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Benefits and Costs of Commissioning: A Case Study Analysis

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Abstract

Commissioning is a "quality assurance process for the design, construction and operation of buildings." Specifically, Building Commissioning is a process of auditing buildings to help them operate with greater efficiency in accomplishing their intended purpose. This typically includes improvements in energy usage, reductions in operation and maintenance costs, improvements in occupant comfort, and reductions in potential future liability.

This report estimates the Benefit-to-Cost Ratio of commissioning-related energy savings for buildings in the International Commissioning Cost-Benefit and Persistence Database. It does so in accordance with ASTM Standards while taking into account the decay of cost savings and the time value of money. Almost all buildings in the database had a Benefit-to-Cost Ratio greater than one. Most had Internal Rates of Return of greater than 100 %. Assuming that the buildings in the database are representative of commercial buildings in general, then nearly all commercial buildings can benefit from Commissioning.

Predictors of commissioning-related non-energy savings are evaluated by estimating which task implemented as part of the Commissioning process correlates with the desired outcome for five non-energy benefits in the Annex 47 Database. Due to the small size of the data set, results should be considered tentative. The most reliable results are for reduction in O&M Costs. Benchmarking, Development of a Commissioning Plan, and the Development of an Energy Model are associated with a reduction in O&M Costs.

Keywords: Commissioning; Commercial Buildings; Benefit-to-Cost Ratio; Economic Analysis; Standards

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List of Acronyms

BCR	Benefit-to-Cost Ratio
IRR	Internal Rate of Return
O&M	Operations and Maintenance

1. Introduction

Commissioning is a "quality assurance process for the design, construction and operation of buildings.[1]" Specifically Building Commissioning is a process of auditing buildings to help them operate with greater efficiency in accomplishing their intended purpose. This typically includes improvements in energy usage, reductions in operation and maintenance costs, improvements in occupant comfort, and reductions in potential future liability.

Recently, the Energy Conservation for Buildings and Community Systems Program, Annex 47: Cost-Effective Commissioning for Existing and Low Energy Buildings produced a report on "Commissioning Cost-Benefit and Persistence of Savings." The objective of the report was to estimate the payback period for commissioning and estimate the persistence of energy savings for commissioning.

As part of the process of generating the Annex 47 report the task force compiled an International Commissioning Cost-Benefit and Persistence Database. That database contains data on 47 buildings from seven different countries (Belgium, Canada, Germany, Japan, the Netherlands, Norway, and the United States). For each building the database sought to include project information (including cost data), information on energy usage and cost savings, non-energy benefits, issues found in each building in the study, and corrective measures taken. Data collected was incomplete for all buildings in the database.

This report set out to use the Annex 47 database to accomplish two goals. First, this report assesses the cost-effectiveness of Commissioning in accordance ASTM Standards maintained by ASTM Subcommittee E06.81 on Building Economics, and published as part of the ASTM Standards on Building Economics[2]. Second, this report attempts to identify predictors of non-energy savings from Commissioning.

Based on the results, almost all buildings in the database had a Benefit-to-Cost Ratio (BCR) greater than one, indicating that commissioning was cost-effective. Most had Internal Rates of Return (IRR) of greater than 100%. For non-energy savings, Benchmarking, Development of a Commissioning Plan, and the Development of an Energy Model are associated with a reduction in O&M Costs.

In what follows, Section 2 evaluates the cost-effectiveness of Commissioning for the buildings in the Annex 47 Database. Section 3 attempts to identify predictors of non-energy savings from Commissioning. Section 4 concludes with a summary and recommendations for future research.

[1] "*Commissioning Cost-Benefit and Persistence of Savings*", a Report of Cost-Effective Commissioning of Existing and Low Energy Buildings. Directed by the Energy Conservation in Buildings and Community Systems (ECBCS) Program.
[2] ASTM International. 2012. "ASTM Standards on Building Economics." 7th Edition. ASTM International. West Conshohocken, PA.

2. Cost-Benefit Analysis of Energy Savings

The first goal this report seeks to accomplish is to compute the BCR[3] and IRR[4] of the commissioning-related energy savings for buildings in the Annex 47 Database. Costs used for this section were the reported costs for Commissioning for each project, while total Benefits were the total of all monetary energy-related benefits reported for each project.

Table 1: Decay Rates

	Savings Remaining	Years	Decay Rate
Texas A&M	83 %	2	9.12 %
Texas A&M [5]	92 %	2	4.04 %
SMUD	81 %	4	5.13 %
Oregon – Elec.	89 %	5	2.30 %
Oregon – Gas	3 %	5	50.00 %
Colo – Elec.	83 %	7	2.63 %
Colo – Demand	86 %	7	2.13 %
Colo – Gas	100 %	7	0.00 %
CA	75 %	4	6.94 %

Data are drawn from the Annex 47 Data Set and report.

2.1. Methodology

Of the 47 projects in the database, 22 reported both costs and energy-related benefits. However, one of them almost certainly contains a reporting error. For that reason, it was deleted from further consideration, leaving 21 projects for the analysis.

Benefits were assumed to accrue as a result of the correction of "Issues." "Issues" are problems identified as part of the commissioning process. Issues commonly include things like sensor problems or sub-optimal setpoints for temperature control.

Each issue was assumed to equally contribute to the total benefits. So, for example, the Wehner building at Texas A&M reported approximately $48,000 in annual savings, and reported five Issues corrected. So, for the purpose of this study, it was assumed that each Issue contributed $9,600 in savings.

Figure 1 shows a histogram of the number of Issues reported for buildings analyzed in this portion of the report. The average number of Issues for buildings that record issues is 6.26. Three buildings have no Issues recorded. Projects where Issues were not reported were assumed to have corrected ten Issues.

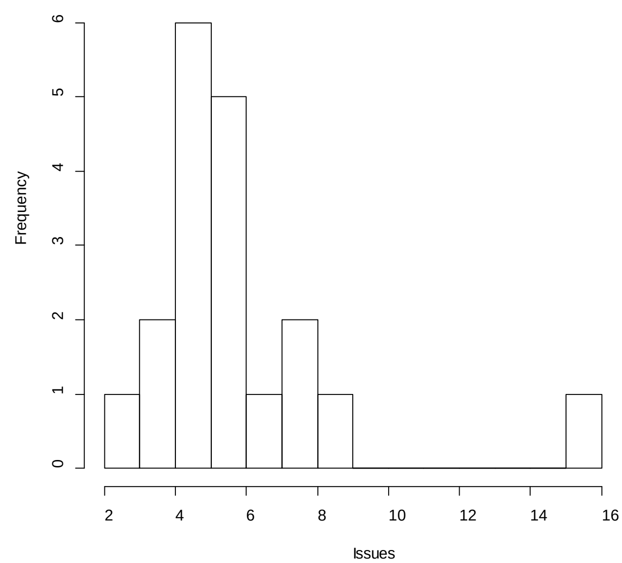

Figure 1: Histogram of Number of Issues for Buildings in the Annex 47 Report

Issues were assumed to revert to their "uncorrected" state with a probability of δ per year. The decay rate (δ) was based on the reports of persistence of benefits from the "Annex 47" report. Computed decay rates for the projects for which persistence was analyzed are listed in Table 1.

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[3] ASTM Standard E964-06, 2010, "Standard Practice for Measur
Buildings and Building Systems," ASTM International, West Conshohocken, PA, 2010, **DOI:** 10.1520/E0964-06R10.

[4] ASTM Standard E4157-06, 2010, "Standard Practice for Measuring Internal Rate of Return and Adjusted Internal Rate of Return in Buildings and Building Systems," ASTM International, West Conshohocken, PA, 2010, **DOI:** 10.1520/E1057-06R10.

[5] This is the Texas A&M results excluding the results for the G. R. White Coliseum and the Kleberg Building, which had large degradations in performance due to one or two major failures.

Based on this data, a 5 % decay rate (which is close to the median decay rate) was used for all computations below. Monte Carlo methods[6] were used to compute BCRs and IRRs using a large number of simulations. For each simulation, failures were randomly generated and distributed by year. Then costs and benefits by year were computed. Finally, based on the assumed (stochastically generated) cash flow, IRR and BCR were computed. This was done for five different study periods (5, 10, 15, 20, and 30 years). The BCRs were computed for four different discount rates (3 %, 5 %, 7 %, 10 %, and 15 %). An example for a single instance is shown in Table 2. In the table "Failures" represents the number of corrected Issues that fail in that year. "Net Benefit" represents the value of energy savings for that year after accounting for the cumulative number of corrected Issues that have failed up to that point. "Discounted" represents the Present value of the net benefits using the 5 % discount rate. For each project-study-period combination, 100 000 simulations were generated.

Table 2: Example randomly generated cash flows for Wehner Building at Texas A&M—Ten Year study period—5 % Discount Rate

Year	Failures	Net Benefit	Discounted
0	0	-$ 66 423	-$ 66 423
1	1	$ 43 255	$ 41 196
2	0	$ 43 255	$ 39 234
3	0	$ 43 255	$ 37 365
4	0	$ 43 255	$ 35 586
5	1	$ 38 449	$ 30 126
6	0	$ 38 449	$ 28 691
7	2	$ 28 837	$ 20 494
8	0	$ 28 837	$ 19 518
9	0	$ 28 837	$ 18 588
10	0	$ 28 837	$ 17 703

2.2. Results

Median IRR and BCR for the ten-year study period and 5 % discount rate are listed in Table 3. The highlighted projects are the only ones with a negative payoff (i.e., were not cost-effective).

Estimated cumulative probability density (estimated using the 'density' function in the 'R' statistical computing environment[7]) for return on investment based on the 21 remaining projects are shown in Figure 2. As study period increases, the percentage of projects that fall below any cutoff decreases. However, once the study period reaches ten years the difference between IRRs becomes minimal.

Based on the estimated densities, about 15 % of projects can be expected to have an IRR of less than 5 %, about 17.5 % of projects can be expected to have an IRR of less than 15 %, and about 19.5 %

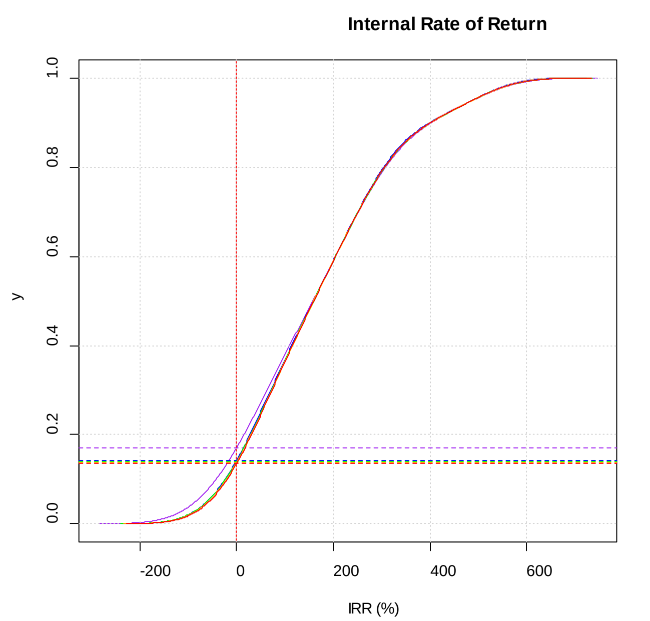

Figure 2: Empirical estimated probability densities for Internal Rate of Return

[6] ASTM Standard E1369-11, 2011, "Standard Guide for Selecting Techniques for Treating Uncertainty and Risk in the Economic Evaluation of Buildings and Building Systems," ASTM International, West Conshohocken, PA, 2011, **DOI:** 10.1520/E1369-11.

[7] R Core Team, 2013, "R: A Language and Environment for Statistical computing." R Foundation for Statistical Computing. Vienna Austria.

of projects can be expected to have an IRR of less than 25 %.

Also computed are Cumulative Distribution Functions for the BCR for all the discount rates examined (see Figure 3). As with IRR, once the study period exceeds ten years, the probability that a project fails to pay off changes very little.

In each of the sub-figures, the horizontal lines show the probability that the BCR falls below one for each study period. In each sub-figure, the probability that the BCR falls below one is highest for the 5 year study period. The probabilities become difficult to distinguish for all longer study periods.

The probabilities that the BCR falls below one also increase as the discount rate increases, but not by much. The probabilities increase because a higher discount rate reduces the value of the future savings, thus reducing the value of commissioning the building. However, since the BCR for most buildings are so high, the increase in discount rate does not increase the probability that BCR falls below one by much.

Table 3: Median Internal Rate of Return and Benefit-to-Cost ratio by project using a 10 year study period and a 5 % discount rate. Projects that have a negative payoff are highlighted.

Country	Project	Commissioning Cost	Annual Savings	Median IRR	Median BCR
Norway	Hotel 1	kr 110 000	kr 570 421	516%	31.63
Norway	Hotel 2	kr 110 000	kr 275 000	246%	15.28
Norway	Hotel 3	kr 110 000	kr 376 750	333%	20.76
Norway	Hotel 4	kr 110 000	kr 257 400	225%	14.21
Norway	Material Teknisk Bygget	kr 33 000	kr 99 667	301%	18.24
United States	Blocker	$ 77 324	$ 80 678	98%	6.38
United States	Eller	$ 99 050	$ 112 047	105%	6.86
United States	G. Rollie White	$ 49 525	$ 124 080	246%	15.48
United States	Harrington Tower	$ 27 344	$ 63 696	229%	14.39
United States	Kleberg	$ 59 054	$ 278 331	468%	28.81
United States	Koldus	$ 41 894	$ 61 802	142%	9.02
United States	Richardson Petroleum	$ 44 541	$ 126 079	279%	17.49
United States	Vet Med Center Addition	$ 52 314	$ 101 892	194%	11.79
United States	Wehner	$ 66 423	$ 48 063	67%	4.47
United States	Allied Plaza	$ 71 693	$ 26 065	28%	2.24
United States	Mark O. Haftield Federal Courthouse	$ 180 554	$ 92 962	43%	3.11
Japan	Kobe Kanden Building	¥ 10 800 000	¥ 390 113	-19%	0.22
Japan	Nakanoshima 3-chome DHC	¥ 19 800 000	¥ 260 876	-29%	0.08
Japan	CEPCO Atsuta Sales Office	¥ 10 480 000	¥ 2 828 432	18%	1.63
Canada	Palais des congrès de Montréal	$ 199 300	$ 309 942	146%	9.41
Canada	CETC-Varennes	$ 90 000	$ 36 831	33%	2.48

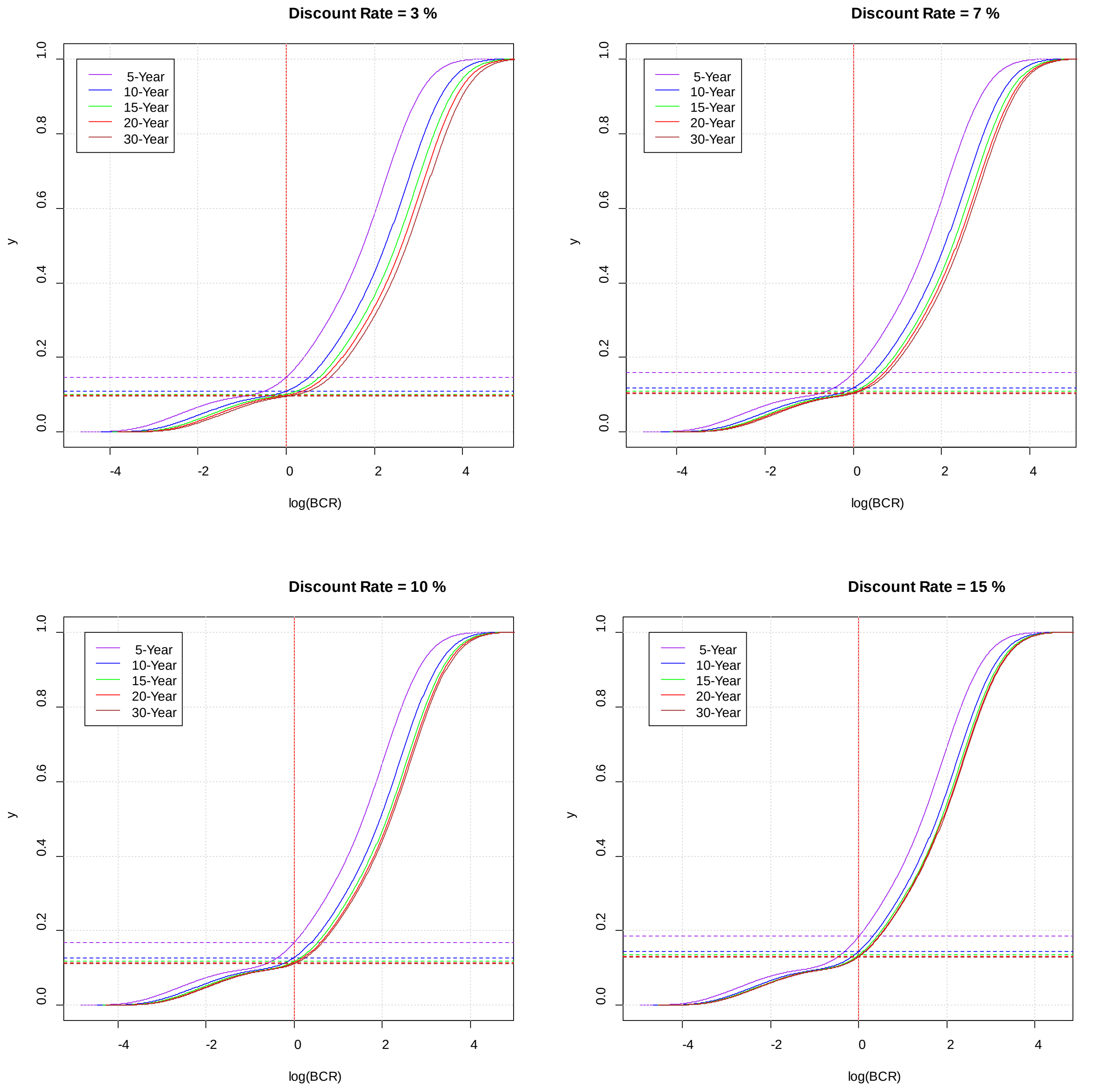

Figure 3: Cumulative Distribution of Log Benefit-to-Cost Ratios. The upper left figure is for a discount rate of 3 %. The upper right figure is for a discount rate of 7 %. The lower left figure is for a discount rate of 10 %. And the lower left figure is for a discount rate of 15 %.

3. Predictors of Non-Energy Savings

The Annex 47 Database includes questions asking about a variety of non-energy related benefits that could result from Commissioning a building. For the most part the questions are qualitative: that is, they ask whether a specific benefit resulted from the Commissioning study, and make no effort to quantify the benefit. The Database includes 26 questions about non-energy benefits. 21 of the questions are qualitative Yes / No questions about the existence of some benefit. The remaining five questions ask to quantify the value of those benefits. The questions were only answered for some of the buildings with a different quantity of answers for different questions. Valuation questions were only answered for O&M costs, and not for enough buildings to be able to reliably estimate cost savings.

Table 4: Questions Analyzed for predictors of non-energy savings.

Item Label	Question	Responses	Yes Responses
Staff	*Do O&M staff report increased ability to operate and maintain the building as a result of Commissioning?*	11	6
Costs	*Were ongoing operations and maintenance costs reduced as a result of Commissioning?*	18	8
Air	*Was indoor air quality improved as a result of Commissioning?*	11	6
Productivity	*Was occupant productivity improved as a result of Commissioning?*	11	7
Liability	*Was liability reduced as a result of Commissioning?*	11	5

This report attempts to identify qualitatively what predicts a positive outcome for a specific type of non-energy savings. In order to estimate that outcome, two characteristics must hold. First, there must be enough answers to the question to produce a reliable result. Second there must be a sufficient variety of answers (that is, both yes and no answers) to distinguish between characteristics that predict yes outcomes and ones that do not.

3.1. Methodology

Five of the non-energy savings items from the list were selected for further analysis. The five are listed in Table 4.

The Tasks that were performed in the Commissioning process were used as predictors of whether a Yes response was given to each of the questions above. The Tasks analyzed and their descriptions are listed in Table 5. There were simply not enough responses to analyze the Tasks simultaneously, so each was regressed individually against each question using a standard Logit analysis.

3.2. Results

The results shown in Table 5 are the probabilities that the Task listed has no effect on the outcome analyzed. So, smaller numbers indicate a stronger relationship (i.e., there is a greater likelihood of a beneficial effect). Cells shown in Red and Blue are significant at the 10 % level and 25 % level, respectively. The latter group should be interpreted as Tasks-Outcome pairs that should be analyzed in more detail if more data become available.

Table 5: Tasks potentially performed as part of commissioning studies.

Task	Description
Benchmarking	Benchmarking
Calculate Savings	Calculate energy cost savings for findings
Capital Improvements	Implement capital improvements
Commissioning Plan	Develop a Commissioning Plan
Diagnostic Tools	Use of Diagnostic Tools and Cx Automation Techniques
Energy Model	Building energy modeling/simulation
Final Report	Final Comissioning Report
Document Findings	Document master list of findings
Manual	Develop systems manual/recommissioning manual
Monitor Persistence	Monitor implemented measures for persistence of benefits
O&M Improvements	Implement operations and maintenance (O&M) improvements
Project Requirements	Document owner's project requirements
Report	Present a findings and recommendations report
Trend Analysis	Trend Analysis (for example, EMCS, data logging, etc.)
Update Documentation	Update system documentation after implementation
Utility Bill Analysis	Utility Bill Analysis
Verify Energy Savings	Monitor and verify energy savings

The greatest significance occurs for Operation and Maintenance Costs, which, not coincidentally, have the most available responses. Benchmarking, Developing a Commissioning Plan, and Development of an Energy Model all are predictors of a reduction in O&M Costs.

Table 6: Results show the probability that the Task listed has no effect on the outcome analyzed. Cells shown in Red are significant at the 10 % level. Cells shown in blue are "significant" at the 25 % level.

Task	Staff	Costs	Air	Productivity	Liability
Benchmarking	74.06%	5.97%	38.26%	31.67%	31.67%
Calculate Savings	81.92%	14.84%	15.76%	55.80%	38.26%
Capital Improvements	99.67%	18.85%	99.65%	66.11%	62.40%
Commissioning Plan	31.67%	6.87%	31.67%	99.61%	31.67%
Diagnostic Tools	38.26%	81.41%	99.58%	89.83%	81.92%
Energy Model	62.40%	8.34%	88.66%	99.66%	88.66%
Final Report	38.26%	67.19%	38.26%	31.67%	15.76%
Document Findings	38.26%	21.74%	74.06%	6.75%	31.67%
Manual	99.67%	80.02%	99.65%	66.11%	88.66%
Monitor Persistence	14.15%	67.19%	31.67%	22.35%	74.06%
O&M Improvements	38.26%	11.72%	38.26%	15.76%	81.92%
Project Requirements	99.65%	19.12%	99.60%	89.83%	81.92%
Report	81.92%	99.54%	81.92%	48.22%	99.60%
Trend Analysis	15.76%	99.54%	81.92%	99.71%	39.85%
Update Documentation	99.67%	99.52%	99.65%	99.65%	88.66%
Utility Bill Analysis	74.06%	11.72%	74.06%	81.92%	31.67%
Verify Energy Savings	81.92%	67.19%	74.06%	6.75%	74.06%

Similarly, Documenting Findings, and Verification of Energy Savings were predictors of reporting

Productivity improvements for the building occupants. None of the other questions are significant predictors of outcomes. Note that these results should be treated very cautiously. The nature of the data makes these results very weak, and additional data would significantly improve the results.

4. Summary and Recommendations for Further Research

4.1. Summary

This report estimates the BCR of commissioning-related energy savings for buildings in the Annex 47 Database. It does so while taking into account the decay of cost savings and the time value of money. Almost all buildings in the database had a BCR greater than one. Most had an IRR of greater than 100 %. Compared to other investments, a 100 % return on investment is exceptionally high. Assuming that the buildings in the database are representative of commercial buildings in general, then nearly all commercial buildings can benefit from Commissioning.

Predictors of commissioning-related non-energy savings are evaluated by estimating which tasks implemented as part of the Commissioning report correlate with the desired outcome for five non-energy benefits in the Commissioning Database. Due to the small size of the data set results should be considered tentative. Best results are for reduction in O&M Costs. Benchmarking, Development of a Commissioning Plan, and the Development of an Energy Model are associated with a reduction in O&M Costs. Results for the other non-energy savings should be understood as suggestive rather than definitive.

4.2. Recommendations for Further Research

Commissioning studies frequently cite comfort as one of the objectives of Commissioning work. However, the Annex 47 database does not include any information on comfort. If it were possible to place a value on the improvements in comfort level, we could get a better sense of the valued added from Commissioning.

The following methodology could aid in valuing the improvements in comfort level. The basic approach is to estimate the average cost to individuals of being in locations with less-than-optimal temperatures. This data would then be used to estimate the hedonic[8] cost to people in a building where temperature is maintained at a suboptimal level.

Even though commissioning is done in commercial buildings, the best source of information for how people value (dis)comfort would be the temperature they maintain in their own homes where they control the thermostat versus the cost. Therefore, we would need the following individual-level data for households:

- Thermostat settings over time
- Approximate location (sufficiently detailed to determine average temperature throughout the year).
- Heated Floor Area

Additional information that would be very helpful in estimating a value of comfort would be:

[8] Rosen, S. 1974. “Hedonic Prices and Implicit Markets: Product Differentiation in Pure Competition.” *The Journal of Political Economy*: 34–55.

- Number of Stories
- Age of structure
- Number of people in the household

It would be possible to substitute similar data for businesses for household data, but the interpretation of the results would be slightly different and the estimation would be potentially more difficult.

The basic approach consists of assuming the people have a utility function of the form:

$$U = u(v) - h(T)$$

where v is other consumption, T is ambient indoor temperature, and h and u are functions.

A number of approaches can be taken, but the simplest is to assume that u is approximately linear over the relevant range of consumption. Then utility becomes:

$$U = m - c(T) - h(T)$$

Where m is household income, and c is the cost of setting indoor air temperature to T.

We would expect thermostats to be set in advance, and changed relatively rarely. On that basis, all of these terms should be understood as being in expectation.

Cost will depend on a number of factors, and will likely need to be estimated. Taking that into account, the utility function would be written as:

$$U = m - c(T; x, \beta) - h(T)$$

where x represents information known about the structure that affects the cost of heating and cooling and β are regression parameters that will be estimated. The function h would be estimated non-parametrically.

We assume that people are utility maximizers, so the problem people solve is:

$$\max_T \big(m - c(T; x, \beta) - h(T)\big)$$

Solution to that problem will be T such that the following equation holds:

$$f(T; x, \beta) = -c'(T; x, \beta) - h'(T) = 0$$

Or

$$\hat{T} = f^{-1}(0; x, \beta)$$

In practice, we would assume that the actual thermostat temperature selected was;

$$T^* = f^{-1}(0; x, \beta) + \varepsilon$$

Where ε is a random variable.

This then reduces to two problems. First, estimating the expected cost of setting indoor air temperature to *T*, and second estimate the function *h* non-parametrically. Most of the data needs above are directed toward answering the first question. The estimation is unambiguously non-linear, but the techniques for doing so are well established. Provided an adequate data set can be obtained, this should be relatively straightforward.