Persistence of Benefits from New Building Commissioning

Hannah Friedman, Amanda Potter, and Tudi Haasl, Portland Energy Conservation, Inc.
David Claridge, Texas A&M

ABSTRACT

The commissioning process is gaining increasing recognition as a cost-effective strategy for reducing commercial building energy use. Although the success and cost-effectiveness of commissioning activities depend on how well the benefits of commissioning persist over time, this aspect of commissioning is not well understood.

The persistence of the benefits of commissioning new construction was recently studied as a part of the California Energy Commission Public Interest Energy Research program. Ten buildings that were commissioned as new buildings at least two years ago were evaluated. The commissioning reports, control algorithms, EMCS point measurements, and energy use data were examined to determine the persistence of selected items that were fixed during commissioning. Operator, owner, and commissioning provider interviews were conducted to help determine reasons for persistence and methods of improving persistence.

The majority of the commissioning fixes that were studied persisted. The items that did not persist were typically changes in occupancy scheduling and cooling plant control strategies. The persistence of commissioning benefits was found to be highly dependent on the working environment for building engineers and maintenance staff. Through this investigation, we identified three main reasons that benefits of commissioning did not persist: limited operator support and high operator turnover rates, poor information transfer from the commissioning process, and a lack of systems put in place to help operators track performance. Four methods for improving persistence are proposed, focusing on operator training and system documentation.

Introduction

Complex building systems are becoming more prevalent in commercial buildings, yet building owners often find that their buildings do not operate at the expected level of performance. Several factors contribute to this lack of building performance. The building industry has become increasingly segmented between the trades, and building industry professionals have been forced to reduce their fees to compete in the prevailing low-bid environment. As a result, quality control mechanisms and building system documentation have been largely eliminated from the building development process, and installation and operational problems have become commonplace.

More and more building owners commission their buildings to verify that the intended design has been implemented and to improve the likelihood that the equipment will maintain this level of performance throughout its life. Commissioning is a systematic process of ensuring that all building systems perform interactively according to the documented design intent and the owner's operational needs (PECI, 1997). Building commissioning prevents problems from developing, anticipates and regulates system interactions, and implements a systematic method to meet the building's mechanical,

electrical and control requirements. In correcting building problems, commissioning has been found to reduce repair and replacement costs, tenant complaints, indoor air quality problems, and liability and tenant turnover costs.

The fledgling commissioning industry, though growing every year, must resolve several issues to achieve greater penetration in the building industry and receive further support from utility energy efficiency programs. One of these issues is how well the measures that were fixed during commissioning persist over time. In August 2001, a California Energy Commission Public Interest Energy Research (PIER) project studied ten buildings that were commissioned as new buildings to address the persistence of benefits of commissioning. This study draws qualitative conclusions about the persistence of benefits from commissioning, focusing on three issues: how well the benefits of commissioning persist, the reasons for declining performance, and methods for improving persistence. A quantitative assessment of persistence by measure ("this measure has an expected persistence of X years") was outside the scope of this project. While this information would be desirable for cost-benefit analysis, a large number of buildings would be necessary to determine the life of each measure.

The Energy Systems Lab has conducted the only known studies on the persistence of commissioning benefits. Researchers studied the persistence of existing building commissioning at ten buildings on the Texas A&M campus and found a 17% increase in energy use over a period of two years (Turner et al., 2001). At these buildings, electricity, chilled water, and heating water use is metered hourly, which provided a sound basis for calibrated simulation and evaluation of savings degradation.

Methodology

The research proceeded according to the steps listed below. The description that follows provides details about each of these steps.

- Solicit and select buildings to participate
- Select measures to study from the commissioning documentation
- Define criteria for persistence
- Conduct interviews
- Perform site visits for selected buildings
- Determine reasons for persistence and methods for improving persistence

Solicit and Select Buildings

The solicitation and selection of buildings to participate in the study began with calls to California building owners and government representatives who had some form of commissioning at their building. After these contacts were insufficient to locate ten buildings, we contacted commissioning providers with projects in California and California utilities that had commissioning incentive programs.

To qualify for the study, the facility had to have been commissioned as a new building or major retrofit between two and eight years ago. Since buildings commissioned in California with adequate commissioning documentation were very difficult to find, we selected five buildings in the Pacific Northwest and five buildings in California. It was

difficult to find buildings with the quality of commissioning documentation promoted by the Building Commissioning Association (BCA, 1999). Furthermore, it was not feasible to limit the study only to buildings that followed the full commissioning process. According to ASHRAE Guideline 1, the commissioning process begins during programming and design and follows through the construction, acceptance, and post-acceptance phases (ASHRAE, 1996). We studied the persistence of the best documented and most complete commissioning processes that were found. These projects included pre-functional checks and functional testing, but design-phase commissioning was not typically implemented.

Select Measures

For each building, we identified three to eight items that were documented and fixed during commissioning. The changes and repairs made during commissioning generally fell into three categories: hardware, control system, and documentation improvements. With a main focus on energy saving measures in this study, our first priority for studying persistence was to select the hardware and control system changes with the greatest energy implications. Additionally, measures that improved comfort or reliability had significant benefits to the owner and were possibilities for selection.

As we reviewed the commissioning documentation, the driving force behind the selection of measures was the amount of information available. We could only select measures that were implemented as a part of the commissioning process and had documented details about how the problems were fixed. Many measures were eliminated from potential study due to a lack of information in the commissioning documentation that would allow us to compare the current operation to the as-commissioned operation. A large number of measures were reported as "recommendations" or "pending" and therefore, were not selected.

With limited site visit and interview time, we selected measures that maximized the value of the study results. Control system fixes were chosen because these measures can have significant impact on energy use and often can be modified easily. Maintenance issues such as typical calibration errors and clogged filters were not studied because the persistence of these items depend more on routine maintenance than the benefits of the original commissioning process. We did not place high priority on checking hardware measures that are fairly static once they are fixed. For example, we did not study instances when the commissioning agent found that equipment was disconnected from the power supply. Finally, we did not include changes that resulted from design review, since only one building underwent design phase commissioning.

Excluding hardware fixes and design changes that are likely to persist will tend to underestimate the overall persistence of commissioning benefits. The act of choosing measures that were feasible to investigate in the time available adds additional selection bias. For example, we could not evaluate discharge air temperature cycling during cooling operation when the building was not calling for cooling. Due to building and measures selection bias, the results of this study are presented in a qualitative manner.

Define Persistence

Before the persistence of new construction commissioning benefits could be determined, we defined what it meant for a measure to persist. In most cases, persistence or lack of persistence was clear. But some measures do not persist in exactly the way they were initially fixed if they were modified to meet real operating conditions. For example, the discharge air temperature reset schedule might be slightly modified if comfort requirements could not be met using the setpoints initially implemented. Even if the original reset schedule was more energy efficient, if the modified reset schedule still significantly improved energy efficiency compared to the pre-commissioning operation, then we defined the measure to persist. If the reset schedule had been disabled or modified to decrease energy efficiency compared to the pre-commissioning operation, then the measure did not persist. In some cases, the persistence of a measure was subjective, since determining persistence required judging whether the change improved or reduced the effectiveness of the commissioning repair.

Conduct Interviews

The person from the facilities staff with the most knowledge about the control system was interviewed by phone. This first interview focused on developing an understanding of the commissioning documentation and control system. To investigate the commissioning measures in detail, we selected six buildings for site visits. In the remainder of the buildings, we performed a second phone interview to discuss the current state of selected measures that were fixed during commissioning. The interviews and site visits gave us valuable insight into the reasons for persistence and the methods for improving persistence.

Perform Site Visits

Given the limited budget for the study, we were able to visit six of the ten buildings for approximately a half-day each. During each site visit, we examined the commissioning documentation, system drawings, O&M manuals, and operator training opportunities to help understand the resources available to the operations staff. We also investigated the persistence of selected measures that were fixed during commissioning at each building. While gaining an understanding of the current state of system operation and documentation, we assessed the environment that the facilities staff operates under, such as the support for training and the time available to troubleshoot – factors directly related to the persistence of benefits of commissioning.

Results

The results of this study can be broken into two categories: findings due to the difficulties in performing the study and findings due to studying the persistence of commissioning fixes. This section presents reasons why buildings were difficult to locate and reports the persistence of the measures studied. A discussion of the level of persistence of specific measures selected for the study must be preceded by stressing the value of the original commissioning process at each facility. The measures that were selected for study

were a small subset of all the items fixed during the commissioning process, from 20 to over 100 commissioning items were documented at each site. Each building operator and engineer felt that an extensive commissioning effort was essential.

Identifying Appropriate Sites to Study

Identifying buildings in California that qualified for the study was a long and difficult process. We began contacting California building owners, commissioning agents, and utility representatives in August 2001. Forty-seven building contacts were made in California, resulting in only five California buildings participating by March 2002. In contrast, five buildings in Oregon were found to participate in the study with only twelve building contacts made. It may have been easier to find commissioned buildings in Oregon because there is a longer history of new building commissioning in the Pacific Northwest, relative to other parts of the U.S. The small sample size of buildings in each state did not allow us to determine if the commissioning process or persistence of benefits differed by state.

Through our efforts in finding buildings, we identified several reasons that California buildings were difficult to locate. First, commissioning summary reports often were not written. Second, if the reports were written, they were often not available to the owner or operators. Third, new construction commissioning activities did not seem to be widespread. Last, many potential measures listed in the commissioning reports could not be investigated because they were only recommendations and may not have been implemented during commissioning. These four reasons are expanded upon below.

The extra effort required to summarize the commissioning findings in a formal report was often not completed. Therefore, there were instances when the volumes of information produced through commissioning were not put in a summary or a systems manual that could be used by facilities staff to better understand their systems. One common format for the commissioning documentation was a series of memos (or "punchlists") that listed items for the contractors to fix. As these problems were fixed and removed from the list, the details of the changes often were not documented.

Even if the reports existed, owners and facility managers often did not have access to them. Commissioning documentation was typically filed away in storage, unavailable, and not organized for easy reference. Commissioning providers, utility representatives, and building staff that had access to these large volumes of documentation did not have sufficient incentive to spend the time sorting through this documentation. Six buildings that had gone through the commissioning process did not have any commissioning documentation available, and therefore, they could not be included in the study.

Buildings that were commissioned as new construction in California between two and eight years ago were difficult to find, although we found many existing building commissioning projects (often referred to as "retro-commissioning") in California. A number of utility programs in California have promoted retro-commissioning in the past, which may have directed the enthusiasm for commissioning toward existing buildings.

Commissioning ideally results in a fully operational building, but often in reality, a number of problems remain after commissioning is formally completed. We found that many items in the commissioning documentation had not been resolved, with a number of measures being labeled as "recommendations" or "pending". Problems left unresolved in the formal commissioning process are often expected to be implemented by operations staff

during the first year(s). Since it was difficult to determine when or if these recommendations were followed, we did not classify these items as benefits of the commissioning process.

The lack of commissioning summary documentation and unresolved building problems point to the use of "commissioning" as an umbrella term for a variety of activities. This finding is supported by previous market research in California. The research identified that education is needed on the commissioning process, since the majority of owners defined commissioning as primarily the testing of systems (Haasl and Friedmann, 2001). Each commissioning process we encountered was defined differently. Troubleshooting activities during construction and simple checklists were referred to as commissioning. As we searched for buildings to participate, commissioning providers and owners told us, "this was not a good example of commissioning" since commissioning was inserted late in the construction process or had a contentious end. In effect, the persistence of the entire commissioning process, from design-phase to post-occupancy, was not investigated. Instead, we studied the variety of ways in which commissioning is implemented in practice.

Persistence of Specific Measures

The analysis of the persistence of specific measures is the heart of the study, from which the qualitative conclusions about persistence are drawn. The availability and use of the commissioning report and written sequences of operation were examined at all sites as possible factors for ensuring persistence. Figure 1 shows the measures that persisted (light gray squares) and did not persist (black squares) at each of the ten sites. A square split in half horizontally indicates that more than one measure was investigated in the category.

Figure 1. Persistence of Equipment and Controls Fixed During Commissioning.

	BUILDING (year commissioned)	DOCUMENTS			CENTRAL PLANT				AIR HANDLING AND DISTRIBUTION								PREFUNCTIONAL TESTS					OTHER		
		Commissioning report on site	Commissioning report used	Control sequences available	Chiller control	Cooling tower control	Boiler control	Hydronic control	Economizer control algorithm	Discharge air temperature reset	Simultaneous heating and cooling	VFD modulation	Dessicant cooling	Duct static pressure	Space temperature control	Terminal units	Piping and fitting problems	Valve modification	Wiring and instrumentation	Sensor placement or addition	Sensor error or failure	Scheduling	Skylight louver operation	Occupancy sensor
California	Lab and Office 1 (1996)	no	-	yes	■	▒		▒							▒				▒			■		
	Office Building 1 (1996)	no	-	yes	▒	■		▒	▒	▒				▒					▒					
	Office Building 2 (1996)	no	-	no				▒	■			▒		▒								▒		
	Office Building 3 (1996)	yes	yes	no								▒	■	■	▒		▒	▒						
	Office Buidling 4 (1994)	no	-																			■	▒	▒
Pacific Northwest	Office Building 5 (1997)	no	-	yes	■		■	▒	▒			■									■			
	Medical Facility 1 (1998)	yes	yes	yes	▒													▒		▒	▒	▒		
	Medical Facility 2 (1997)	yes	yes	yes					▒	▒	▒					■		▒			▒	■		
	Lab and Office 2 (1997)	no	-	yes	▒					▒						■					■			
	Lab and Office 3 (2000)	no	-	no				▒			▒											■		

Light gray boxes show measures that persisted and black boxes show measures that did not persist.

Across the ten buildings studied, patterns for the types of commissioning fixes that persisted emerged. Fifty-five commissioning fixes were studied, and the large majority of the measures persisted. Items such as repiping and correcting wiring, once addressed, become relatively passive elements in the system, and therefore persisted. Other hardware fixes, such as adding a control valve, also tended to persist. When control programming code was modified, these changes often persisted, especially when occupant comfort was not compromised. Most of the hydronic control problems were fixed with control programming changes. Many design-phase fixes may also persist, but we were not able to study this issue since only one building had design-phase commissioning.

Control strategies that could easily be changed without modifying the programming code had the most problems with persistence. Four out of six occupancy schedules did not persist. Chilled water system control strategies did not persist in three out of eight cases. We limited our study of sensor issues to major sensor problems that were corrected during commissioning, such as sensor failure or excessively faulty readings. With these selection criteria applied, two out of four sensor repairs did not persist.

Additional Findings

Some new or "exotic" technologies did not have documented commissioning repairs, and thus were not selected for the study, but it became apparent that these measures tended to have problems. For example, evaporative cooling was disabled, demand control ventilation was not maintained, dimmable ballasts failed prematurely, desiccant cooling failed, and a natural ventilation cycle was problematic. While some of these persistence problems may have originated from a mechanical problem, the lack of operator training in these technologies contributed to the lack of persistence. Operators were often not trained in the proper control sequences and maintenance procedures for these systems.

Almost every operator interviewed stressed that design problems continue to require their attention. Nine of the buildings did not include standard design phase commissioning. Regardless of whether or not the design problems were fixed during commissioning, these problems are significant to persistence because operators that constantly battle design problems had less time to troubleshoot the performance of the rest of the building. The operators were aware of the lack of design phase commissioning and expressed that these problems should have been caught during a design review process.

Discussion

The findings on the persistence of the measures studied, coupled with an understanding of the operating environment at each building, point to probable reasons for declining or persisting performance and methods for improving persistence. These issues are discussed below.

Reasons for Lack of Persistence

Through this investigation, we identified three main reasons that benefits of commissioning did not persist: limited operator support and operator turnover, poor information transfer from the commissioning process, and a lack of performance tracking.

First, many of the operators we interviewed did not have adequate support for maintaining their buildings. This support includes training on the intended system operation and control sequences, the time to proactively assess building operation, and guidance and motivation for assessing energy use. Operator turnover was a major factor in the lack of knowledge about the intended system operation. Operators became more knowledgeable about the operation of their systems when they were involved in the commissioning process, and when these operators left the facility, the knowledge was often lost. In general, a new operator's training consisted of about a one-day walk-through with the former operator. In some cases, operator training at the end of the commissioning process was inadequate. At one building, forms for retesting a lighting system were provided with the commissioning report, but the operators were not trained on system operation.

In addition to operator training, transferring information from the commissioning process to building operation can occur through documentation. This information, in the form of a systems manual or a commissioning report, aids persistence by giving operators the necessary systems information to maintain equipment and troubleshoot problems. In almost every case, it was difficult to locate the commissioning report. For the buildings selected, seven out of ten commissioning reports were not available on-site.

Building engineers told us that commissioning focused on the short-term goal of providing a well-functioning building before the contractors leave. The commissioning documentation was a secondary benefit, but one that has implications for the future operation of the building. If commissioning documentation is not available, there may not be a reference point for how the building should run. For a new owner or operator, this lack of information limits the understanding of the intended operation, and ultimately could result in problems with troubleshooting and decreased performance. If the systems knowledge gained from the commissioning process is not available to the current operators through documentation or training, the value of commissioning is lessened in the long run.

Finally, the complexity of HVAC and lighting systems requires tracking to understand current performance. These activities were most often not established through commissioning or implemented after the final report was provided. The original commissioning process had little effect on the current operating environment or practices. Point histories and other control system data were only viewed to troubleshoot a specific problem, and almost never for performance tracking. It was clear that the operators were too busy responding to comfort complaints, performing routine maintenance, and troubleshooting problems to assess system efficiency. The baseline (as-commissioned) energy use was determined at only one building. The result is that operators would need to establish this baseline for comparison to the current performance.

Performance tracking begins with the utility bills. Operational problems such as off-hour operation and high base load energy consumption can be analyzed from utility bill data, but this practice occurred at only one building. In four out of the ten buildings, the building operations staff had been alerted by administration of suspicious changes in energy use, but the operators did not view the utility data directly. In five buildings, the operations staff did not have access to information about energy use.

Reasons for Persistence

The persistence of commissioning benefits was found to be highly dependent on the working environment for building engineers and maintenance staff. A working environment that was supportive of persistence included adequate operator training, dedicated operations staff with the time to study and optimize building operation, and an administrative focus on building performance and energy costs. Trained operators were knowledgeable about how the systems should operate and, with adequate time and motivation, they evaluated and improved building performance. In five buildings, operators participated in the commissioning process and came away with a good understanding of their systems. In addition, good system documentation in the form of a system manual served as a troubleshooting resource for operators at two buildings. Administrative staff can help enable a supportive working environment by placing a high priority on energy efficient systems and operator training. Only a few of the buildings studied seemed to operate in this supportive environment, and the measures investigated at these facilities had the highest rate of persistence.

Other measures persisted because there was no reason for change, and the measure could persist without maintenance. For example, if a controls repair during commissioning did not affect comfort in the subsequent years, then the controls most likely were not modified. Additionally, if a controls fix was buried in the programming code, most operators could not change it without hiring the controls contractor. Hardware repairs, often found during prefunctional tests, also tended to persist because there was no reason to intervene.

Four Methods for Improving Persistence

As the final goal for this study, we have identified ways in which persistence can be improved. These methods were developed with building engineers and operators in mind - the people who have the most control over the persistence of commissioning.

1. **Provide operators with training and support.** High operator turnover makes training and documentation critical to help ensure that the benefits of commissioning persist over time. A supportive environment for the building staff facilitates energy tracking and proactive troubleshooting. Building operator certification is one means of providing this advanced training (Price, 2001).

2. **Provide a complete systems manual at the end of the commissioning process**. The systems manual is the institutional memory for the building, and this information assists the staff in ensuring that the benefits of commissioning persist. The systems manual should include the design intent, system descriptions, sequences of operation, and a commissioning report. The commissioning report should summarize the deficiencies found during commissioning and set the baseline performance of the building. If the systems knowledge gained from the commissioning process is not available to the current operators, the value of commissioning is decreased in the long term.

3. **Track building performance.** New building commissioning efforts should help implement mechanisms for performance tracking, including what information to track,

how often to check it, and the magnitude of deviations to address. Using the baseline operation documented in the systems manual, operators can monitor whole building energy use and the efficiency of major equipment. The performance tracking system could also provide assistance in troubleshooting when deviations from the baseline are detected. These performance tracking activities are beginning to be automated by a number of diagnostic software tools (Friedman and Piette, 2001). Training for these tracking efforts is essential for success.

4. **Start commissioning in the design phase to prevent nagging design problems.** The most cost effective benefits of commissioning often occur during the design phase, when changes in design are made on paper, rather than during construction or after construction is complete. These changes would likely have high rates of persistence.

Next Steps

The preceding persistence analysis is based on evidence from a limited set of interviews and site visits, which has provided an understanding of the issues involved in persistence. In the second phase of the project during the summer of 2002, these findings will be supplemented with quantitative analysis. Using energy simulation software and utility data, we will create calibrated models of selected buildings. These simulations will use a detailed HVAC system model and typical load profiles (Liu and Claridge, 1998). The goal of the modeling is to quantify any observed degradation in energy performance, normalized for weather and building changes, and correlate any changes in performance with previous findings on the persistence of measures repaired during commissioning.

Conclusions and Future Study

We conclude that there was a lack of commissioning documentation and a limited level of support for operators in the commissioned buildings we studied. These factors did not promote the persistence of commissioning benefits. Without adequate system documentation, the baseline operation of the systems after commissioning was unknown. The current operation of the commissioned buildings studied often had a limited connection to the knowledge gained from the commissioning process. Even with these shortcomings, a large number of the measures fixed during the commissioning process persisted. The commissioning process was considered by operators and owners as essential to providing well-functioning HVAC and lighting systems - views that are supported by the large number of problems identified and resolved at each building.

As the first study of the persistence of commissioning benefits for new construction, this work has begun to address the reasons for persistence and lack of persistence. Through studying ten buildings, we have assessed the persistence of commissioning at an overview level. For cost-benefit analyses that require estimates of the "life" of commissioning repairs (commissioning of measure X in a new building has an expected persistence of Y years), a more involved analysis of the persistence of new building commissioning will be necessary. To do this type of quantitative analysis, a larger sample of buildings should be investigated. Future studies should attempt to investigate all measures that were documented during the commissioning process, which is an effort that may require analysis during multiple seasons.

A major goal of PIER projects is to bring research ideas into current practice. To put the findings from this study to practical use, a manual of guidelines for improving persistence should be developed. The guidelines would help direct building engineers and operators that wish to maintain the benefits of the new building commissioning process. Case studies could be carried out to examine and improve the effectiveness of the guideline implementation methods. In addition, building engineers and operators could participate in group training sessions on implementing the guidelines.

The success and cost-effectiveness of commissioning depends on how long the benefits persist. Without a good understanding of how to improve persistence, many benefits of commissioning will be lost. Bridging the gap between new building commissioning and day-to-day operations is a challenge that should continue to be addressed by the commissioning industry.

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