Panel 5 Introduction

Commissioning, Operation, and Maintenance

Do buildings use energy, or do the people who occupy the structures use energy? Where are the most important places to look when inspecting a facility for commissioning, operation, and maintenance (CO&M) opportunities: the building itself and the inherent inefficiencies in the equipment that has been installed, or the day-to-day actions of the building's occupants? This compound question has been posed, answered, and elaborated on in past ACEEE Summer Studies. The answers to these questions are not as simple as one might think. In the 1986, 1988, 1990 and 1992 ACEEE Summer Studies, panels were formed to assess the Performance and Analysis of building energy use. In the 1992 ACEEE Summer Study, methods for accurately and cost-effectively measuring and analyzing DSM performance were presented. To follow on, the 1994 ACEEE Summer Study dedicates this whole panel to the subject of building CO&M.

CO&M is a re-emerging profession that provides greater assurance that the building and its related equipment operate efficiently to provide the occupants with the necessary services in a cost-effective manner. The profession ancestors are the services provided by the architects, engineers, builders, and building maintenance staff. Since the CO&M profession is re-emerging, its expectations and performance levels have yet to be defined.

Who pays for CO&M? What does it cost and is it worth the expense? What are the reliable methods to monitor building performance? Does anybody have solid proof that CO&M really works? To bring these divergent factors into better focus, this panel commissioned nine sessions to discuss CO&M. To accomplish this, 168 abstracts were reviewed by the co-panel leaders and trimmed-down to a selection of 32 papers that are the best practice from around the world.

After an exhausting review of 32 accepted abstracts, the following topical areas emerged as the most likely way to group the papers for publication in this year's ACEEE, Panel 5 Proceedings:

Commissioning for Indoor Air Quality (one session).
Verification of Commissioning, Operation, and Maintenance (one session).
Field Diagnostics and Measurements (one session).
Commissioning, Operation, and Maintenance Surveys (one session).
Methods for Commissioning, Operation, and Maintenance (two sessions).
Case Studies of Effective Commissioning, Operation and Maintenance (two sessions).
Commissioning, Operation, and Maintenance. (discussion session).
Commissioning, Operation, and Maintenance (overview session).

Our synopsis of each of the sessions follows. We are sure you will agree that these papers truly are a representative snapshot of the state-of-the-art in Commissioning, Operation, and Maintenance. The papers are discussed in this overview in the sessions in which they appeared at the conference. In the Proceedings, the papers are listed alphabetically by the first author's last name.

Commissioning for Indoor Air Quality

Quite often building owners and operators are reluctant to consider the expense of recommissioning a building, especially if the recommendations lead to degraded indoor air quality (IAQ). Three papers in Panel 5 discuss CO&M and IAQ. In the first paper, Per Levin and Per Wickman show that, during the heating season, proper ventilating can result in better occupant comfort and increased energy efficiency. The design of an HVAC system is usually a compromise between winter and summer design conditions. Often, air flows can be lowered, which results in reduced noise and draft and lowered maintenance. In order to validate these assumptions, Levin and Wickman used air exchange, CO_2, Temperature, Humidity, and VOCs measurements at three different levels.

In the next paper, Paul W. Francisco and Larry Palmiter discuss the impacts of tighter buildings on indoor air quality and healthy living conditions. They document the ventilation and infiltration measurements performed on three electrically heated multifamily buildings during a typical Pacific Northwest heating season. Tests performed include a comparison of the parameters during periods of all fans on, all fans off, and fans in individual units on or off.

The third paper in this session by Greg Wheeler documents the performance of energy management systems and how they succeed and fail. Wheeler shows they succeed more often than fail with a savings range of 10 percent to 29 percent and an average of 13 percent savings. EMCS savings are higher when operators maintain good records, alter systems very little, and where the buildings have low after-hours use. Wheeler also found that there is little or no correlation between building size, system sophistication, or building age.

Verification of Commissioning, Operation, and Maintenance

Three papers in this session present three very different perspectives concerning the verification of CO&M. In the first paper by Dianne M. Griffith, and Kenneth J. Anderson, a commercial building/system characteristics sensitivity analysis was performed for two different commercial buildings. This was accomplished with calibrated DOE-2 simulations of an office building and grocery store in the Northwest. In the grocery store, the important parameters dealt with the refrigeration system. In the office building the important parameters included the minimum CFM across the terminal box, setpoints, equipment capacity, and operating hours. This paper provides useful advice to utilities with constrained budgets that dictate they gather only the minimum important information for a study.

In the second paper, Christopher O'Brien and Drury B. Crawley discuss the USEPA's Energy Star Program and the staged implementation that has been developed to achieve the anticipated 27 to 60 percent energy reductions that DOE-2 simulations show are possible around the country. This staged implementation consists of Green Lights, building tune-up, heating and cooling load reductions, improved fans and air handling systems, and improved heating and cooling plants. Estimated costs for the measures are $0.72 to $2.00 per square foot.

The final paper in this session takes a detailed look at a case study building commissioning and savings verification project applied to a 311,000-square-foot office tower in the Northwest. One of the interesting aspects of this paper by Howard S. Reichmuth and Kevin C. Fish is that the case study considered a building that had already completed a $2.1 million retrofit consisting of efficient glazing, a lighting retrofit, and improved HVAC systems. To accomplish this, a calibrated DOE-2 simulation was used to analyze the effects of the O&M measures identified. Monitoring via the EMCS was used to confirm the results. The commissioning uncovered some surprising results: 40 percent of terminal VAV boxes were malfunctioning, automatic lighting sweep controls were not working, chiller was short-cycling, and the space temperature was unstable. The conclusion: Commissioning ensures that retrofits work!

Field Diagnostics and Measurements

Panel 5 is blessed with three papers that actually report on how to accomplish the often nebulous task of measuring a commissioning effort. In the first paper by J. Douglas Balcomb, Jay D. Burch, Robert Westby, Kris Subbarao, and C. Edward Hancock, NREL's methodology for Short-Term Energy Monitoring (STEM) for commercial buildings is discussed. The original STEM procedures, which were developed for residential buildings, have been extended to commercial buildings using multizone renormalization and multi-tracer-gas techniques. The commercial building STEM is capable of disaggregating complex multizone energy heat flows using measured parameters that can then be fed into a simulation program. Of special interest to CO&M, STEM can be used to perform diagnostics and/or measure energy savings from building retrofits because it relies on measured data.

The second paper in this session by Peter C. Jacobs, Stuart S. Waterbury, Donald J. Frey, and Karl F. Johnson, discusses short-term measurements to support impact evaluation of commercial lighting and HVAC programs. To accomplish this, the authors report on extensive efforts to develop and deploy a network of small, portable, battery-powered loggers that make possible short-term energy measurements of such a quality that they can be substituted for more expensive, hard-wired, long-term end-use measurements. Such surrogate measurements using on/off status, fixture operating status, and one-time circuit measurements can be used to replace certain end-use measurements and provide accuracies in the range of 80-90 percent of hard-wired measurements at substantial cost savings–an important issue for resource-constrained DSM evaluation programs.

The final paper in this session presents exciting results from CO&M efforts in hot and humid climates. In this paper, Mingsheng Liu, John Houcek, Aamer Ather, Agami Reddy, David Claridge, and Jeff Haberl identify O&M opportunities after the implementation of retrofits from standard audits in agencies participating in the Texas LoanSTAR program. Most of the opportunities identified occurred by shutting down unnecessary equipment after hours and improving maintenance practices that have led to deteriorated equipment. The investigators used monitored hourly whole-building and submetered loads together with weather data. As a result of CO&M implementations, measured saving of $733,000 per year have been obtained. Projects in the process of being implemented will save $1,865,000 annually when completed.

Commissioning, Operation, and Maintenance Surveys

The three papers in this session present results from surveys of CO&M practices, tune-up programs in homes and methods that are being developed for streamlining DSM practices. In the first paper by Nancy Benner, Deborah Dodds, Tudi Haasl, Tracy Narel, and Mark Bailey, current O&M practices are defined, including best practices. Energy savings are also calculated for those practices. This paper also addresses the major benefits of CO&M including tenant health and comfort, energy efficiency, and long equipment life.

In the second paper in this session, William P. Levins and Mark B. Terries report on the energy efficiency results of oil-fired heating system retrofits and tune-up programs in over 300 homes. Levins and Terries show that system replacements yield the most benefits and are the most expensive. Less expensive measures such as cleaning and tune-ups are either not effective or have benefits with short lifetimes.

In the final paper by Rachel A. Yoder and Michael B. Kaplan, DSM programs are documented for new commercial buildings. Yoder and Kaplan also discuss the evolution of commissioning. The results from 50 completed projects support the value of commissioning. The pressure on lower DSM budgets requires the contractor to share in the cost cutting effort and find ways to streamline the overall program. Potential methods for program savings are also explored in areas such as program and process evaluations.

Methods for Commissioning, Operation, and Maintenance: Two Sessions

Two of the sessions in Panel 5 had so many great papers that it was decided to have double sessions. In this first double session on methods for CO&M, six papers are included. In the first exciting paper by Lennart Jagemar, energy-efficient HVAC systems in commercial buildings are investigated. Jagemar defines and cites examples of performance ratios that characterize energy-efficient HVAC systems, particularly air distribution systems in commercial buildings. Measured data from office buildings in Denmark and Sweden are also provided.

The next paper, by William D. Biesmeyer and Jeffrey Jowett, discusses the facts and fiction of HVAC motor measuring for energy savings. In this paper, the authors present rare comparisons of HVAC motor efficiency tests using dynamometer versus slip tests. They show that the commonly used slip test can result in unacceptable inaccuracies of 40 percent. By using a more accurate efficiency measurement, they conclude that replacing electrical motors loaded at 50 percent and above does not always save energy. The careful analysis of their motor replacement program has redirected motor replacements in the State of Arizona toward those motors that are loaded 50 percent or less as measured by a new method that relies on amperage measurements. They also recommend downsizing motors as part of the motor replacement program. Anybody attempting a motor replacement program, be advised. Read this paper before attempting a motor replacement program.

The third paper in this double session, by Patrick O'Neill and Katheleen Radke, evaluates commissioning needs and discusses automating the commissioning process. O'Neill and Radke propose specific technical approaches and tools for commissioning and suggest research and development that will be needed to accomplish the overall goal of an automated commissioning process. They envision an automated commissioning process that would take a building from the architect/engineer's first CAD drawing, through the construction process, and live with the building throughout its lifetime operation.

The fourth paper in this double session, by Robert J. Rose and William L. Kopko, proposes two methods of reducing fan power by resetting duct static pressure. One method requires advanced energy management systems that can monitor all terminal box units. The second method is more universally applicable and monitors and controls duct static pressure at two points.

In the fifth paper, Stuart S. Waterbury, Donald J. Frey, and Karl F. Johnson present the results of applying HVAC diagnostics to three commercial buildings. They describe a system that is designed to cost effectively measure and evaluate HVAC performance.

The final paper in this double session, by Paul C. Tseng, Dale R. Stanton-Hoyle, and William Withers, discusses the value of using onsite, project-specific data monitoring and energy management control systems during the construction and commissioning of a County-owned building. The design features include low-e glazing, daylighting, high-efficiency lighting, and upgraded wall and roof insulation.

Case Studies of Effective Commissioning, Operation, and Maintenance: Two Sessions

In the first paper of the second double session, Kent G. Bouma discusses energy conservation options available for pumped agricultural irrigation. In this ground-breaking paper, he discusses work performed by one California utility that investigated several options for improving pumping efficiency, from replacing the twenty-year-old motor with a high-efficiency motor to polishing the pump bowl and pump impellers. In one extensively studied case study, careful attention to detail raised the existing pump efficiency from 51 percent to 82 percent. This paper is a "must read" for anybody who is looking for ways to save energy in a large pumping project.

In the next paper, Janice C. Peterson and Tudi Haasl present a commissioning cost-effectiveness case study. In this paper they report on efforts to perform post-retrofit commissioning of a 75,000-square-foot office building in the Northwest using a calibrated DOE-2 model to simulate the commissioned conditions. Their study uncovered errors in the EMCS operation, poor maintenance practices, a refrigerant leak in the 30-ton heat pump, and disabled controls.

The third paper, by Karen C. Miller and Alexander Othmer, presents a look at opportunities for energy efficiency in restaurants in Florida. Their needs assessment across 46 restaurants uncovered an average 20 percent improved energy use by fixing O&M problems. The primary fixes included optimizing on-off equipment schedules, turning equipment off when not in use, repairing seals, and replacing broken equipment.

In the fourth paper, Grant J. Brohard and George R. Hernandez describe the commissioning process for a pilot commercial building retrofit. In this study, a large California utility used its own facility to document the energy savings available in improved HVAC and lighting efficiencies. Monitored savings were used to show the effectiveness of the measures and to recommission an errant energy management and control system.

The fifth paper, by John J. Tooly, Jr., and Bruce Eugene Davis, examines the impacts of powered attic ventilators in several residences. Their study was motivated by claims that powered attic ventilators increased shingle life and improved attic moisture levels. Unfortunately, their results showed just the opposite—that attic fans can increase moisture conditions and actually impose a negative pressure on the conditioned space below, as all the cracks and penetrations are not sealed. Clearly, their paper confirms the need for the building industry to insist on independently measured data to confirm a manufacturer's product claims.

The final paper in this double session, by Paul Williamson, Bill Koran, Glen Wallace, and Walt Stamper, describes how commissioning can be cost-effective in an energy-intensive industrial facility. Their paper points out that the application of commissioning to an industrial facility can be different than typical commercial and residential commissioning where human comfort is over-ridden by efficiency savings.

Commissioning, Operation, and Maintenance: Discussion Session

The final session of Panel 5 contains five papers that round out the topical area of CO&M. In the first paper, by Armin Rudd, Srinivasa Katakam, and Subrato Chandra, side-by-side testing and monitoring of two Louisville, Kentucky, homes was used to test conventional stud frame construction against stress-skin, insulated core panel construction for the outside walls and second floor ceiling. The stress-skin insulated core home used 12 percent less electric heating and 15 percent less gas heating than the conventional home.

The second paper, by Tracy Narel and Tudi Haasl, discusses the business of running buildings, especially: Whose Business is it? In this paper, they address what the profitable opportunities are in running buildings, who is selling these services, and how successful they have been. They also discuss programs that use employee rewards for improving energy efficiency.

The paper by Deborah Dodds, Tudi Haasl, Cathy Chappell, and Christie Kjellman attempts to answer the question: How Much does Commissioning Cost and How Much Does it Save? To do this they provide cost and savings data about commissioning that use DOE-2 simulations to assess the impact of commissioning. New approaches, short-term diagnostics, and recommendations for a comprehensive commissioning program are also provided.

In the fourth paper, by Diana Bjornskov, Nancy Benner, Deborah Dodds, and Tudi Haasl, the obstacles and solutions to the requirements of commissioning are discussed. One of the important findings they have noticed is that financial, organizational, attitudinal, and legal obstacles tend to disappear in proportion to the speed in which the savings and benefits of commissioning are demonstrated. They note that commissioning costs range from $1 to $2.50 per square foot. Their survey results show that utilities can play a role in promoting state-of-the-art commissioning. Commissioning standards already help pave the way in areas such as thermal energy storage performance, smoke detection, IAQ, and insurance.

The final paper in this session, by Aaron R. Byerly and Jeffrey E. Christian, discusses the long-term thermal performance of Radiation Control Coatings (RCC, i.e., white roofs). Recently, RCCs have begun to be promoted as a simple way to reduce cooling loads and improve interior comfort conditions. However, very little experimental data exists concerning how long these coatings maintain their high solar reflective properties. This study shows that RCCs can reduce summertime roof temperatures by 60°F, but have the reverse impact on wintertime heating requirements (32 percent increase). Most importantly, several years of tests have revealed that RCC solar reflectance reduces from 79 percent to 60 percent. Luckily, they found that washing the reflective surface reduces this degradation significantly.

Commissioning, Operation, and Maintenance: Overview Session

Out of the 165 abstracts submitted for review, the paper by David E. Claridge, Jeff Haberl, Mingsheng Liu, John Houcek, and Aamer Athar was chosen to be one of the CO&M overview papers. But first, before you cry "foul" about favoritism because one of the co-panel chairs participated in the paper, here's the real story behind the paper's selection. At the Panel leader's meeting in January of 1994, it was Haberl who asked Guy Nelson, "Have you seen an abstract that might be a good one for an overview paper?" and Guy's response, "That Texas LoanSTAR program sure is producing some amazing measured results. You're from Texas. Do you know anything about that program?" and Haberl's response, "Yes, as a matter of fact..." and so the Claridge et al. paper ended up in the overview session. Suffice it to say, because the abstracts were double-blind, Nelson was unaware that Haberl was involved in the LoanSTAR program. Now he is.

The Claridge et al. paper begins by reviewing CO&M opportunities from the 1970s and concludes that, almost without exception, the same recommendations keep popping up over and over: turn off the lights and equipment when not in use, replace worn-out or broken equipment, use efficient temperature and operation settings—sound familiar? Claridge then reviews 15 years of experience with CO&M from a Rec Center in Colorado (presented in the 1986 ACEEE Proceedings) to the USDOE Forrestal Building (1988 ACEEE Proceedings) and finishes with CO&M efforts in the Texas LoanSTAR program that have identified over $2 million per year in potential savings. He concludes with a shopping list of recommendations that has been assembled from successful case studies. One of the important recommendations to come out of the Claridge et al. paper is that CO&M doesn't always happen just because an impressive report is presented that shows substantial savings. Experiences over the years have shown that sometimes it takes extraordinary means to get simple measures to come about, in some cases: trial shut-downs, accompanied by continuous measurements of energy use and interior conditions to confirm that the building can be shut down without imposing severe indoor temperature swings. Pass this paper along to any commissioning fence-sitters—commissioning works!

Future Directions

We can see from the papers presented in this panel that there is quite a diversity in the practices used to commission, operate, and maintain buildings. In a perfect world building operators would receive all the resources they need to operate and maintain their buildings in near-perfect condition. In 1994, realistically speaking, we see that few buildings are operated at their optimum efficiency. In fact, you can almost count the exceptional case studies around the world on one hand. In case after case we hear that better maintenance is needed, systems are broken, not enough resources are being

made available to maintain facilities at efficient and healthy levels. So we conclude that these are challenging times which present both great barriers to improved CO&M and great rewards to those who choose to break the mold and get the job done right. As for the future, stay tuned: more efficient, well-commissioned buildings are just around the corner!

Jeff Haberl *Guy Nelson*