Surpassing the Roadblocks in Incorporating Measurement and Verification into the Building Design Process

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ABSTRACT

Measurement and verification (M&V) of building systems is touted as an exemplar method for maintaining optimal building performance and energy efficiency. M&V offers the capabilities to understand how occupants use buildings and how energy efficiency technologies perform in real-world settings.

This paper examines the process of integrating M&V systems into the commercial building design process. Monitoring-based commissioning (MCx) relies on continuous measurement of building systems combined with retro-commissioning to ensure proper operation and maintenance. Recent studies have shown that through proper MCx, energy savings can be substantial with a short payback time. LEED requirements incorporate M&V into the certification process and ASHRAE is currently developing a similar program that utilizes operational building data. Both programs attempt to understand what happens after a new building or renovation is occupied, relying on real measurements rather than estimated energy use and savings. In spite of M&V benefits, roadblocks remain in the design process that often prevents the incorporation of effective M&V into buildings. This paper also examines the challenges—such as value-engineering, financial constraints, minimal understanding of M&V benefits, and concerns of building design liability—with recommendations for overcoming them. Specific building case studies are analyzed to provide a basis for understanding the roadblocks in successful M&V integration.

Measurement and Verification - Making the Case for It

Measurement and verification (M&V) refers to the capabilities of understanding building energy use, water use and thermal and air quality through direct measurement over time. There is a growing consensus by the building industry and building owners of the importance of understanding building operation and performance. The Leadership in Energy and Environmental Design (LEED) certification process has helped M&V become part of the building vocabulary with the Energy and Atmosphere Credit 5 awarding those buildings that include an M&V plan. However, mounting criticism of LEED-certified buildings not holding up to their predicted energy savings are making people think twice about how buildings actually perform once occupied (Navarro, 2009; Scofield, 2009; Gifford, 2009; Newsham, Mancini & Birt, 2009). It is not enough that we *design* for building efficiency, but we need to *prove* its efficiency. Moreover, understanding building energy performance will lead to greater control over energy management capabilities, which allows for greater precision in building control, benchmarking capabilities and retro-commissioning activities. For example, monitoring-based commissioning (MCx) maximizes energy savings of M&V through the use of measured data and diagnostic tools at the sub-building or building level to retro-commission and commission on an ongoing basis (Mills and Mathew, 2009).

M&V can be a misunderstood energy savings mechanism and is often left out of the design process because of high upfront costs. More meters and sensors are necessary to achieve M&V LEED credits, which generate higher first costs. The payback is difficult to calculate during design because energy savings are seen only when action is taken using information from M&V components.

Even so, the market and policies are driving the industry towards M&V-capable buildings. This paper examines the challenges of integrating M&V services into commercial building design from the perspective of a design professional mechanical/electrical/piping (MEP) firm, Affiliated Engineers, Inc (AEI). In many cases, the design professional is simply responding to what the market is promoting. However, to make a stronger impact, design professionals should be proactive in understanding the benefits of and need for M&V. M&V offers a significant opportunity for energy savings by the building owner but also can offer a mechanism to inform future integrated design using a whole-building design approach.

This paper begins with a review of the researched energy benefits from M&V and the policies that affect future growth in M&V and building performance measurements. Next, internal development steps will be outlined to not only understand how M&V can help our clients but also how M&V can help our organization improve the building design process.

The Rationale for M&V in the Commercial Building Sector

Increased Energy Savings

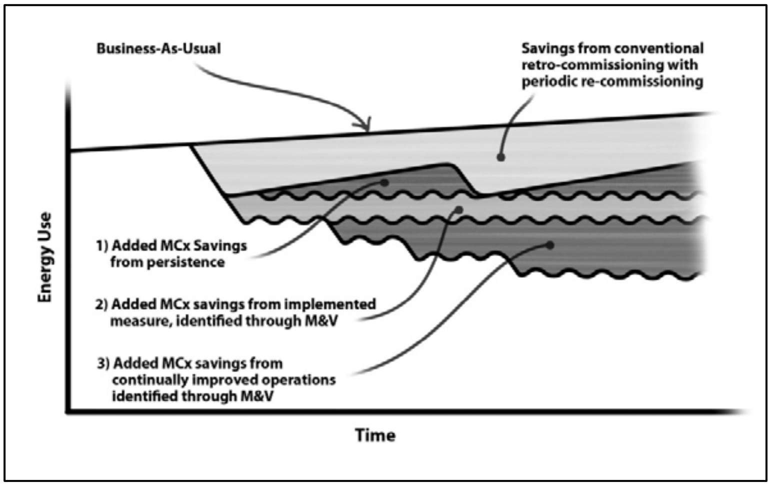
Integrating sensors and meters into building design does not automatically produce energy savings, but provides the information upon which to optimize building performance (Sullivan, Pugh & Hunt, 2007). The challenge of estimating energy savings before the building is built is that every building is unique such that energy savings is a function of how an operator responds to the data provided. However, a number of recent studies show that the buildings with M&V show higher savings, a greater persistence of savings and reduced variability of savings.

A recent study by Lawrence Berkley National Laboratory (LBNL) suggests that when M&V is coupled with commissioning or retro-commissioning activities, payback times of around 2.5 years can be achieved (Mills and Mathew, 2009). In a similar study of 13 California university buildings retro-fitted with MCx capabilities showed that energy savings of less than two years for five buildings and less than five years for five other buildings and just three buildings not meeting project goals. An average simple payback time of less than three years was achieved (Brown, Anderson & Harris, 2007).

M&V has proven useful in studies of high performance buildings, such as laboratories or data centers. Demand-controlled filtrations, which utilize direct measurement of contaminants, have shown a 60-80% energy savings when airflow is reduced. Increased measurement and control of air flow and particle counts can lead to substantial energy savings related to the reduction of fan energy, while still maintaining safety standards (Tschudi, Faulkner & Hebert 2005).

Savings can be maintained or increased over time if there is a continuous effort on the part of owners and maintenance staff to observe the operation of the building in detail. A study of 37 buildings by Texas A&M University's Energy Systems Laboratory investigated how long the benefits of traditional commissioning last. It was determined that on average the savings from traditional commissioning and retro-commissioning are diminished by 10-30% after 3 years of building operation with a total range of 1-7 year (Toole & Claridge, 2006). The persistence of energy savings and the patterns of commissioning efforts are represented in Figure 1.

Figure 1: Savings over Time from M&V (Toole & Claridge, 2006)



Operations and Maintenance Saving (O&M)

Commercial buildings can have significant O&M costs to ensure proper functionality of the building systems. M&V can help provide the diagnostic data necessary to address O&M issues (Piette, Khalsa and Haves, 2000). The accuracy of targeting O&M concerns is dependent on the measurement system's sensor density. If more equipment is measured, then troubleshooting becomes more focused. The graphic below represents the potential of meters on a finer scale to help operations and maintenance.

Figure 2: Representation of Increasing M&V Capabilities to Target O&M Opportunities

While M&V can help target maintenance issues, it should be noted that it can also be a source of maintenance costs as well. Sensor and meter calibration should be performed on a regular basis as specified by the manufacturer to ensure proper measurement of consumption.

Help Demonstrate and Capture the Value of Reduced Emissions

Currently there are a number of voluntary carbon emissions reporting organizations, such as EPA's Climate Leaders (for Commercial and Industrial building owners) and American College and University Presidential Climate Commitment (for Higher Education building owners) (EPA, 2010; ACUPCC, 2010). By measuring building performance in coordination with energy conservation measures, M&V offers a way to accurately account for carbon emissions associated with building energy. This can be invaluable information for building owners to publically represent themselves as effectively reducing their negative impact on the environment. Publicly viewable kiosks or displays offer a compelling way for a building owner to showcase an energy efficient building or process.

M&V, in combination with building performance policies and initiatives, can enrich current national benchmarking information. Currently, Commercial Building Energy Consumption Survey (CBECS) is the largest building energy use benchmarking database—however, at only 5,215 buildings, it does not always provide a fine enough scale to be useful for commercial buildings by type and region (EIA, 2007). A more detailed prototype for commercial building benchmarking is being developed by LBNL. Touted as an action-oriented benchmarking tool, Building IQ is currently in prototype only for California buildings, but may prove very useful when expanded nationally (Mills, Mathew & Piette, 2008). Widespread adoption of M&V combined with data collection policies such as LEED Building Performance Initiative (to be addressed below) will strengthen the database of building energy consumption data and provide more accurate feedback to building operators.

Inform Future Building Design

Once a building is occupied, the architectural and engineering firms most often do not hear about how the building is operating, unless it is operating badly. The keys are handed over to the building owner with the assumption that the building will operate as designed. M&V offers the opportunity to provide feedback on the installed building systems to not only ensure they are operating according to design but that they were optimally designed to begin with. This information can be invaluable to building designers to continually augment their technical skills.

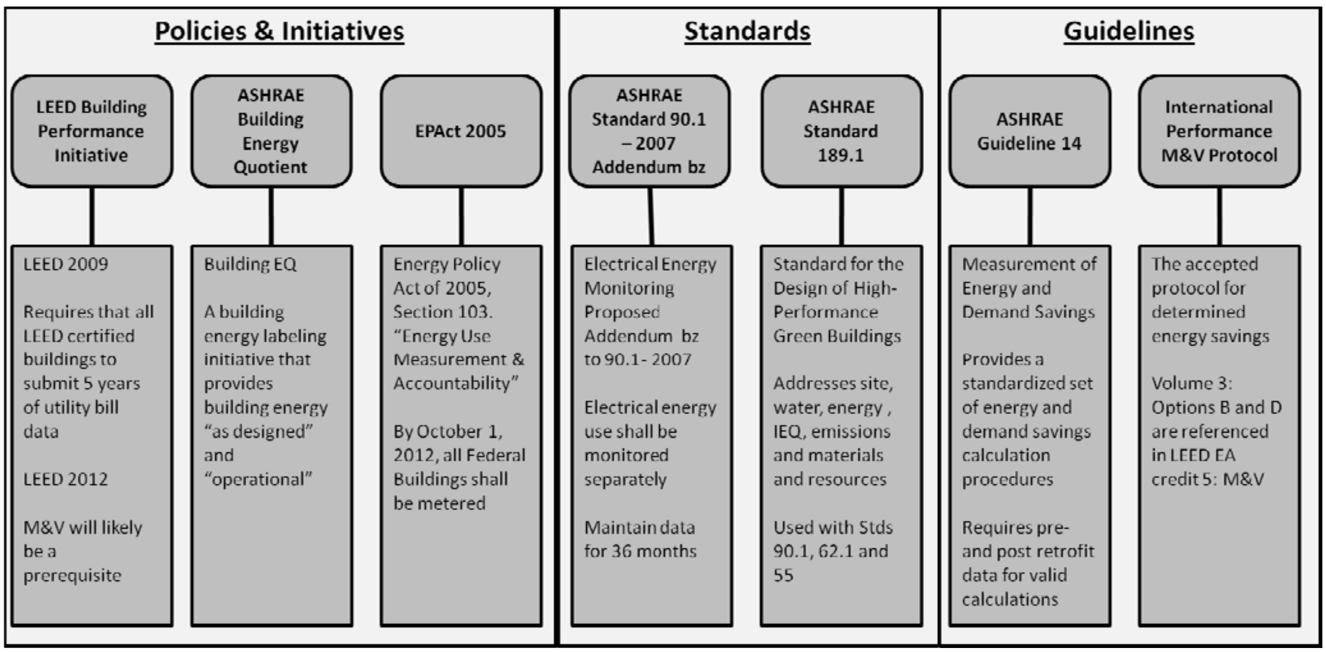
This is especially true for the newer sustainable technologies. Engineers may lack experience with a particular system resulting in suboptimal performance. If detailed measurements are made, then the design or operation can be refined, resulting in less costly installation or design in the future.

Energy modeling is an important documentation tool for LEED and other building performance systems. There has been much criticism of the modeling community in the last few years due to inaccurate energy consumption projections (Katz, 2009). There are several causes for these inaccurate projections, which include: software limitations, poor modeling practices and inaccurate inputs. M&V can address all these to a certain extent by providing benchmarks for whole buildings and individual systems that can be used as a reality check. This information collected over time will lead to better models and more accurate results.

External Policies Affecting M&V in Commercial Buildings

Commercial building mechanical/electrical/piping (MEP) engineering firms need to pay close attention to the external forces that drive changes within the industry as they are constantly evolving. Figure 3 summarizes the major policies, standards and guidelines that focus on M&V as they stand today. There are also a number of state policies that also address building performance measurements for commercial buildings (IMT, 2010). These external forces represent a shift in the market towards a greater understanding of building performance. The building industry needs to be aware of present policies and potential changes in the future that may affect how building design.

Figure 3: Policies, Standards and Guidelines Addressing M&V (USGBC, 2009; ASHRAE, 2010a; EPAct, 2005; ASHRAE, 2010b; ASHRAE, 2009; ASHRAE, 2002 ; EVO, 2006)



M&V Integration into the Design Process

The challenges to integrating M&V into the design process are two-fold. There are external challenges, in that a building owner may not feel M&V is a necessary building component nor understand M&V's potential energy benefits. These external challenges will hopefully be addressed with further research of building performance measurements and M&V-related policy.

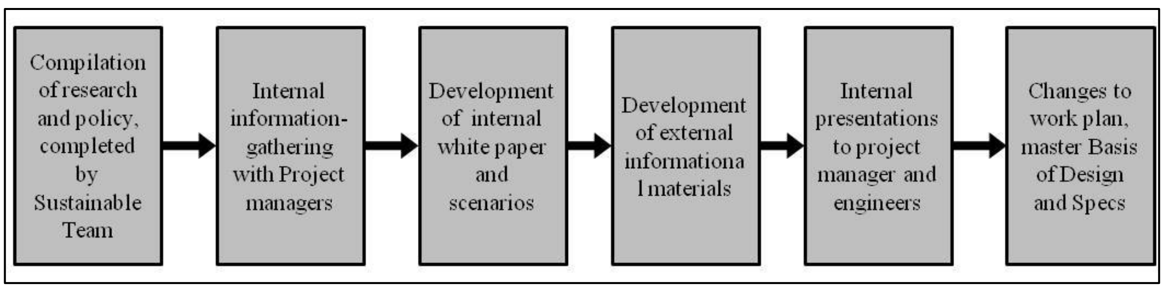
The challenges can also be internal where design professionals may not understand how to communicate M&V's usefulness to the client. It is important for the building industry to increase knowledge of M&V benefits to better respond to future policies. Armed with a deeper understanding of M&V's mutual benefits to both the building owner and design professional, the policies will be able to gain momentum more swiftly. This section outlines the internal challenges and how they were addressed.

Internal Development

The Sustainable team within AEI helped develop a plan to internally educate and encourage the incorporation of M&V into all buildings. As an MEP consulting firm, AEI has historically focused on technically complex commercial buildings from the higher education, healthcare, government and laboratory sectors. Many of our clients would benefit from incorporating M&V into their building systems in the ways outlined above. However, even with policies encouraging increased monitoring, the market is only beginning to signal a shift towards more highly metered and managed buildings.

Without incorporating M&V early in the building design process, the costs of M&V become prohibitively high due to the work needed to change designs to include meters and extra piping/wiring. The value-engineering process, while reducing the cost of the building design, may write off M&V due to these initial costs. Therefore, M&V needs to be addressed in the early phases of concept or schematic design and incorporated into discipline work plans, Basis of Design (BoD) and Specifications with a strong communication of the potential benefits associated with M&V. With that goal in mind, tools were developed to introduce M&V in initial conversations with the client. This process is graphically represented in Figure 4.

Figure 4: Internal Development to Encourage M&V in Building Design



The process began with an exhaustive effort to understand current M&V policies and research to provide direction to the planning. This research was coupled with internal conversations with key project managers from each market sector (Health Care, Higher Ed, Government, etc) to understand current M&V understanding and practices. Major issues associated with additional metering and building performance verification were outlined. The output was an internally distributed white paper outlining M&V benefits to both the client and to AEI.

A difficult aspect of explaining M&V lies in the complexity of M&V systems; M&V does not have one single product, but rather amalgamates the goals of the owner and building programming needs. A building owner may want to simply adhere to LEED requirements and nothing more; on the other end of the spectrum, the owner may want to intensively monitor building systems coupled with retro-commissioning and maintenance. M&V scenarios were developed to address the spectrum of client goals, providing a high level view of what design professionals might encounter during client interactions. It should be stressed that there are many shades of grey between each of the scenarios.

Figure 5: Scenarios of M&V

Scenario 1: Code/Utility Minimum Requirements	90.1-2010: Electrical energy use shall be monitored separately for the total building, and individual tenant spaces as required. Active building performance verification is not required.
Scenario 2: LEED 2009 Requirements for M&V	Provide sufficient electrical and HVAC metering to validate the energy model with one-year of measurements. Provide a plan of action to address any shortfalls in system or building performance.
Scenario 3: Active M&V on MEP Systems	Includes Scenario 2 AND owner wants to take an active role in building performance optimization. Owner is committed to analysis and follow-up action.
Scenario 4: Active M&V with Occupant Monitoring	Includes Scenario 3 AND monitoring occupant actions related to energy consumption as related to impacting energy consumption (e.g. fume hood sash positions, operable windows and thermostat settings)

With these scenarios in mind, the Sustainable Team developed handout materials and provided guidance through a series of internal presentations outlining the benefits of M&V to the building owner and the potential benefits to AEI for internal benchmarking of building performance. The process should engage all the design team members (architects, engineers, building owner/operator, etc.) to not only address LEED design but overall sustainable concepts in a whole-building design approach as early as possible in the design process. Questions to be asked should include:

- What loads should be measured?
- To what detail are the loads measured?
- Who accesses the data and in what form?
- How is the data processed into meaningful information?
- How does the information get disseminated?

To ensure that M&V becomes a more commonplace component to our building designs, M&V concepts were included in discipline work plans, the Master Basis of Design (BoD) and Master Specifications.

Without communicating expectations of M&V early in the design process, there is also a perceived risk that a design firm may be held liable to the designed building performance. What if we say a building should perform one way and, upon measurement, the building owner finds it operates differently? Conversations regarding M&V should be transparent about the capability of pre-construction building analysis and modeling to exactly replicate building operations. If necessary, contracts should be drawn up to alleviate concerns of legal ramifications from building performance estimations.

Case Studies

While M&V is relatively new to the design process, a few case studies are provided that highlight AEI's work to date to integrate M&V. These case studies show a spectrum of M&V, drawing from the experiences of one building whose owners are simply hoping to achieve the M&V LEED credit and two buildings whose owners want to make their buildings a showcase of M&V application. While none of these case studies have been occupied long enough to have results from their M&V pursuits, they do demonstrate how important strong owner buy-in and early M&V integration are to the design process. The hope is to draw from these experiences as well as capture the energy data extracted from the metered points to add to the benchmarking of high-performance laboratory buildings in the future.

Wisconsin Institute for Discovery/Morgridge Institute for Research

Wisconsin Institute for Discovery/Morgridge Institute for Research (WID/MIR) is a showcase building for highly metered buildings and is scheduled to be occupied by December 2010. The building, at 300,000 square feet, is designed to achieve an energy use intensity of 179 kBtu/SF which is approximately 70% more efficient than a nearby metered lab facility on University of Wisconsin Madison campus. The design includes many energy savings technologies such as an urban-designed vertical geoexchange field, solar domestic hot water, chilled beams and heat recovery.

With over 300 sensors, each lab "pod," or zone, is sub-metered. Detailed metering is included for the electrical and HVAC systems. The building is designed and wired to show energy use for numerous building systems, such as heating/cooling, process chilled water, lighting, air handling units, lab and domestic hot water and the geoexchange system. Looking beyond these building level systems, there will also be zone level metering which includes fume hood air flows, plug loads and server room energy. The zones will be broken into laboratory pods, which will provide a discrete look into how different researchers use their laboratory space.

In many respects, WID/MIR is an exception for M&V building integration. The owners wanted to make this building not only a showcase in energy efficient design but also in energy efficient performance, which required the inclusion of many meters for performance verification. The owners also had a strong motivation to make the building itself a learning opportunity by providing public kiosks and network access to real-time energy use. The building energy data will be available to anyone on the building wireless network with every lab pod data separated out and visible. The building also includes data systems integration software that collects and reports data from 19 different systems, using a variety of data protocols and displays that on a single screen. There are already graduate students lined up to begin researching the effects of how real-time data can be applied as a means to encourage energy efficient behavior.

The full support for creating a highly metered building from the building owners eliminated many of the challenges that are typically expected in M&V. As a resource for future building design, the WID/MIR building will provide an in-depth look into how a complex laboratory building utilizes and saves energy.

Stony Brook University

In July 2010, Stony Brook will move into the Advanced Energy Research and Technology Center, which is a cooperative effort between Stony Brook University and participating institutions, industrial partners, and federal laboratories to provide space for work on various types of alternative fuels and fuel sources. The unique building goal is to combine energy research with modeling and simulation, testing and evaluation. Research efforts will include: renewable energy sources, hydrogen fuels and fuel cells, improving the efficiencies and health impacts of conventional fuels, smart grid power distribution systems and conservation.

Like WID/MIR, Stony Brook demonstrates a process of M&V by which the owners and designers worked together from the outset to understand what meters need to be put in place, not only to meet the LEED M&V credits but also to research the performance of energy efficiency and renewable energy technologies. The owners recognized the need to have a high density of instrumentation and controls to be able to perform research on state-of-the art energy technologies. The building is smaller than WID/MIR, at 50,000 square feet, which made M&V less complex to integrate having less data points to pull together. However, rather than studying lab pods, the owners required the capability to understand how each technology their researchers were studying contributed to the goal of sustainability. Extensive metering is being implemented to clearly understand what each technology contributes to the goal of sustainability. Metered components include heating/cooling metering, solar domestic hot water metering, extensive electrical panel submetering and an Aircuity system which monitors indoor air quality. Contrary to other experiences where M&V was taken out of the project because of costly meters, Stony Brook University owners provided additional fee to ensure the inclusion of M&V.

Iowa State University- Biorenewables Research Laboratory (ISU-BRL)

ISU-BRL is a new four story, 72,000 square foot building in Ames, Iowa with 24,000 square feet of laboratory space for teaching, chemistry and microbiology, cold rooms, computer labs, as well as office space. It is the first phase in a planned 240,000 square foot Biorenewables Complex which will include the future Agriculture and Bioengineering office and teaching buildings (ABE), which will be connected to the BRL by an atrium. BRL administration spaces are cooled utilizing a chilled beam system. Heat recovery is provided to preheat/precool incoming outside air via a glycol loop. A storm water reclaim system provides water to water closets and urinals. Information technology, chilled water and steam systems were designed to seamlessly integrate into the campus networks.

Compared to the previous two examples, the ISU-BRL is more representative of a standard approach to M&V, with the simple goal of achieving the M&V LEED credit and verifying the energy model's accuracy and building performance. M&V was not considered at the very beginning of the design process; in fact, it was not seriously considered until the design was 50% complete. This became a more serious concern for the electrical system design which placed panels and power meters in particular locations throughout the building without considering how the data would be extracted. Once it was decided that M&V should be included, the electrical design needed to be changed, costing the design team time and money. The electrical engineer stated that the design would have been different had they started with M&V in mind from the beginning. This project was a learning process for the engineers involved, not only in the design but also in the creation of an M&V plan that incorporates the meters and data collection process necessary to verify post-occupancy building performance.

Recommendations for M&V Advancement

What is difficult to demonstrate are case studies of the many buildings in which M&V was *not* included. AEI's project managers will anecdotally describe experiences in conversations with clients where M&V was crossed off the list at the outset of the project or halfway through the design process when costs became too prohibitive. Yet as stated above, it is necessary – and we believe possible— to address this initial strike off the list with the following recommendations:

- **Integrate design as early as possible.** This recommendation could not be stated enough times. Starting early in the design process allays increased costs and ensures more successful integration into the building systems.
- **Increased dissemination of the costs and benefits of M&V**. Through increased research on M&V and its building performance benefits as well as a growing amount of building data, we will be able to more strongly focus in on the costs and benefits associated with the inclusion of M&V in commercial buildings.
- **Follow the codes and standards closely**. As the market becomes aware of the benefits of M&V, the standards that require its inclusion will grow. This paper provides an initial list of performance based/M&V standards, but these standards need to be watched and local/regional standards/codes may also apply.
- **Ensure that the BoD and the specifications include M&V.** The Basis of Design and Specifications should be written in a way that M&V can be seamlessly integrated into the design of all building systems. Without a strong BoD and Specification, it becomes more difficult to ensure that not only will M&V be included in building design but also that it will integrated effectively.
- **Develop benchmarking tools.** With an increased knowledge base of M&V results—both internally and externally— we will better be able to understand and justify the inclusion of M&V into commercial building design. Internally, AEI is in the process of developing a benchmarking tool where all of the AEI designed, built or modeled buildings will be tracked. As part of the quality control process, verification of building models and systems will be incorporated as the data becomes available. It is also hoped to obtain data from past building designs to understand their energy performance. This information will be used to focus AEI's efforts towards improved building design. Externally, this information could be used to expand the current CBECS database to include more sample buildings, making CBECS a stronger benchmarking tool.

Conclusion

Based on current trends, M&V will become an integral part of the building delivery and operating processes. To be effective in cost and energy savings, early engagement is required by all parties. The costs and benefits need to be communicated early and effectively. Poor decisions are often made due to incomplete information or too little planning if M&V is considered late in the design process. More research should be undertaken to add to the knowledge base of the costs and benefits of M&V. In addition, it would be worthwhile to focus future research and discussion on ensuring that M&V becomes a long-term and viable mechanism for achieving energy savings, through an owner's active involvement in realizing optimal building performance. While there are no guarantees that a facility will save a specified quantity of energy due to M&V, integrating the right meters and providing a plan for data collection and analysis takes a strong first step in the right direction.

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