Existing Building Commissioning: Exploration of Use and Impacts

Master of Science in Energy Thesis Defense

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Background

THE OHIO STATE UNIVERSITY
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https://students.cfaes.ohio-state.edu/sites/ap/files/events/SENR_CFAES.jpg

Presentation Outline

- Introduction
- Objectives
- Literature Review
- Key Literature Review Values
- Methodology
- Calculations and Assumed Values
- Sample
- Results
- Considerations/Caveats
- Conclusion
- Future Work

Introduction - Definitions

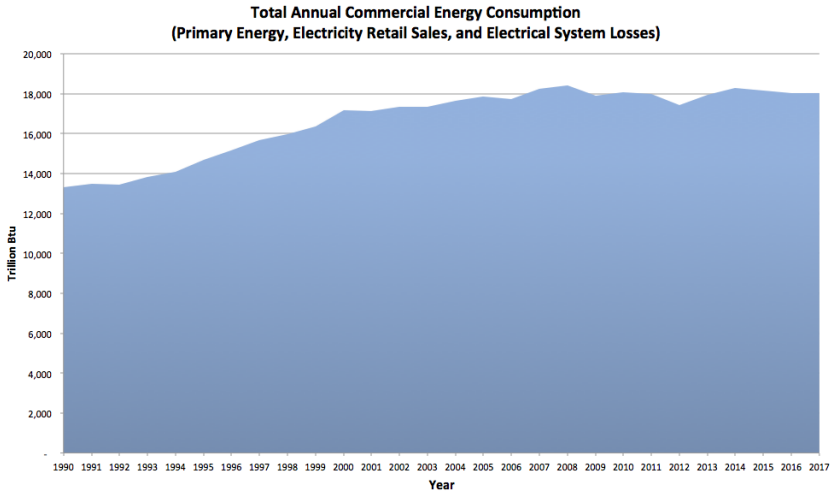
- Existing Building Commissioning (EBCx)
  - Definition: “a systematic process for investigating, analyzing, and optimizing the performance of building systems through the identification and implementation of low/no cost and capital-intensive Facility Improvement Measures and ensuring their continued performance.” (BCxA)

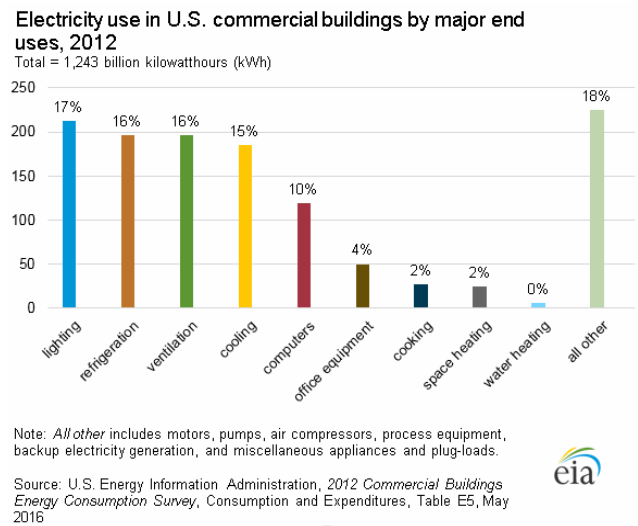
- New Construction Commissioning (NCCx)
  - Definition: an intensive quality assurance process that is performed throughout the design, construction, occupancy, and operations phases of new building construction. The intent is to ensure that the new building operates to the owner’s specifications and that building staff is adequately trained to operate and maintain the building systems. (LBNL)

https://www.bcxa.org/wp-content/pdf/BCA-Best-Practices-Commissioning-Existing-Construction.pdf
http://cx.lbl.gov/definition.html

Introduction – Commercial Sector Energy Consumption

- Total Commercial Energy Consumption
  - 18,040.45 trillion Btu in 2017 [18 Quads] (EIA)
- Commercial Building Energy End Uses 2012 (EIA)
  - Electricity – 61%
  - Natural Gas – 32%
  - District Heat – 5%
  - Fuel Oil – 2%
- Commercial Electricity End Uses 2012 (EIA)
  - Refrigeration – 16%
  - Ventilation – 16%
  - Cooling – 15%
  - Other – 18% (includes pumps, compressors, etc.)





https://www.eia.gov/totalenergy/data/browser/?tbl=T02.03#/?f=M
https://www.eia.gov/energyexplained/index.cfm?page=us_energy_commercial#tab2

Objectives

- Primary Objective:
  - Quantify the implementation and impact of EBCx in the United States
    - Estimated Annual Revenue
    - Estimated Annual Cost Annual Savings
    - Estimated Annual Energy Savings
- Secondary Objective:
  - Quantify the implementation and impact of Cx in the United States (EBCx + NCCx)
    - Estimated Annual Revenue
    - Estimated Annual Cost Savings
    - Estimated Annual Energy Savings

Literature Review

- Range of meta-analyses and case studies
  - EBCx, NCCx, and CC
- Primary data for analysis
  - Project-level metrics
    - Implementation by building type
    - Costs, cost savings, energy savings, simple payback periods
- Secondary data for additional context
  - Improvements in occupant comfort
  - Measure-level trends and metrics

Key Literature Review Values: Costs and Savings (EBCx)

Study	Cost per Unit Area	Cost Savings per Unit Area	Energy Savings	Simple Payback
Mills et al. 2004[8]	$0.27	$0.27	15%	0.70
Mills 2011[9]	$0.30	$0.29	16%	1.10
Coyner et al. 2017[12]	$0.41	-	10 -15%	1.80
PECI et al. 2009[10]	-	-	0.95 - 5.60 kBtu/ft^2	0.35 - 1.30
Friedman et al. 2011[15]	$0.08 - $0.40	$0.11 - $0.26	-	-
Bynum et al. 2008[11]	$0.42	$0.36	12.75%	1.68
Jones et al. 2008[17]	-	$0.84	19.99%	0.38
Oh et al. 2014[18]	-	$0.29	-	-
Claridge et al. 1994[19]	-	-	23%	-
Turner et al. 2007[20]	$0.42	$0.16	10% - 14%	2.50
Deng et al. 2006[21]	-	-	35%	-
Deng et al. 2008[22]	-	-	35%	-
Turner et al. 2009[23]	-	$0.61	7.9% Elec, 17.3% CHW, 41.6% NG	-
McCown 2009[24]	-	-	11.40%	2.00
Liu et al. 2006[25]	-	-	33.2% Elec, 51.2% NG	-
Wei et al. 2006[26]	-	-	-	5.40
Range	**$0.08 - $0.42**	**$0.11 - $0.84**	**10% - 35%**	**0.35 - 5.40**

Key Literature Review Values: Costs and Savings (NCCx)

Study	Cost per Unit Area	Cost Savings per Unit Area	Energy Savings	Simple Payback
Mills et al. 2004[8]	$1.00	$0.05	-	4.80
Mills 2011[9]	$1.16	$0.18	13%	4.20
PECI 2002[13]	$0.30 - $2.60	-	-	-
Friedman et al. 2011[15]	$0.19 - $1.00	$0.05 - $0.64	-	-
D'Antonio 2007[14]	$0.19 - $1.50, $0.55 avg.	-	-	-
Range	**$0.19 - $2.60**	**$0.05 - $0.64**	**13%**	**4.20 - 4.80**

Key Literature Review Values: Building Use Types (EBCx and NCCx)

Building Use Type	EBCx			NCCx	
	Mills et al. 2004[8]	Mills 2011[9]	Bynum et al. 2008[11]	Mills et al. 2004[8]	Mills 2011[9]
K-12	4.73%	2.73%	27.9%	7.12%	7.44%
Higher Education	10.81%	12.61%		3.91%	7.12%
Outpatient	13.01%	4.78%	30.8%	2.52%	2.34%
Inpatient	5.74%	7.51%		24.28%	3.42%
Laboratory	4.19%	5.05%	8.1%	12.78%	7.81%
Lodging	2.86%	10.93%	0.1%	1.83%	1.78%
Office	49.29%	44.21%	20.9%	7.89%	10.15%
Public Assembly	1.78%	2.74%	3.7%	8.66%	7.82%
Public Order/Safety	3.41%	2.75%	0.0%	26.45%	25.77%
Total Floor Area	22,246,000 ft^2	90,410,885 ft^2	21,798,180 ft^2	8,164,000 ft^2	8,813,924 ft^2

Methodology

- Commissioning Provider Data
  - Companies
  - Annual Revenue and Company Size
  - Percentage of Revenue from Cx, EBCx, NCCx

- Assumed Values for Calculations (From Literature Review)
  - Cost and Cost Savings per Unit Area, Simple Payback
  - Floor Area Makeup by Building Type, Percent Energy Savings, EUI by Building Type

- Calculation of EBCx and Cx market estimates
  - Estimated Annual Revenue
  - Estimated Annual Floor Area Commissioned
  - Estimated Annual Cost Savings
  - Estimated Annual Energy Savings

Commissioning Provider Data

- Building Commissioning Association (BCxA) Member List
  - Comprehensive list of member companies, spanning the United States, Canada, and a select few other countries
  - 198 U.S. companies included from list
  - Kept anonymous in published work

- Estimated Annual Revenue and Company Size
  - Texas A&M University Libraries Business Source Ultimate Database (59% of sample)
  - buzzfile.com, glassdoor.com, manta.com (41% of sample)

Commissioning Provider Data – Estimated Revenue Makeup

Company Category	Percent Revenue from Commissioning
Building Commissioning	100%
MEP Design/Engineering	50%
Energy Services	40%
Building/Facilities Engineering and Architecture	20%
Architecture, Engineering, Environmental and Construction Services	5%
Construction, Utility, Misc.	2%

Commissioning Type	Percent of Total Commissioning Revenue
Existing Building Commissioning	14.3%
New Construction Commissioning	85.7%

Calculations – Estimated Commissioning Revenue

- Cx Revenue = [Estimated Revenue] * [Assumed Percent Revenue from Commissioning], for each i company
- Total Cx Revenue = sum of all i Cx Revenue values included in set I

$$CxR_i = ER_i * \%Cx_i$$

$$CxR_{Total} = \sum_{i \in I} ER_i * \%Cx_i$$

- EBCx Revenue = [Cx Revenue] * [Percent Cx Revenue from EBCx], for each i company
- Total EBCx Revenue = sum of all i EBCx Revenue values included in set I

$$EBCxR_i = CxR_i * 0.143$$

$$EBCxR_{Total} = \sum_{i \in I} CxR_i * 0.143$$

i = *Each individual firm included in the analysis (n = 198)*

$i \in I$ = *{all included firms}*

Assumed Values for Calculations – Commissioned Floor Area and Cost Savings

- Values were taken from two key comprehensive studies, Mills et al. 2004 and Mills 2011 and were averaged for use in calculations
  - Mills et al. 2004 – 106 EBCx projects (150 buildings) and 69 NCCx projects (74 buildings)
  - Mills 2011 – 332 EBCx projects (561 buildings) and 77 NCCx projects (88 buildings)
- Dollar values given in 2003$ (Mills et al. 2004) and 2009$ (Mills 2011), adjusted to 2017 using the following:
  - $Dollars_{Analysis} = Dollars_{Study} * (1 + 0.0189)^{13}$ [Mills et al. 2004]
  - $Dollars_{Analysis} = Dollars_{Study} * (1 + 0.0176)^{8}$ [Mills 2011]

Commissioning Type	Average Cost per Unit Area	Average Savings per Unit Area	Average Simple Payback Period
Existing Building Commissioning	$0.35/ft^2	$0.34/ft^2	0.90 years
New Construction Commissioning	$1.40/ft^2	$0.14/ft^2	4.50 years

Calculations – Total Estimated Floor Area Commissioned

- EBCx Floor Area = EBCx Revenue divided by Typical EBCx Cost per Unit Area for each i company, summed across set I

$$GFA_{EBCx} = \sum_{i \in I} \left(\frac{CxR_i * 0.143}{0.35} \right)$$

- Total Cx Floor Area = EBCx Revenue divided by Typical EBCx Cost per Unit Area plus NCCx Revenue divided by Typical NCCx Cost per Unit Area, for each i company, summed across set I

$$GFA_{Cx} = \sum_{i \in I} \left(\frac{CxR_i * 0.143}{0.35} + \frac{CxR_i * 0.857}{1.40} \right)$$

i = *Each individual firm included in the analysis (n = 198)*

$i \in I$ = *{all included firms}*

- In this case, commissioning costs are assumed to be equivalent to commissioning revenue

Calculations – Total Estimated Cost Savings using Simple Payback

- EBCx Cost Savings = [EBCx Revenue]/[Typical EBCx Simple Payback], for each i company, summed across set I

- Total Cx Cost Savings = [EBCx Revenue]/[Typical EBCx Simple Payback] + [NCCx Revenue]/[Typical NCCx Simple Payback], for each i company, summed across set I

$$TCS_{EBCx} = \sum_{i \in I} \left(\frac{CxR_i * 0.143}{0.90} \right)$$

$$TCS_{Cx} = \sum_{i \in I} \left(\left(\frac{CxR_i * 0.143}{0.90} \right) + \left(\frac{CxR_i * 0.857}{4.50} \right) \right)$$

i = Each individual firm included in the analysis (n = 198)

i ∈ I = {all included firms}

Calculations – Total Estimated Cost Savings Using Cost Savings per Unit Area

- EBCx Cost Savings = [EBCx Floor Area] * [Typical EBCx Cost Savings per Unit Area], for each i company, summed across set I

- Total Cx Cost Savings = [EBCx Floor Area] * [Typical EBCx Cost Savings per Unit Area] + [NCCx Floor Area] * [Typical NCCx Cost Savings per Unit Area], for each i company, summed across set I

$$TCS_{EBCx} = \sum_{i \in I} \left(\frac{CxR_i * 0.143}{0.35} * 0.34 \right)$$

$$TCS_{Cx} = \sum_{i \in I} \left[\left(\frac{CxR_i * 0.143}{0.35} * 0.34 \right) + \left(\frac{CxR_i * 0.857}{1.40} * 0.14 \right) \right]$$

$i = Each\ individual\ firm\ included\ in\ the\ analysis\ (n = 198)$

$i \in I = \{all\ included\ firms\}$

Assumed Values for Calculations – Energy Savings

- Floor area distributions from Mills et al. 2004 and Mills 2011 based on similar CBECS building labels, condensed and averaged for both commissioning types
  - Mills et al. 2004 - 22,246,000 ft^2 (EBCx) and 8,164,000 ft^2 (NCCx)
  - Mills 2011 – 90,410,885 ft^2 (EBCx) and 8,813,924 ft^2 (NCCx)
- Percent annual energy savings taken from Mills et al. 2004 and Mills 2011 and averaged for both commissioning types
- Median Source Energy Use Intensities matched to CBECS building types used in studies based on ENERGY STAR values

Commissioning Type	Percent Annual Energy Savings
Existing Building Commissioning	16%
New Construction Commissioning	13%

Building Type, j	% GFA EBCx	% GFA NCCx	Source EUI (kBtu/ft^2-year)
K-12	3.73%	7.28%	141.4
Higher Education	11.71%	5.51%	262.6
Inpatient	6.63%	10.29%	389.8
Outpatient	8.90%	2.43%	155.2
Laboratory	4.62%	24.99%	123.1
Lodging	6.90%	1.80%	162.1
Office	46.75%	9.02%	148.1
Public Assembly	2.26%	8.24%	85.1
Public Order/Safety	3.08%	26.11%	169.9

Calculations – Total Estimated Energy Savings

- EBCx Energy Savings = [EBCx Floor Area] * [Typical Percent Floor Area EBCx] * [Energy Use Intensity] * [Typical EBCx Percent Energy Savings], for each j building use type, summed across set J
- Total Cx Energy Savings = [EBCx Floor Area] * [Typical Percent Floor Area EBCx] * [Energy Use Intensity] * [Typical Percent Energy Savings] + [NCCx Floor Area] * [Typical Percent Floor Area NCCx] * [Energy Use Intensity] * [Typical NCCx Percent Energy Savings], for each j building use type, summed across set J

$$TES_{EBCx} = \sum_{j \in J} \left(\left(\sum_{i \in I} \frac{CxR_i * 0.143}{0.35} \right) * \%GFA_{EBj} * EUI_j * 0.16 \right)$$

$$TES_{Cx} = \sum_{j \in J} \left\{ \left(\left(\sum_{i \in I} \frac{CxR_i * 0.143}{0.35} \right) * \%GFA_{EBj} * EUI_j * 0.16 \right) + \left(\left(\sum_{i \in I} \frac{CxR_i * 0.857}{1.40} \right) * \%GFA_{NCj} * EUI_j * 0.13 \right) \right\}$$

i = Each individual firm included in the analysis (n = 198)

$i \in I$ = {all included firms}

j = Each individual building use type included in the analysis (n = 16)

$j \in J$ = {K-12, Higher Education, Food Sales, Food Service, Inpatient, Outpatient, Lab, Lodging, Retail, Service, Office, Public Assembly, Public Order/Safety, Religious Worship, Warehouse/Storage, Other}

Sample - Overview

- 198 BCxA member companies
- 38 states based on provided locations
  - Top 5: WA, CA, NY, CO, TX (35% of sample)
- Variety of ASHRAE Climate Zones
  - 2A, 2B, 3A, 3B, 3C, 4A, 4B, 4C, 5A, 5B, 6A, 6B, 7A

Sample – Estimated Annual Revenue and Company Size

- Estimated Annual Revenue ($/year)
  - Range: $51,000 to $12,800,000,000
  - Mean: $117,000,000
  - Median: $5,650,000
- Company Size (Employees)
  - Range: 1 to 49,000
  - Mean: 466
  - Median: 42
- Revenue per Employee ($/employee)
  - Range: $12,200 to $1,180,000
  - Mean: $145,000
  - Median: $121,000

Sample – Company Category Distribution

Company Category	Count	Percent of Sample
Building Commissioning	67	34%
MEP Design/Engineering	66	33%
Energy Services	9	5%
Building/Facilities Engineering and Architecture	14	7%
Architecture, Engineering, Environmental and Construction Services	30	15%
Construction, Utility, Misc.	12	6%

Results – Existing Building Commissioning

- Total Estimated Annual Revenue
  - $260,000,000/year
- Total Estimated Annual Floor Area Commissioned
  - 740,000,000 ft^2/year
- Total Estimated Annual Cost Savings
  - Using Simple Payback Period: $290,000,000/year
  - Using Cost Savings per Unit Area: $250,000,000/year
  - Average: $270,000,000/year
- Total Estimated Annual Energy Savings
  - 21,000,000,000 kBtu/year

Results – Building Commissioning (EBCx and NCCx)

- Total Estimated Annual Revenue
  - $1,800,000,000/year
- Total Estimated Annual Floor Area Commissioned
  - 1,900,000,000 ft^2/year
- Total Estimated Annual Cost Savings
  - Using Simple Payback: $630,000,000/year
  - Using Cost Savings per Unit Area: $460,000,000/year
  - Average: $550,000,000/year
- Total Estimated Annual Energy Savings
  - 48,000,000,000 kBtu/year

Results Discussion

Commercial Energy Consumption Type	2017 Consumption (Trillion Btu)	EBCx Savings as Percent of Total	Cx Savings as Percent of Total
Total Commercial Energy	18,000[4]	0.12%	0.27%
Total Retail Electricity Sales and Natural Gas	7,900[4]	0.27%	0.61%
Total Primary Energy	4,400[4]	0.48%	1.1%

- Navigant Commissioning Market Projections (2015)[36]
  - Global Market (Primarily North America and Europe) Revenue - $3.8 billion in 2017
    - EBCx and NCCx ~$3.6 billion
    - EBCx ~$1.2 billion
- Study Results
    - EBCx and NCCx $1.8 billion
    - EBCx $260 million
- Results reasonable in terms of magnitude, likely underestimating the U.S. market

Considerations and Caveats

- Sample consists of a portion of the commissioning market – does not capture entire market
  - Some BCxA member companies did not have estimates available online and were excluded
  - Non-BCxA commissioning firms/providers exist
- Revenue values and percentages are strictly estimates – may be over or underestimates
  - Difficult to acquire actual revenue values from private companies
  - Time constraint prevented BCxA survey of included companies, broadly applied estimates
  - Some significant outliers in the sample
- Inherent variability in commissioning values – static values are applied in calculations
  - Costs - Building size, system complexity, building age
  - Energy Savings – Building types, project goals, operating requirements, baseline energy efficiency

Conclusions

- Successful approximations that can be useful in understanding the magnitude of the existing building commissioning market in the U.S.
- Likely underestimates of true market implementation and impact, but adequately approximates the scale of revenue and savings within the industry
- Further updating and refining the presented methodology could prove useful in generating improved approximations

Future Work

- Approximate avoided CO2e emissions based on calculated savings
- Apply savings degradation to understand cumulative savings over time
- Build upon framework to account for variability in typical commissioning metrics, more comprehensive surveys to better estimate revenue distributions

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Questions

Thank You!