Determining the Total Costs and Benefits of Commissioning Public Buildings

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ABSTRACT

The Northwest Energy Efficiency Alliance is currently sponsoring a program to expand and institutionalize the practice of building commissioning among state and local governments in the Pacific Northwest. An important facet of this effort is providing government officials with detailed case studies that document the costs and benefits of the commissioning process. This paper presents the methodology and results of a cost-benefit analysis of 21 commissioning efforts undertaken as part of the program. These included 13 new and eight existing facilities. Through telephone surveys with key commissioning team members and engineering analysis of project documentation, this study determined the overall incremental costs of commissioning, as well as the economic value of the corresponding benefits. These benefits included direct impacts such as reduced energy use, as well as indirect non-energy impacts, such as improved occupant comfort and fewer building operational problems. The payback ratios calculated for each project provide useful insights into the cost-effectiveness of commissioning. The results also show that assessing the value of associated difficult-to-quantify non-energy benefits yields a more complete economic perspective. The study found average paybacks for sampled new and retrocommissioning projects to be about seven and four years, respectively. Including the value of indirect non-energy impacts, however, reduced the paybacks to six and three years, respectively.

Background

The Northwest Energy Efficiency Alliance is currently undertaking a long-term effort to expand and institutionalize the practice of building commissioning among state and local governments in the Pacific Northwest (Jennings 2000). Started in 1998, this *Commissioning in Public Buildings* project is coordinated on behalf of the Alliance by the Oregon Office of Energy. An important component of this effort is providing government officials with detailed case studies of commissioned buildings and the costs and benefits of the commissioning process for these buildings. Both commissioning service providers and potential recipients of commissioning services place high value on case studies that target buildings of interest to them, and provide well-documented, reliable estimates of the costs and benefits (SBW Consulting 1998). To that end, the Alliance funded a study to analyze the costs and benefits of commissioning by quantifying both energy and non-energy impacts for 21 of the 33 projects currently underway or already completed[1].

Building commissioning is the systematic process of ensuring that building systems, such as HVAC and lighting, are designed, built, and operate according to the owner's operational needs. Commissioning for new buildings typically involves design review, construction review, testing, adjustment, and maintenance planning. Commissioning existing buildings, often referred to as

[1] Copies of the full report can be obtained from the Northwest Energy Efficiency Alliance website at http://www.nwalliance.org/resources/evalreports.asp.

retrocommissioning, can restore facilities to high productivity through renovation, upgrade and tune-up of existing systems (OOE 2002).

The primary objectives of the study were to develop quantitative estimates of the monetary impacts that resulted from the commissioning effort for each project, and to calculate payback ratios for each project. These include direct payback, which only considers direct impacts, and total payback, which includes both direct and indirect impacts.

Analysis Methodology

For each commissioning project included in this study, we obtained extensive project documentation that permitted us to identify critical project personnel, as well as significant issues that the commissioning process uncovered. We administered two telephone surveys, one to all key commissioning team members, and another to a subset of these, the agency managers and decision-makers. Data from these surveys formed the basis for calculating the incremental costs and the value of the indirect non-energy benefits of commissioning. Technical information in the project documentation, coupled with supporting information from project personnel, permitted us to quantify the direct energy and cost impacts of the significant commissioning issues that have been or soon will be resolved for the 21 projects. The primary elements included in the analysis were:

1. Ongoing energy impacts: direct cost savings from reduced electric and gas usage.

2. Ongoing non-energy impacts: reduction in direct maintenance costs.

3. One-time impacts: up-front costs (both direct and indirect) to find and resolve commissioning issues, as well as additional and avoided change orders resulting from commissioning. Also included in this category are the present-value benefits from non-energy impacts, such as improved occupant comfort.

Combining this information yielded simple payback ratios for each project, as well as by commissioning type and overall. The flowchart in Figure 1 summarizes this methodology.

Select Projects

These 21 projects selected by the Alliance for inclusion in the study comprise 64% of the 33 commissioning projects that have been completed or are currently ongoing through the Commissioning in Public Buildings project. These particularly projects were chosen primarily because the commissioning was complete in time to be studied, and project team members and adequate documentation were still accessible. Table 1 provides details about the associated facilities and the commissioning efforts for each of these projects. Combined, the commissioned buildings in this study account for nearly 2.2 million square feet of building area.

Review Project Documentation

Through preceding studies as well as this study, we collected all pertinent documentation for each project available as of early 2003. Key information sources included: (a) commissioning reports, (b) commissioning issue logs, (c) commissioning design review memoranda and project correspondence, (d) energy savings estimates prepared by the commissioning agents for most of the retrocommissioning projects, (e) energy life cycle cost analyses that examine energy efficiency of alternative building

systems, and (f) draft case study reports. Once information was collected for a project, we reviewed it to determine how much information about commissioning issues and building parameters was available.

Table 1: Selected Commissioning Projects

State	#	Building type	Cx type*	Building size (ft2)	Cx agent cost to agency** ($)	($/ft2)
Idaho	1	Courthouse	New	340,000	220,000	0.65
	2	Recreation center	New	90,148	40,280	0.45
	3	Offices	Retro	23,000	19,300	0.84
Montana	4	Maint. facility	Retro	56,000	12,300	0.22
	5	Middle school	Retro	64,000	8,700	0.14
	6	College/University	Retro	110,380	24,800	0.22
	7	Prison office	New	23,300	24,000	1.03
Oregon	8	Elementary school	Retro	65,000	11,044	0.17
	9	Library	New	69,500	83,380	1.20
	10	Transit center/office	New	160,000	60,880	0.38
	11	Day care center	New	18,300	12,400	0.68
	12	High school	New	250,000	85,000	0.34
	13	Offices	Retro	170,000	20,900	0.12
	14	College/University	Retro	213,000	14,280	0.07
	15	Elementary school	New	49,000	32,660	0.67
Washington	16	High school	New	144,000	41,860	0.29
	17	Museum	New	78,000	100,000	1.28
	18	Elementary school	Retro	95,405	65,102	0.68
	19	Prison	New	58,000	80,000	1.38
	20	Hospital	New	51,000	70,000	1.37
	21	College/University	New	60,000	82,820	1.38
Sum				2,188,033	1,109,706	n/a
Average				104,192	52,843	0.65

Cx = commissioning.

** Excludes additional costs associated with participation in the Alliance program, such as case study development.

Assess Issue-Level Impacts

We categorized all commissioning issues/deficiencies documented in the commissioning reports and issue logs for each project according to these criteria:

- Significant: An issue (or group of related issues) was considered "significant" if it: (a) affected a large area or number of people (in relative terms for each project), (b) resulted in major immediate costs to resolve, and/or (c) resulted in long-term impacts had the issue not been found. As part of categorization, we briefly documented the rationale for selecting issues as being significant.

- Resolved: Significant issues were grouped based on whether or not they had already been or were likely to have been resolved within one year after the commissioning was complete. In cases where the documentation did not make this clear, we based our determinations on the opinion of the commissioning agent and/or facility manager.

For each significant issue or issue grouping, we estimated both ongoing and one-time impacts, each of which could be positive or negative. *Ongoing impacts* included:

- Energy: Measurable, quantifiable impacts on electric or gas usage of the project facility, as determined by standard engineering calculations or parametric modeling. For costing, we used average electric and gas rates of $0.07/kWh and $0.85/therm, respectively, as provided by the Northwest Energy Efficiency Alliance, based on U.S. Energy Information Administration data for four Pacific Northwest states. These standardized rates made it easier to compare results across projects.

- Non-energy: Measurable, quantifiable impacts on facility costs, such as less frequent lamp replacement and reduced water usage. Difficult-to-quantify non-energy impacts, such as improved occupant comfort, were assessed at the project level.

One-time impacts included:

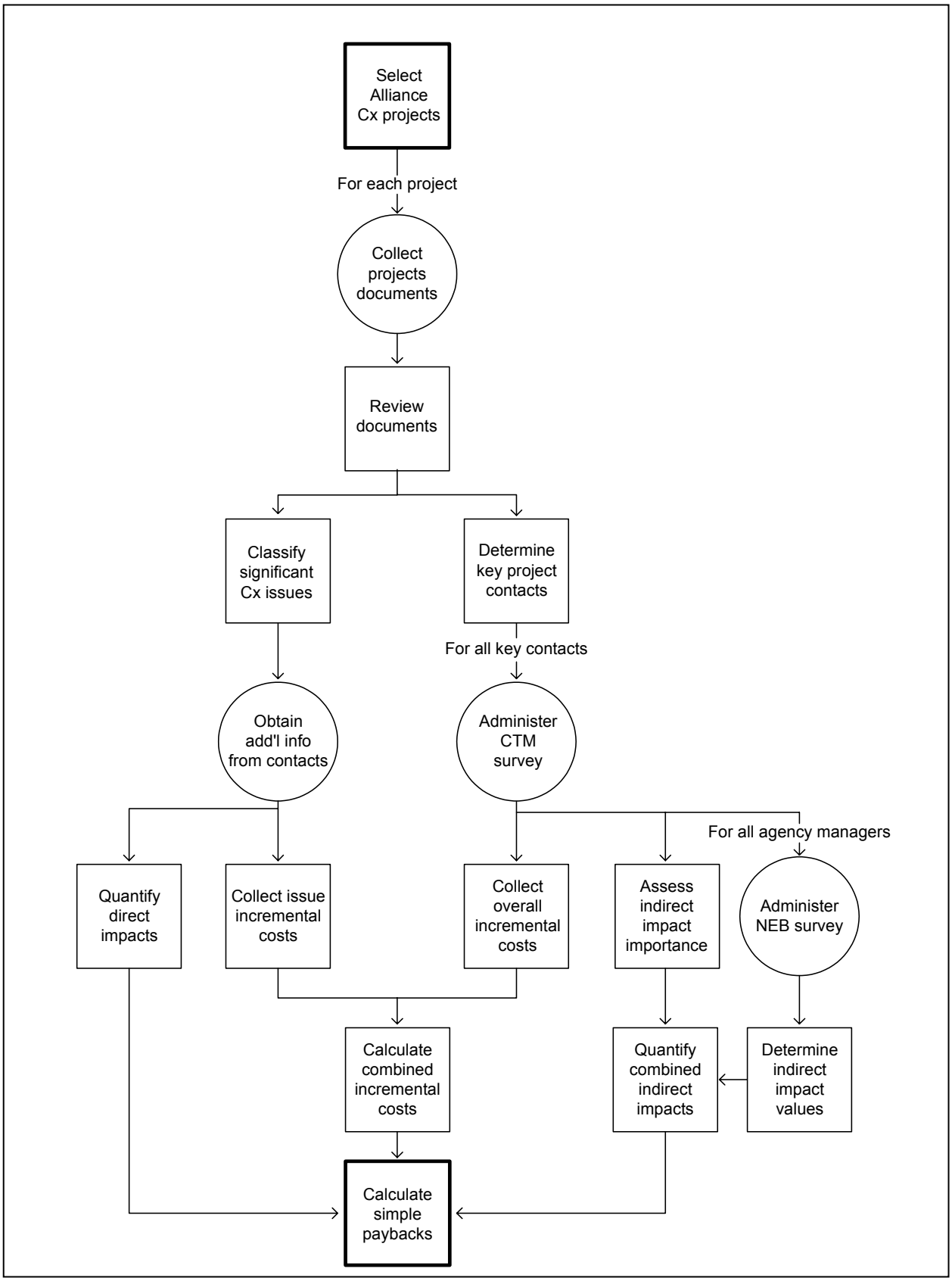
- Issue resolution costs: Costs incurred to remedy a problem or deficiency that the commissioning process revealed. These costs could be direct, that is, resulting in a documented cost increase, as would be the case in a retrocommissioning project where a contractor was hired to install a new HVAC time clock. On a new commissioning project, if a contractor issued a change order to make a commissioning-issue-related modification, then the cost of the change order would be considered a direct cost. They could also be indirect, in that the problem required some time to rectify, but that increment of time was not charged to the agency, so the agency saw no additional cost. Examples would be a controls contractor reprogramming an improper controls sequence without a change order within the warranty period, or regular maintenance staff resetting thermostats.

- Avoided repair costs: Direct and/or indirect costs that the project avoided because the commissioning process found and resolved issues early. An example would be a commissioning agent performing a design review that showed that temperature sensors were poorly located. Changing the design before construction was complete avoided a contractor change order to relocate the sensors later in the project.

Assess Non-Quantifiable Energy Impacts

Certain significant energy impacts still proved impossible to quantify with the approaches described above. An example of this was a project with outside air dampers that stuck randomly in different positions. Without an extensive monitoring effort, it would be impossible to determine if fixing the problem would increase or decrease energy use. We flagged such issues in the database, and after evaluating all the significant issues for a given project, we compared the non-quantifiable issues to the quantified ones, and assigned a subjective rating of "high," "medium," or "low" to indicate the magnitude of all non-quantifiable energy impacts compared to all quantified energy impacts.

Figure 1: Methodology Flowchart



Assess Project-Level Impacts

The primary tool for assessing commissioning costs and impacts at the project level was the commissioning team member (CTM) survey. This survey was administered to all who had a key role in the commissioning process for each project, including commissioning agents, designers, contractors, and agency personnel. Data from this survey permitted us to estimate one-time impacts for each team member. As with the issue-level assessment, these impacts were classified as direct and indirect, and could be positive or negative. The impacts could include additional change orders, avoided repairs, resolution of commissioning issues, and identification of commissioning issues. The latter refers to the incremental costs associated with commissioning-related activities designed to identify issues and problems. These would occur regardless of whether or not specific problems were actually found. Examples include the time building engineers spent explaining HVAC control strategies to the commissioning agent, increases to contractor's initial bids to allow for commissioning activities, and commissioning agent fees.

Assign Dollar Values to Indirect Non-Energy Impacts

Indirect non-energy impacts (also commonly referred to as non-energy benefits, or "NEBs") are inherently difficult to document and assign quantitative values to. They can include beneficial and detrimental impacts relating to the following:

> During design & construction: Contractor call-backs, change orders or warranty claims, potential for litigation, coordination and relationships between team members, project schedules, and time needed to get building systems working right.
>
> For facility operations: Operational deficiencies, system documentation, staff knowledge, and equipment lifetime.
>
> For building occupants: Comfort, indoor air quality, productivity, and safety.

The quantification process we developed for this study involves two key parameters. The first, an *impact importance factor*, reflects commissioning team members' collective sense of the importance of a particular impact. The telephone surveys asked each respondent to identify which commissioning indirect impacts were significant to their project. We developed a scheme for averaging and weighting their responses that took into account two things: the fact that the number and type of respondents varied from project to project, and the assumption that the commissioning agents and facility staff, as a rule, had a better overall perspective on the commissioning effort than contractors and designers.

The second parameter was monetized estimates of the economic worth of particular indirect impacts (NEBs) from the project agency's perspective. Individuals who had a sufficient overview of their agency's operations or the particular construction project to assess the value of the commissioning project to the agency and building occupants were asked about the presence and values of non-energy impacts on the project. We asked respondents to assess the relative value of the non-energy impacts compared to a known value, the commissioning agent fees. This value could be either positive or negative in the quantification.

Since prior studies of this type have commonly found discrepancies between computations of non-energy impacts based on the various measurement methods, we asked multiple sets of questions to derive a range of estimates. We assessed the total benefits three ways – willingness to pay (WTP), sum of the individual computed benefits, and the "overall net" value computed as the respondent's "overall net" value multiplier times the commissioning cost. We then kept the most conservative value – the

minimum of these three values. The net value of a given non-energy impact is the product of its impact importance factor and its gross dollar valuation. If both are high, then the impact's net value will also be high. Since the value of many of the non-energy impacts, such as improved occupant comfort, could be expected to last over an extended period, these impacts were expressed as present values that accounted for the accumulated value over the life of the building.

Calculate simple paybacks

Table 2 summarizes how we grouped the data developed in the previous steps to calculate simple paybacks for each project. The commissioning impacts fell into several broad categories, ongoing energy, ongoing non-energy, one-time direct, and one-time indirect. Costs fell into two categories, direct and indirect. We calculated two payback ratios for each project. The direct payback only considers direct one-time and ongoing impacts, while the total simple payback also includes indirect one-time impacts.

Findings

Survey Disposition

From reviewing project documentation and contacting commissioning team members, we identified 128 people who appeared to have played important roles in the commissioning efforts for the 21 projects included in this study. This corresponds to slightly over six people per project. Nearly half of these were agency personnel, with the remainder divided somewhat evenly among commissioning agents, contractors, and designers. We were able to complete CTM surveys for 97 of these people, or 76% of the identified population. Of those we were unable to survey, nearly most either could not be reached were either not familiar enough with the project to be able to answer the survey questions. Of the 97 CTM survey respondents, we identified 29 potential respondents for the NEB survey who had a sufficient overview of the project of agency operations to assess the value of commissioning to the design/construction team, agency, or occupants. We were able to complete interviews for 27 of them, who collectively represented all but two of the sample projects. Nearly all of the respondents were facility managers or staff.

Issue Analysis

From the commissioning documentation and discussions with commissioning team members, we identified 1,554 commissioning issues (sometimes also called deficiencies) among the 21 projects. About 15% on average could be considered significant, and were or are about to be resolved. The number of unresolved issues was small: only 16 spread across four projects. It seems reasonable to conclude that significant issues are generally resolved during or soon after the commissioning process.

The preponderance of significant resolved issues (93%) pertain to the HVAC system and associated controls. This is not surprising, since many commissioning projects focused mostly or solely on HVAC.

Table 2: Framework for Calculating Simple Paybacks

	ONGOING IMPACTS ($/year)		ONE-TIME IMPACTS($)	
	Energy	***Non-Energy***	***Direct***	***Indirect***
Elements (with examples)	**Electric savings** (reduced fan run time lowers electric bills)	**Other utility savings** (lower water bill from reduced cooling tower evaporation)	**Issue identification** (cost to hire Cx agent)	**Issue identification** (labor cost for agency staff to attend Cx meetings)
			Issue resolution (billed cost to agency to fix a problem that is out of scope)	**Issue resolution** (labor costs for agency staff, or contractors if no change order, to rewrite control sequence)
	Natural gas savings (optimized boiler controls reduce gas bills)	**Reduced maintenance expenses** (reduced lamp burn time delays replacement costs)	**Additional change orders / project costs** (billed cost to agency to add variable speed drives)	**Additional change orders / project costs** (labor cost for agency staff to administer direct cost activities)
			Avoided change orders / project costs (saved cost to agency for not relocating thermostats)	**Avoided change orders / project costs** (labor cost for agency staff to administer direct cost activities)
				Other non-energy impacts (value to agency of improved coordination among construction team, improved occupant comfort*)

* Some indirect non-energy impacts may be ongoing, but for methodological reasons, their value over time is treated as a one-time net present value.

Direct payback = |Direct one-time impacts| ÷ Ongoing impacts

Total payback = |Direct + indirect one-time impacts| ÷ Ongoing impacts

Ongoing Energy Impacts

Ongoing energy impacts consist of the net savings in electricity and natural gas that resulted from resolved commissioning issues. We estimated that the average quantifiable impacts per project are about 110,400 kWh/year and 4,200 therms/year, with a combined value of about +$11,300 annually. Normalized by floor area, these impacts are +1.06 kWh/SF/year and +0.04 therms/SF/year, respectively. The normalized combined value is +$0.11/SF/year. On average, retrocommissioning projects, at +$0.14/SF/year, yield much higher larger energy impacts than new commissioning projects (+$0.09/SF/year). Based on a qualitative assessment of the amount of engineering uncertainty in these estimates, we found that the majority of the energy value resides with projects with low uncertainty, so it seems reasonable to conclude that the portion of energy impacts that is non-quantifiable is relatively small.

Ongoing Non-Energy Impacts

Ongoing non-energy impacts consisted of two types: (a) impacts to utilities other than electricity or gas, such as water, sewer, or propane service, and (b) quantifiable changes to operations and maintenance expenses. Examples of the latter were reduced air compressor maintenance costs and lamp replacement costs. On average, the direct non-energy impacts for these projects were minuscule.

One-Time Direct Impacts

One-time direct impacts include (a) issue identification costs, such as the cost to hire the commissioning agent, (b) issue resolution costs, such as billed cost to an agency to fix a problem that is out of scope, (c) additional change orders/project costs, such as billed cost to agency to add variable speed drives, and (d) avoided change orders/project costs, such as the money the agency saves by not having to pay to relocate thermostats. The latter are subtracted from the other direct costs. The net one-time direct impacts per project were about -$66,000, or -$0.63/SF/year. The bulk of this cost is issue identification costs (-$53,600) and issue resolution costs (-$13,400). The net impact of change orders is +$1,000/project.

One-Time Indirect Impacts

One-time indirect impacts are those that the project or agency experiences, but that do not lead to changes in the billed amounts to the agency as part of project costs. These can include (a) issue identification, such as labor cost for agency staff to attend commissioning meetings, (b) issue resolution, such as the labor costs for agency staff, or contractors if no change order, to rewrite a control sequence, (c) additional change orders/project costs, in the form of labor cost for agency staff to administer direct impact activities, and (d) avoided change orders/project costs, in the form of avoided labor costs for agency staff to administer direct impact activities. The net indirect incremental costs per project were about -$11,200, or -$0.11/SF/year. This is 17% of the corresponding direct cost of -$0.63/SF/year. This cost is split nearly equally between issue identification costs and issue resolution costs.

The final category of indirect impacts is non-energy impacts that affected design and construction (such as project schedules), facility operations (such as operational deficiencies), or building occupants (such as indoor air quality). The value of these impacts is about +$23,600 per project, or +$0.23/SF/year. To provide a sense of the relative importance of all impacts, we calculated the percentage of the total impact that each individual impact comprised. By far the most significant impacts overall were reducing operational deficiencies and improving occupant comfort, with 28% and 22% shares, respectively, of the total dollar value of all indirect non-energy impacts. Other important impacts were reducing the time needed to get building systems working properly (9%), improving indoor air quality (7%), and increasing O&M staff's knowledge of how the building functions (7%).

Paybacks

Table 3 draws together the ongoing energy and non-energy impacts, and the one-time direct and indirect impacts derived in the previous sections. The average combined ongoing impact was about +$11,200/year per project. Dividing the average one-time direct impact of -$66,000 by this figure yields a direct payback of 5.9 years. The retrocommissioning projects on average had much lower paybacks than the new commissioning projects, with an average direct payback of 4.0 years, versus 7.5 years for new.

Table 3: Aggregate Results

		Ongoing Impacts					One-Time Impacts			Payback*	
		Electricity (kWh/yr)	Natural gas (therm/yr)	Energy ($/yr)	Non-energy ($/yr)	Total ($)	Direct ($)	Indirect ($)	Total ($)	Direct (years)	Total (years)
ABSOLUTE VALUES											
By Cx type, per project	New (N=13)	102,732	3,135	9,856	3	9,858	-73,536	13,609	-59,927	7.5	6.1
	Retro (N=8)	122,979	5,964	13,678	-259	13,419	-53,776	10,534	-43,242	4.0	3.2
	All (N=21)	**110,445**	**4,212**	**11,312**	**-97**	**11,215**	**-66,009**	**12,438**	**-53,571**	**5.9**	**4.8**
NORMALIZED VALUES (per SF)											
By Cx type	New	0.96	0.03	0.09	0.00	0.09	-0.69	0.13	-0.56		
	Retro	1.23	0.06	0.14	0.00	0.13	-0.54	0.11	-0.43		
	All	**1.06**	**0.04**	**0.11**	**0.00**	**0.11**	**-0.63**	**0.12**	**-0.51**		

* Direct payback = -(Direct one-time impacts) / Ongoing impacts
Total payback = -(Direct + indirect one-time impacts) / Ongoing impacts

Including the indirect costs impacts changes this significantly. The indirect one-time impacts are about $12,400/year per project. Including them in the payback calculation yields total payback of 4.8 years. The average paybacks for new and retrocommissioning are 6.1 and 3.2 years, respectively.

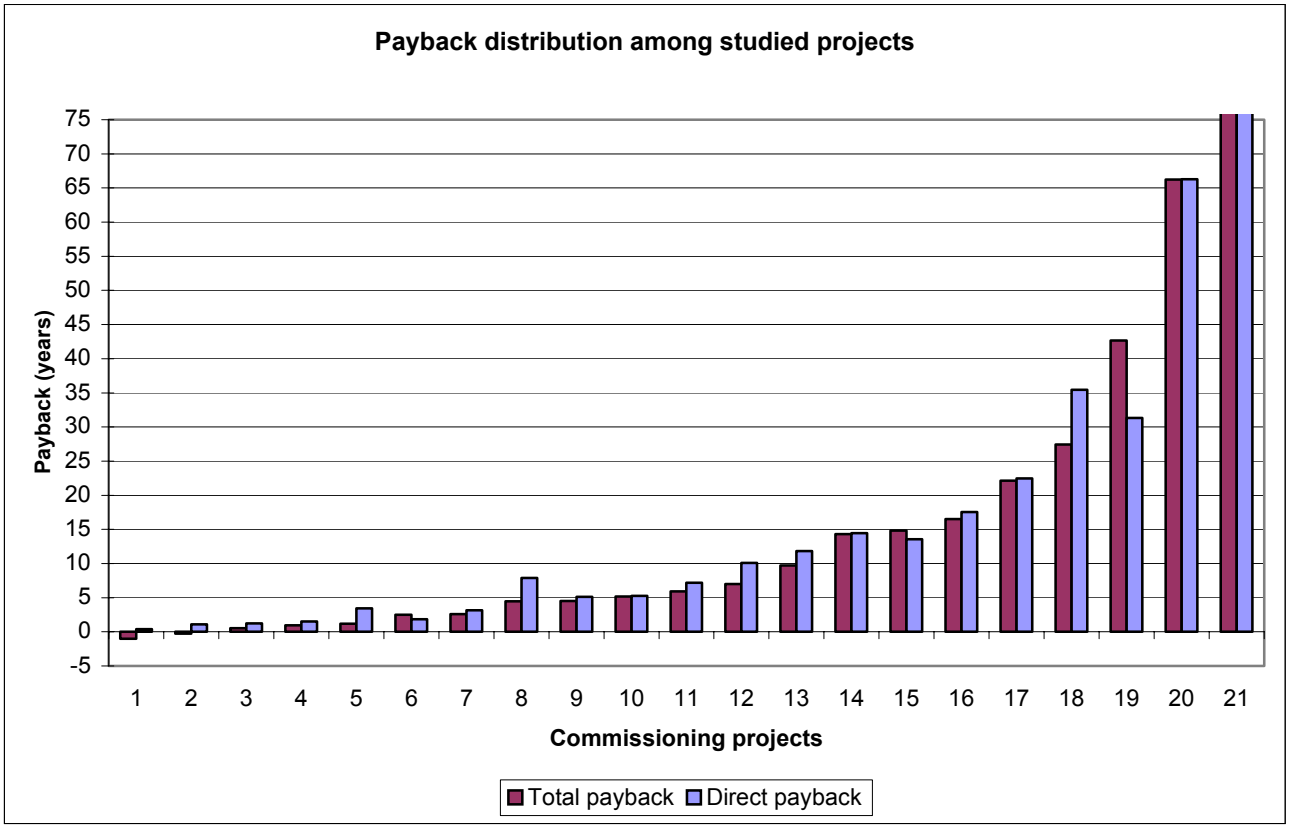
Figure 2 shows the wide variation in simple payback ratios among the projects. Direct paybacks ranged from 0.4 to 200 years, while total paybacks ranged from –1 to 158 years. The effect of including indirect impacts in the cost-effectiveness calculation also varied widely: percentage changes from direct to total payback ranged from a 353% decrease to a 36% increase.

Conclusions

This study has demonstrated how a thorough cost and energy impact evaluation, coupled with systematic quantification and valuation of non-energy impacts, can provide a more complete estimate of the value of commissioning. The payback for all projects studied was 5.9 years, when only considering direct costs and impacts, such as energy savings. Adding in the value of indirect effects, such as improved building comfort and operability, reduces the payback to 4.8 years. Retrocommissioning, on average, has a lower payback (3.2 years) than new commissioning (6.1 years). This may be partially explained by difficulties incorporating design-phase commissioning into the new construction projects. Individual projects exhibited widely varying results. This suggests that while commissioning on average may be cost-effective, it is difficult to predict whether it will be so for a particular project.

Personnel involved with the commissioning efforts were generally very pleased with the process. They particularly valued the reduced operational deficiencies and improved occupant comfort that commissioning can bring.

Figure 2: Distribution of Project Simple Payback Ratios



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