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Piette, Mary Ann

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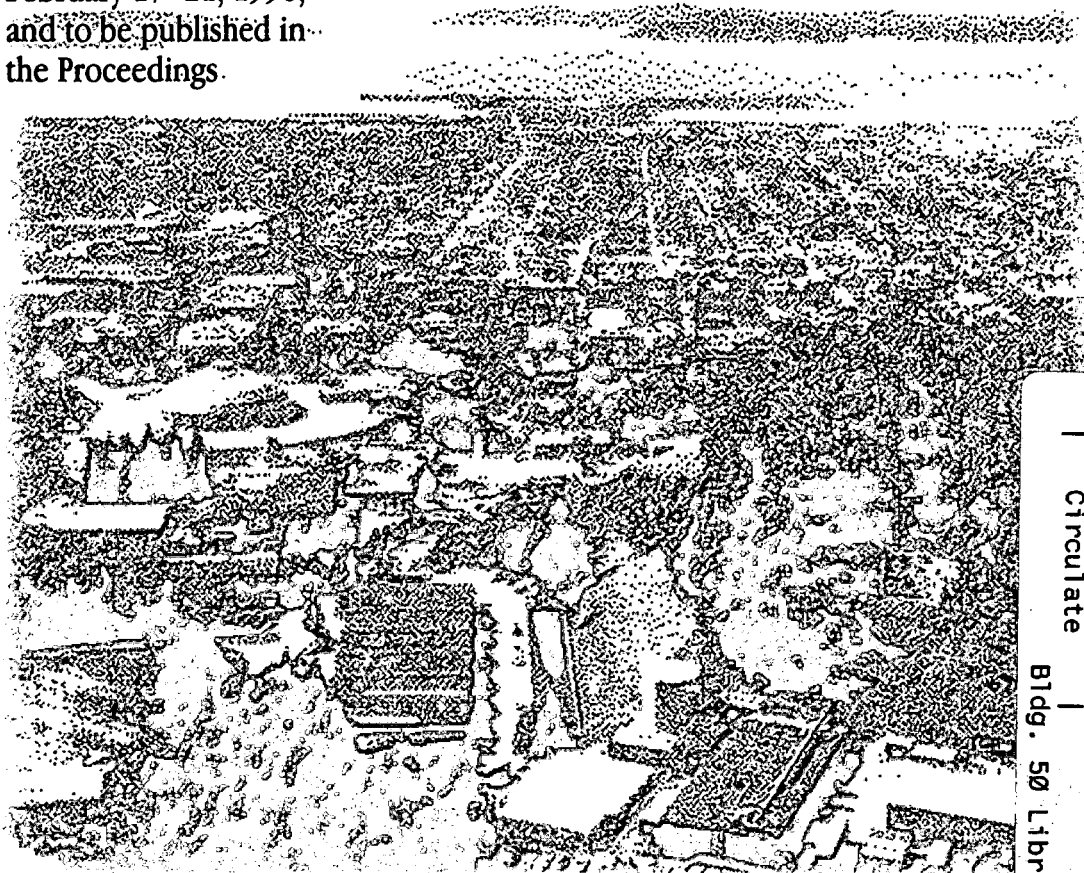


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Costs and Benefits from Utility- Funded Commissioning of Energy- Efficiency Measures in 16 Buildings

M.A. Piette and B. Nordman
Energy and Environment Division

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**Costs and Benefits from Utility-Funded Commissioning of
Energy-Efficiency Measures in 16 Buildings***

Mary Ann Piette and Bruce Nordman

Energy & Environment Division
Lawrence Berkeley National Laboratory
University of California
Berkeley, CA 94720

October 1995

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Costs and Benefits from Utility-Funded Commissioning of Energy-Efficiency Measures in 16 Buildings

Mary Ann Piette and Bruce Nordman
Lawrence Berkeley Laboratory

Abstract

This paper describes the costs and savings of commissioning of energy-efficiency measures in 16 buildings. A total of 46 EEMs were commissioned for all 16 buildings and 73 deficiencies were corrected. On average, commissioning was marginally cost effective on energy savings alone, although the results were mixed among all 16 buildings. When considered as a stand-alone measure, the median simple payback time of 6.5 years under the low energy prices in the Pacific Northwest. Under national average prices the median payback time is about three years.

In estimating the present value of the energy savings from commissioning we considered low and high lifetimes for the persistence of savings from deficiency corrections. Under the low-lifetime case the average present value of the energy savings (\$0.21/ft²) were about equal to the average commissioning costs (\$0.23/ft²). Under the high-lifetime case the savings (\$0.51/ft²) were about twice the costs. Again, the savings would be about twice as large under national average prices.

The results are subject to significant uncertainty because of the small sample size and lack of metered data in the evaluation. However, the findings suggest that investments in commissioning pay off. Building owners want buildings that work as intended, and are comfortable, healthy, and efficient. It is likely that the non-energy benefits, which are difficult to quantify, are larger than the energy-savings benefits.

Introduction

Building systems and energy-efficiency measures (EEMs) often don't perform as well in practice as expected at the design stage. This fact has become clear to many organizations concerned with ensuring building performance. What to do about these problems is less clear. Several electric utilities around the U.S. have begun to take action to address the start-up, control, and operational problems that are found in nearly every building (PECI, 1994). One of the most beneficial periods to intervene in the building life cycle is during the start-up phase of a new building. Building commissioning during start up is such an intervention. Commissioning can be defined as:

a set of procedures, responsibilities, and methods to advance a system from static installation to full working order in accordance with design intent (Yoder and Kaplan, 1992).

In broad terms, commissioning can extend from design reviews through operations and maintenance planning and training. With such a broad scope aimed at the entire building life cycle, commissioning is often likened to "Total Quality Management." Yet the heart of commissioning are the procedures

developed and executed to ensure that all building systems function as intended. The incorporation of energy-efficiency criteria into building commissioning is a new development.

This paper examines the costs and benefits of utility funded commissioning of energy-efficiency measures in 16 buildings (Piette et al., 1995). PacifiCorp's program has been the most aggressive utility sponsored commissioning program in the U.S. Over 75 buildings have participated. The program was developed as a result of direct experience with the energy performance of energy-efficiency improvements in new commercial buildings. The utility worked with the Bonneville Power Administration to administer a research-oriented new commercial construction and demonstration project called Energy Edge (Yoder and Kaplan, 1992, Piette et al., 1994). Energy Edge was perhaps the most detailed evaluation of EEMs in new commercial buildings ever conducted. The Energy Edge buildings were not commissioned, and therefore many of the 200 EEMs tracked in the program did not perform as well as expected, and could have been prevented or corrected with commissioning. In 1991 PacifiCorp began to offer direct financial payment for commissioning. These incentive payments were available for buildings that participated in their new commercial building demand-side management program, Energy FinAnswer, described below.

Commissioning is not common practice, and it means different things to different people. There are several factors that have driven the development of commissioning as a stand-alone practice. These include increasing complexity of controls, interests in energy-efficiency and demand-side management, growing knowledge (from detailed metering projects) of the frequency of operating problems in buildings, and indoor air quality concerns.

In general, improvements in indoor air quality and other non-energy benefits may be more important than the energy saving benefits from commissioning. Ensuring proper air flow in a building influences the health, safety, and productivity of the occupants (Sterling and Collett, 1994). Energy costs in office buildings are low compared to salaries of employees, which are about two orders of magnitude greater. Showing quantified occupant productivity gains in a well commissioned building compared to a building that is not commissioned is extremely difficult. However, we can show that the types of problems found during commissioning, left uncorrected, result in suboptimal building performance.

In order to evaluate the benefits of commissioning it is important to understand the broad range in the scope of commissioning as it is done today. There is no universal or even dominant approach utilized in this emerging activity. The American Society for Heating, Refrigeration, and Air-Conditioning Engineers is currently updating their commissioning guidelines (ASHRAE, 1989). These guidelines are probably the most widely utilized document on this subject in the U.S. The ASHRAE guidelines focus on HVAC commissioning, while many commissioning projects involve building systems beyond HVAC.

This study focused on commissioning of individual EEMs. The performance of an EEM is often linked to other building systems. Many of the commissioning agents responsible for commissioning of the 16 buildings described in this study performed EEM commissioning with a broad eye for how the EEM integrated with other building systems. Others took a more narrow view, and might have missed broader control and system integration issues. As noted throughout the analysis, we found significant energy savings benefits from EEM commissioning that went beyond the savings of the individual EEM.

In light of the complex interactions of building systems, commissioning is particularly helpful in improving the performance of the connective systems within a building, such as thermal distribution systems or controls. These subsystems are often weak links in whole-building performance. Specific components, such as chillers, heat pumps, or motors, are currently subject to standardized performance

tests to rate their energy performance with a metric such as a coefficient of performance (COP), or energy-efficiency ratio (EER). Such tests are defined by the American Refrigeration Institute, ASHRAE, and others. Installed building systems, however, are not usually subject to any standard acceptance tests. Commissioning tests are designed to help identify problems with both individual pieces of equipment and with their connection to other building systems. For example, the fans and pumps of a cooling tower fan should be on when needed to cool chiller condenser water. We found several examples of improper integration of the controls between cooling towers and chillers, such as the cooling tower pump running continuously and variable frequency drives on the cooling tower fans running at constant speed.

Project Goals and Scope

The broad goal of this study is to improve understanding of the value of commissioning and its potential for enhancing commercial energy-efficiency programs and policies. We address this goal by analyzing the energy savings and economic benefits of commissioning in 16 buildings (labeled Building A through P). The costs for the energy-efficiency measures and for commissioning are compared against the monetary value of the predicted energy savings for each measure, and the savings from correcting deficiencies found during commissioning. We explicitly address the question of how much of the predicted savings from the EEMs might have been lost without commissioning. The broader questions are, "are the EEMs still cost effective with the added cost of commissioning?" or perhaps "are they more cost effective with commissioning?" The costs for commissioning are also assessed with commissioning as a stand-alone measure.

Case studies of the costs and benefits of commissioning were considered a top need for increasing awareness of commissioning (Benner and Bjornskov, 1994). There is not much information available on this topic. Only one other study has been published that discusses the costs and benefits of utility funded EEM commissioning. The scope of this study by Stum and Haasl (1994) was more limited, focusing on inspecting economizers and programmable thermostats. This study is unique in that we look at the cost-effectiveness of commissioning a broad range of EEMs. The lack of information about the costs and benefits of commissioning is a clear gap in the information available to encourage further investments in commissioning. Although the results discussed below are based on a small sample (16) of buildings, the results are favorable, showing a need for further investment in this type of analysis in order to better understand how to optimize investments in commissioning. It is important for utilities and building owners to carefully track what was done during "commissioning," and attempt to quantify the benefits, or at least track the findings from commissioning.

As a result of the uncertainties associated with quantifying the benefits from commissioning, the estimates in this study are generally conservative. The estimates are a defensible lower bound of the savings. The actual savings are probably larger than those we're able to quantify. In several cases we discuss savings from deficiency corrections that are higher than the savings we track in the economic analysis. Another reason that the estimates are conservative is that we only quantified energy savings for deficiencies that we knew were corrected. In many cases the commissioning agent listed deficiencies that were not-corrected, or were outstanding at the time that they did their final inspections. It is likely that the building operations staff addressed many of these outstanding issues, but without hard evidence, we avoided claiming benefits from simply identifying a deficiency.

Commissioning within the Energy FinAnswer Program

The commissioning activities sponsored by PacifiCorp are offered as part of the Energy FinAnswer demand-side management program, which includes financial and engineering services for energy-efficiency measures. Commissioning services are available for new commercial buildings larger than 12,000 ft² and for major renovations.

The Energy FinAnswer program is based on economic analysis of energy savings estimates modeled for each EEM. The estimates were developed with DOE-2 simulations performed parametrically against a baseline simulation. An interactive model is also run with all of the static and dynamic EEMs included, defined in the following paragraph. Dynamic EEMs are those involving controls and heating, ventilating, and air-conditioning (HVAC) systems; these are checked during commissioning. Static EEMs, by contrast, are those that stay in place and do not receive control signals, low-e windows or wall insulation. Lighting systems have both static and dynamic components. Lighting controls, such as sweeps and daylighting systems were considered dynamic systems. Occupancy sensors were generally considered by PacifiCorp as static systems. Several of the commissioning agents examined their performance because they are dynamic, or active, in nature, and therefore are subject to potential control and operations errors.

Energy FinAnswer provides loans to the building owner for the incremental cost of the EEMs. The package of measures must reduce energy use by at least ten percent beyond the simulated code baseline. The utility recovers the investment through a service charge on the utility bill. The customer benefits from the reduced monthly bill, which, in theory, is reduced by more than the service charge.

Commissioning of each building project begins with the selection of a Commissioning Agent (CA). The CA's primary responsibility is to ensure that all of the funded dynamic EEMs are installed and operating according to the design intent. CAs sometimes assist in training building personnel in proper equipment operations and maintenance (O&M). The commissioning procedure consists of the following elements:

- Scoping Meeting
- Commissioning Outline
- Pre-Commissioning Tests
- Functional Performance Tests
- Operations and Maintenance Summary and Training
- Documentation and Final Commissioning Report

The most common arrangement in non-utility funded commissioning is for the CA, whether an independent contractor or part of the mechanical and electrical team, to work directly for the building owner. In this program, however, the CA is under contract with the utility to provide the commissioning services. That is, the utility pays for the commissioning. The contractors are normally responsible for correcting deficiencies identified by the CA. Usually the CA tracks the activities required to correct deficiencies. Nearly every building, however, has some outstanding deficiencies, which are usually minor in nature.

As mentioned, the PacifiCorp program continues to evolve. Recent changes involve developing standardized specifications for EEMs and related commissioning activities. These procedures will be developed from the documentation on commissioning tests performed over the last few years. The

utility may also change the contractual agreements by requiring the building owner to contract directly with the CA.

Methodology

This section discusses the procedures used to quantify the energy and associated dollar savings from commissioning. We also discuss non-energy benefits. The evaluation methodology was designed to make maximum use of the building documentation developed by PacifiCorp as part of their program. Two buildings were selected for a pilot analysis conducted to refine the evaluation methodology.

In the pilot analysis we explored several issues that were beyond the scope of the analysis for all 16 buildings. These issues included examining the method used to detect the deficiency (e.g., trend logs, spot metering, observation), actions taken to correct the problem (e.g., call to contractor or manufacturer) and results of the action (repaired or not). This information could be useful, however, in considering the likelihood that a problem would have gone undetected without commissioning. This analysis would also have required more details than those typically available in the Commissioning Reports. We did, however, carefully track the last item for all of the buildings: the result of the action.

This study explored the benefits of deficiencies we know were corrected. The evaluation consisted of the following steps:

- Select case study buildings
- Compile general building information
- List corrected deficiencies by building
- Quantify energy savings
- Conduct cost-effectiveness analysis
- Characterize non-energy benefits by building
- Compare results among buildings

In many cases it was unclear if a deficiency was corrected or not. The construction contractors, such as the mechanical, electrical, and controls contractors, were responsible for making the corrections. In most cases the final commissioning report included a discussion of the deficiencies found during commissioning, which sometimes included notes on when they were corrected. There were often outstanding deficiencies left uncorrected. The aim of commissioning was to identify the most important operational problems, and our primary concern was to characterize the energy saving benefits of the most important deficiencies that were corrected. The fact that there are outstanding deficiencies highlights the fact that the technical potential for energy savings from commissioning is greater than the savings captured by the current scope of activities. The economic potential, however, is not easy to assess. There are diminishing returns for a CA to follow up on small details that don't make a large impact on energy or other operating costs. Defining the appropriate level of intervention and associated funding for commissioning is difficult, but a topic of great interest to PacifiCorp and other utilities.

In defining a deficiency, we generally assumed that a commissioning action or intervention addressed a problem that would have gone uncorrected without commissioning. This may be incorrect in some cases. A building operator could identify and correct an operating problem, such as a non-varying variable frequency drive (VFD) within the first year of building occupancy. Some of the uncertainty as to whether a deficiency would have been corrected is incorporated in the economic analysis. As further described below, two correction lifetimes, a low and high value were assumed.

An important part of the methodology was to evaluate how the deficiencies relate to the energy savings estimates for the EEMs. We have defined three categories of relationships: directly related to the EEM, indirectly related to the EEM, and unrelated to or beyond the EEM. These definitions are as follows:

- **Directly Related to EEM** -- These deficiencies are directly related to the EEM. For example, correcting a VFD control problem that prevented the motor from varying addresses a problem with the energy saving characteristics of the EEM. Correcting a deficiency directly related to an EEM results in energy savings that are some fraction of the savings from EEM itself. Once an EEM is commissioned we assume that the savings are 100 percent of the predicted savings. This is a simplification in the analysis methodology because we did not have the resources to conduct detailed monitoring for EEM verification.
- **Indirectly Related to EEM** -- There are two types of indirect savings. First are deficiencies indirectly related to the EEM because they also would have been found in a baseline system without the EEM. For example, the EEM funds may cover the purchase of a heat pump with a COP beyond the code baseline COP. In several buildings construction debris dirtied filters, which decreases heat pump efficiencies because air flow rates are reduced and heat pump coil temperatures rise. This reduction in efficiency would have also been present in the baseline heat pump system. Second, a commissioning agent may fine-tune an EEM, going beyond the basic design intent, which is sometimes referred to as "super commissioning." For example, one of the CAs optimized the heat recovery system control, thereby reducing the occurrence of simultaneous heating and cooling. The energy savings from this improvement was not included in the original design study.
- **Unrelated to EEM** -- These deficiencies are not related to the EEMs at all, and could have been found in a baseline building that did not have the EEMs. For example, one building had a problem in the wiring of the resistance heat that did not directly involve the EEMs. The wiring problem had nothing to do with the fact that the heat pump had a higher COP than the baseline system.

Figure A illustrates how the energy savings from the EEMs relate to the energy savings from deficiency corrections. The total energy savings from the financing of the dynamic EEMs and the commissioning combined is the savings from EEMs plus the savings from the indirect and unrelated corrected deficiencies.

Quantifying Energy Savings

After developing the list of deficiency corrections, we examined information available about the building and the description of the corrected deficiencies to determine which corrections would be subject to further analysis to estimate their energy savings benefit. Deficiencies that were corrected but that appeared unreasonable to quantify energy savings benefits were assigned one or more non-energy benefits, as further described below. For example, there were several examples of missing thermostats being added or thermostats recalibrated. These improvements clearly improve the ability to control space temperatures, but the net effect on energy use is unclear. Energy use could increase or decrease depending on how the zone related to other zones and the overall control scheme.

The techniques used to estimate the energy savings from commissioning fall into the following five categories:

- **Prediction** -- Direct use of the design-phase predicted savings. This is appropriate if the EEM was completely defeated without commissioning.

- **Engineering Estimate** -- Hand calculation based on engineering principles.
- **Monitored** -- Extrapolated from short-term monitored data to annual savings.
- **DOE-2 Simulation** -- Simulation based on changes to design model.
- **Combined Approach** -- Combined DOE-2 simulation from design model with hand calculations.

By far the most common method used in this study was the DOE-2 simulation approach. Modeling of the energy savings from correcting a deficiency is the difference between the final interactive model (with all of the EEMs working) and the model we develop changed to represent the improper system. A significant benefit of using DOE-2 as the foundation for energy savings estimates is that it captures the interactions that occur between complex building systems, such as thermal interactions between lights and HVAC systems. Another advantage of DOE-2 is that the savings estimates are replicable, easily archived and documented, and referenced to a specific set of simulation files.

Again, this study is not one oriented toward verifying how the measures worked in the field. Rather, our objective is to quantify energy saving benefits of commissioning. We assume that the design predictions are reasonable estimates of the savings for each measure. One shortcoming of this approach is the fact that actual buildings and installed system characteristics often differ, sometimes dramatically, from assumptions used in design models. These differences complicate the use of DOE-2 in evaluating energy savings from commissioning. We have not made extensive changes to the design models to reflect information about the actual building or used monitored data to calibrate the models. The information needed to conduct such model tuning was beyond the scope of this study.

Three types of energy savings benefits were tracked: electricity (kWh), natural gas (kBtu), and peak electric demand (kW). All of the electricity savings are in site energy units. The estimates of demand savings from deficiency corrections are estimates of the average monthly peak demand shift. Some demand shifts occur only during the heating or cooling seasons. In such a case we estimated that the shift would have occurred for only 6 months of the year, but still averaged the peak shift over the entire year. For example, a chiller COP improvement that saved 1 kW/month for six months is equivalent to shifting 0.5 kW each month for the entire year. (As described below, the demand savings were treated in this manner because the peak demand cost savings were estimated to be \$5.5/kW per month, for all 12 months.)

Non-Energy and Non-Quantified Benefits

The primary motivations for commissioning within Energy FinAnswer is to capture energy savings by ensuring that building systems work as intended. It is extremely difficult, however, to quantify non-energy benefits from commissioning. While not quantifying the benefits from these factors, we tracked them by assigning one or more non-energy benefits to each deficiency correction for which there were no energy savings benefits developed. Many of the corrections for which there were energy savings also had non-energy benefits assigned. This categorization scheme expands upon one developed for PacifiCorp by Kaplan (1993). The non-energy benefit categories are described below.

- **Improved Indoor Environmental Quality and Comfort (IEQ)** -- This broad category is concerned with the quality of the indoor environment. As mentioned, deficiencies corrections that improve the indoor environment can greatly enhance the comfort and productivity of building occupants. For example, improved air flow helps ensure that minimum ventilation requirements are met or exceeded. Improved temperature control helps ensure that the zone thermal conditions are adequate. One commissioning agent found a shipping block that was not removed from a new

compressor. Removing it reduced a significant amount of vibration and noise, and improved occupant comfort.

- **Improved Controls and Zoning (CON)** -- Similar to improved environmental comfort, this non-energy benefit is oriented toward the robustness of the building control system itself. Correcting malfunctions and optimizing operations of building controls is one of the primary benefits of commissioning, as discussed below.
- **Reduce Operations and Maintenance Costs (O&M)** -- Many corrected building deficiencies improve overall operations and maintenance beyond the controls and zoning described in the previous paragraph. This is a general benefit. Commissioning should help ensure that O&M problems found during start-up will be less likely to occur during ongoing O&M.
- **Improved Equipment Life (EQT)** -- Commissioning helps to correct system deficiencies that may reduce useful equipment life. Increasing equipment life is related to improvements in O&M since proper servicing can greatly reduce the wear and tear on many systems. In fact, the benefits from correcting the operating conditions of some equipment may far outweigh the energy savings benefits when deficiencies are corrected that might have lead to serious equipment failures. As discussed below, there were several instances where equipment cycled too frequently, placing undue stress on motors and other components, which may have lead to premature and extreme failures.
- **Reduced EEM Dollars** -- Part of the commissioning was to verify that the installed system was consistent with the design specifications. Financing was reduced or dropped if there were significant differences. There were several changes in the EEM funding of both static and dynamic measures among the 16 buildings. The CA was responsible only for the dynamic EEMs.

There were several miscellaneous benefits that were outside the scope of the above categories. For example, there was a change in the temperature of a grocery freezer that will improve the quality of the frozen food. Another benefit of commissioning is the reduction in contractor call-backs or change orders. This benefit can reduce construction costs. We were unable to explicitly track this latter non-energy benefit because of a lack of information on whether the deficiency would have warranted a call-back or change order. It is quite likely, however, that this was an important benefit in many circumstances.

Cost Effectiveness

The economic analysis was designed to address the broad question: was commissioning cost effective? To address this question we examined the question two ways. First, we looked at the cost-effectiveness of commissioning as a stand-alone measure. Here we compare the total energy cost savings from commissioning with the total costs paid by Energy FinAnswer for commissioning. The total cost savings include direct, indirect, and unrelated savings. Second, we looked at the cost-effectiveness of commissioning when combined with predicted costs and savings of the EEMs. Here we assume that once commissioned, the EEM saves 100 percent of the design predicted energy savings. But, in addition to those savings, there are additional indirect and unrelated savings from commissioning. So, here we compare the costs for commissioning plus the EEMs with the savings from the EEMs plus indirect and unrelated energy savings.

As mentioned earlier, in general the economic analysis is conservative. That is, we have not been aggressive in quantifying the economic benefit of every possible positive attribute of commissioning that can be defined for each building. Rather, we have sought to establish the energy savings and related economic benefit of the most important and well understood deficiency corrections.

Predicted energy savings estimates are available for each measure. Similarly, the energy savings from commissioning are estimated for each deficiency correction. The economic analysis was conducted on a whole-building basis. This is because commissioning costs were not generally available by EEM. The data available consisted of total costs for commissioning the package of measures for each building.

We estimated the simple payback time, or the ratio of first costs (for commissioning) to the annual energy savings. Second, a series of present value (PV) savings estimates were developed. The PV considers the number of years that the energy savings are present and the time-value of money. By definition, the PV is the annual savings divided by the appropriate capital recovery factor, or:

$$PV = \frac{\text{annual energy savings (\$/yr)}}{d} \times (1 - (1+d)^{-n})$$

where d is the real annual discount rate (3.5 percent, which is equivalent to the cost of capital at 8.5 percent less inflation at 5 percent) and n is the EEM or commissioning deficiency correction lifetime in years. The present value of the energy savings from an EEM or from commissioning can be compared to the initial investments to estimate the net present value of an investment, or a cost-benefit ratio.

Three different components of energy costs were tracked: electricity (kWh), natural gas (kBtu), and electric peak demand (kW). The energy cost savings include all three components of energy costs whenever applicable. All electricity data are in site units. Energy prices vary greatly among the buildings. To simplify the comparison of the economic parameters we choose to use a consistent set of energy prices for all 16 buildings: 4.0 cent/kWh for electricity, \$4.5/MBtu for gas. The peak demand costs were estimated to be \$5.5/kW per month, for all 12 months. These energy costs are midrange values representative of average costs for PacifiCorp. National average energy prices are approximately a factor of two greater than those assumed in this analysis.

There is significant uncertainty in the lifetime of a deficiency correction. To help account for this uncertainty we estimated a high and a low correction lifetime. The high correction lifetime assumes that the deficiency correction remains effective for the life of the measure as defined within the design study. The low lifetime represents the conditions under which the deficiency may not remain corrected. About 80 percent of the 36 quantified deficiency corrections had 5 years as the low lifetime estimate and 15 years as the high lifetime estimate. One to two-year lifetimes were assumed for the economizer corrections because of they are notorious for having recurring problems (Piette et al., 1994; Kaplan, 1994).

Results

A total of 46 dynamic EEMs were commissioned for all 16 buildings and 73 deficiencies were corrected. On average, commissioning was marginally cost effective on energy savings alone, although the results were mixed among all 16 buildings. Although we did not quantify the economic value of the savings from the non-energy benefits (except for two examples), it is likely that these benefits were often greater than the energy savings.

Example of Energy Savings at Building B

In this section we present an example of the energy savings from commissioning at one building. Building B is a 21,800 ft² office building. The problems at this office building were all HVAC (heating, ventilation, and air-conditioning) related, as were the EEMs. The EEMs were high COP heat pumps and economizers. The top section of Table 1 lists the predicted energy savings for the two dynamic EEMs and the total energy savings for both EEMs. The EEM savings are parametric estimates. The lower section of Table 1 lists the three deficiencies corrected during commissioning and the energy savings estimates for the corrections. For this building there are direct and indirect corrections. Unlike the EEM energy savings estimates, the energy savings estimates for commissioning are based on the interactive model.

Three problems were identified and fixed. The first involved improving the heat pump efficiency by cleaning filters that were dirtied by construction debris and improving the refrigeration charge. In estimating the energy savings we assumed that the dirty filters and inadequate refrigerant charge would have degraded the COP by 15 percent. The dirty filters influence the COP because the air flow is reduced and the temperature differential across the coils increases. If the air flow is greatly reduced the coils can freeze, which occurred at this building. The second correction involved a problem with the heating sequence; the resistance heat was on whenever the heating was on. The controls were rewired. The third correction improved the economizers. The economizers on half of the ten rooftop systems were defeated because of poor linkages or blocked ducts. Two outdoor air ducts were blocked by plastic membranes left over from construction. Another duct was blocked by a closed fire door.

Overall, about 17 percent of the energy savings would not have been present without commissioning. Additional indirect energy savings of 0.8 kWh/ft²-yr were obtained from addressing the heat pump problems.

Table 1: EEM and Commissioning Savings for Building B

	Electricity		Demand
	kWh/ft ² yr	% of EEM	W/ft ² month
Predicted Savings From Dynamic EEMs			
Efficient Heat Pumps	0.87		0.18
Economizer Cycles	0.87		
Total--Dynamic EEMs	1.74		0.18
Savings From Direct & Indirect Corrections			
Efficient Heat Pumps			
<i>Filters Changed; Refrigerant Charged</i>	0.36		
<i>Resistance Heat Reduced</i>	0.43		0.57
Economizer			
Economizer Dampers Repaired	0.30	35	
Total--Direct Corrections	0.30	17	
Total--Indirect Corrections	0.79		0.57
Total--All Corrections	1.09		0.57

Indirect savings are shown in *italics*.

Energy Savings Among Buildings

The total energy savings from the dynamic EEMs for each building, and the total energy savings from commissioning are shown in Table 2. Electricity savings from commissioning vary from zero to 4.4 kWh/ft²-yr per building, with an average of 0.97 kWh/ft²-yr. All three categories of deficiency corrections are included: direct, indirect, and unrelated. All sixteen buildings are included in the average although there were no quantified savings at Buildings K or M. It is likely that some savings were gained from commissioning at these sites, but it was unclear if the deficiencies identified during commissioning were corrected.

We compared the total savings from commissioning to the total dynamic EEM savings at the whole-building level. Savings in annual electricity from commissioning ranged from zero to three times the EEM savings, with an average of about 40 percent. The case where the savings were greater than the EEM (Building C) is because the EEM was oriented toward saving gas, not electricity. When Building C is excluded, the average savings from commissioning are 24 percent of the EEM savings and the median is 18 percent. In other words, the savings from commissioning were generally equivalent to about one-fifth to one-quarter of the EEM savings. There were no savings quantified for two buildings (Buildings M and K); it is likely that there were in fact some savings, but we did not find sufficient evidence from the building documentation to develop an estimate. Most of the energy savings from deficiency corrections were direct savings.

Table 2: Annual Energy Savings from Dynamic EEMs and Commissioning

Code	Type	Area (kft ²)	Dynamic EEM Savings			Correction Savings		
			Electricity (kWh/ft ²)	Gas (kBtu/ft ²)	Demand (W/ft ²)	Electricity (kWh/ft ²)	Gas (kBtu/ft ²)	Demand (W/ft ²)
A	Office	19.8	2.88		2.73	0.04		0.02
B	Office	21.8	1.74		0.18	1.09		0.57
C	Office	24.8	0.07	121.93	0.20	0.22	1.42	
D	Office	34.0	4.27	56.15	0.56	0.42	3.53	0.26
E	Office	66.0	3.48	1.42	0.24	0.51	-0.25	0.03
F	Office	66.4	3.52	-16.42	0.75	0.70	-0.75	0.07
G	Office	84.1	7.53	-5.26	1.42	3.30	0.57	0.10
H	Office	312.0	8.67		3.04	0.56		0.03
I	Theater	12.5	0.60	1.28	0.08	0.54		
J	Retail	17.0	0.69	-0.93	0.06	0.12		0.03
K	Retail	17.0	0.77					
L	Grocery	19.4	27.50	1.86	2.99	4.38		0.54
M	Hospital	23.0	1.46		0.44			
N	Motel	29.0	1.17	10.38	0.07	0.20		0.03
O	Grocery	38.5	11.46	-8.04	1.82	3.45	-3.10	0.12
P	Hotel	64.5	2.39		0.82	0.03		0.00
Average		53	4.89	10.15	0.96	0.97	0.09	0.11

Non-Energy Savings Benefits

There are important benefits from commissioning that go beyond energy savings. We have tracked four general categories of non-energy benefits, and several additional types of benefits lumped into a miscellaneous category. These benefits are assigned to deficiency corrections that were not quantified in the energy savings analysis. Many of the deficiencies for which we developed energy savings estimates also have non-energy benefits that are also tracked. Table 3 lists examples of the corrections and their non-energy benefits. Most of the corrections were related to HVAC systems, with a few related to lighting and one related to refrigeration equipment. The four categories of non-energy benefits are:

Improved Controls and Zoning (CON),
Improved Equipment Life (EQT),
Improved Operations and Maintenance (O&M),
Improved Indoor Environmental Quality and Comfort (IEQ).

The corrections listed in the table are categorized as 1) hardware or 2) software or calibration corrections. We refer to hardware corrections as those which required the addition or modification of specific devices. By contrast, the software and calibration corrections are those that required improvements such as adjusting control sequences or calibrating sensors.

Another benefit not shown in the tables was the reduction in spending within the Energy FinAnswer program that occurred when the commissioning agent reported that an installed measure or building system differed greatly from design. There were five instances of reduced EEM dollars. One additional miscellaneous correction improved the quality of frozen foods.

Table 3: Examples of Non-Energy Benefits from Deficiency Corrections

	Building Code	Quantified ^a	Non-Energy Benefit Code			
			CON	EQT	O&M	IEQ
Hardware Corrections						
Installed Missing Thermostat	A		C			I
Static Pressure Reset Fixed	E	Q	C			I
Discharge Sensor Missing	O			E		I
Economizer Circuits Corrected	I	Q		E	O	
Reheat Fans Enabled	G	Q			O	
Resistance Heat Reduced	B	Q	C		O	
VAV Box Flow Sensor Replaced	F		C		O	I
Compressor Shipping Block Removed	O			E		I
Damper Failure to Shut Fixed	G			E	O	
Duct Obstruction Removed	G					I
Filters Changed; Refrigerant Charged	B	Q	C			I
Daylighting Sensors Modified	G	Q		E	O	
Software and Calibration Corrections						
Airflow Algorithm Corrected	H		C			
Cooling Tower Fan Interlock Fixed	E	Q	C	E		
Condenser Water VFD Control Fixed	E				O	
Static Pressure Adjusted	G					I
After Hour Override Enabled	E		C		O	
Air Damper Cycling Reduced	H		C	E	O	
Discharge Air Temp. Swings Minimized	F	Q		E		
Minimum OSA Programming Added	F		C		O	I
Supply Air Reset Modified	G	Q			O	
Chiller Cycling Reduced	H	Q	C	E	O	
Daylight Dimming Adjusted	A	Q			O	
Lighting Sweeps Rezoned	E	Q		E		
Occupancy Sensors Adjusted	J		C		O	
Refrigeration Equip. Cycling Reduced	L	Q		E		

^aEnergy savings were also estimated.

Cost-effectiveness of Commissioning

The average present value of the savings from commissioning was \$0.21/ft² for the low-lifetime case and \$0.51/ft² for the high-lifetime case. In the low-lifetime case the present value of the savings is slightly less than average cost for commissioning, which was \$0.23/ft². In the high-lifetime case the present value of the savings is about twice as large as the commissioning costs. These data are shown in Figure 2, which illustrate that commissioning was generally cost effective. The figure shows the present value of the total savings from commissioning compared to the cost of commissioning for each building, and for the average of all 16 buildings. The present value of the energy savings from commissioning are shown as a range based on the high and low lifetime values. The line of equality is shown, representing where the benefits equal the costs. Half of the building's are above the line of equality, showing that the benefits exceeded the costs, and half are below the line.

The average payback for commissioning as a stand alone measure in which the cost for commissioning is compared against the total savings from all three categories of commissioning (direct, indirect, and unrelated) was 13.7 years. The median simple payback time is much lower at 6.5 years. Five buildings had payback times less than three years.

It is useful to compare the cost-effectiveness of commissioning combined with the EEMs to evaluate the total investment in energy efficiency. The total costs for commissioning plus the dynamic EEMs ranged from \$0.2/ft² to \$15.8/ft², with an average of \$2.6/ft². The energy savings benefit from commissioning combined with the total EEM savings is based on the following assumptions. First, after commissioning the EEM saves 100 percent of the predicted savings. Next are additional savings from indirect and unrelated deficiency corrections that were not considered in the original design prediction. When the total costs for the EEMs and commissioning are compared with the energy savings from the EEMs plus additional indirect and unrelated savings the average payback time is 9.6 years, with a median of 9.9 years. These payback times are dominated by the payback of the EEM independent of commissioning since commissioning was only one-fifth of the total cost. Again, assuming that national average prices are about twice as high as those for the Pacific Northwest, the payback times are half as long.

Implications

This study has shown that for most buildings, the investment in commissioning was cost effective based on energy savings alone. Energy prices are low in the Pacific Northwest, and the cost-effectiveness would be higher in other regions of the U.S. The findings are subject to significant uncertainty because of the small sample size and lack of metered data in the evaluation; additional case study analysis is needed. Commissioning should be considered in demand-side management activities. In an era when utilities and energy providers are positioning themselves for a deregulated energy marketplace, companies that offer performance assurance and commissioning are likely to be at an advantage because of their more direct involvement in understanding and addressing building performance.

The distinction between EEM and whole-building commissioning was blurred, especially among the large buildings. This suggests the need to commission not only the most energy-saving EEMs, but the most energy-consuming building systems. Greater use of metering, Energy-Management and Control System trend-logs, and enhanced links to O&M will help improve the effectiveness of commissioning by increasing the ability to evaluate its value and ensure persistence of savings from deficiency corrections. A further goal is to develop building systems that provide feedback on performance characteristics used in commissioning and ongoing operations.

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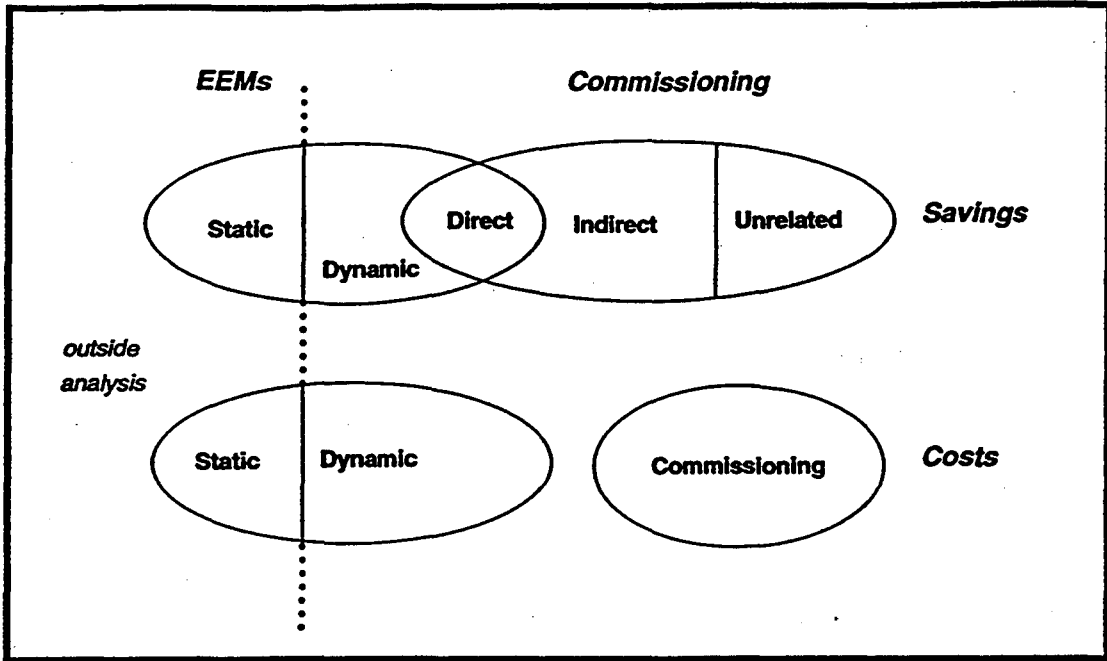


Figure A. Relationship between Costs and Savings from the EEMs and Commissioning.

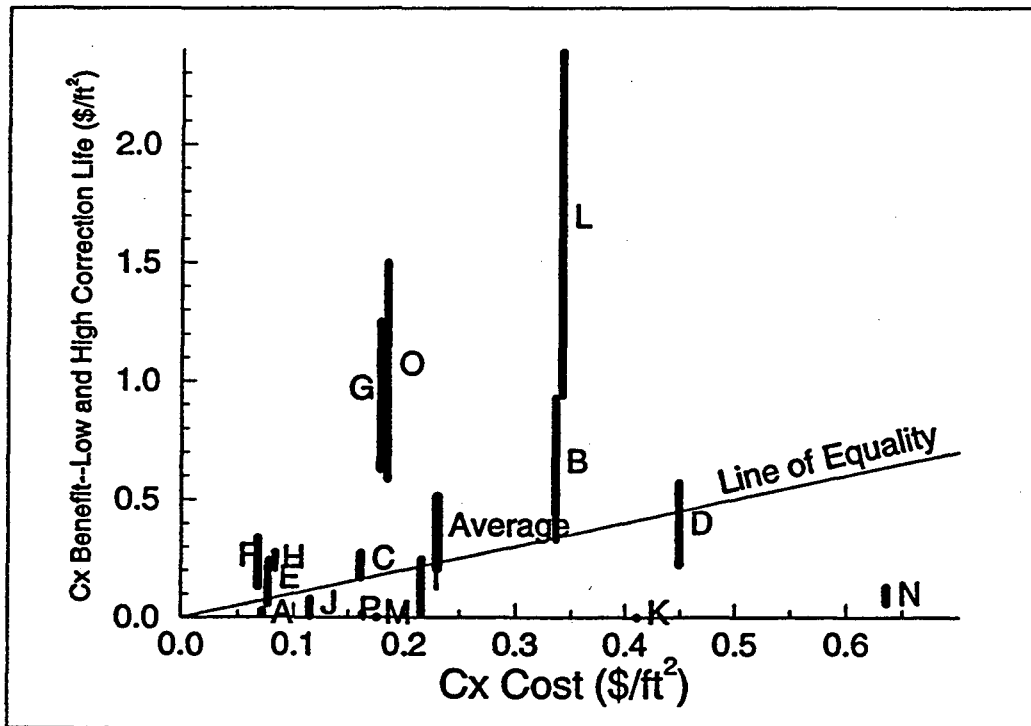


Figure B: Present Value of the Savings (Benefits) from Commissioning versus Cost of Commissioning

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ONE CYCLOTRON ROAD | BERKELEY, CALIFORNIA 94720**