Strategies for Improving Persistence of Commissioning Benefits: Making Lasting Improvements in Building Operations

Tudi Haasl, Hannah Friedman, and Amanda Potter, Portland Energy Conservation, Inc.

ABSTRACT

More and more building owners are turning to commissioning (Cx) and retrocommissioning (RCx) as cost-effective, quality assurance strategies for their building operations and maintenance. Commissioning ensures that a new building works correctly from day one, and retrocommissioning gets existing buildings' systems back on track. Although the building's systems may be well tuned at the end of the commissioning process, buildings may change over time, drifting away from their intended design and operating requirements.

What can an owner, building manager, or operator do to avoid these problems and improve the long-term operations of their building? This paper describes a recently published set of strategies to improve persistence of benefits from commissioning. Based on California Public Interest Energy Research (PIER) completed in 2002, the following strategies that improve persistence are discussed:

- Design review
- Building documentation
- Operator training
- Building benchmarking
- Utility tracking
- Trend analysis
- Recommissioning
- Continuous Commissioning®

Introduction

More and more building owners are turning to commissioning (Cx) and retrocommissioning (RCx) as cost-effective, quality assurance strategies for their building operations and maintenance. Commissioning ensures that a new building works correctly from day one, and retrocommissioning gets existing buildings back on track. Although the building's systems may be well tuned at the end of the commissioning or retrocommissioning process, buildings can change over time, drifting from their intended design and operating requirements. Therefore it is not surprising that owners and policy makers want to know if they can count on the Cx and RCx benefits to persist.

To better understand the persistence of benefits from commissioning, a California Public Interest Energy Research (PIER) project studied buildings that had undergone new construction commissioning (Friedman et al, 2003a) or existing building commissioning (Turner et al, 2001). As the first study on persistence of benefits from commissioning, qualitative conclusions were drawn about persistence by focusing on three issues: how well the benefits of commissioning persist, the reasons for declining performance, and methods for improving persistence. The study had two parts: a new building commissioning study of ten buildings in California and

Oregon between two and seven years old, and a study of ten buildings in Texas and California retrocommissioned two years earlier. The study examined commissioning reports, control algorithms, EMCS point measurements, and energy use data to determine the persistence of select measures identified as problems and fixed during commissioning, as well as analyzing whole building energy performance over time. Operator and commissioning provider interviews were conducted to help determine reasons for persistence and methods of improving persistence.

The measures selected for study are only a small subset of the total items fixed during the commissioning process since 20 to over 100 findings were documented at each site. Most of the building operators and managers felt that an extensive commissioning effort was essential. Across the ten buildings studied that underwent commissioning as new construction, patterns for the types of commissioning fixes that persisted emerged. Fifty-five commissioning fixes were studied, and the large majority of the measures persisted (70%). Hardware and control programming that was not user adjustable most often persisted. Control strategies that could easily be changed without modifying the programming code had the most problems with persistence. These control strategies include schedules, setpoints, and strategies related to newer energy efficiency technologies. For example, evaporative cooling was disabled, demand control ventilation was not maintained, dimmable ballasts failed prematurely, and desiccant cooling failed. 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.

In the limited number of buildings studied, the investigation identified three main reasons for these problems with persistence: limited operator support and operator turnover; poor information transfer from the commissioning process; and a lack of performance tracking. Persistence of commissioning benefits seemed to be dependent on operator training, a dedicated operations staff with the time to study and optimize building operation, and an administrative focus on building performance and energy costs. A few well-trained operators were knowledgeable about how the systems should operate and, with adequate time and motivation, they evaluated and improved building performance.

Persistence Strategies

As a result of the interviews and findings from this research, eight strategies to improve persistence were published in the guide, *Strategies for Improving Persistence of Commissioning Benefits* (Persistence Guide) (Friedman et al., 2003b). The strategies, rooted in our experience with ongoing building operations, were supported by the study's findings that these strategies are rarely utilized. The eight persistence strategies discussed in this paper include:

- Design phase commissioning
- Building documentation
- Operator training
- Building benchmarking
- Utility tracking
- Trend analysis
- Recommissioning
- Continuous Commissioning®

Ideally, all eight strategies should work together to form a holistic plan for maintaining building performance. However, even incorporating a few of the strategies can make a difference in how well building performance improvements persist. Since the strategies focus on making sure building performance is up to par as well as helping identify problems and needs for improvement, they are just as relevant for buildings that were never commissioned as they are for commissioned buildings. Providing building documentation to operators is the foundation for making building operational improvements last. Further, operators should have enough training that they fully understand how the systems should operate. Building on these core strategies are tracking methods that help facility managers and operators know when things have gone wrong: building benchmarking, utility tracking, and trend analysis. Recommissioning may need to occur every few years depending on how well the operators have been able to identify issues and correct them. Beyond recommissioning, Continuous Commissioning® is a strategy for obtaining long-lasting benefits through ongoing system evaluation. As a preventative measure to avoid problems that can plague a building for its life, design phase commissioning is essential.

The Persistence Guide describes how these strategies can be used to prevent operational problems and move beyond band-aid solutions. In addition, the Persistence Guide discusses why a particular strategy is important, gives practical examples, provides tips, and lists resources for implementing each strategy. For managing long-term operations of a building, the guide is intended to be a resource to building owners, facility managers, and operators. This paper provides an overview of the eight persistence strategies in the context of past research and future research recommendations.

Design Review

Almost every operator interviewed in the study of new building commissioning benefits stressed that it is design problems continue to require a significant amount of their time. The commissioning process at nine of the buildings in the new construction commissioning persistence study did not include design phase commissioning. The value of design phase commissioning should not be underestimated, as many buildings may never recover from serious design flaws. While design problems vary greatly, their result is often the same: building operators are forced to spend time figuring out work-around solutions, cutting into their time to troubleshoot the building's other systems. Preventing the problems that can plague a building throughout its life is a major objective of design phase commissioning.

Constructing a building can be thought of as a complex manufacturing process, and even with the most diligent and experienced design team, things can go wrong. Most manufacturers would not think of selling their product straight off the production line without quality control during product design, and neither should building developers, owners, and contractors. In short, design phase commissioning is a quality control check for new building design. It brings the talent and field expertise of an experienced engineer on board early in a project when it is less costly and disruptive to make improvements and corrections to the building design.

As many as one-third of major commissioning problems can be traced back to the design phase of a project (Sellers 2001). Problems in a building's design become the building operator's problem for life. One building operator, when explaining why design phase commissioning is important, stated, "It works per design, but does the design work?" (Friedman et al, 2003). The design phase topics described in the Persistence Guide include:

- Test ports
- Equipment accessibility
- Load calculations and minimum flow settings
- Control system sequences and point lists
- Standard design details

Building Documentation

Having accurate building documentation is one of the most fundamental persistence strategies. Operations and maintenance staff need clear, complete, and accurate building documentation to effectively operate building systems. However, these documents are often missing and when available, are rarely written with building operators in mind. At the end of a thorough commissioning or retrocommissioning process, the commissioning provider and building operators have become intimately familiar with all of the building systems as they test, troubleshoot, and resolve issues. Without a way to document this knowledge, much of the long-term value of commissioning is lost. By gathering and organizing certain information, the documentation becomes the memory of the building. The following section summarizes three of the most important pieces of building documentation for ensuring persistence.

1. Design intent documentation. The starting point for any design is to understand its goals. Documenting these goals summarizes the owner's project requirements for the building (the expectations of how it will be used and operated) and the acceptance criteria that were used to measure if those requirements have been met. With clear and complete design intent documentation, all parties will understand in detail the owner's goals for the building. Without clear design intent documentation, it becomes nearly impossible to commission or retrocommission a building in a way to ensure that it works per the intended design and owner's operating requirements. Furthermore, building operators cannot be expected to operate their buildings according to the design when these basic instructions are non-existent. Information on the design documentation necessary for commissioning is included in Energy Design Resources's Building Commissioning Guidelines (EDR, 2001).

2. Sequences of operation. Sequences of operation that are verified as correct are another practical tool for building operators. Without a thorough understanding of how the control system should operate, it is unclear how to fix problems. Interactions between systems are often left out of the typical standard sequences of operation - for example, the relation of building pressure control and economizer operation. Consider the following air handling unit sequence of operation, typical of today's contract documents.

The control system shall modulate the economizer dampers, heating valve and cooling valve in sequence as required to maintain the discharge set point of the system. The discharge set point shall be reset from 55°F to 65°F as a function of the outdoor air temperature.

At first glance, the sequence may seem reasonable. But there are many unanswered questions, such as:

- How is the minimum outdoor air setting maintained?
- What is the optimal point in the cooling mode for locking out the economizer?
- Will one control signal serve all actuators, or will each actuator have independent signals?
- What positions should the actuators return to when the unit is shut down?
- Is a freezestat necessary to protect the cooling coil from freezing?
- What is the relationship between outdoor air temperature and discharge air reset setpoint?
- Is the reset schedule in effect year round or only when dehumidification is not an issue?
- What alarms should be programmed?
- Are the set points adjustable without reprogramming the system?
- Are the safety devices and interlocks independent of the DDC system?

For new construction, if issues like these are not cleared up before the contractor develops the control program, the door is left open for many potentially costly problems that can continue into the occupancy phase of the project. Without detailed sequences of operation, operators may never fully understand how one strategy integrates with another and may inadvertently circumvent an energy efficient, reliability, or safety strategy.

For retrocommissioning projects, the sequences should also be carefully documented, with emphasis on describing the reasons for any changes. Improvements are more likely to persist when operators understand the rationale for the changes and agree with their implementation.

3. System diagrams. Creating a system diagram is an invaluable tool for troubleshooting throughout the life of the facility. A system diagram enables the user to see the entire process of heating, cooling, and ventilating the spaces and visualize potential interactions. A system diagram depicts the *entire system* in schematic format, rather than simply *pieces* of the system. A well-developed air handling system diagram includes the following features:

- The system's complete airflow path is shown, from point of entry to point of exit.
- All significant components are labeled, including dampers, coils, filters, fans and all final control elements and sensors.
- Equipment operating parameters are stated, including flow ratings, horsepower ratings and other pertinent operating data.

Inaccurate mechanical and controls drawings are a common occurrence. A system diagram laid out in the simplest way possible goes a long way to clarifying the intended operation of the entire system.

In addition to the three documents listed above – design intent documentation, sequences of operation, and systems diagrams – a number of documents give the building operators the "big picture" perspective they need without overwhelming detail. These documents include:

- *As-built documents*: These marked-up construction drawings include changes made to the design during and after construction.
- *Commissioning summary report*: A commissioning summary report lists the deficiencies found during commissioning and their resolution.

- *Operator's log*: This log keeps record of significant events such as equipment replacement, maintenance or testing, and problems and their resolution.
- *Description of each system and interactions between systems*: A description of each system's capabilities, baseline performance and troubleshooting tips is a practical reference.
- *Location of all control sensors and test ports*: This documentation allows building operators to quickly reference the location of control sensors and test ports.
- *Capabilities and conventions of the DDC system*: Documenting the DDC system trending procedures and capabilities streamlines trending.

Putting all the documents described in this section of together is often called a systems manual. Further description of systems manuals is provided by Gillespie (2003).

Operator Training

A well designed and executed training plan supported by the operations and maintenance manuals, systems documentation, and videotapes of the training sessions will help ensure that the building is operated efficiently and that performance benefits persist for the life of the building.

There are many real-life situations where better training for building operators could have prevented problems. In one office building that was a part of the persistence study, the operator was never taught how to service the carefully designed daylighting control system. As a result, the system was in need of calibration and the louvers rarely operated to vary lighting level. In another building that was a part of the persistence study, the operator disabled the evaporative cooling system because he was not trained on how to maintain it, and it became a nuisance to operate. As a result, the building owner's investment in energy efficiency was wasted.

Perhaps the most needed area for improvement in training lies in the trending functions of the DDC system. The wide gap between the capabilities of DDC systems and the ability of building operators to fully utilize them leads to missed opportunities every day, in both the early identification of building problems and significant energy savings. A Chief Engineer from a Portland, Oregon property management firm stated, "*There is a real shortage of well-trained people who can effectively operate and maintain buildings. Where are we going to find them? It's scary. My management is beginning to understand trained building operators are crucial to risk management*." The following summarizes three critical areas of training, which are emphasized in the Persistence Guide.

1. Training during commissioning. Involving operating staff in the commissioning process during construction observation, start-up, and functional testing can provide training that is difficult to duplicate in a classroom setting. Early involvement allows the operating staff to observe the fabrication of the systems – and reveals the exact configuration of components that will be concealed when the building is complete. Participating during start-up and testing provides first-hand insight into the operating fundamentals of the systems. In retrocommissioning, building operating staff should be involved in development and implementation of improvements and should received training to maintain the improvements.

2. Manufacturer/vendor training. Owners of large buildings or campuses may benefit from sending their key personnel to factory schools run by equipment manufacturers, for example, air handling systems, chillers, pumps, and steam specialties. Although these programs apply specifically to the manufacturer's equipment, much of the knowledge gained is transferable to other manufacturers.

3. Training for newly hired operators. When a building operator leaves, his or her experience with the building systems will often be lost – unless precautionary measures are taken. A new operator can be trained on the building's systems through an in-depth building walk-through with an existing building operator along with help reviewing existing documentation. A well-executed handover will go a long way toward ensuring building performance.

The Persistence Guide includes a list of training topics and also expands on two curriculum-driven training opportunities: the Building Operator Certification (BOC) program and the Systems Maintenance Technician and Systems Maintenance Administrator courses offered by the Building Owners and Managers Institute (BOMI).

Building Benchmarking

In order to improve building performance in existing buildings, energy use must first be evaluated. Benchmarking has become a popular place to begin studying energy use. Benchmarking a building measures the energy use of a *particular* building relative to *other* buildings. This process provides a way for building owners and operators to track their energy use over time and see how they stack up against the competition. Thus the act of benchmarking can drive building owners and managers to greater achievements in energy efficiency. As an owner or manager of multiple facilities, building benchmarking can help prioritize which buildings have the greatest need for improvement. These benchmarking activities can be automated using Energy Information Systems (EIS), which are also discussed in the Persistence Guide. There are several free tools to help with the benchmarking process. The Persistence Guide provides information on two of these tools, summarized below:

1. The ENERGY STAR® Portfolio Manager. www.energystar.gov/benchmark ENERGY STAR® Portfolio Manager is the most widely used building benchmarking tool. The US Environmental Protection Agency (EPA) developed the tool in 1999. Over 2,220 million total square feet - approximately 12% of the total building market - have been benchmarked using this rating system. ENERGY STAR® Portfolio Manager is a web-based tool that uses the energy bills and building characteristics to calculate a score that indicates where a building ranks compared to a pool of similar buildings. If the building scores higher than 75% of the competition, an owner or manager can apply for the ENERGY STAR® label (buildings must also pass an inspection for environmental quality by an engineer). With their benchmarking tool and award system, the EPA has developed a systematic way to rank the energy efficiency of buildings against their peers, track improvements, and receive credit for them.

2. The Cal-Arch Building Energy Reference Tool. http://poet.lbl.gov/cal-arch/ The Cal-Arch Building Energy Reference Tool (Kinney and Piette, 2002 and 2003) provides a simple way to benchmark buildings using a database of California buildings. Unlike the ENERGY STAR® tool, Cal-Arch does not take building attributes like occupancy, climate, or hours of operation into account. It simply ranks a building's energy consumption per square foot. This type of benchmarking is more straightforward and much faster to do because it requires fewer inputs.

The downside is that the tool does not correct for other factors that may affect energy use like occupancy or operating hours. For example, Cal-Arch may rate a building among the worst when it consumes a great deal of energy, even though it supports a high number of occupants. Alternately, a building may be rated among the most efficient with operating hours that are 50% less than other buildings. Cal-Arch is most effective when ranking a building against others in its sector (for example: office, healthcare, lodging, school) because these buildings share common characteristics that can level the playing field.

Utility Tracking

In the persistence study, 9 out of 10 facility managers did not look at utility bill data on a regular basis. While benchmarking a building compares the utility consumption to other buildings, tracking utility use is the first step in understanding a building's consumption patterns. Tracking monthly bills or more frequent metered data is an essential part of monitoring building performance over time since it can help spot emerging problems before they cause occupant discomfort, energy waste, or premature equipment failure.

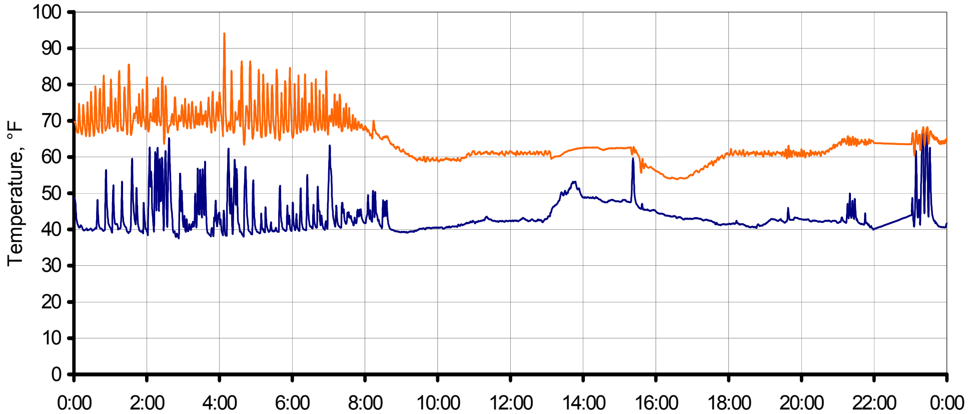
The Persistence Guide offers ways to look at utility data to discover energy waste by comparing average daily consumption curves and analyzing the peaks and valleys. It goes on to discuss how utility tracking can be automated through Energy Information Systems (EIS) and describes the benefits of these systems. The guide also describes the four EIS categories: utility information systems, demand response systems, the enterprise energy management, and web-based energy management and control systems (Motegi and Piette, 2002).

Trend Analysis

Experienced retrocommissioning providers, facilities engineers, and operators all know that most buildings will "tell you" where their problems are if you only spend a little time looking. The data handling capabilities of DDC systems provide a powerful tool for "listening" to a building. Some of the most costly operational problems do not affect comfort, so tracking may be the only way that these problems get recognized. If the DDC system is not well equipped for trending, portable data loggers can be used to provide short-term trending for analysis. Figure 6 shows trending that uncovered a hunting problem. Hunting can decrease valve life and lead to comfort problems.

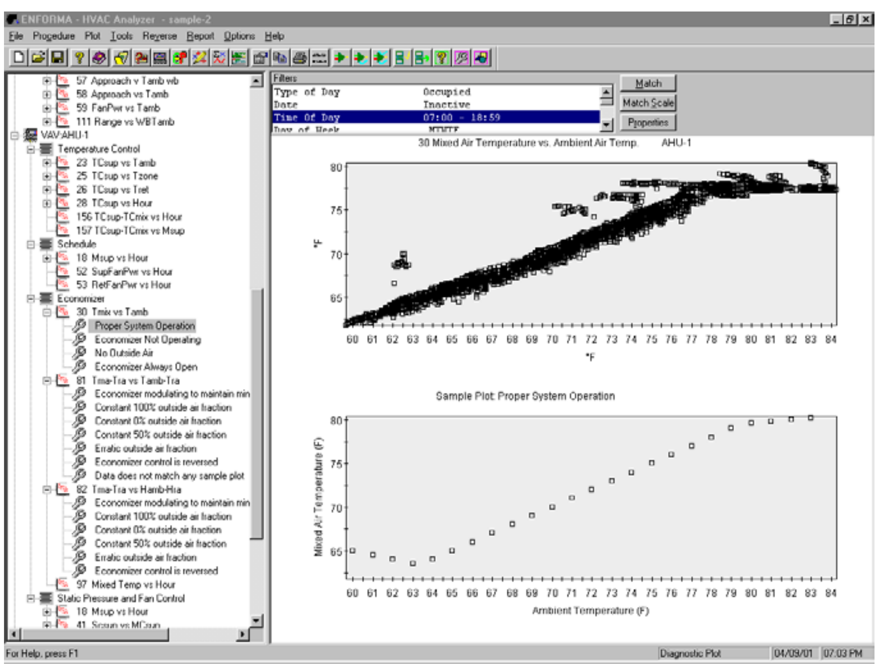
But simply gathering data does not ensure lasting building performance. Knowing how to interpret that data and following up with troubleshooting is essential. This section of the Persistence Guide discusses trending techniques along with tools that help automate the process of gathering data and analyzing it.

Figure 1. Identifying Hunting Through Trending



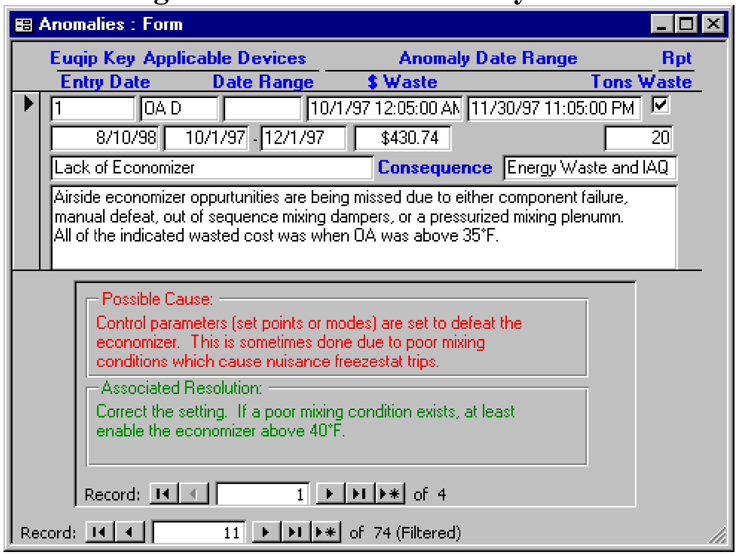
Automated fault detection and diagnostic (FDD) tools can help analyze data to identify when the problems occur, at which piece of equipment, for how long, and then give direction as to the possible cause. This facilitates the operator's ability to quickly pinpoint the root cause and implement a solution. A few of the tools quantify the energy waste related to specific problems, allowing prioritization of operation and maintenance tasks. FDD tools are still and emerging technology, each with varying degrees of automation. The Persistence Guide provides an overview of the types of tool capabilities, including: data acquisition; archiving and pre-processing; detection; and diagnosis. Two commercially available tools, ENFORMA® and PACRAT, are discussed in some detail in the Guide. Figures 2 and 3 are examples of diagnostic output from these tools.

Figure 2. ENFORMA Economizer Plot with Example Reference Plot



For more information, go to http://boulder.archenergy.com/enforma/

Figure 3. PACRAT Anomaly Form



For more information, go to www.facilitydynamics.com/pacrat.html

In the future, tools that automate fault detection and diagnostics is expected to play a stronger and stronger role in ensuring the persistence of building performance improvements as well as identifying where improvements are needed. However, there are barriers that need to be addressed before these tools can realize their potential. For example, set up is often difficult, time consuming and expensive because the tools do not easily interface with the buildings energy management system. Overcoming this barrier will be a major milestone in getting these tools to market.

Recommissioning

Recommissioning is the process of commissioning existing buildings that have already been commissioned sometime in the past. Building owners and managers that carefully document their building systems, provide good training for facility operators, and perform ongoing benchmarking, utility tracking, and trending activities may not need to recommission their facilities very often, if at all. But in the real world, these practices are rare.

The study on persistence showed that all buildings had the potential for improved operations, even only two years after commissioning occurred. When comparing current and past performance, cost-effective recommissioning takes advantage of the documentation compiled during the previous commissioning process. The Persistence Guide gives guidance on when recommissioning should be done and who should do the recommissioning.

Continuous Commissioning®

The Energy Systems Laboratory (ESL) at Texas A&M University has employed the *Continuous Commissioning®* (CC℠) process in more than 130 large buildings over the last ten years (Liu, Claridge, and Turner, 2002). By their definition, continuous commissioning is "an ongoing process to resolve operating problems, improve comfort, optimize energy use and identify retrofits for existing commercial and institutional buildings and central plant facilities".

CC^{SM} involves many of the same planning and investigation procedures as retrocommissioning. Like retrocommissioning, continuous commissioning activities consist of a systematic way of identifying and correcting building system problems and optimizing system performance in existing buildings. The main difference is that continuous commissioning activities more rigorously address the issue of persistence than retrocommissioning. In other words, continuous commissioning activities are ongoing, rather than an event that occurs once or twice in the lifetime of the building. This continued attention helps ensure that the savings from commissioning do not degrade over time. The Persistence Guide briefly discusses the tasks involved in the Texas A&M CC^{SM} process.

Future Study

The persistence study on which these strategies are based was limited to ten buildings commissioned as new construction and ten retrocommissioned buildings. The next step in understanding the persistence of commissioning is to study more buildings in more areas of the country. The findings regarding persistence are only preliminary, yet show commissioning as a promising process for long-term energy and operational savings.

Through additional study, there is a need to further relate the findings on how well fixes persist back to effective strategies to ensure persistence. While the strategies are generally universal, appropriate implementation of these strategies is expected to depend on a number of factors, including O&M staffing structure (minimal in-house staff or in-house staff with specialized training), training budgets, and service contracts. Case studies on how facilities use these persistence strategies will guide persistence recommendations for different facility types.

Conclusions

With the Persistence Guide's emphasis on describing how to actually implement the strategies rather than merely what the strategies are, commissioning programs and owners across the country can use the Guide to help improve building performance. Incorporating persistence requirements within utility or public goods funded commissioning programs is also expected to lead to more widespread adoption. Commissioning programs may wish to require systems manuals, operator training using those manuals, and performance tracking.

In our experience and anecdotally through the persistence research, the strategies set forth in this paper are keys to improving building performance or keeping it from degrading over time. In fact, these persistence strategies are just as relevant for buildings that were never commissioned as they are for commissioned buildings. Through common sense activities like good documentation, relevant operator training, and keeping tabs on how systems are performing, operational improvements in buildings can be made to last.

Acknowledgements

This work was funded by the California Energy Commission under LBNL's High Performance Commercial Building Systems Program. See **http://buildings.lbl.gov/hpcbs** for the results from a wide range of building energy research projects.

References

Energy Design Resources. 2001. *Building Commissioning Guidelines: Design Documentation Necessary for Commissioning*. Prepared for Pacific Gas and Electric Company by PECI for the statewide Energy Design Resources program. Available at: **www.cacx.org/library**.

Friedman, Hannah, Amanda Potter, Tudi Haasl, David E. Claridge, and S. Cho. 2003a. "Persistence of Benefits from New Building Commissioning," *Proceedings of 11th National Conference on Building Commissioning*. Available at: **www.cacx.org/library**.

Friedman, Hannah, Amanda Potter, Tudi Haasl, and David E. Claridge. 2003b. "Strategies for Improving Persistence of Commissioning Benefits," *Public Interest Energy Research*. Available at: **www.cacx.org/library**.

Gillespie, Ken. 2003. "Developing Systems Manuals for Existing Buildings in a Corporate Environment," *Proceedings of 11th National Conference on Building Commissioning*. Available at: **www.cacx.org/library**.

Kinney, Satkartar and M. Piette. 2002. "Development of a California Commercial Building Energy Benchmarking Database". *Proceedings from the ACEEE 2002 Summer Study on Energy Efficiency in Buildings*. LBNL Report 50676. Available at: **www.cacx.org/library**.

Kinney, Satkartar, and M. Piette. 2003. *California Commercial Building Energy Benchmarking - Final Project Report*. LBNL Report 53479, Lawrence Berkeley National Laboratory.

Liu, Mingsheng, Claridge, David E. and Turner, W. Dan. 2002. *Continuous Commissioning® Guidebook: Maximizing Building Energy Efficiency and Comfort.* Federal Energy Management Program, U.S. Dept. of Energy. For more information: **http://esl.tamu.edu/cc/**

Motegi, Naoya and M.A. Piette. 2002. *Web-based Energy Information Systems for Large Commercial Buildings.* Report for the California Energy Commission, Public Interest Energy Research Program. Available at: **http://buildings.lbl.gov/hpcbs/Element_5/02_E5_P2_2_1.html**

Putnam, Cynthia and A. Mulak, 2002. "Building Operator Certification: Improving Building Efficiency Through Training and Certification". *Proceedings of 10th National Conference on Building Commissioning*. Available at: **www.cacx.org/library**.

Sellers, David. 2001. "Using Utility Bills and Average Daily Energy Consumption to Target Commissioning Efforts and Track Building Performance," *International Conference for Enhanced Building Operations*: July 16-19, 2001. Available at: **www.cacx.org/library**.

Turner, W.D., Claridge, D.E., Deng, S., Cho, S., Liu, M., Hagge, T., Darnell, C.,Jr., and Bruner, H.,Jr. 2001. "Persistence of Savings Obtained from Continuous Commissioning℠." *Proceedings of 9th National Conference on Building Commissioning*. Available at: **www.cacx.org/library**.