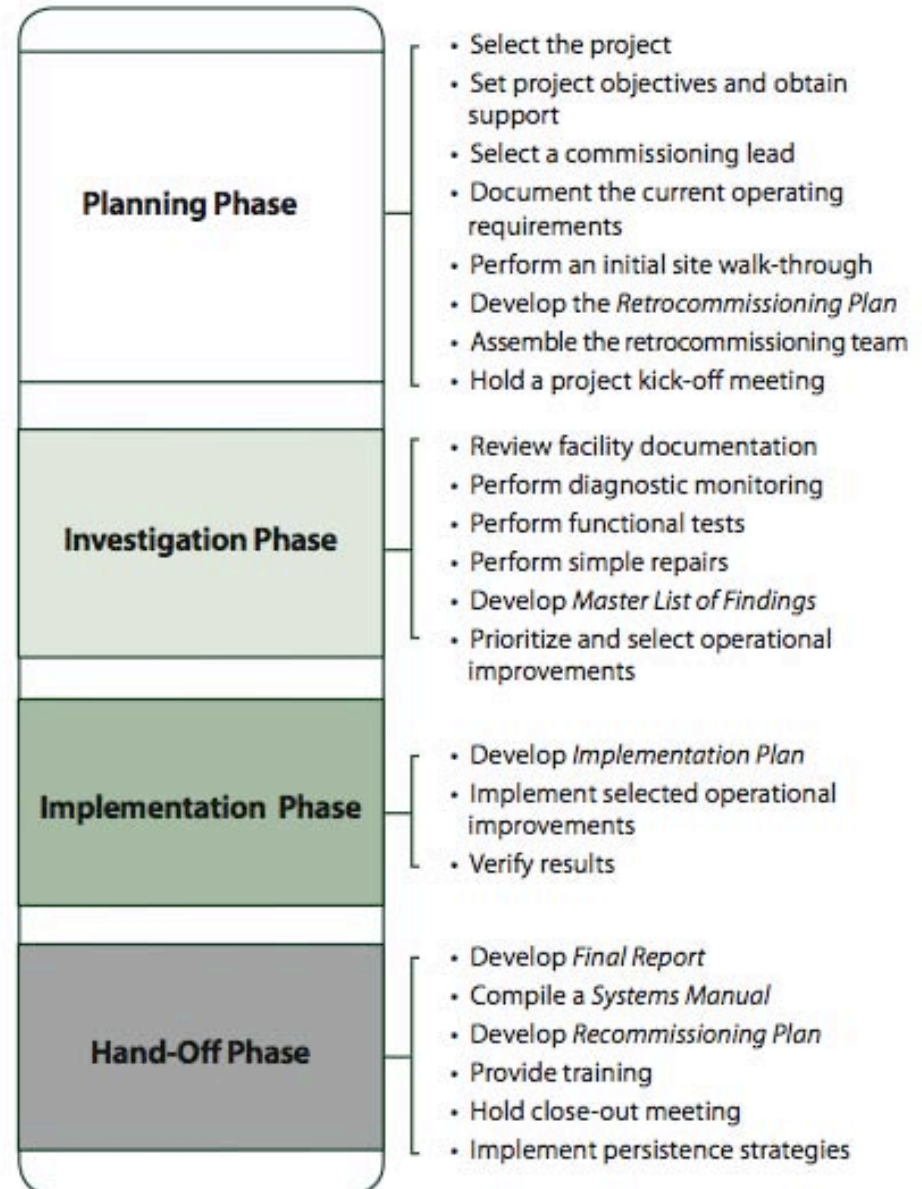
Illustrative Relationships between commissioning and energy efficiency measures



Commissioning Process Overview



Retrocommissioning Process Overview



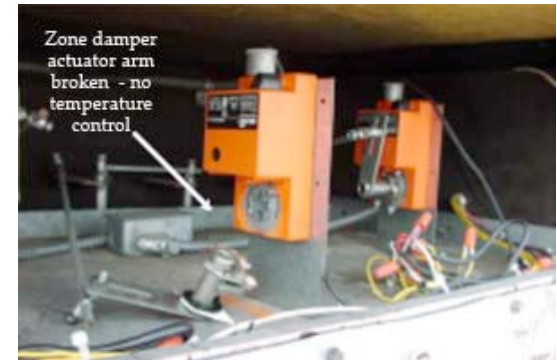
Hall of Shame



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



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



Zone damper actuator arm broken (no temperature control) [Martha Hewett, MNCEE]



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



Inadequate fan cooling and excessive fan power due to poor fit between the light fixture and ducting, causing significant duct leakage [Martha Hewett, MNCEE]

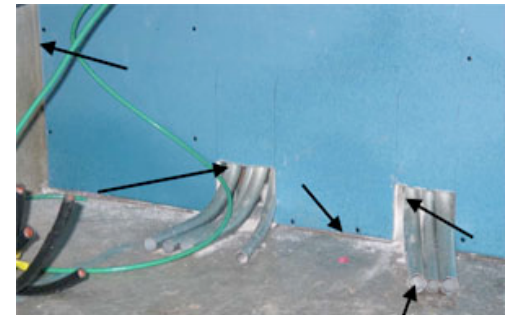
Hall of Shame



Damage to brick façade of pool building due to lack of proper sealing and air management [Martha Hewet, Minnesota Center for Energy and Environment (MNCEE)]



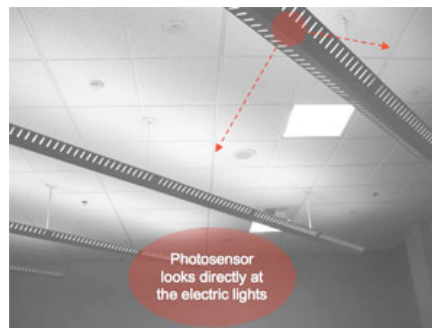
Building envelope moisture entry [Aldous 2008]



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



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



Photosensor “sees” the electric lamps rather than task-plane illumination [Deringer 2008]



Failed window film applications

Common faults in commercial buildings

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

	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

Commissioning as Risk Management

- Commissioning is more than “just another pretty energy-saving measure.”
- It is a risk-management strategy that should be integral to any systematic approach to garnering energy savings or emissions reductions.
 - Ensures that a building owners get what they pay for when constructing or retrofitting buildings
 - Provides insurance for policymakers and program managers that their initiatives actually meet targets
 - Detects and corrects problems that would eventually surface as far more costly maintenance or safety issues.

Key Findings (1 of 3)

- Commissioning is arguably the single-most cost-effective strategy for reducing energy, costs, and greenhouse-gas emissions in buildings today.
- Energy savings tend to persist well over at least a 3- to 5-year timeframe, but data over longer time horizons are not available.
- Median commissioning costs: \$0.30/ft² and \$1.16/ft² for existing buildings and new construction, respectively (and 0.4% of total construction costs for new buildings).
- Median whole-building energy savings: 16% and 13%.
- Median payback times: 1.1 and 4.2 years.
- Median benefit-cost ratios: 4.5 and 1.1, cash-on-cash returns of 91% and 23%.

Key Findings (2 of 3)

- Large reductions in greenhouse-gas emissions are achieved, at a negative cost of -\$110 and -\$25/tonne CO₂-equivalent.
- High-tech buildings particularly cost-effective, and saved large amounts of energy due to their energy-intensiveness.
- The database incorporates the work of 37 commissioning providers.
- Projects with a comprehensive approach to commissioning attained nearly twice the overall median level of savings, and five-times the savings of projects with a constrained approach.
- Non-energy benefits are extensive and often offset part or all of the commissioning cost.

Key Findings (3 of 3)

- Annual energy-savings potential of \$30 billion by the year 2030, and 360 MT CO₂-eq emissions reductions. The corresponding future industry would have a sales volume of \$4 billion per year
- Approximately 24,000 jobs need to be created in order to deliver the potential. This is “small” in the context of the number of people currently employed in related trades.
- “Commissioning America” in a decade is an ambitious goal, but “do-able” and very consistent with this country’s aspirations to simultaneously address energy and environmental issues while creating jobs and stimulating economic activity.

Outcomes from previous large studies

Examples of existing-building costs and savings from completed projects.

Target	Location	Sites (Msf = millions of square feet floor area)	Energy Savings	Peak Demand Savings	Project Cost (\$/sf)	Payback Time (years)	Source
Local government buildings	California	11 sites; 1.5 Mxf	14.3% source energy (11% electricity; 34% gas)		1.01	3.5	Amarnani and Roberts (2006); Pierce and Amarnani (2006); Amarnani et al. (2007)
Offices and hotels	New York	6 sites; 6 Mxft		10%	0.34	2.0	Lenihan (2007) - projected
Offices	Connecticut	5 buildings; 2 Mxf	8.5% electricity (range: 3%-20%)			0.5	Building Operating Management (2006)
Class A Offices	Connecticut	3 bldgs; 1.2 Msf	7.3% electricity		0.62	1.37	McIntosh (2008)
Mixed comercial	Colorado	27 buildings; 10 Msf	7% electricity	4.2% (range: 0%-26%)	0.185	1.51	Franconi et al. (2005)
Three offices & hospital	Colorado	4 buildings; 1.8 Msf		6%	0.026	0.38	Mueller et al. (2004)
University buildings	California	26 buildings; 3.4 Msf	10% total source (range: 2%-25%)	4% (range: 3%-11%)	1.00	2.5	Mills & Matthew (2009)
Elementary schools	Michigan	4 schools			0.38	2.5	Friedman (2004)
Supermarkets	Central California	10 stores; 0.5 Msf	12.1% electricity (range: 4.3%-18.3%)		0.14	0.25	Zazzara and Ward (2004); Emerson (2004)
Mixed commercial	Northwest	8 buildings			0.430	3.2	Tso et al (2003)
Mixed commercial	Oregon	76 projects	10%-15% electricity (range: 5%-40%)		0.175	1.24	Peterson (2004)
Mixed commercial and educational	California	All California Programs (2007-2008)	Range: 1.7%-8.1% electricity		0.40	3.0	PECI and Summit Building Engineers (2007) - estimates
Total or simple average values		186 Msf	~10%-15% source energy	~7%	0.43	1.8	

Notes: All impacts shown using local energy prices and commissioning costs; averages are floor-area-weighted averages.

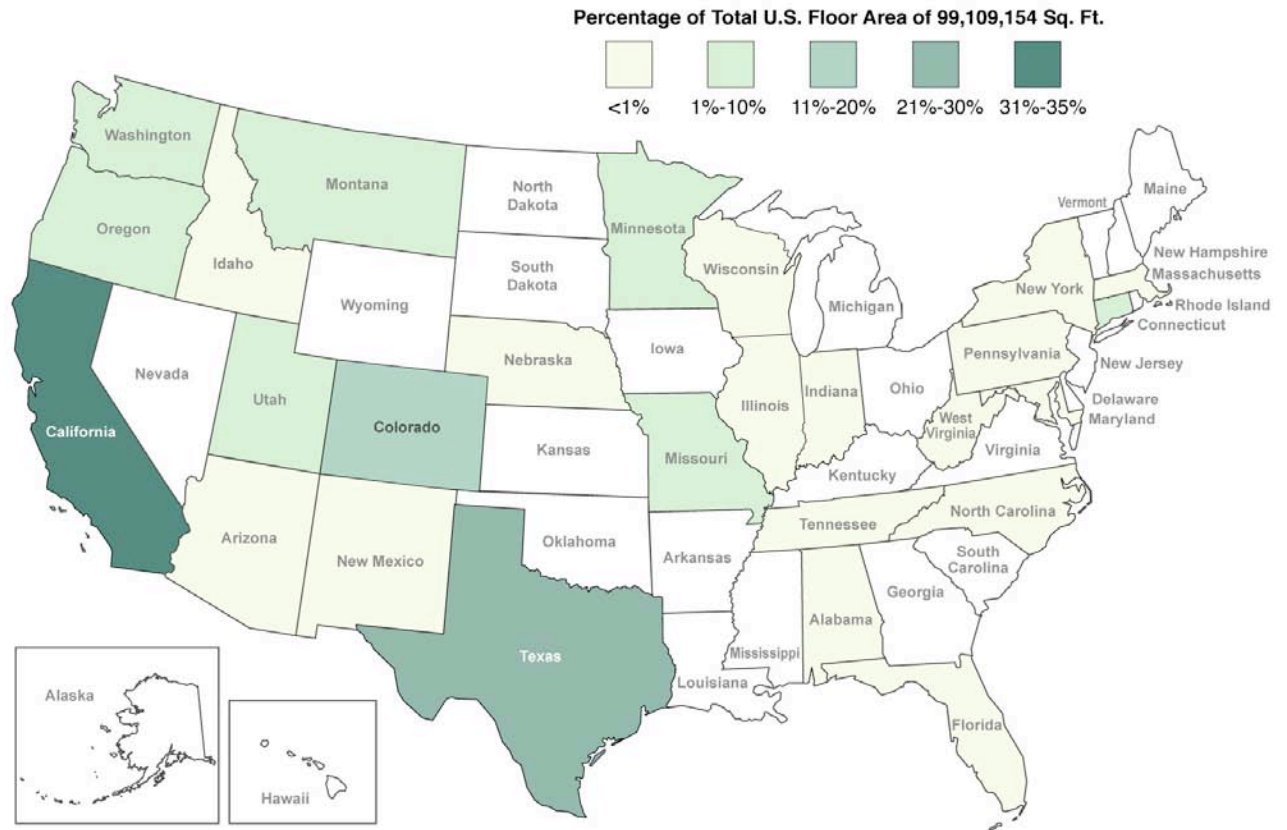
Methodology

- Gather raw data from diverse sources:
 - Previously published studies
 - Unpublished data from commissioning practitioner files
- Apply screening rules
 - Full cost data
 - No mixed-in capital retrofit data
 - Measure verification
 - Etc.
- Normalize for floor area, energy prices (national average), inflation (US\$2009), and weather
- Develop metrics for analyzing the data

Location of projects in the database

SAMPLE

- 643 buildings
 - 562 existing
 - 82 new
- 99 million square feet
- \$43 million investment
- 26 states



Caveats & conservatisms

Underestimation of benefits

- Costs for non-energy measures
- Measures implemented after data collected
- Non-energy impacts
- Limited scope/ambition
- End use data omitted
- Delayed benefits (e.g. via training)

Overestimation of benefits

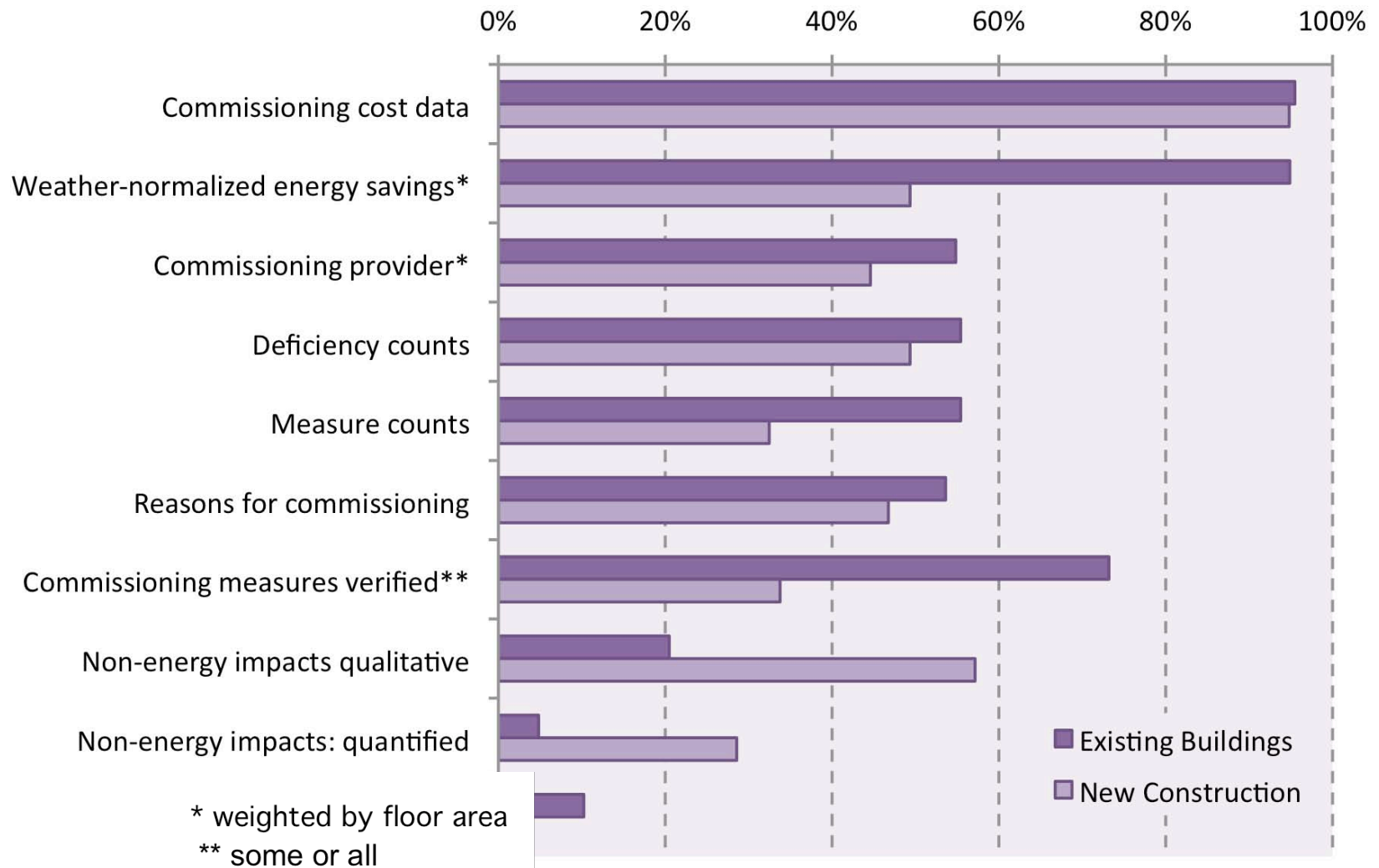
- Persistence
- Recommended measures not implemented
- Undocumented retrofit

Type and size of buildings in database

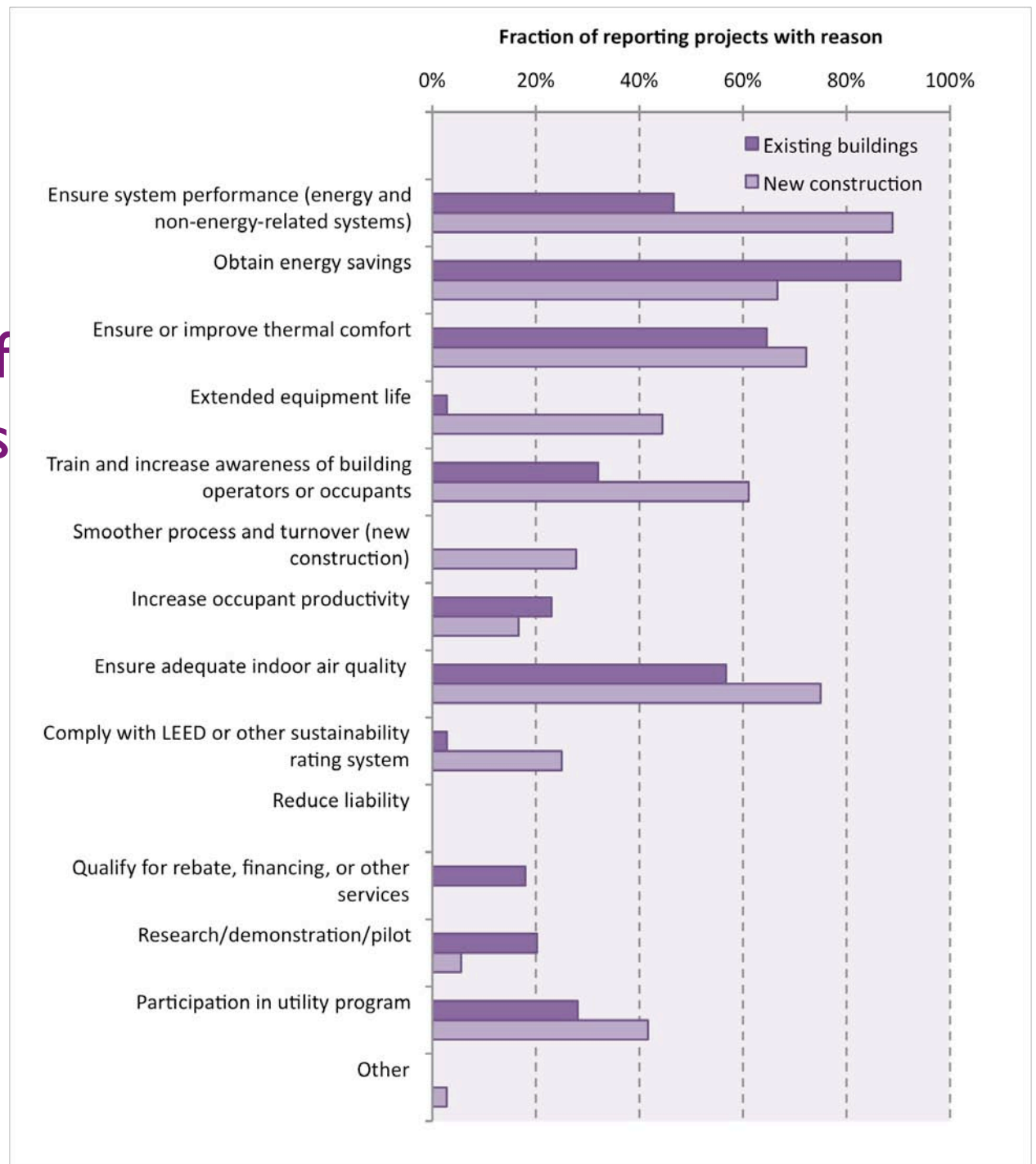
	Total	Existing	New Construction
Education			
K-12	3,123,754	2,467,661	656,093
Higher education	12,029,520	11,401,833	627,687
Food Sales	983,402	848,039	135,363
Food Service	187,724	187,724	-
Health Care			
Outpatient healthcare	4,525,424	4,319,124	206,300
High-tech Facilities	-	-	-
Cleanrooms	301,000	-	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	-	-	-
Total	99,224,809	90,410,884	8,813,925

* Note in some cases floor area is apportioned among more than one building type.

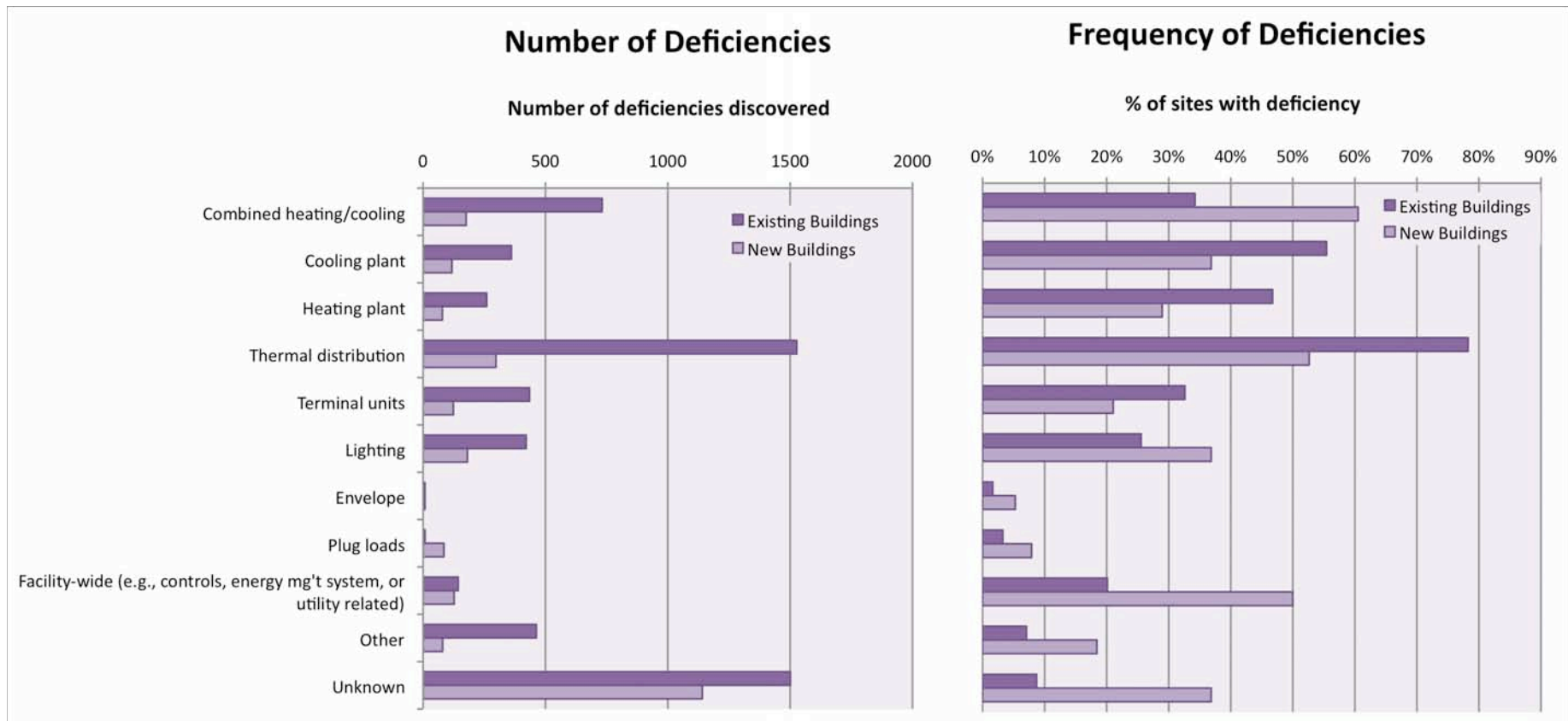
Sample depth



Wide diversity of
reported reasons
to embark on
commissioning
projects



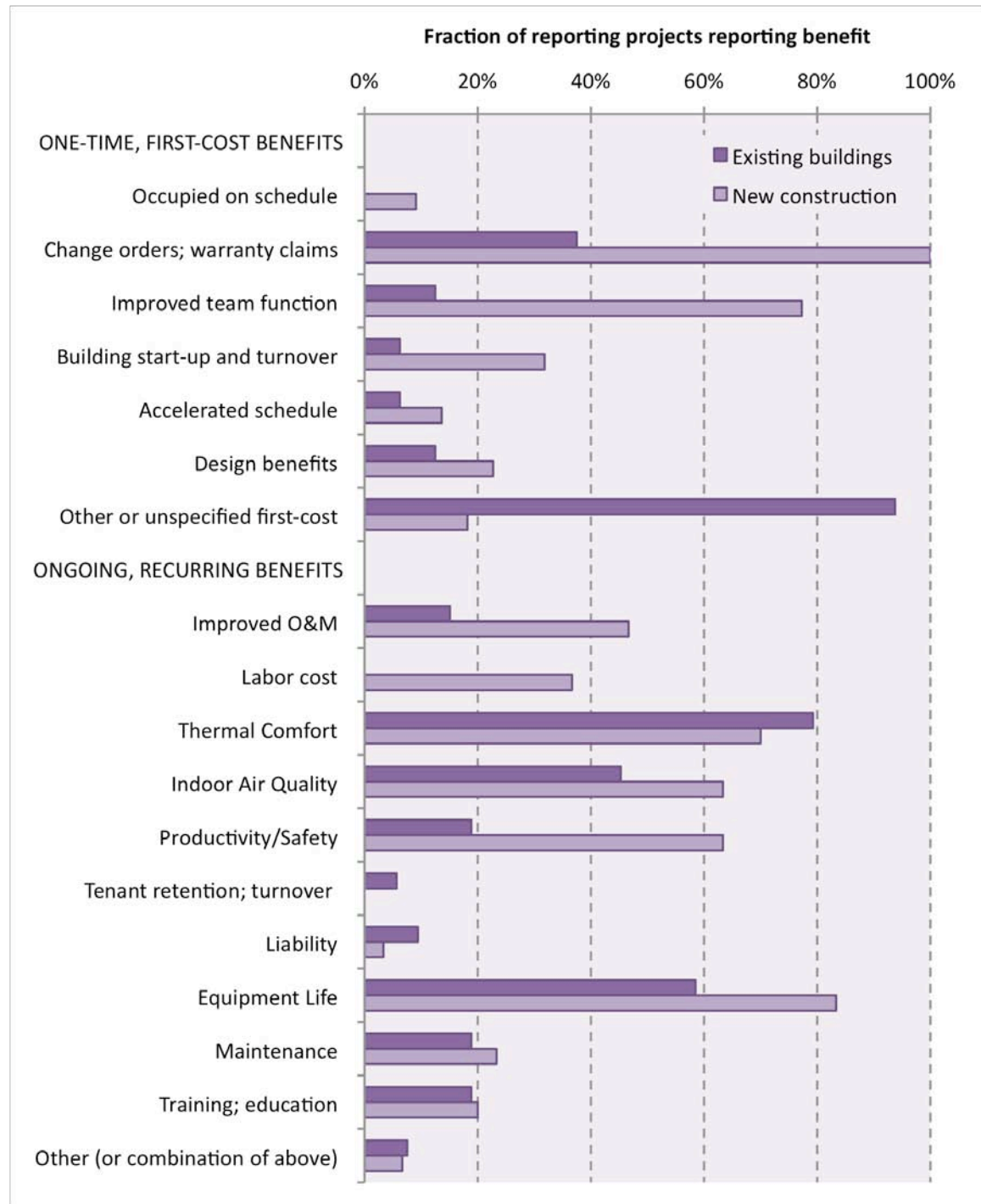
Deficiencies discovered ...



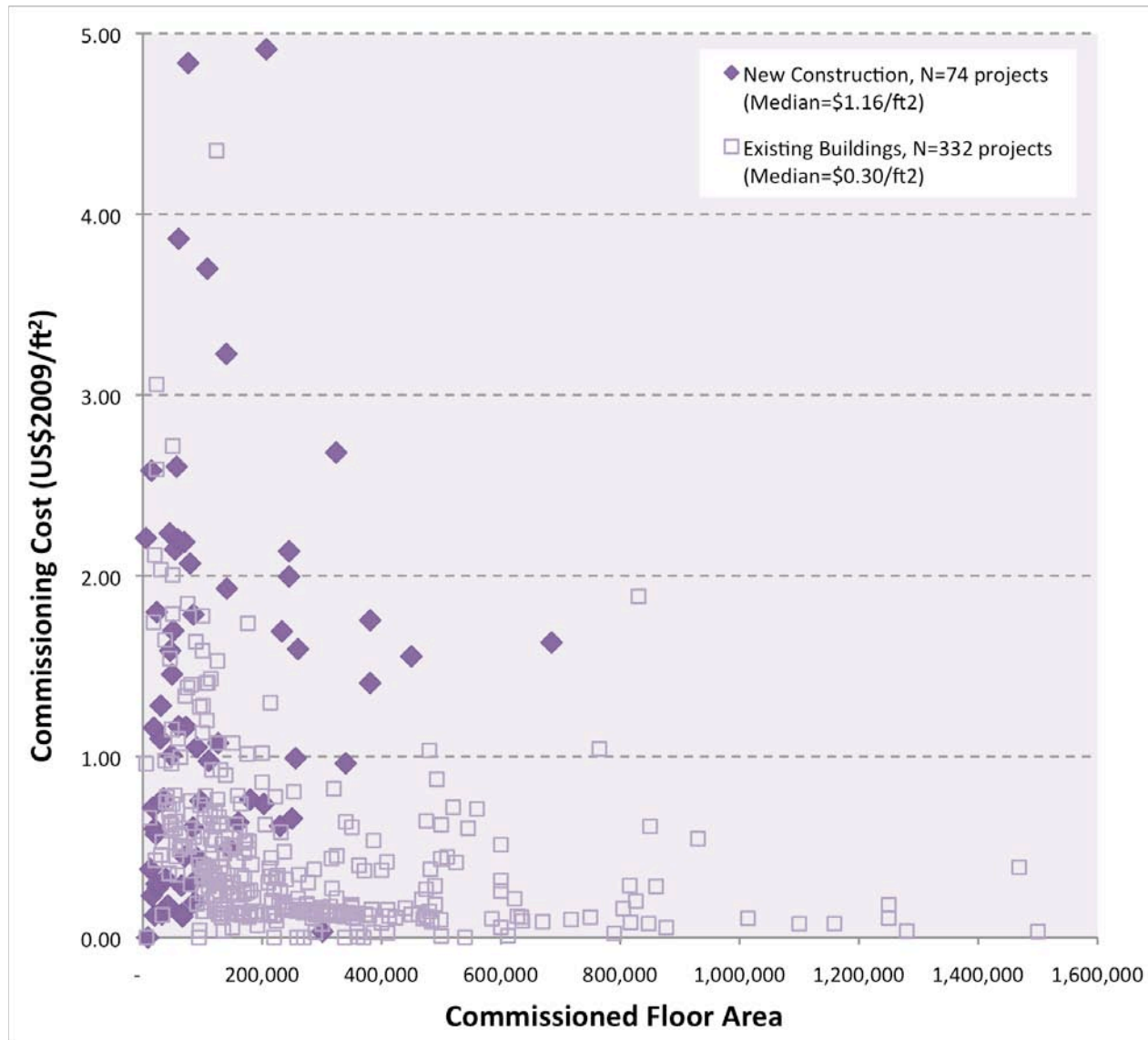
..And the measures to correct them



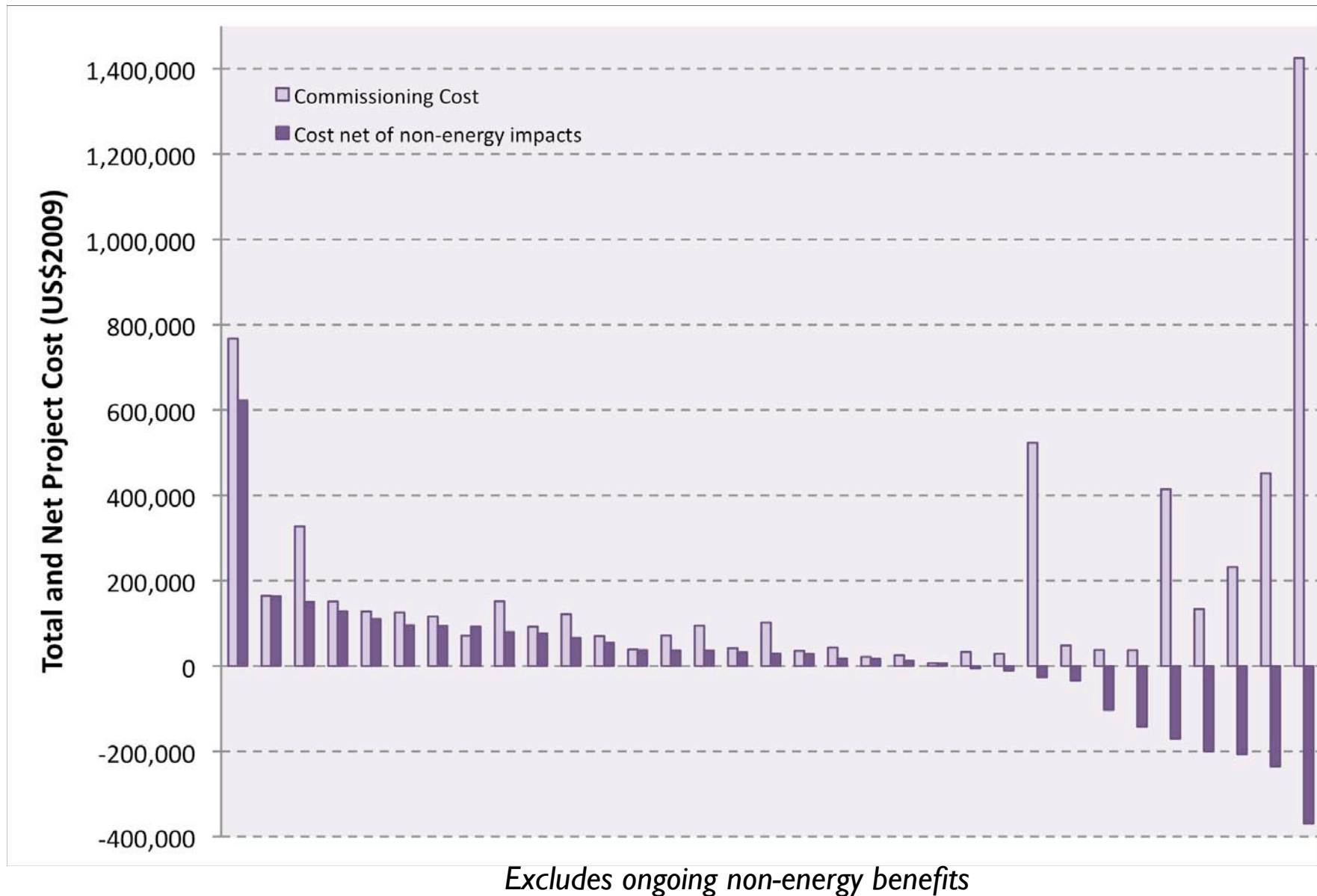
Significant non-energy benefits observed following commissioning



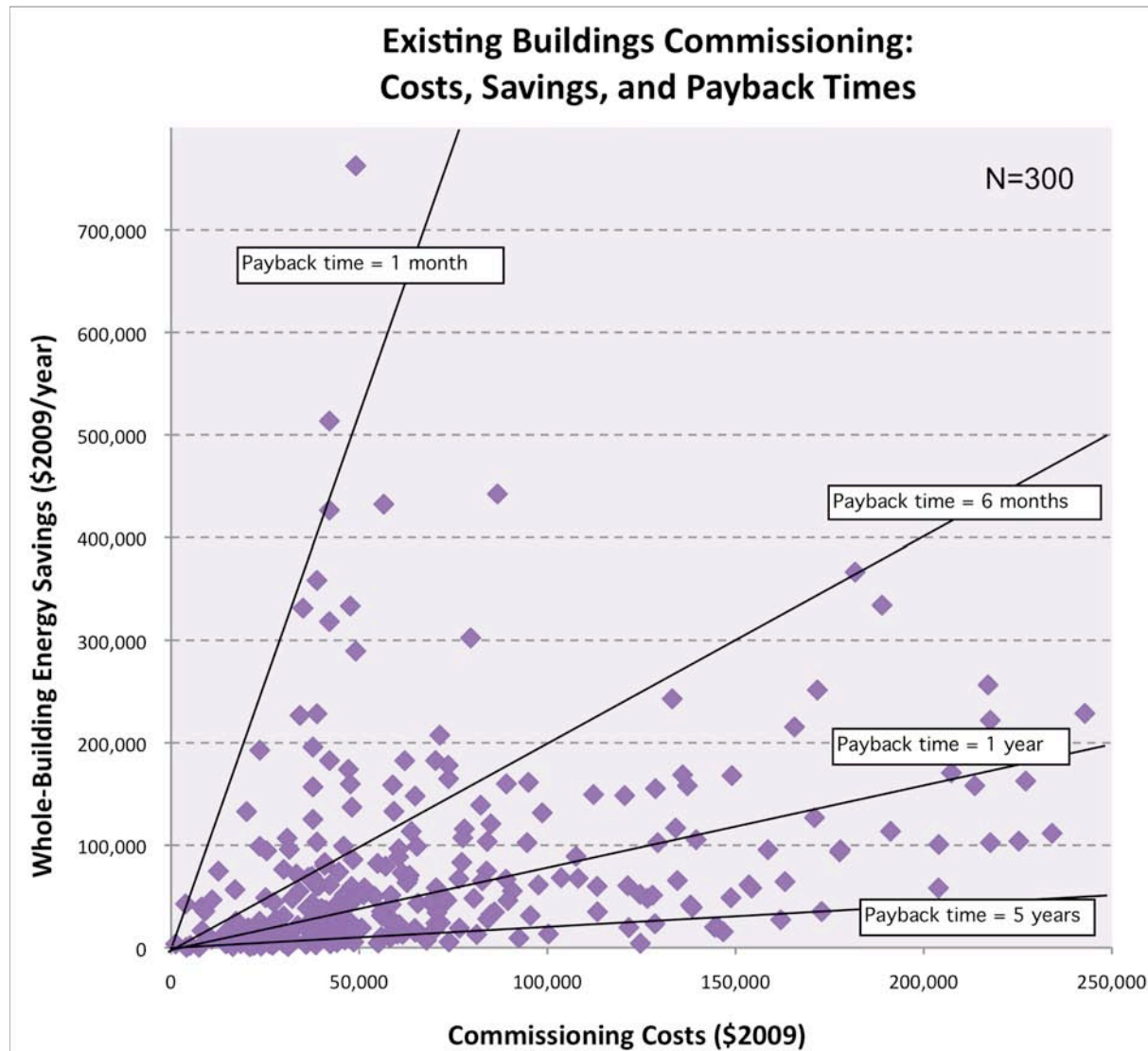
Commissioning costs: new & existing buildings



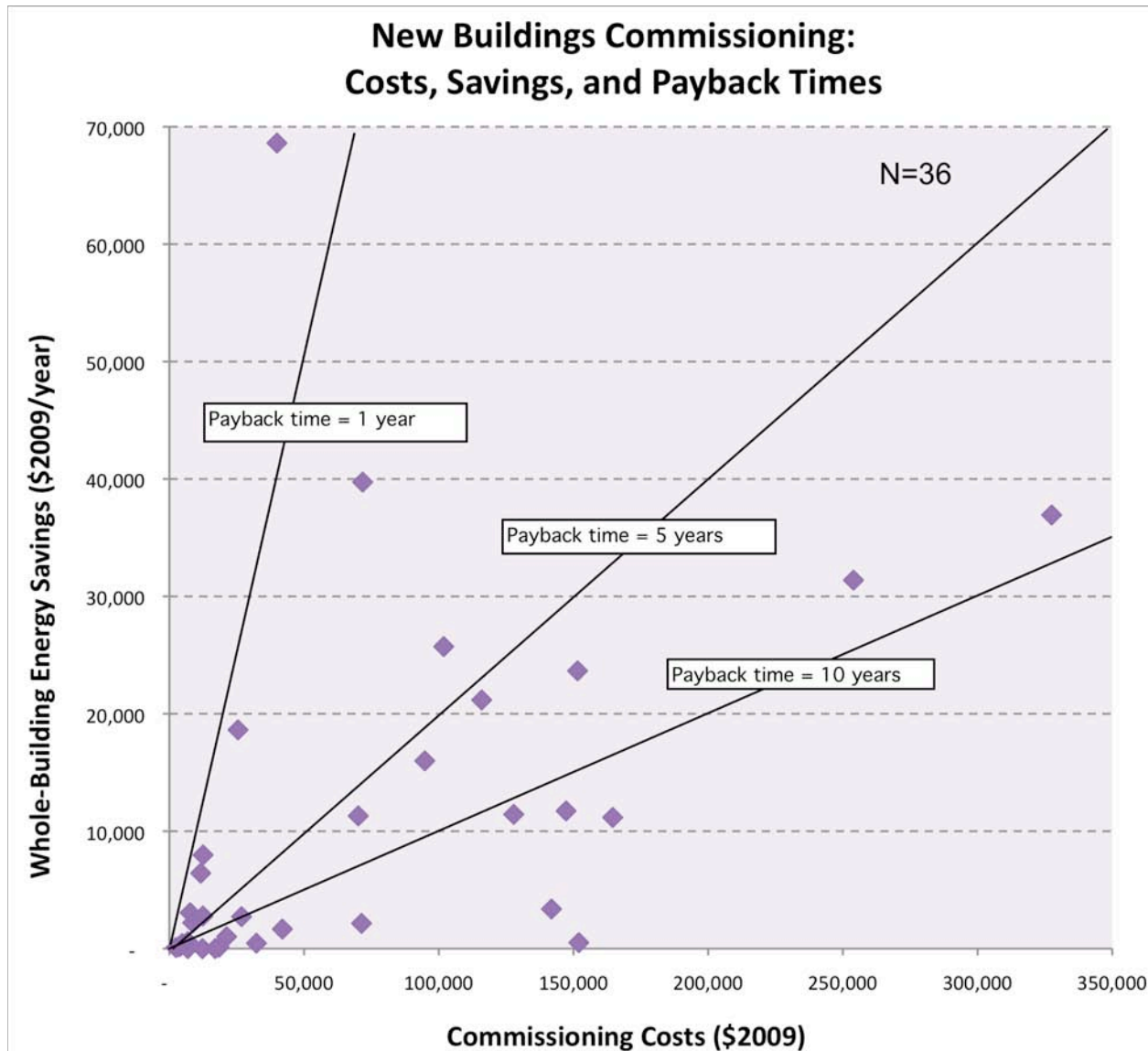
First-cost savings offset part or all nominal commissioning project costs



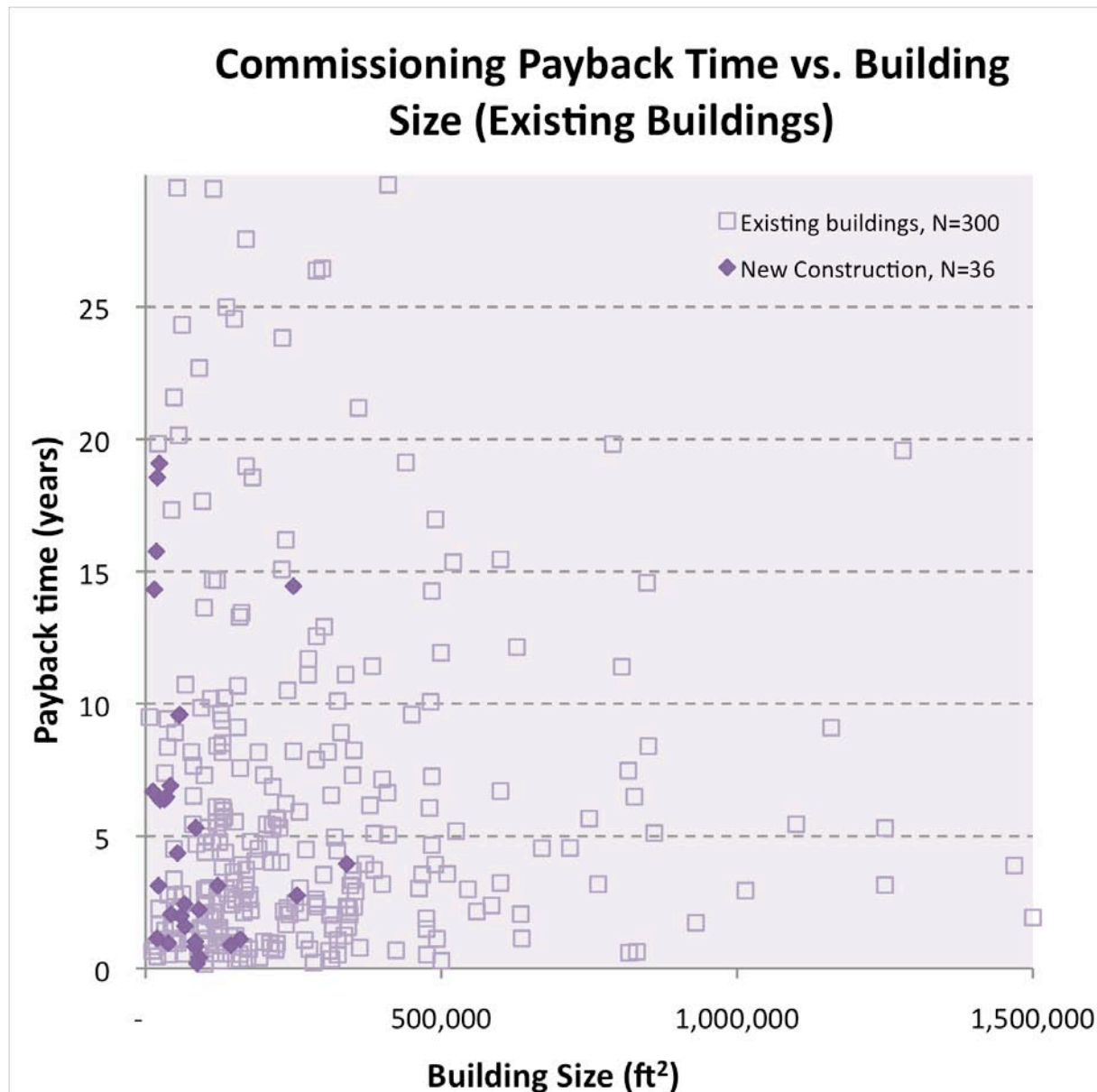
Payback times: existing buildings



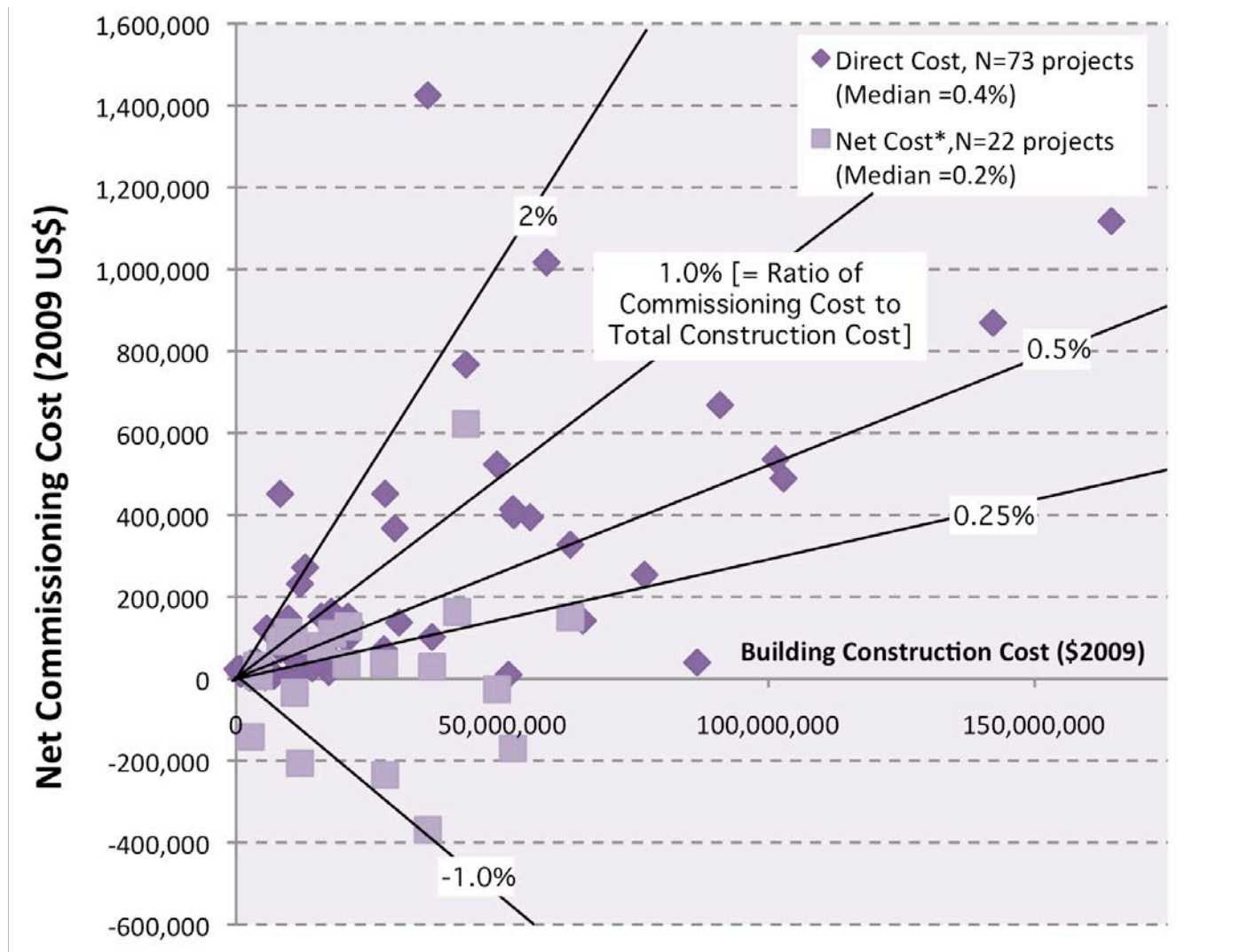
Payback times: new construction



No correlation between payback time and building size

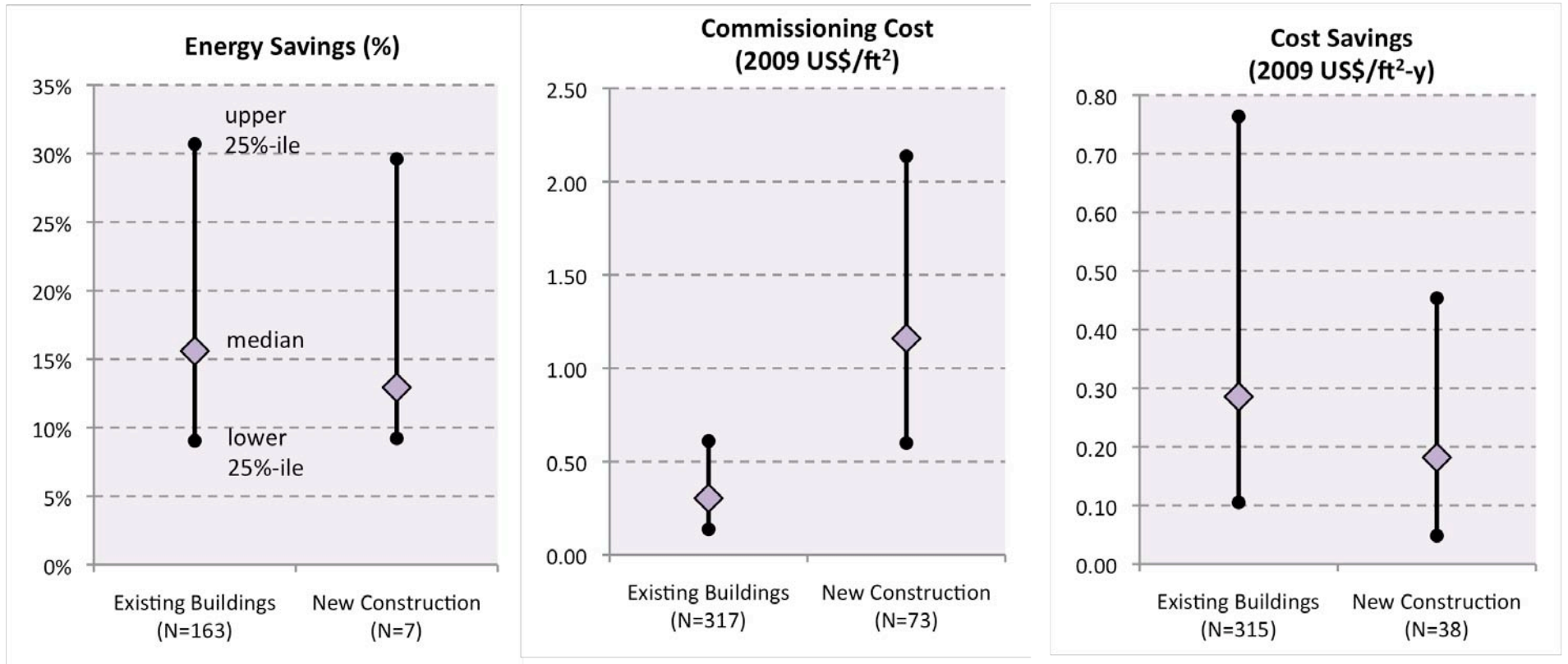


First-cost savings offset half of the commissioning cost



“Net Cost” includes first-cost savings where applicable.

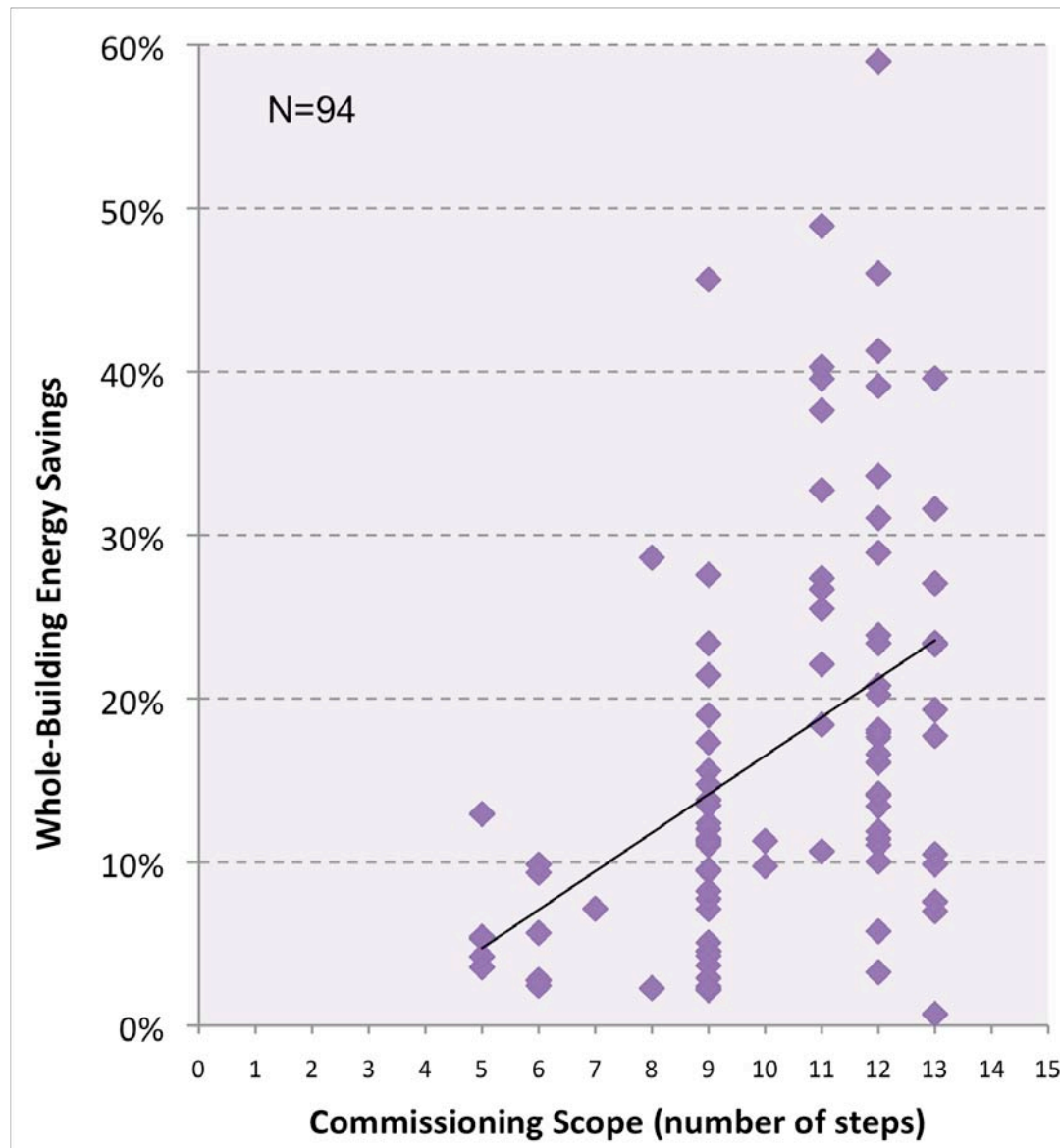
Performance benchmarks



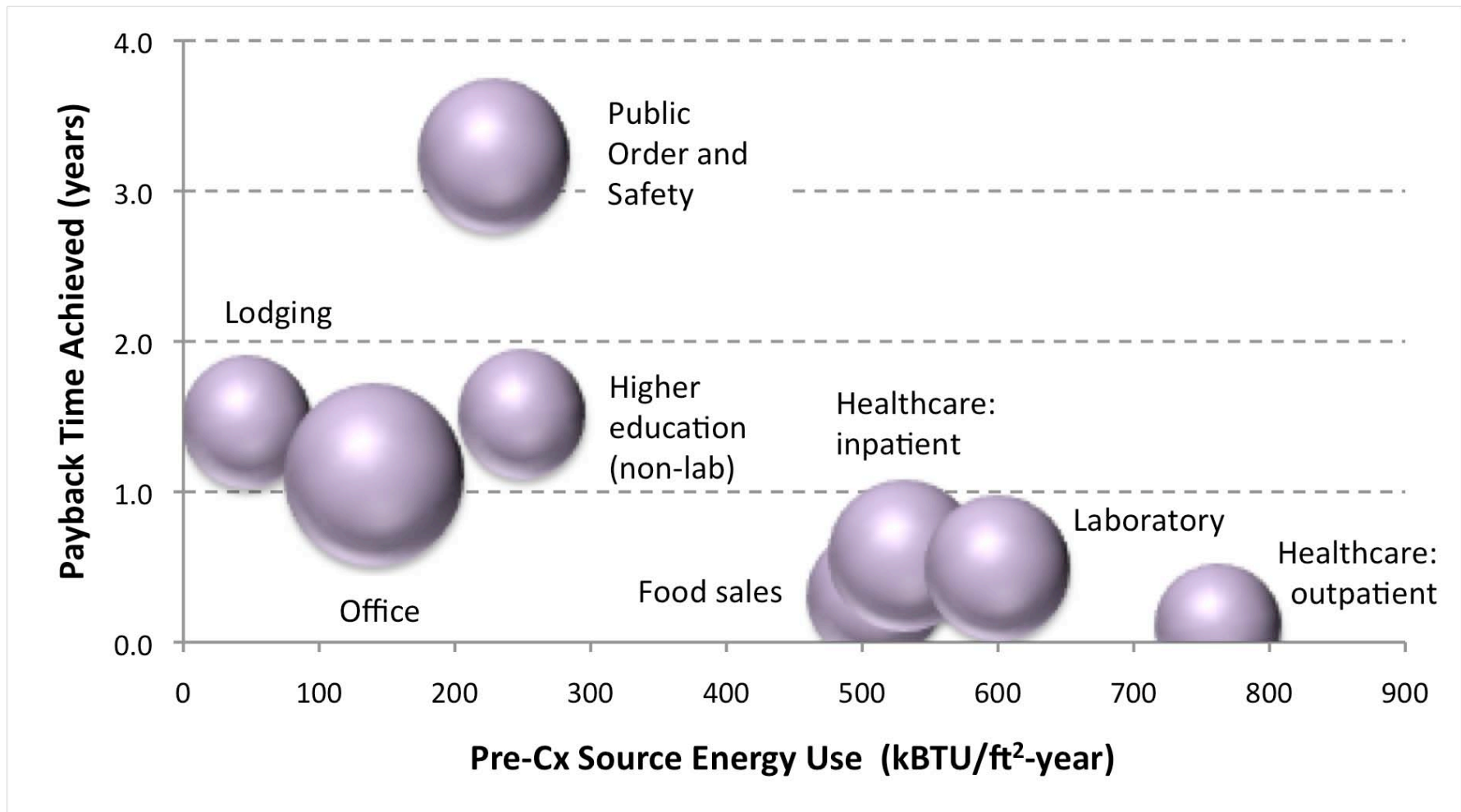
Projects are highly cost-effective



Depth of commissioning versus savings achieved (existing buildings)



High-Tech buildings attain greatest savings and lowest payback times

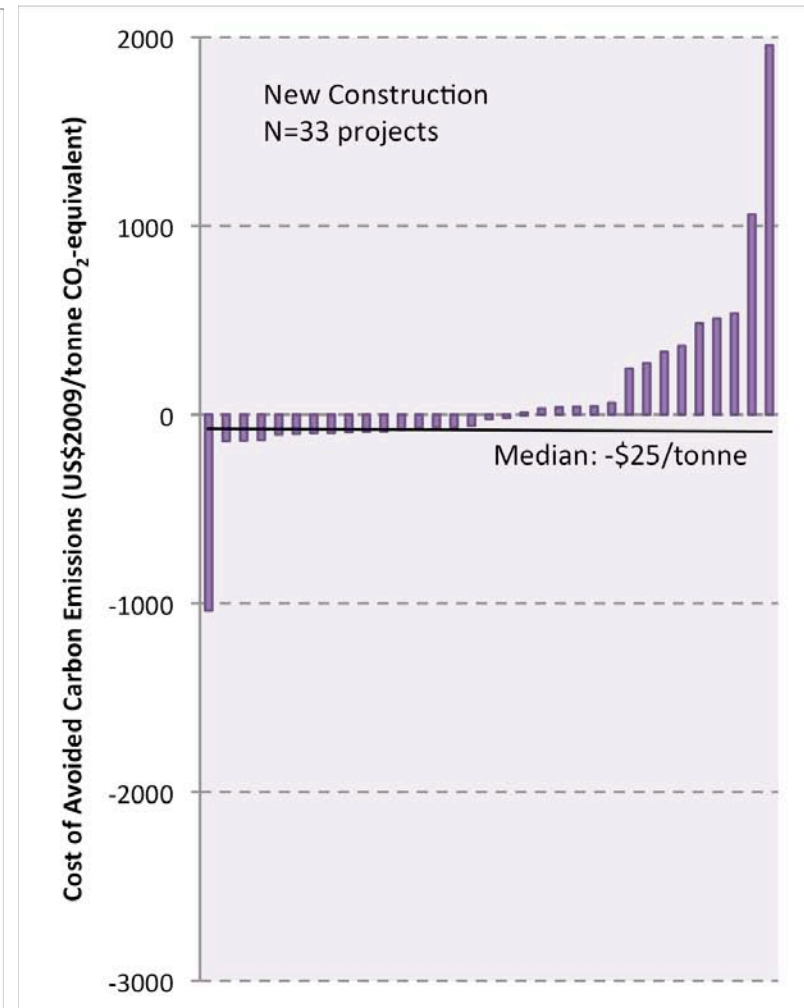
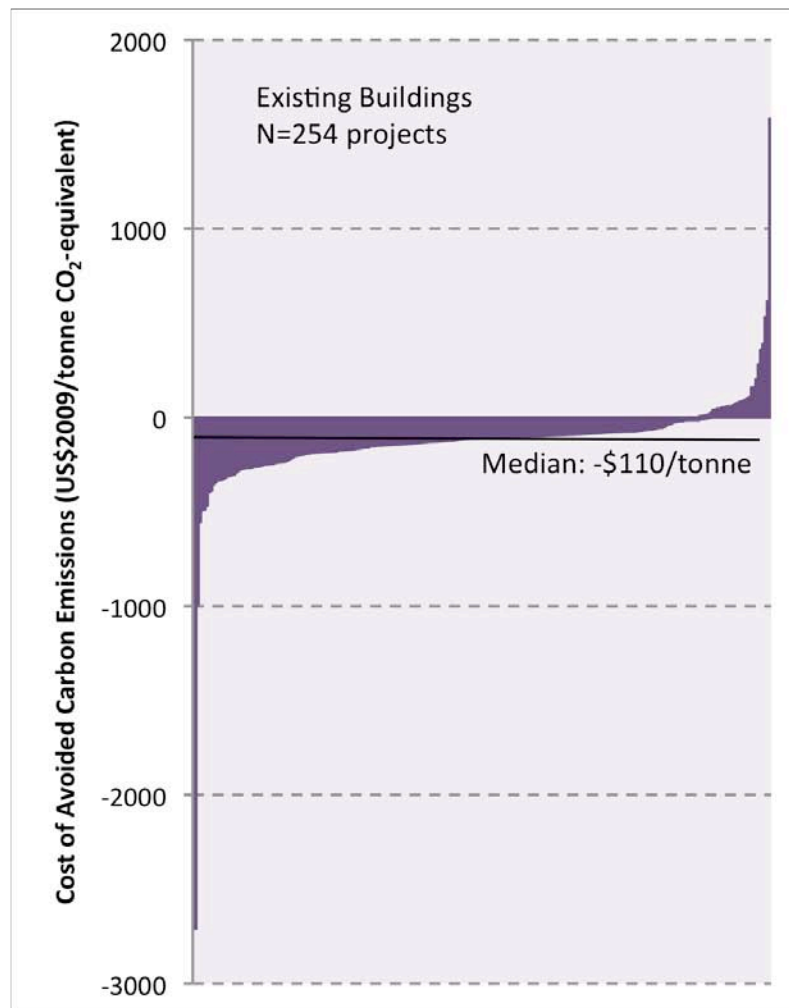


Excellent outcomes for all building types

	Pre-Cx EUI (kBTU/ft ² -year)	Source Energy Savings (%)	Simple Payback Time (PBT - years)	Number of buildings (by PBT)
K-12			3.3	19
Higher education	250	11%	1.5	165
Food Sales	510	12%	0.3	10
Food Service				
Inpatient	532	15%	0.6	15
Outpatient	764	10%	0.1	13
Cleanrooms				
Data Center				
Laboratory	600	14%	0.5	50
Lodging	48	12%	1.5	38
Retail			1.4	9
Service				
Office	141	22%	1.1	145
Public Assembly			1.0	6
Public Order and Safety	229	16%	3.2	15

Values only shown when the sample size is five or more buildings.

The ranked cost of conserved carbon for existing-building projects in the database: Existing buildings and new construction

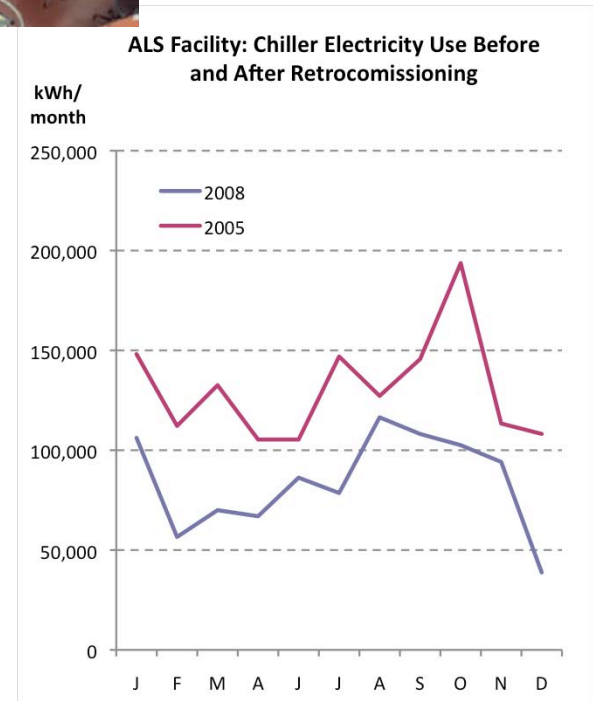


High-Tech buildings in the database

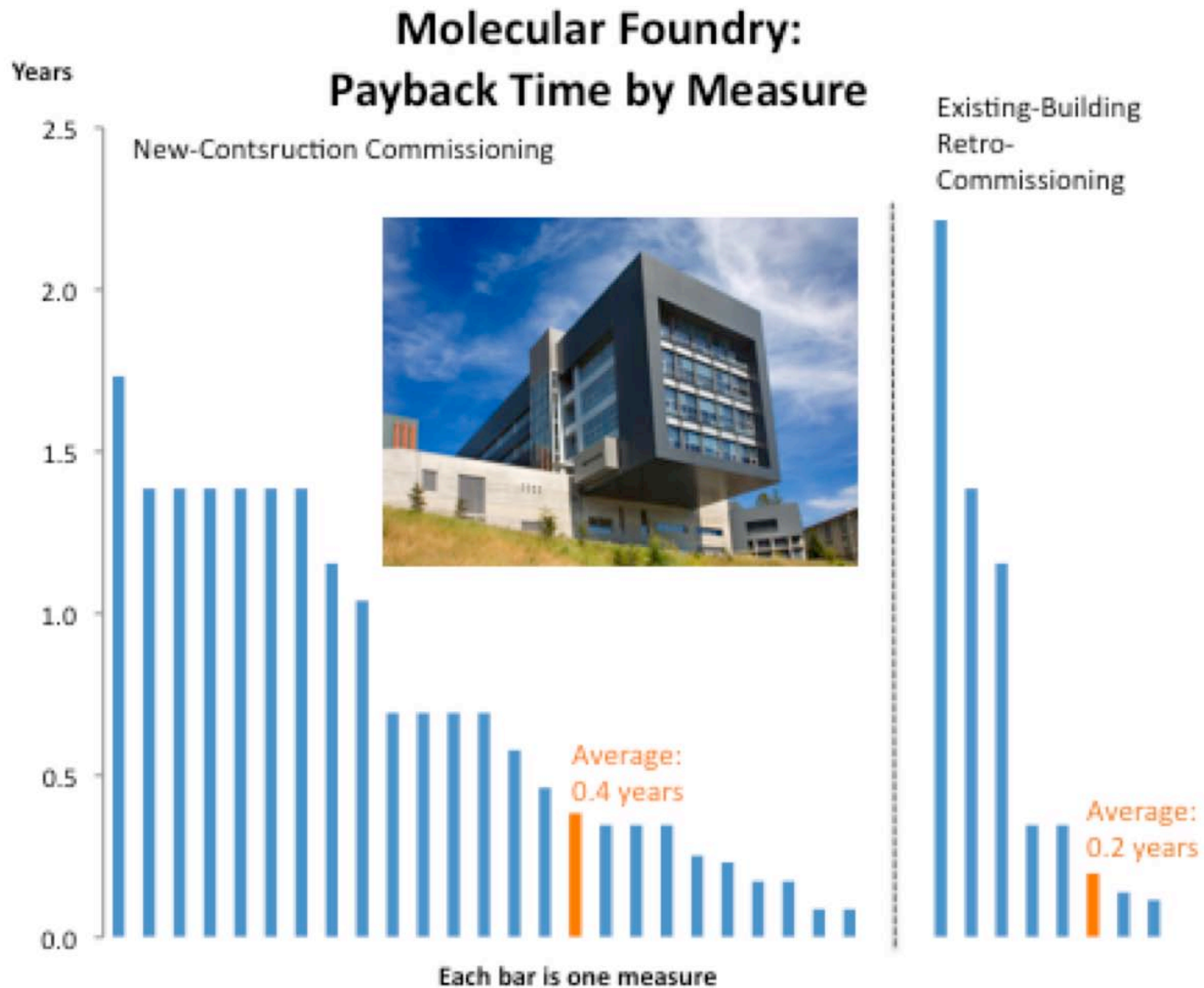
	Existing Buildings		New Buildings		TOTAL	
	# bldgs	ft ²	# bldgs	ft ²	# bldgs	ft ²
Cleanrooms	0	0	1	301,000	1	301,000
Data Center	2	12,888	0	0	2	12,888
Laboratory	50	4,561,593	18	1,965,065	68	6,526,658
Healthcare: inpatient	17	6,791,029	9	687,959	26	7,478,988
Healthcare: outpatient	14	4,319,124	4	206,300	18	4,525,424
Total	83	15,684,633	32	3,160,324	115	18,844,957

High-Tech Case Study: The Advanced Light Source

- Floor area: 118,573 square feet
- Project cost: \$32,000
- System commissioned: Chillers
- Energy savings: 45.7% (weather-normalized)
- Payback time (commissioning cost/annual energy savings) less than one year
- Avoided capital cost thanks to chiller replacement downsizing from 450 to 350 Tons: \$120,000 (based on \$1,200/tonne), i.e., four times the cost of the commissioning project



Two Tales of One Building



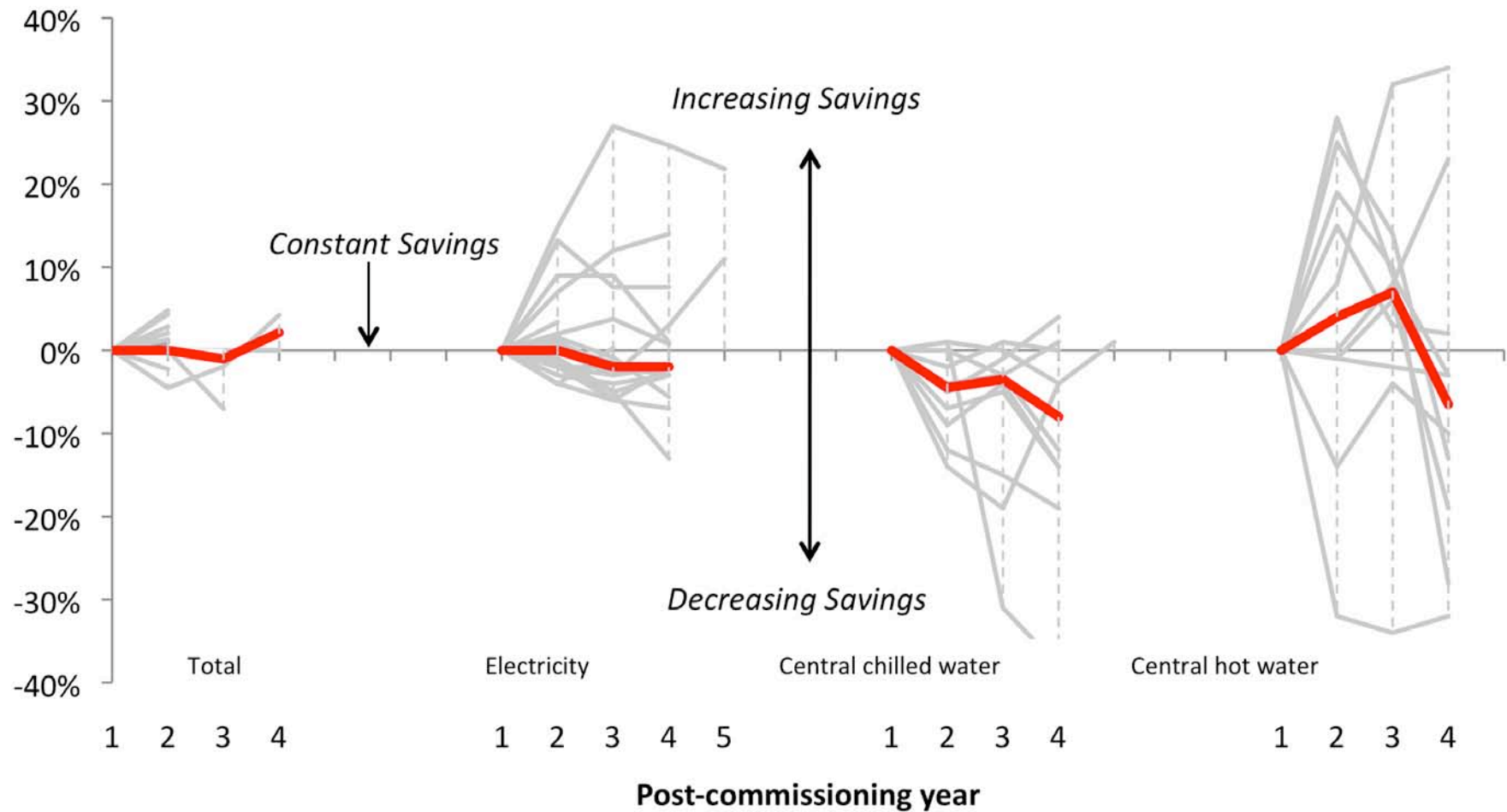
Two Tales of One Building (cont'd....)

	Commissioning (new Construction)	Retrocommissioning (post- construction)	Total
Year	2006	2006	
Measures Implemented to Resolve Problems	Modify controls' sequences of operations	Replace inefficient, oversize cooling terminal units & perform other HVAC upgrades .	
	Modify setpoints; and start/stop operation	Eliminate false loading of oversized chiller.	
	Calibrate terminal unit damper position feedback	Buffer tank modification to optimize return water temperature	
	Calibrate lighting occupancy sensors	Modify air compressor system to reduce need for frequent blowdown.	
	Bring air-compressor operation into spec		
Electricity savings (kWh/year)	441,500	223,200	664,700
Fuel savings (MBTU/year)	3,840	4,370	8,210
Cost Savings (\$/year)*	93,369	77,132	170,501
Commissioning Cost (US\$2009)	39,932	16,992	56,924
Simple Payback Time (years)	0.4	0.2	0.3

* at standardized national prices

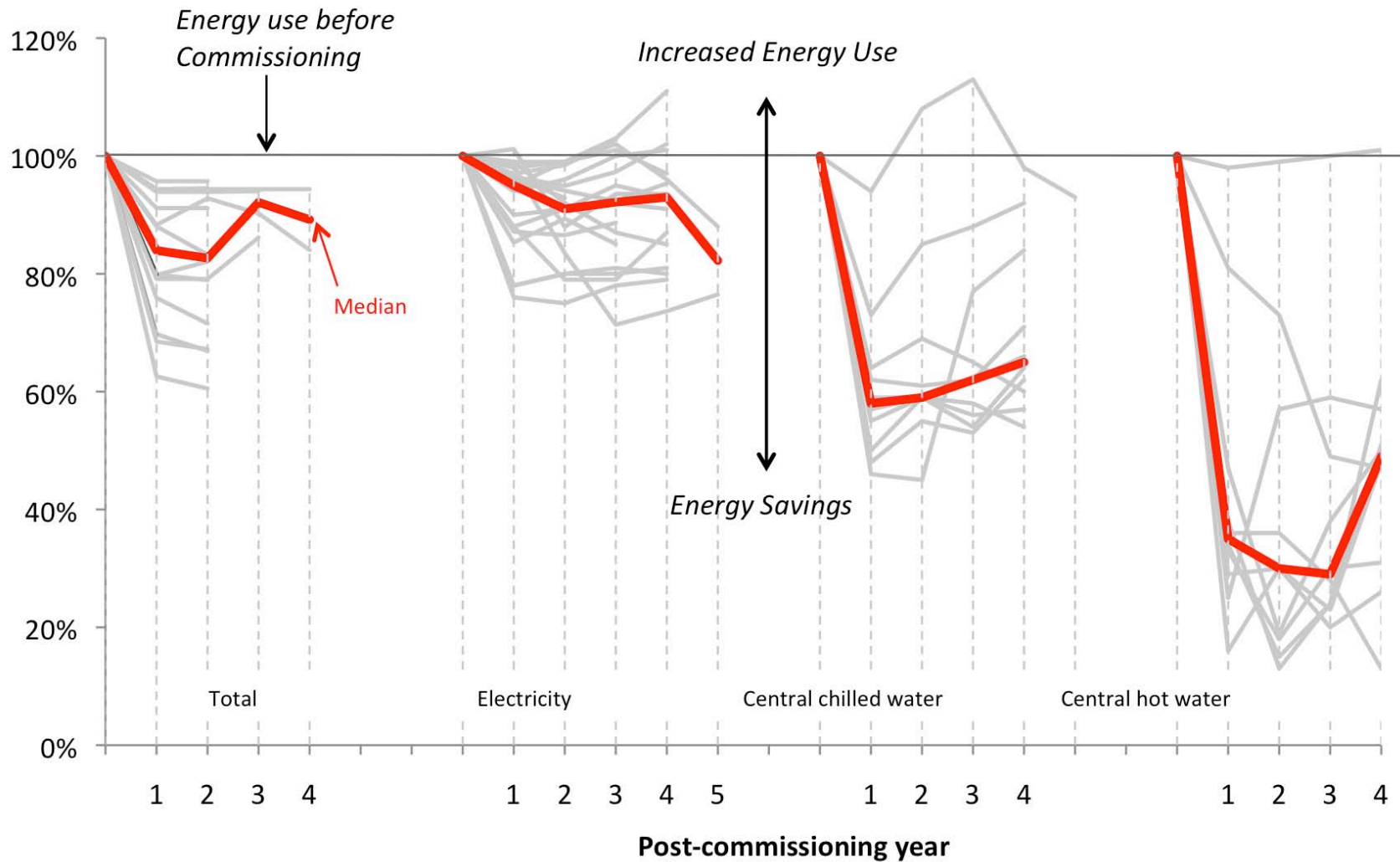
Persistence of Commissioning Savings (Change from first-year savings, %-points)

N = 36 projects



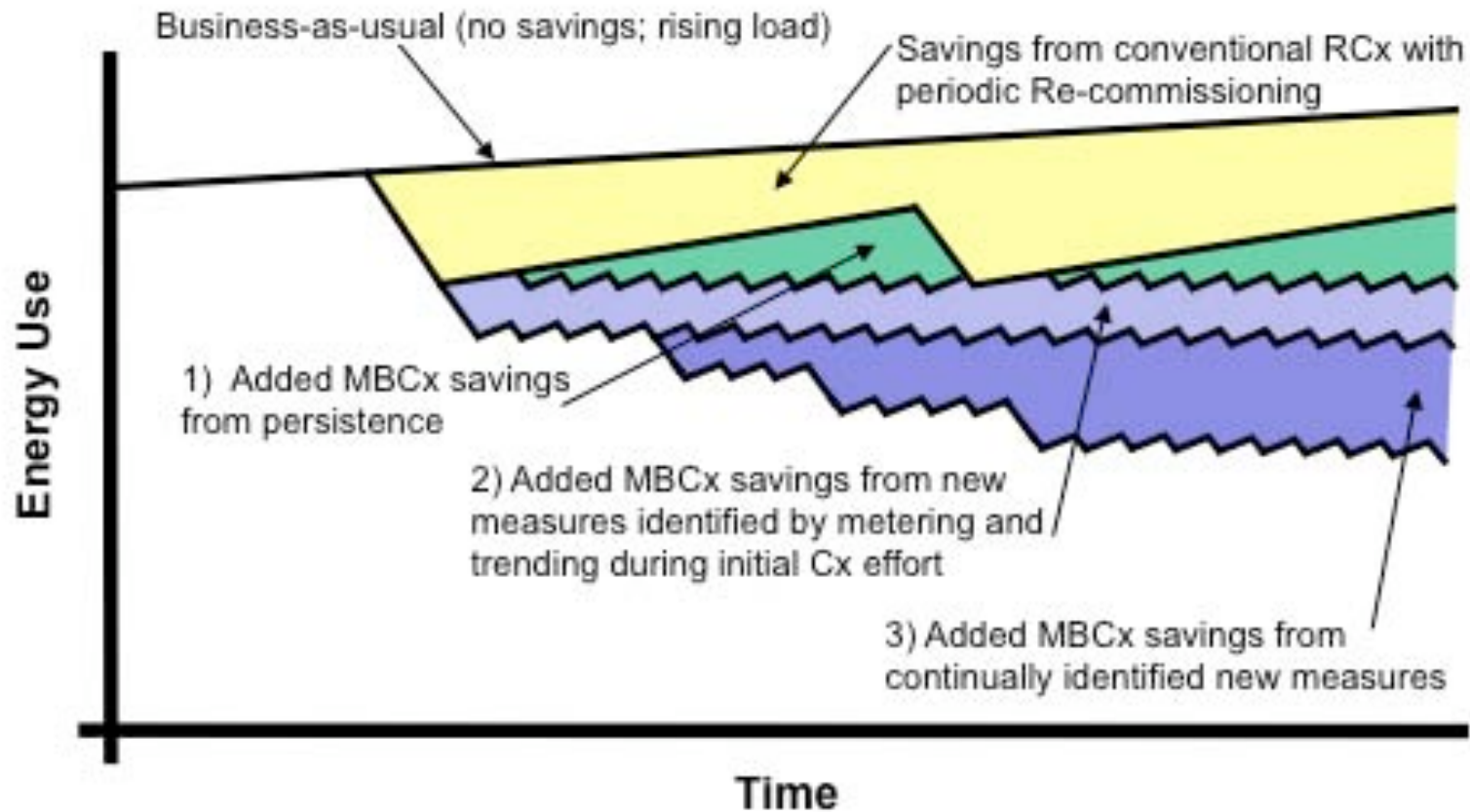
Persistence of Commissioning Savings (Consumption as % of base year)

N = 36 projects

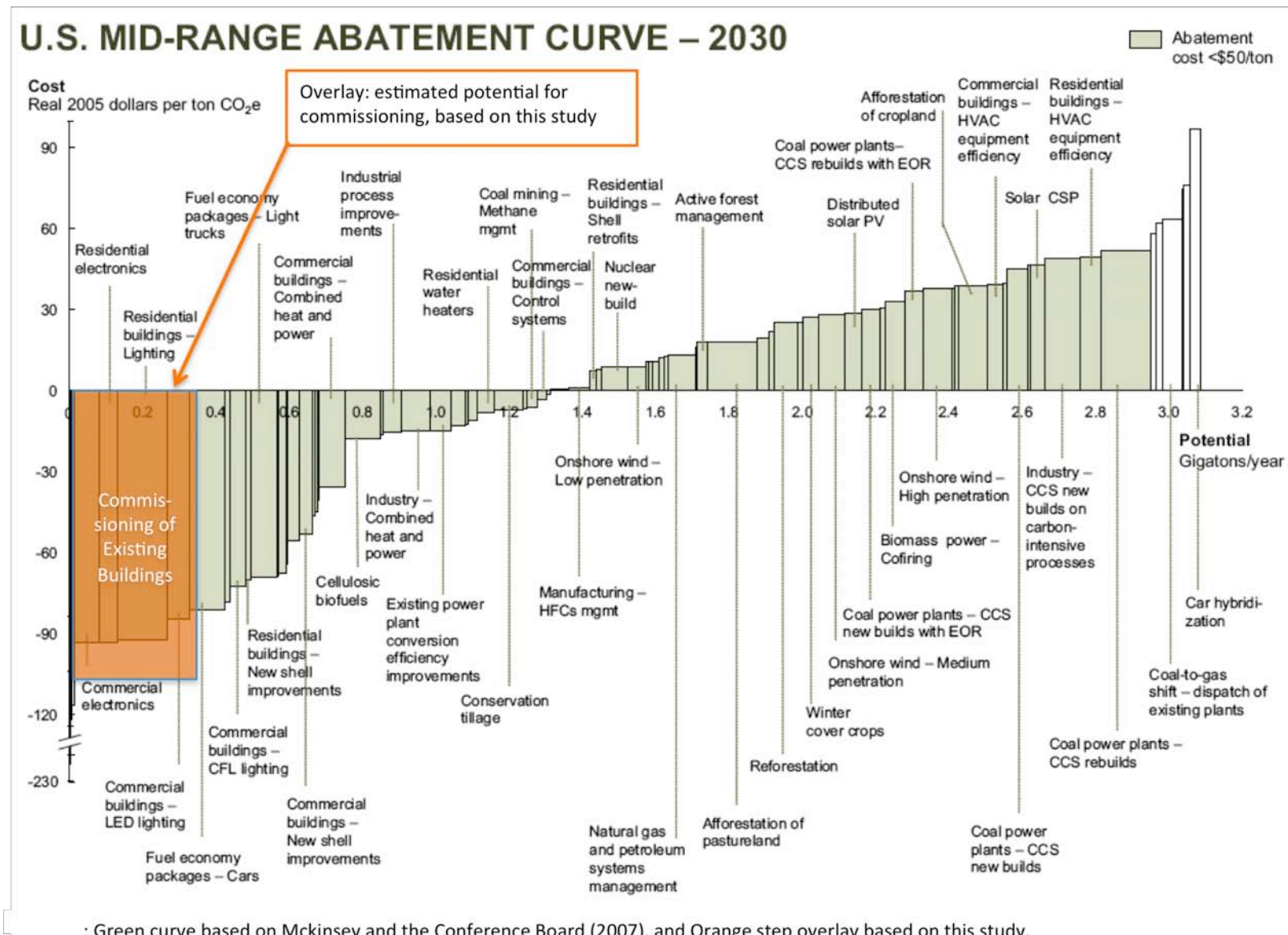


TRUST BUT VERIFY:

Monitoring-based commissioning



- Potential is huge: \$30 billion/year by 2030 in U.S.
- but Cx rarely treated well in savings potential studies



: Green curve based on McKinsey and the Conference Board (2007), and Orange step overlay based on this study.

Barriers

- Commissioning is an underutilized strategy for saving energy and money and reducing greenhouse gas emissions while managing related risks.
- Reasons for this underutilization:
 - widespread lack of awareness of need and value on the part of prospective customers
 - insufficient professionalism within the trades
 - splintered activities and competition among a growing number of trade groups and certification programs
 - misperception that it is not cost-effective in smaller buildings
 - the absence of commissioning-like requirements in most building codes
 - omission or obfuscation of the strategy in most energy-efficiency potentials studies.
 - tension between standardization and recognition that each building is unique and must be approached with an open mind.

Market Potential

- The fledgling existing-buildings commissioning industry has reached a size of about \$200 million per year in the United States.
- Based on a goal of commissioning each building every five years, the potential size is about \$4 billion per year, or 20-times the current number.
- To achieve the goal of keeping the U.S. building stock commissioned would require an increase in the workforce from about 1,500 to 25,000 full-time-equivalent workers, a realistic number when viewed in the context of the existing workforce of related trades.

“Commissioning America” in a decade is an ambitious goal, but “do-able” and very consistent with this country’s aspirations to simultaneously address energy and environmental issues while creating jobs and stimulating economic activity.

Thank You

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SUPPLEMENTARY INFORMATION

Not included in main report

Table 3. Energy and non-energy impacts (positive or negative) of commissioning.

	Cost	Benefit	Comment
Direct			
Cost of (retro)commissioning service	x	x	Cost can be partially or completely offset by the indirect effects listed below
Energy consumption	x	x	In rare circumstances, energy use can increase if equipment is found in "off" or under-utilized state
Indirect			
Accelerated repair of a problem (assuming it would have been identified and corrected, eventually, without commissioning)		x	
Avoided premature equipment failure		x	
Changes in ioperations and maintenance costs	x	x	
Changes in project schedule	x	x	Can shorten or lengthen schedule
Clarified delineation of responsibilities among team members		x	
Contractor call-backs		x	
Occupant comfort/productivity		x	
Equipment right-sizing	x	x	
Impacts on indoor environment		x	
Documentation	x	x	
In-house staff knowledge	x	x	
Disruption to occupancy and operations	x	x	Early detection of problems
More vigilant contractor behavior (knowing that Cx will follow their work)		x	
Operational efficacy		x	
Potential for reduced liability/litigation		x	
Change orders	x	x	Timely introduction of commissioning (early in process); otherwise potential for increase
Disagreement among contractors		x	
Testing and balancing (TAB) costs		x	Can be reduced by solving problems that the TAB contractor would otherwise have encountered
Safety impacts		x	
Warranty claims		x	
Water utilization		x	
Worker productivity		x	

Table 2. Rules for inclusion of costs in scope of commissioning.

Cost Factor	Include Cost?	Relevance (New Construction, Existing buildings)		Examples
Cx provider's fixed costs	Yes	N; E		Costs of developing commissioning spec, reviewing design documents, conducting inspections, construction observation
Other contractors' costs				
Contract compliance	No	N; E		Construct building; install systems
Testing and balancing (TAB)	No	N; E		Precedes commissioning; separate service with separate fees
Coordination with commissioning provider	Yes	N; E		Assist in performing functional tests
Correcting design flaws	No	N		Included in design contract and warranty
Improving design or operations	Yes	N		Recommendations to reduce pressure-drop, improved control sequences
"Non-billable" in-house operations staff fixed costs	As desired by owner	N; E		Staff time to work with commissioning provider
Functional tests	Yes	N; E		Validating intended damper positions or variable-speed drive operating cycle
Resolution costs related to optimizing systems	Yes	N; E		Corrections during start-up; tune-up
Costs related to ensuring other trades' adherence to contract documents	Yes	N; E		Verifying as-built condition meets design intent
Resolution costs related to installing a system beyond project scope	No	N		Installing energy management and control systems; major capital retrofits
Resolution costs related to operations and maintenance	Yes	E		Cleaning fouled filters
Minor capital improvements to resolve deficiencies	Yes	N; E		Operations and maintenance
Major capital improvements to resolve deficiencies: new construction	No	N		Replacing incorrectly sized chiller
Major capital improvements to resolve deficiencies: existing buildings	Yes	E		Replacing faulty control system elements
Training or on-site staff	Yes, if in scope	N; E		
Utility rebates, grants, or other external financial assistance	Yes	N; E		Represents part of true project cost
Research-related costs	No	N; E		Development of research reports; not essential to efficacy of commissioning project
Travel	Yes	N; E		To and from project site
Non-energy impacts	Yes	N; E		Often not quantified

Table 1: Overview of M&V Options

M&V Option	How Savings Are Calculated	Typical Applications
<p>A. Partially Measured Retrofit Isolation</p> <p>Savings are determined by partial field measurement of the energy use of the system(s) to which an ECM was applied, separate from the energy use of the rest of the facility. Measurements may be either short-term or continuous.</p> <p>Partial measurement means that some but not all parameter(s) may be stipulated, if the total impact of possible stipulation error(s) is not significant to the resultant savings. Careful review of ECM design and installation will ensure that stipulated values fairly represent the probable actual value. Stipulations should be shown in the M&V Plan along with analysis of the significance of the error they may introduce.</p>	<p>Engineering calculations using short term or continuous post-retrofit measurements and stipulations.</p>	<p>Lighting retrofit where power draw is measured periodically. Operating hours of the lights are assumed to be one half hour per day longer than store open hours.</p>
<p>B. Retrofit Isolation</p> <p>Savings are determined by field measurement of the energy use of the systems to which the ECM was applied, separate from the energy use of the rest of the facility. Short-term or continuous measurements are taken throughout the post-retrofit period.</p>	<p>Engineering calculations using short term or continuous measurements</p>	<p>Application of controls to vary the load on a constant speed pump using a variable speed drive. Electricity use is measured by a kWh meter installed on the electrical supply to the pump motor. In the baseyear this meter is in place for a week to verify constant loading. The meter is in place throughout the post-retrofit period to track variations in energy use.</p>
<p>C. Whole Facility</p> <p>Savings are determined by measuring energy use at the whole facility level. Short-term or continuous measurements are taken throughout the post-retrofit period.</p>	<p>Analysis of whole facility utility meter or sub-meter data using techniques from simple comparison to regression analysis.</p>	<p>Multifaceted energy management program affecting many systems in a building. Energy use is measured by the gas and electric utility meters for a twelve month baseyear period and throughout the post-retrofit period.</p>
<p>D. Calibrated Simulation</p> <p>Savings are determined through simulation of the energy use of components or the whole facility. Simulation routines must be demonstrated to adequately model actual energy performance measured in the facility. This option usually requires considerable skill in calibrated simulation.</p>	<p>Energy use simulation, calibrated with hourly or monthly utility billing data and/or end-use metering.</p>	<p>Multifaceted energy management program affecting many systems in a building but where no baseyear data are available. Post-retrofit period energy use is measured by the gas and electric utility meters. Baseyear energy use is determined by simulation using a model calibrated by the post-retrofit period utility data.</p>

Table 1: Overview of New Construction M&V Options

M&V Option	How Baseline is Determined	Typical Applications
<p>A. Partially Measured Retrofit Isolation</p> <p>Savings are determined by partial measurement of the energy use of the system(s) to which an ECM was applied, separate from the energy use of the rest of the facility. Some parameters are stipulated rather than measured.</p>	<p>Projected baseline energy use is determined by calculating the hypothetical energy performance of the baseline system under post-construction operating conditions.</p>	<p>Lighting system where power draw is periodically measured on site. Operating hours are stipulated.</p>
<p>B. Retrofit Isolation</p> <p>Savings are determined by full measurement of the energy use and operating parameters of the system(s) to which an ECM was applied, separate from the rest of the facility.</p>	<p>Projected baseline energy use is determined by calculating the hypothetical energy performance of the baseline system under measured post-construction operating conditions.</p>	<p>Variable speed control of a fan motor. Electricity needed by the motor is measured on a continuous basis throughout the M&V period.</p>
<p>C. Whole Facility</p> <p>Savings are determined at the whole-building level by measuring energy use at main meters or with aggregated sub-meters.</p>	<p>Projected baseline energy use determined by measuring the whole-building energy use of similar buildings without the ECMs.</p>	<p>New buildings with energy-efficient features are added to a commercial park consisting of buildings of similar type and occupancy.</p>
<p>D. Calibrated Simulation</p> <p>Savings are determined at the whole-building or system level by measuring energy use at main meters or sub-meters, or using whole-building simulation calibrated to measured energy use data.</p>	<p>Projected baseline energy use is determined by energy simulation of the Baseline under the operating conditions of the M&V period.</p>	<p>Savings determination for the purposes of a new building Performance Contract, with the local energy code defining the baseline.</p>

Deficiencies		Design, Installation,				Operations & Control								Maintenance					Deficiency unmatched to specific measure	Total Accepted	Rejected																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																											
		D1	D2	D3	D4	OC1	OC2	OC3	OC4	OC5	OC6	OC7	OC8	OC9	M1	M2	M3	M4				M5																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																										
		Design change (design detail, improper equipment, improper system, etc.)				Implement advanced reset (air, water, lighting)				Start/Stop (environmentally determined)				Scheduling (occupancy determined) - equipment or lighting				Modify setpoint (high VAV setpoint minimum, setpoint suboptimal)				Equipment staging				Modify sequence of operations				Loop tuning				Behavior modification/manual changes to operations				Other				Calibration				Mechanical fix (flow obstructions, leaky valves, leaky ductwork, etc.)				Heat transfer maintenance (dirty heat transfer component, improper refrigerant charge, etc.)				Filtration maintenance				Other																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																						
		Installation modifications (construction out of spec, equipment out of spec, O&M access, etc.)																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																														

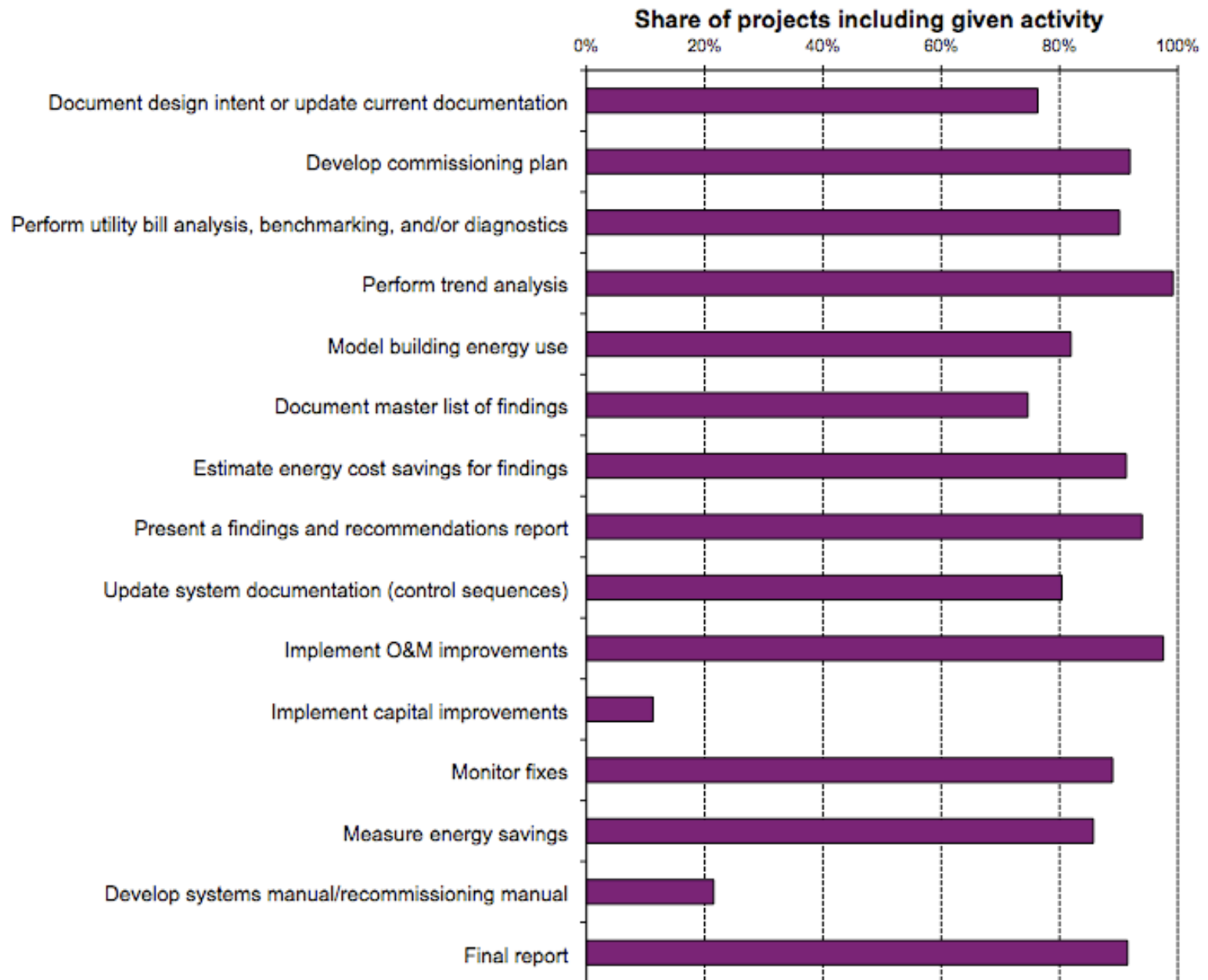
* Note: Count is number of projects with one or more instances given deficiency/measure (as opposed to a total sum of individual deficiencies/measures)

Deficiencies

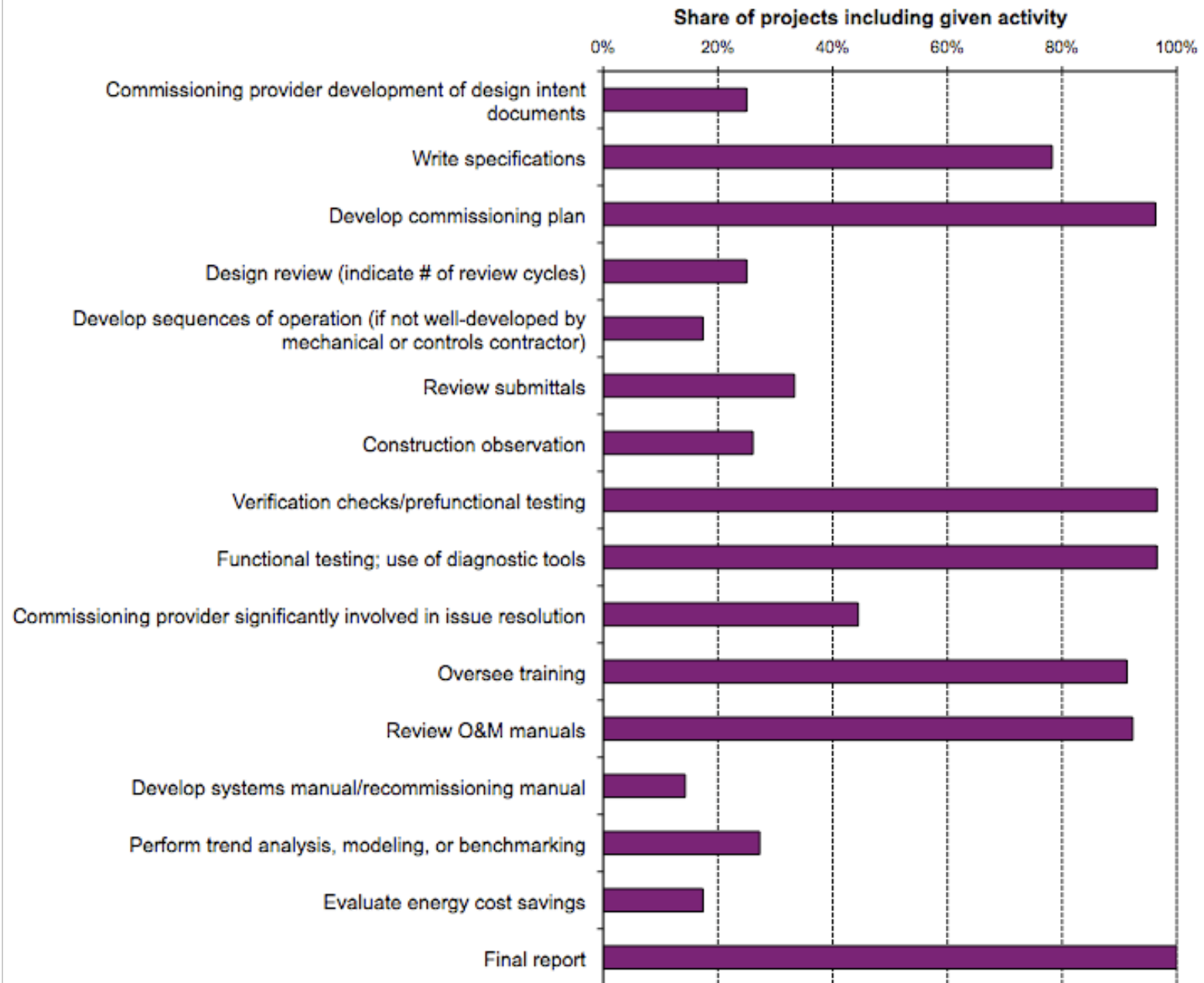
Deficiencies		D1	D2	D3	D4	OC1	OC2	OC3	OC4	OC5	OC6	OC7	OC8	OC9	M1	M2	M3	M4	M5	Deficit	Total	Reject
HVAC (combined heating and cooling)	V	1	11	0	0	2	0	0	3	2	2	1	0	3	6	9	1	2	2	124	169	0
Cooling plant	C	0	3	1	0	1	1	0	1	0	3	1	0	1	2	2	0	0	0	90	106	4
Heating plant	H	1	2	1	0	0	0	0	1	1	2	1	0	1	2	1	0	0	0	57	70	0
Air handling & distribution	A	0	10	2	0	1	0	0	3	0	8	2	0	4	2	14	1	0	3	234	284	0
Terminal units	T	1	5	0	0	0	0	2	5	0	2	1	0	0	4	1	0	1	0	98	120	1
Lighting	L	0	0	0	0	0	0	1	0	0	0	0	0	0	9	1	0	0	0	163	174	0
Envelope	E	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6
Plug loads	P	0	1	0	0	0	0	0	0	0	1	0	0	0	2	0	0	0	0	81	85	4
Facility-wide (e.g. EMCS or utility related)	F	3	3	1	0	0	0	0	0	1	2	0	0	8	0	3	0	0	1	77	99	3
Other	O	2	1	0	1	0	0	0	0	1	0	0	0	0	1	1	0	0	0	124	131	8
Measure unmatched to specific deficiency		22	90	16	22	4	0	0	90	37	56	133	0	14	82	146	16	5	263		1137	
Total Accepted		30	126	21	23	8	1	3	103	42	76	139	0	31	110	178	18	8	269	1186		26
Rejected		5	4	6	0	2	0	0	0	0	2	0	0	0	2	3	1	1	0		26	

* Note: Count is number of projects with one or more instances given deficiency/measure (as opposed to a total sum of individual deficiencies/measures)

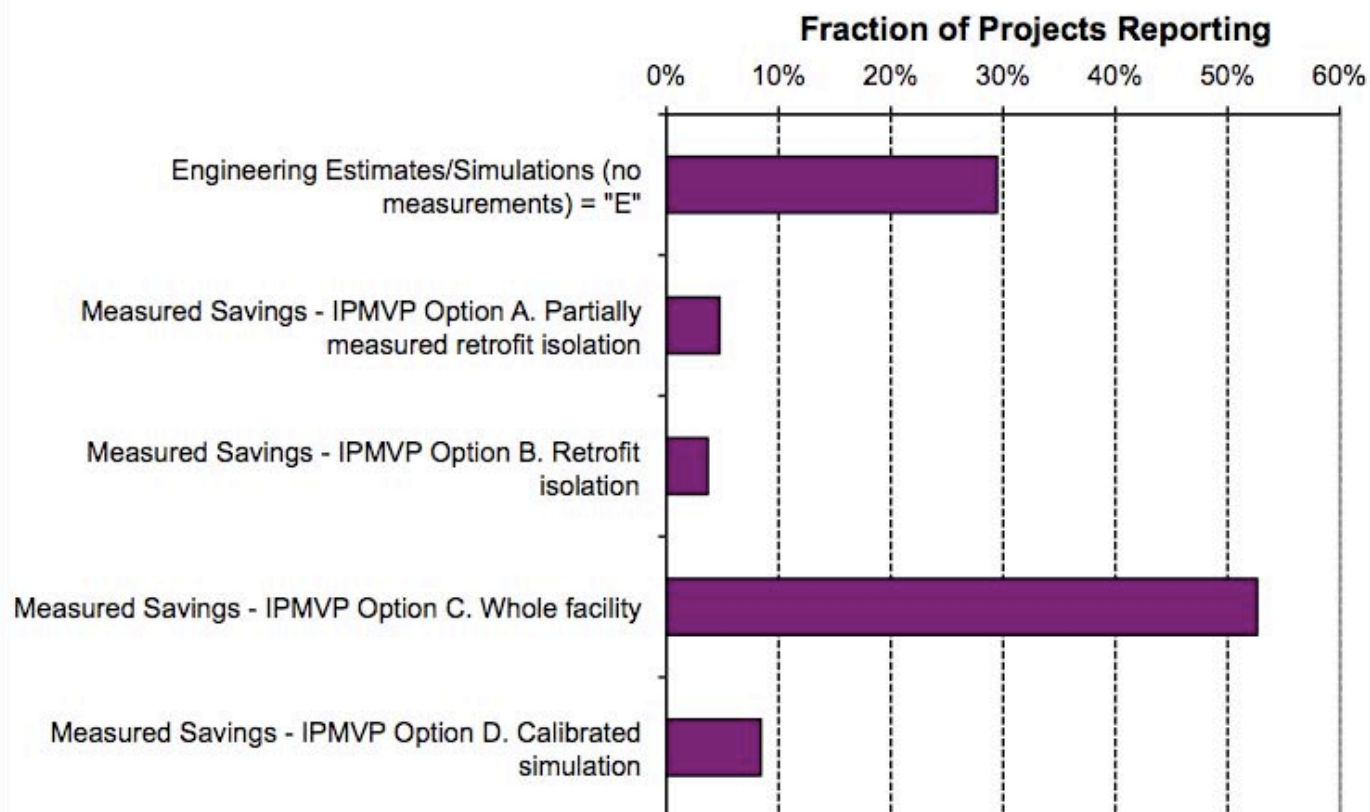
Scope of Existing Buildings Commissioning (N=73)



Scope of New-Construction Commissioning (N=26)



Primary Commissioning Savings Verification Methods (Existing Buildings, N=190)



IPMVP - Dominant Method	
Engineering Estimates/Simulations (no measurements) = "E"	49%
Measured Savings - IPMVP Option A. Partially measured retrofit isolation	3%
Measured Savings - IPMVP Option B. Retrofit isolation	3%
Measured Savings - IPMVP Option C. Whole facility	38%
Measured Savings - IPMVP Option D. Calibrated simulation	6%