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Long Term Benefits of Building Commissioning: Should Owners Pay the Price?

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Abstract

This research paper explores the long-term benefits of building commissioning and the persistence of benefits over time. The lack of a strong financial business case has led to a slow uptake of the practice within the building industry. The purpose of this paper is to examine the background of building commissioning and its benefits, determine whether an initial investment by a building owner will result in cost savings and long term benefits, and provide an unbiased perspective on the value of building commissioning.

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Keywords: building commissioning, MEP, commissioning, owner-client

Introduction and Background

"The long-term life-cycle benefits of commissioning far outweigh the short-term up-front investments, as borne out by many documented case studies, both in the public and private sector building and facility infrastructure." [1]

Public agencies such as the Department of Veterans Affairs were among the first to adopt building commissioning as common practice and they still comprise the bulk of the industry today. Since commissioning is not commonly practiced internationally, the United States remains the leader in the use of building commissioning with many commissioning agent companies, professional organizations, and published research and guidance. Despite the growing popularity of commissioning in the public sector, it is still far from standard practice in private industry. Many factors have contributed to the slow uptake of the practice within the industry, the most important of which is a lack of a strong financial business case. In the time since building commissioning was introduced to the construction industry nearly four decades ago, building owners have sought information on the benefits and cost effectiveness of the practice [2]. There are many publicly available case studies and research papers which have been published on the topic, many of which attempt to quantify the benefits of commissioning. This research examines the background of commissioning and its benefits to building owners and whether the benefits of commissioning persist over time.

Commissioning: Ships to Buildings

The concept of commissioning is taken from the ship building industry which has been using commissioning to ensure the readiness of ships for decades. This quality assurance process is an essential aspect of ship building primarily because the risk of loss of life is high for a ship at sea. It is critical that the systems and equipment on the ship function as designed and that all operation and maintenance personnel are thoroughly trained prior to use of the ship. Because the risk is high, the rigorous quality assurance process of commissioning justifies the expense. The concept of commissioning began to be applied as a building construction quality assurance process during the environmental movement of the 1970s and 1980s as an energy saving measure, and gained a great deal of momentum in response to the energy crisis of the 1970s. Throughout the 1980s and 1990s building commissioning became more common, especially in public sector projects. In the decades that followed, commissioning committees were formed to create guidance on the practice and articles began to appear in trade journals. In addition to these early efforts, the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) and the California Commissioning Collaborative have published widely recognized guidance for building commissioning. One of the largest advances for building commissioning is its incorporation into the Leadership in Energy and Environmental Design (LEED) certification [3]. Building commissioning is now common practice for building projects in the public sector and is also very popular among some private owners, especially those interested in obtaining LEED certification. As evidence of its increased visibility, building commissioning even has a Wikipedia page [4].

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The U.S. federal government has contributed significantly to the development of the building commissioning industry. In 1994 Executive Order 12902 mandated that all federal buildings utilize commissioning for quality assurance of building systems [3]. In 2007, Executive Order 13423 – Strengthening Federal Environmental, Energy, and Transportation Management reinforced the 1994 order and requires that Federal Agencies ensure new construction and major renovations include building commissioning in the contract requirements (VA, 2013). Each federal organization has implemented this order in various ways. The Department of Veterans Affairs Commissioning Manual states the following drivers for conducting building commissioning, "In addition to the performance needs of healthcare and mission critical facilities, another factor driving demand for commissioning is a desire to obtain certification through the LEED program and the Green Globes program. These rating systems have been developed to improve energy efficiency and environmental performance in buildings – and commissioning is a pre-requisite for LEED certification and a requirement for Green Globes" [1]. The US Government Services Administration (GSA), the Navy Facilities Acquisition Command (NAVFAC), and the US Army Corps of Engineers (USACE) have also published guidance which incorporates the requirement for building commissioning into their contracts. Just recently, the USACE published an Engineering and Construction Bulletin which requires the monitoring of commissioning performance after project completion [5]. Most of the technical research on building commissioning has been done by government organizations such as the US Department of Energy, State Universities, and the California Energy Commission.

Commercial Buildings and Commissioning

In the 21st century, the built environment is becoming increasingly complex. High performance energy efficient buildings are touted by owners and net-zero buildings are being constructed by both public and private owners. Building systems in particular have grown in complexity in that they now often incorporate an electronic Building Management System (BMS) which allows for the control of heating, ventilating, air-conditioning, and refrigeration systems as well as lighting, fire suppression, alarm, and security systems. These control systems produce real-time data which allow the building owner to monitor the system performance [6]. As buildings have become more complex, the need for more sophisticated quality assurance measures has increased. Building commissioning helps fulfill this need by ensuring that the building systems are installed, tested, and are operating as designed. "Building commissioning brings a holistic perspective to design, construction, and operation that integrates and enhances traditionally separate functions. It does so through a meticulous "forensic" review of a building's disposition to identify suboptimal situations or malfunctions and the associated opportunities for energy savings" [2]. Building commissioning can vary widely in scope depending on the type of building, budget constraints, and owner preferences. The commissioning agent, who is normally a third party hired by the owner to conduct the commissioning process, can be involved in the project as early as pre-design or as late as construction completion. For most new construction projects, the bulk of the commissioning effort will occur towards the end of the project after the building mechanical, electrical, and HVAC systems have been installed and tested by the respective subcontractors. While the general contractor, along with their subcontractors, are ultimately responsible for the quality of the installation and testing of the building systems, a commissioning agent can provide an unbiased analysis of the installation and hopefully detect any issues which would cause operation or maintenance problems in the future. Any deficiencies found by the commissioning agent are normally communicated to the general contractor for resolution prior to occupancy by the building owner.

A building which has never been commissioned but is already occupied and operational can be retro-commissioned if problems with the building systems arise or if the owner is seeking additional energy savings. In this case a commissioning agent is hired to inspect the system, analyze available building metering data, and in some cases conduct testing in the field to understand the operation of the systems. The commissioning agent will then provide a report to the owner with suggested improvements. It is usually up to the building owner and operations and maintenance staff to implement the improvements. The 2009 Building Commissioning report authored by Evan Mills of the Lawrence Berkeley National Laboratory (LBNL) includes a graphic (Figure 1) which effectively presents the commissioning and retro-commissioning processes [2].

Despite the permeation into the federal project landscape, commissioning is still relatively uncommon. Industry practitioners admit that the uptake by building owners has been slow, possibly due to the lack of knowledge about the commissioning process combined with a lack of financial business case [2]. Also, an unwillingness to invest in an independent third party to conduct validation, start-up, and system certification instead of leaving this responsibility to the designer or contractor installing the system can deter owners. This sentiment was expressed in an Engineering News-Record article on building commissioning where the author stated "…many in our industry can't believe that we have to pay extra to make sure our capital projects actually "work." While modern building systems are more complex, it would seem that hiring quality architects, engineers, contractors or construction managers and subcontractors would be enough to ensure that your new building operates efficiently and effectively" [7]. This point has been made by building owners nationwide who are equally frustrated with the increase in the cost of capital improvements and the need to spend additional funds to hire a commissioning agent to back check the work of the designer and contractor. The commissioning industry will need to present a solid case in order to overcome this attitude, if the industry is to expand in the future.

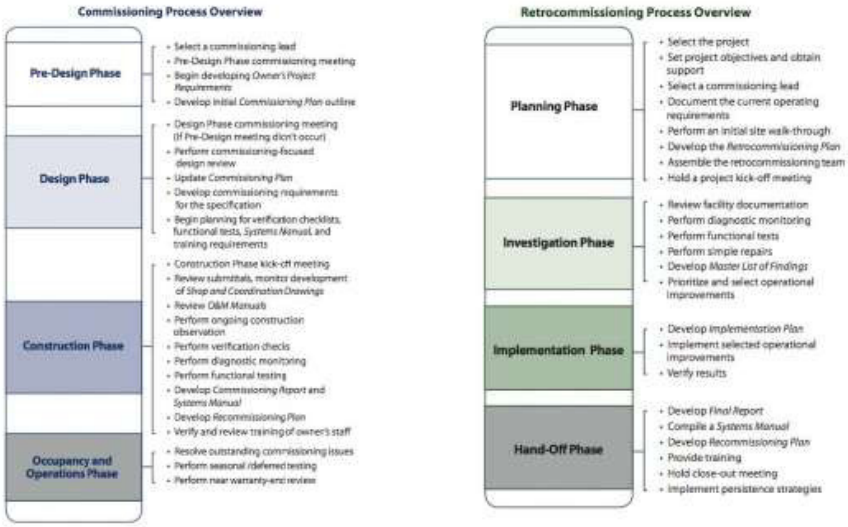

Figure 1. Process Charts for the 2009 LBNL Report [2]

Current Status of Building Commissioning

One of the most referenced reports on building commissioning is "Building Commissioning: A Golden Opportunity for Reducing Energy Costs and Greenhouse Gas Emissions" authored by Evan Mills of the Lawrence Berkeley National Laboratory (LBNL). This study builds upon a 2004 study also conducted by Lawrence Berkeley National Laboratory which is home to the "world's largest compilation and meta-analysis of commissioning experience in commercial buildings" [2]. The 2009 report is based upon a database of 643 buildings representing nearly 100 million square feet of floor space, and $43 million in commission expenditures. This report is possibly the most comprehensive analysis of commissioning data publicly available, so it is understandable why it is referenced regularly in other publications. It is interesting to note that the bulk of the literature referenced in this research is overwhelmingly in support of building commissioning. The 2009 LBNL report goes so far as to state, "These findings demonstrate that commissioning is arguably the single-most cost-effective strategy for reducing energy, costs, and greenhouse gas emissions in buildings today" [2]. An ASHRAE article published in 2011 summarizes the results of the LBNL study, "The results are compelling. The median cost to deliver commissioning was $0.30/ft2 ($3/m2) (in 2009 dollars) for existing buildings and $1.16/ft2 ($12/m2) for new construction (or 0.4% of the overall construction cost). More than 10,000 specific deficiencies were identified across one-third of the sample for which data were available. Correcting these problems resulted in 16% median *whole-building* energy savings in existing buildings and 13% in new construction, with payback times of 1.1 years and 4.2 years, respectively. Median benefit-cost ratios of 4.5 and 1.1, and cash-on-cash returns (a common statistic used in the real estate industry) of 91% and 23% were achieved" [8]. Resources for this research paper were obtained through various means including a search of the Auburn University library, Engineering News-Record database, ASCE and ASME databases, as well as several Google searches. Given that the resources were acquired by different means, it is interesting to note that nearly every publication references the 2009 LBNL study. Given that the LBNL study is overwhelming in support of building commissioning, it is not surprising to find that the other publications seem to echo a similar sentiment. In fact, the only article found in this literature review, which was not overwhelmingly in support of building commission, was the ENR viewpoint article, *Don't Farm Out Commissioning*, authored by Thomas Gormley [7].

Long Term Analysis

For new construction, the commissioning process generally occurs towards the end of the construction timeframe, before the building is turned over to the owner. It is one final quality assurance check to ensure the building systems are optimized and operating efficiently. The scope of commissioning can vary widely building to building depending on the requirements of the owner. "Unlike an efficient light bulb, commissioning is not a *commodity* product (or process). Each building is unique and presents unique problems for unique owners. Aspiration and budget can also vary; commissioning is performed at widely varying levels of effort and applied buildings as a whole (preferred) or to a specific sub-system or energy end-use" [2]. Budget restrictions can also affect the scope of the commission process, and in some cases not all systems will be commissioned. The Department of Veterans Affairs Building Commissioning Manual states that, "While buildings are comprised of static systems (e.g., building envelope, building structure) and dynamic systems (e.g.,

HVAC, emergency power, elevators), the commissioning process is intended to address the 'integrated dynamic performance of the 'building system'. Therefore, when considering which building systems to commission, the primary considerations are driven by the impacts of any given system on the overall performance of the building as a whole" [1]. The fact that building commissioning scope varies widely from building to building, makes it difficult to prepare an accurate comparative analysis of a large sample of commissioned buildings. Additionally, commissioning is not only applicable to new construction. The commissioning of existing buildings, known as retro-commissioning, is another category that is considered in many reports. The results of retro-commissioning are somewhat easier to compare given that the buildings which undergo this process are already in operation at the time of commissioning and therefore a baseline can be established from which to measure the commissioning results. Retro-commissioning can be completed for nearly any type of building. Table 1 from the 2009 LBNL report presents a list of existing buildings types, which were studied for project costs and savings.

Table 1 presents energy savings and payback time for a sampling of 186 existing buildings, which were retro-commissioned. The average energy savings were found to be 10-15% with an average payback time of 1.8 years. This type of short-term analysis is typical of the data presented in the report for both new construction and existing buildings. Unfortunately, this publication like most publications only goes so far as to determine the simple payback time and not the persistence of benefits over the life of the building. The simple payback time will tell the owner that they 'broke even' on their investment, but the question remains, will the energy savings persist over time.

Table 1. *Examples of existing-building commissioning project costs and savings*

Target	Location	Sites	Energy Savings	Peak Demand savings	RCx Cost ($/sf)	Payback time (years)*	Source
Local government buildings	California	11 sites; 1.5 MSf	14.3% source energy (11% electric; 34% gas)		1.01	3.5	Amaranani et al (2005); Amarani and Roberts (2006); Pierce and Amarani (2006)
Offices and hotels	New York	6 sites; 6 MSft		10%	0.34	2.0	Lenihan (2007) - projected
Offices	Connecticut	5 buildings; 2 MSf	8.5% electricity (3% to 20%)			0.5	Building Operating Management (2006)
Class A Offices	Connecticut	3 bldgs; 1.2 MSF	7.3% electric		0.62	1.37	McIntosh (2008)
Mixed comercial	Colorado	27 buildings; 10 MSf	7% elect	4.2% (0-26%)	0.185	1.51	Franconi et al. (2005)
Three offices + hospital	Colorado	4 buildings; 1.8 MSf		6%	0.026	0.38	Mueller et al. (2004)
University buildings	California	26 buildings; 3.4 MSf	10% total source (2-25%)	4% (3-11%)	1.00	2.5	Mills & Matthew (2009)
Elementary schools	Michigan	4 schools			0.38	2.5	Freidman (2004)
Supermarkets	Central California	10 stores; 0.5 MSf	12.1% elect (4.3-18.3%)		0.14	0.25	Zazzara and Ward (2004); Emerson (2004)
Mixed commercial	Northwest	8 buildings			0.221	3.2	Tso et al (2003)
Mixed commercial	Oregon	76 projects	10-15% electric (5%-40%)		0.175	1.24	Peterson (2004)
Mixed commercial and educational	California	All California Programs (2007-2008)	1.7-8.1% electric		0.40	3.0	PECI and Summit Building Engineers (2007) - estimates
Total or simple average values		**186**	**~10-15%**	**~7%**	**0.41**	**1.8**	

Notes: All impacts shown using local energy prices and commissioning costs; averages are floor-area-weighted averages.

Case Study

One article which presents an interesting case study is, *Building Commissioning: What Can Denmark Learn from the U.S. Experience?* authored by Rúnar Örn Ágústsson and Per Anker Jensen [3]. While the bulk of the article focuses on how to translate the U.S. building industry implementation of commissioning in Denmark, a large section of the article is dedicated to the examination of a case study involving two shopping malls. There are several reasons this case study is particularly interesting. First, it can be difficult to find two buildings which are similar enough to directly compare, and second, there are often too many variables between the scope of construction and commissioning to perform a direct comparison. However, in this case study the two shopping malls are very similar in scope and geographical location and were built under the same building code by the same owner and contractor. One shopping mall underwent the commissioning process and the other did not. The data available included monthly values for consumption of electricity, energy used for heating and hot water production, and water consumption. The data from three years of operation (2008 to 2010) was analyzed. The results are compelling on initial analysis. The shopping mall which was not commissioned was found to use 40-50% more electricity, about 50% more water, and nearly 40% more energy for heating and hot water production. These results appear to make a strong case for commissioning as the shopping mall which was not commissioned is performing poorly compared with the

shopping mall which was commissioned. The author dug deeper and found some reasons why the electricity consumption in the non-commissioned mall might have been so much higher. The article cites the following reasons: 1) problems with O&M providers, 2) high turnover of O&M personnel, 3) limited focus on data analyzing to identify upcoming problems and possible improvements, and 4) no specific O&M-related focus on technical installations, HVAC, cooling, building management systems, and so forth, during the building process, which resulted in below average installations. The article concludes that "high performance level and efficiency are not guaranteed and even though it is achieved at the beginning of operation, it needs to be sustained. To sustain the performance level, competent O&M staff is needed that is capable of maintaining the building system so energy savings are sustained throughout the lifetime of the building" [3]. This is a very important point which is echoed in several of the articles referenced in this research paper. The bottom line is that commissioning may help ensure the building is operating per the design requirements on day one, but it is those who operate and maintain the system over time which will help ensure that the benefits persist over the life of the building.

This case study shows that even when many of the variables are minimized or eliminated, it is still difficult to quantify the benefits of commissioning, especially over a long time frame. A building is similar to a living organism in that it is constantly changing and responding to the feedback given by the occupants of the building and the building managers. In this sense, it is difficult to attribute changes, both positive and negative, solely to the initial efforts of commissioning.

Benefit Persistence

It is clear from the statements presented in the cited references that the benefits of commissioning do not simply persist on their own without any effort by the building owner or their operations and maintenance personnel. Therefore, it can be said that the factor which is even more important than the commissioning itself are the people who monitor, operate, and maintain the systems over the life of the building. An article on building commissioning published by the American Society of Civil Engineers (ASCE) titled "Building Commissioning: Ensuring Quality and Savings" suggested that owners should continue commissioning the building after it is turned over for operation. The article states, "To continue commissioning the building, the authority sets up monthly monitoring programs during the first year or a predefined period that suits the owner. This ensures that the building systems continue to run optimally and that any costly malfunctions are identified quickly. It is difficult to simulate these conditions for testing during the construction phase. After the first year, yearly monitoring programs can be set up with the help of the building's staff to continue to monitor the buildings systems" [9]. This recommendation is echoed in many of the more recent references included in this research, yet most building owners choose not to continue this monitoring. This lack of data makes it difficult if not impossible to determine whether the benefits of commissioning persist in the long term.

A Golden Opportunity

One of the caveats of the oft cited 2009 Lawrence Berkeley National Laboratory report, "Building Commissioning: A Golden Opportunity for Reducing Energy Costs and Greenhouse Gas Emissions", is that there is not a multitude of data available for time frames greater than five years. The report states, "The persistence of commissioning energy savings is perhaps the most significant caveat in analyses such as that presented in this report, although some concerns about the issue are ill-founded. Indeed, commissioning itself is needed largely *because* system performance does not persist. Commissioning can arguably increase the persistence of other energy measures. We acquired data on energy savings over multi-year periods following some of the projects. Negligible post-commissioning energy use/savings data have been collected for timeframes more than five years. However, the payback times we observe are within the likely period of savings persistence" [2]. This caveat sheds doubt on the both the accuracy of the study and the need for building commissioning all together. It is worrisome that so many publications establish support for commissioning based on this study which in reality does not present a strong case for the long term benefits of commissioning. This leaves owners to decide for themselves whether the initial investment in commissioning is worth the time, effort, and cost of hiring a commissioning agent and ensuring that the process is implemented, or whether that money may be better spent on an effort such as training operations and maintenance personnel who will likely have a greater impact on the long term effectiveness of the building systems.

Federal Adoption of Monitoring

Federal agencies have also been slow to adopt monitoring programs despite being early adopters of building commissioning. The Department of Veterans Affairs commissioning manual is one hundred and fifty-five pages yet only reserves one paragraph to discuss "Systems Performance Monitoring". The manual states that the commissioning agent, VA staff, and representatives of the A/E team and the contractor's team should verify on-going system performance during the warranty period [1]. It does not state a time frame for this phase, but it is typically a period of one year for federal construction contracts. Unfortunately, the probability of these parties re-grouping during the warranty phase is slim, especially if this follow-up visit is not specifically written into each of the contracts. The Whole Building Design Guide [10] is the hub for information for most federal agencies and provides guidance on building commissioning. However, in their guidance there is no mention of performance monitoring or performance checks during the warranty period [10]. The U.S. Army Corps of Engineers released an Engineering and Construction Bulletin (ECB) dated 30 October 2014 which provides direction and guidance for the verification of building performance in order to determine whether buildings are

performing as designed. The ECB states, "USACE designs to achieve a prescribed level of energy savings and traditionally have not verified if that expectation is achieved" [5]. The guidance suggests that analysis of the building meters, trend log data, and manual meter readings will occur during the warranty inspections which occur at four and nine months after building turnover. While this process will not reveal the long term persistence of energy savings, it is a step in the right direction.

Continuous Commissioning

One effort aimed at ensuring benefit persistence over the life of a building is a process known as Continuous Commissioning. This trademarked process was developed by the Energy Systems Laboratory at Texas A&M University [11]. Continuous commissioning is a strategy used throughout the life of the building to ensure that building systems not only start optimized but also stay optimized as the building is occupied. It is important to note that continuous commissioning is not the same as traditional building commissioning or retro-commissioning. Instead, continuous commissioning is an ongoing process which is designed to help resolve operating problems, improve comfort, optimize energy use, and identify retrofits for existing buildings. "Throughout this process, the design intent is only considered as a reference, not as the performance target, realizing that 1) the building designer rarely has enough information to specify optimal operation of the design, and 2) the building function and use have often changed significantly from original expectations. The continuous commissioning process is not limited to solving operation and maintenance problems. It focuses on innovative engineering solutions using state-of-the-art technologies" [11]. A case study presented in "Continuous Commissioning of Building Energy Systems" authored by David Claridge and W.D. Turner of Texas A&M University looked at a 123,000 SF research building which is metered such that the whole building's chilled water and steam consumption could be viewed on an hourly basis. With this data collection, the commissioning agent was able to optimize the heating and cooling loads for the buildings. The building performance was continually monitored for several years and as a result of the continuous commissioning process the annual heating energy consumption was reduced 63% and the annual cooling energy reduced 42%. The total thermal energy costs were reduced from $1,037,753 to $510,067 for a savings of 51% [11]. This case study shows that when commissioning is conducted over a longer time frame, the picture is clearer as to how the building is actually operating. With this data and analysis in hand, systems can be better optimized and cost savings realized. This case study also falls into the 'high tech' building category which means its systems stand to gain the most from the commissioning process. While this case study focuses on only one building, the same ASME article states that well over 100 large buildings have implemented continuous commissioning and the process has typically decreased building energy consumption by 20%.

Trust, but Verify

Commissioning in and of itself is not a bad idea. It will not cause any harm to the building systems, nor result in less efficient systems overall. In fact, most short term case studies have shown that commissioning results in cost savings during the first one to five years such that the money spent on the commissioning effort is recouped through energy savings. The concern expressed in this research is statements such as the one made in the 2009 LBNL report which states, "As with most other energy-efficiency measures, commissioning savings are often roughly estimated or out-and-out stipulated based on little more than best guesses" [2]. Without reliable data to prove long term benefits, many owners will simply not make the upfront investment for commissioning. The technology to gather real-time performance data from building systems exists and is regularly installed in commercial buildings, and private owners and federal agencies alike could benefit from the knowledge gained from long term monitoring. However, if the effort is not made to go back and analyze the data being gathered, there is effectively no benefit. It is imperative that the collected data be analyzed and then acted upon to continually improve building performance. Several barriers to monitoring include budget constraints, lack of staff, and monitoring data that is not useful or hard to understand. A pertinent section of the LBNL report states, "Persistence of the corrections (and associated energy savings) tends to be a concern, as many commissioning measures are operational and thus easily reversed if not monitored" [2]. Due diligence during and after the commissioning of a project by the contractor, A/E team, and commissioning agent will help ensure buildings are optimized to perform as designed at the time of project completion. It is the responsibility of the building owner and those who maintain the building systems to monitor the performance in order to find creative strategies for maintaining energy efficient systems long after the A/E and contractor have moved on to the next project.

Conclusion

Building owners stand to gain the most from research on the benefit persistence of building commissioning. Owners will need to decide whether a simple payback of the commissioning cost is enough to persuade them to go to the effort of hiring a commissioning agent in the first place. Not enough is known about the long term benefits of commissioning beyond the simple payback period to adequately inform financial decisions by building owners. It is apparent from the case studies that building commissioning can be more beneficial for some types of buildings, especially those in the high tech industry. These complex building systems require a holistic view and additional quality assurance that commissioning agents can provide. The argument for commissioning every building seems to be one that is manufactured by those in the commissioning industry. The 2009 LBNL report asserts that commissioning is an essential risk-management tool for every building and to not commission is to assume a multitude of risks and undetrattainment of goals. Given the shear amount of publications that reference this study, the overwhelming support for building commissioning in the LBNL report

makes it seem as though the whole body of research is open to question. Very few publications take an un-biased look at commissioning and openly acknowledge the fact that very little reliable long term data analysis is available. Instead of applying a 'commissioning for all' mentality across the board, as seems to be the case for many federal programs, building owners should carefully consider the benefits and costs of commissioning for their particular case and determine whether or not the designers and contractors hired to construct the building can achieve the same goal. In reality, a talented A/E team and constructor along with a thorough quality assurance process should eliminate the need for the added effort and cost of commissioning. Alternately, owners could consider diverting funds which would have gone to commissioning to an investment in the training of their operations and maintenance staff so that they can properly monitor the performance of the building systems and identify when changes are required. Continuous commissioning is yet another alternate approach that is gaining momentum, and it could be a promising source of information on the long term benefits of commissioning in the future. Ultimately, owners are concerned about the long term performance of their building and the return on their investment. Therefore, it is up to each owner to determine whether commissioning is an appropriate strategy for their building and whether they should "pay the price" of commissioning. Traditional building commissioning comes to an end with the performance testing and turnover of the building or in some cases the end of the warranty period, yet for the building owner and their staff, the job of ensuring building performance has just begun.

References

[1] U.S. Department of Veterans Affairs (VA). (2013). *Whole Building Commissioning Process Manual.* Washington, DC.

[2] Mills, E. (2009). Building Commissioning: A Golden Opportunity for Reducing Energy Costs and Greenhouse Gas Emissions. Lawrence Berkeley National Laboratory, Berkeley, CA.

[3] Ágústsson, R. & Jensen, P.A. (2012). Building Commissioning: What Can Denmark Learn from the U.S. Experience? *American Society of Civil Engineers, J. Perform. Constr. Facil.*, 26(3), 271–278.

[4] Wikipedia. (2014). *New-construction building commissioning.* URL http://en.wikipedia.org/wiki/New-construction_building_commissioning

[5] U.S. Army Corps of Engineers (USACE). (2014). *Engineering and Construction Bulletin, Verification of Building Performance.* No. 2014-23.

[6] U.S. Department of Energy (DOE). (2011). *A Guide to Building Commissioning.*

[7] Gormley, T.C. (2003). Don't Farm Out Commissioning. *Engineering News-Record, McGraw Hill Construction*. URL http://enr.construction.com/opinions/viewpoint/archives/031117.asp

[8] Mills, Evan. (2011). Capturing the Potential. *ASHRAE Journal:* pp.1-2.

[9] Nicholson, M. & Molenaar, K. (2000). Building Commissioning: Ensuring Quality and Savings. *American Society of Civil Engineers, Construction Congress VI*: pp. 1074-1082.

[10] Whole Building Design Guide (WBDG). (2014). *Building Commissioning.* URL http://www.wbdg.org/project/buildingcomm.php

[11] Claridge, D.E. & Turner, W.D. (2003). Continuous Commissioning of Building Energy Systems. *Journal of Solar Energy Engineering, American Society of Mechanical Engineers,* 125 (8), 275-281.