

Measurement and Verification Guide: Post-Occupancy

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Many tenants want to be certain that the energy performance measures (EPMs) they have invested in during design and construction yield the best return on investment (ROI) possible and provide the comfort and control desired by occupants. When construction of an energy-efficient tenant space is completed and occupied, the tenant and Tenant Energy Optimization partners should consider implementing a measurement and verification (M&V) process. This formal approach shows whether the energy value analysis projected during design is actually achieved once the space is occupied.

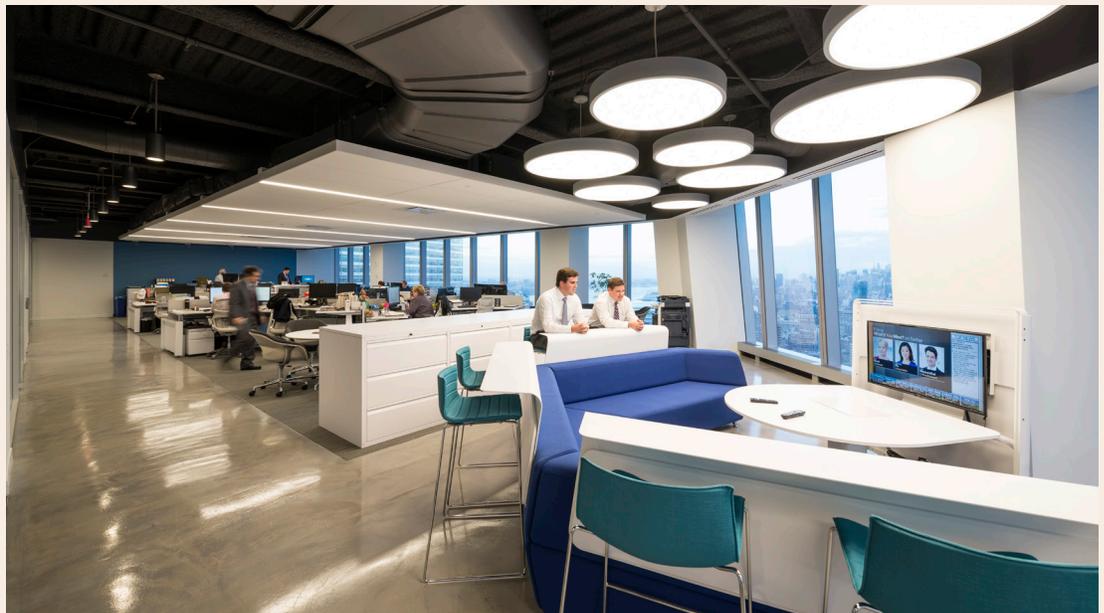
Why Conduct an M&V Process

Predicting energy use is based on assumptions, but operations and behavior during occupancy can alter design intent. If the actual results are lower than the projected results, operational schedules likely differ from design projections, a piece of equipment was possibly not programmed optimally, or a product is not performing to its specifications.

If the M&V process shows results different from those expected, the team should reexamine the initial model and review recommended actions from the post-occupancy analysis to more closely align actual energy performance with design predictions. M&V also provides an opportunity for facilities managers to use the data, observations, and recommendations to further optimize energy consumption, reduce costs, and enhance comfort.

M&V offers benefits beyond simply verifying that savings achieved from investments in efficiency were justified, which can include the following:

- Verifying lights are turned off when possible;
- Identifying when daylighting systems require adjustment to provide savings;
- Evaluating the value of shutting off computers at night;
- Considering the energy cost benefits of switching employees from desktop to laptop computers;
- Estimating the energy cost of allowing electric foot heaters upon employee request;
- Identifying and correcting heating, ventilating, and air conditioning (HVAC) system scheduling problems;
- Identifying out-of-control reheat or dehumidification operation; and
- Pursuing credits toward sustainable building accreditations.



Measurement and verification has been implemented in all initial Tenant Energy Optimization case study projects, providing the first available data set of lighting, plug load, and HVAC tenant energy use. Photo by Timothy Schenck.

The M&V process should begin after equipment has been commissioned, all occupants are settled in the space, and a facility operations routine has been established. Although the process will occur post-occupancy, developing a plan during the design phase for how and when M&V will take place is important. The M&V process should be conducted over a two-week period to capture all weekday and weekend occupancy patterns. The tenant may choose to conduct a second M&V period if the first reveals a significant divergence from the original projections or if additional energy monitoring detail is desired.

Depending on the tenant space, M&V can be performed based on data from either permanent or temporary subpanel meters, which can be broken out by end use—lighting, HVAC, plug load, and information technology (IT) loads—to accurately profile energy resources at a more granular level than is achievable through the main utility meter. Examining end-use data can help determine how each individual EPM is performing.

It Starts with Design

The logistics of carrying out a successful M&V implementation should be considered from the earliest part of design through the final acceptance of the completed space. Getting input from both landlord and tenant engineers on energy-monitoring dashboards and reporting options during the vendor selection process, as well as assigning a point person to manage metering and reporting, will help streamline the process to take full advantage of the value of subpanel metering, even if temporary.

Allowing for useful power monitoring either with permanent or temporary subpanel meters (which is much less useful, but significantly cheaper) is best done in the early design phase. It needs to be clearly and explicitly defined as a project requirement. The loads that are to be subpaneled also need to be defined at the earliest stage.

Regardless of whether permanent or temporary end-use metering is to be used, laying out the circuits and panels to separate each category of loads to be subpaneled (i.e., dedicated lighting panels, dedicated plug-load panels, dedicated HVAC panels, etc.) is critical. Although excellent products are available that can meter electrical loads down to the individual circuit level, metering can be done most cost-effectively on a per panel basis—if the design properly segregates loads by panel.

The most common breakdown desired is to separately monitor lighting, plugs, and HVAC. This breakdown allows both the month-to-month identification of operational inefficiencies—ranging from lights being left on overnight to widespread use of electric heaters—and the calibration of common energy modeling. In cases with specific high-process loads (for example, a commercial kitchen), additional separation may be desired. In general, any large load where efficiency was a selection consideration can benefit from monitoring to ensure that the desired efficiency is attained during operation and maintained over time.

Metering of subpanels is not an all-or-nothing measure; a project does not need to implement comprehensive end-use metering with a detailed measurement plan following detailed protocols to be beneficial. Including subpanel meters, using only plug loads to help maintain the efficiency configuration of ENERGY STAR computers and monitors over the long term, or perhaps monitoring only lighting to help tune a daylight harvesting system in a well-daylit space may all have value. Indeed, some advanced lighting control systems integrate end-use metering of the lighting power consumption directly to allow system optimization, presumably to justify past and future investment in their control product.

The Process Itself

All energy-use trend data are valuable, and therefore temporary metering for even a single 24-hour period can provide informative data on the operational schedules of the space lights and HVAC systems. To provide enough information for a meaningful calibration of a typical energy model, however, a seven- to 14-day period of monitoring is recommended to capture all workday and weekend hours. The tenant may choose to conduct additional M&V periods if the first reveals significant deviations from the original projections or if more detailed energy-use data are desired. Depending on HVAC design, conducting M&V periods at different points throughout the year may be beneficial to account for seasonal variation.

After the monitoring period, a calibrated model is developed to compare the information gathered during M&V to the original energy model. The calibrated model may revise assumptions about factors such as occupancy hours, peak office plug loads, peak lighting power, minimum lighting power, daylight harvesting, HVAC fan schedule hours, peak IT power, and total tenant electricity consumption. One example comparing an uncalibrated model to a calibrated model is shown in the following table.



A typical temporary monitoring installation: the blue box at the bottom is the meter, the white current sensor clamps are on the upper left, and the voltage clips are on the bottom.

Assumptions	Uncalibrated model	Calibrated model
Occupancy hours (weekday)	7 a.m.–7 p.m.	8 a.m.–10 p.m.
Peak office plug load power design—office/conference space (watts per square foot [W/SF])	1.2	1.1
Peak office plug load power design—other spaces (W/SF)	0.20	0.15
Peak lighting power (W/SF)	0.70	0.70
Minimum lighting power (W/SF)	0.015	0.14
Daylight harvesting controlled kilowatt fraction of perimeter lights	0.3	0.3
HVAC fan schedule hours	7 a.m.–5 p.m.	12 a.m.–12 a.m.
Peak IT power kilowatts (intermediate distribution frame and main distribution frame total)	29.6	19.3
Total tenant electricity consumption—implemented package (kilowatt-hours)	655,968	705,959

The results show that the original energy model was fairly accurate, underestimating total tenant electric consumption by approximately 7 percent. Design power densities and peak HVAC energy were modeled accurately; however, occupancy profiles and HVAC system configuration have been modified to reflect actual tenant operation.

The calibrated model can also be broken down by specific implemented EPM, as seen in the following table.

Original Model Results: Tenant Electricity

Description		Total tenant electricity (kWh)					Tenant electricity reduction (%)	
#	Name	Total	Lighting	Equipment	HVAC	IT (including CRACs)	vs. Building baseline (B-1)	vs. ASHRAE baseline (B-2)
BL-1	Building baseline	916,606	192,831	202,731	127,636	393,408	—	—
BL-2	ASHRAE 90.1 2007	857,594	192,831	202,731	72,467	389,566	6.4	—
G-1	High-efficiency lighting (.986 W/SF)	818,434	153,952	202,731	72,918	388,833	10.7	4.6
G-2	Daylight harvesting	803,083	138,207	202,731	73,354	388,791	12.4	6.4
G-3	Occupancy sensor-controlled lighting	801,887	137,019	202,731	73,357	388,780	12.5	6.5
G-4	Water-side economizer on computer room air conditioner (CRAC) units	784,540	137,019	202,731	73,357	371,433	14.4	8.5
G-5	Demand-controlled ventilation	784,498	137,019	202,731	73,305	371,444	14.4	8.5
G-6	No humidity control in main distribution frame (MDF)	705,986	137,019	202,731	73,344	292,892	23.0	17.7
B-3	Low-velocity air handlers	695,615	137,019	202,731	62,975	292,890	24.1	18.9
BB-1	High-efficiency lighting (0.7 W/SF)	655,968	97,275	202,731	63,280	292,682	28.4	23.5
		Incremental savings vs. previous run (kWh)					Percentage savings	
BL-1	Building baseline	n/a	n/a	n/a	n/a	n/a	—	—
BL-2	ASHRAE 90.1 2007	59,011	0	0	55,168	3,843	6.4	6.9
G-1	High-efficiency lighting (.986 W/SF)	39,160	38,878	0	-451	732	4.3	4.6
G-2	Daylight harvesting	15,351	15,745	0	-436	42	1.7	1.8
G-3	Occupancy sensor-controlled lighting	1,196	1,188	0	-3	11	0.1	0.1
G-4	Water-side economizer on CRAC units	17,347	0	0	0	17,347	1.9	2.0
G-5	Demand-controlled ventilation	42	0	0	52	-11	0.0	0.0
G-6	No humidity control in MDF	78,512	0	0	-39	78,552	8.6	9.2
B-3	Low-velocity air handlers	10,371	0	0	10,369	2	1.1	1.2
BB-1	High-efficiency lighting (0.7 W/SF)	39,647	39,744	0	-305	208	4.3	4.6

Calibrated Model Results: Tenant Electricity

Description		Total tenant electricity (kWh)					Tenant electricity reduction (%)	
#	Name	Total	Lighting	Equipment	HVAC	IT (including CRACs)	vs. Building baseline (B-1)	vs. ASHRAE baseline (B-2)
BL-1	Building baseline	1,041,383	315,707	175,034	318,709	231,932	—	—
BL-2	ASHRAE 90.1 2007	916,128	315,707	175,034	195,856	229,531	12.0	—
G-1	High-efficiency lighting (0.986 W/SF)	854,812	252,055	175,034	198,513	229,211	17.9	6.7
G-2	Daylight harvesting	836,443	233,549	175,034	198,716	229,145	19.7	8.7
G-3	Occupancy sensor-controlled lighting	830,643	227,464	175,034	199,025	229,120	20.2	9.3
G-4	Water-side economizer on CRAC units	813,871	227,464	175,034	201,571	209,801	21.8	11.2
G-5	Demand-controlled ventilation	813,865	227,464	175,034	201,565	209,801	21.8	11.2
G-6	No humidity control in MDF	800,628	227,464	175,034	201,572	196,557	23.1	12.6
B-3	Low-velocity air handlers	768,925	227,464	175,034	169,870	196,557	26.2	16.1
BB-1	High-efficiency lighting (0.7 W/SF)	705,959	161,486	175,034	173,132	196,307	32.2	22.9
		Incremental savings vs. previous run (kWh)					Percentage savings	
BL-1	Building baseline	n/a	n/a	n/a	n/a	n/a	—	—
BL-2	ASHRAE 90.1 2007	125,255	0	0	122,854	2,401	12.0	13.7
G-1	High-efficiency lighting (0.986 W/SF)	61,316	63,653	0	-2,658	321	5.9	6.7
G-2	Daylight harvesting	18,369	18,506	0	-202	66	1.8	2.0
G-3	Occupancy sensor-controlled lighting	5,800	6,085	0	-309	25	0.6	0.6
G-4	Water-side economizer on CRAC units	16,773	0	0	-2,546	19,319	1.6	1.8
G-5	Demand-controlled ventilation	6	0	0	6	0	0.0	0.0
G-6	No humidity control in MDF	13,237	0	0	-7	13,244	1.3	1.4
B-3	Low-velocity air handlers	31,703	0	0	31,703	0	3.0	3.5
BB-1	High-efficiency lighting (0.7 W/SF)	62,966	65,979	0	-3,262	250	6.0	6.9

When an M&V process has been implemented in tenant projects, partners have gleaned many important insights, including the following:

From tenant occupiers and facilities managers:

- *Update energy-modeling assumptions.* Predicted energy and cost-savings models depend upon assumptions about when people will be in the office, how much power they will need for plug loads, and how lighting will be used. Carrying out an M&V process with metered subpanels allows these initial schedule and use assumptions to be corrected. When the energy modeling is rerun with the measured data, it is more accurate.
- *Focus on trending data.* A trend of the power consumption every ten minutes over a 24-hour period is a powerful tool to identify efficiency problems that the tenant can correct. A 24-hour trend can quickly identify simple operational changes, such as requiring cleaning crews to turn on lights when they arrive (rather than leaving them on for the hours between the end of the business day and when they arrive). Incorrectly scheduled HVAC systems running 24 hours a day are a common source of excessive energy use that are typically invisible to the nine-to-five occupants of the space but are easily identified from trended data.
- *Measure energy by end use.* The value of many efficiency interventions (such as high-efficiency lighting or low-e solar film) can be determined and confirmed only by metering individual subpanel loads. It is difficult to put a monetary value on subpaneling and end-use metering alone, because the payback from this measure comes from identifying an operational problem that can often be easily corrected. For example, end-use metering can reveal that the lights are being left on too long or HVAC units are not shut off overnight.
- *Pay attention to net results.* The gross results in the baseline model versus the calibrated model should be expected to differ once initial assumptions have been updated. The important results to assess are the net energy savings: those are the results that represent the actual energy and cost savings achieved.
- *Confirm electrical circuit labels.* Labeling of electrical circuits at the panel level is an easily overlooked aspect of the construction closeout that can become very apparent when end-use data are examined. An incorrectly labeled panel may violate code, but it does not cause any immediate operational problems and often is not noticed during the project closeout. As described below, separating panels by type of load should be part of the design process, but checking panel labeling during commissioning, or at least during the final project checkout or punch list walk, is recommended as well.
- *Verify daylight harvesting measures.* Advanced daylight harvesting controls are growing in popularity as wireless technology eases their deployment. In practice, daylighting controls are often poorly commissioned for dimmable fixtures. It was common to find that in operation they were failing to dim (and therefore failing to save energy).
- *Determine how data will be accessed and presented.* Tenants need a simple way to be able to access and graph power consumption. Getting input from both landlord and tenant engineers on dashboard and reporting options during the vendor selection process and assigning a point person to manage metering and reporting will help take full advantage of the value of submetering.

From the architecture, engineering, and construction team:

- *Separate electrical circuits during design.* Power monitoring by type of load is often made nearly impossible by circuit types being mixed at the panel level and provides significantly lower operational information, thereby limiting the ability of the tenant to improve efficiency. Plug-load, HVAC, and lighting-power circuits should be kept separate and assigned independent panels from the earliest stages in the design. Doing so allows the installation of permanent subpanels, if that is part of the design, or a future energy audit to easily use temporary monitoring to trend the power consumption.

- *Focus on lighting power.* Lighting power can often creep up through the use of decorative lighting or product display and result in a measured peak lighting power that is higher than the code allowance or designed lighting power. Display lighting located in furniture can pose a high-level breakout problem because wiring the display lighting directly into the same circuits as the wall outlets is often simplest, thus mixing the loads in a way that creates difficulty in breaking them out at the panel level. Moreover, lighting loads often change during construction as a result of long lead times and last-minute lighting substitutions that change the energy consumption but never get reflected in as-built drawings.
- *Ensure subpanels are designed and installed.* Although a submeter to measure tenant space separately from the whole building is becoming more common, additional subpaneling to separate the plug, lighting, and HVAC loads is not. If subpaneling is included in design, the tenant and construction teams should ensure that it is installed. In one instance, a subpanel meter was installed but removed by the building—since the building was not connected to it for the required tenant-billing metering system, the building facilities team mistook the meter as abandoned in place and “cleaned up” the electrical room. This case also highlights the importance of open communication and collaboration among all stakeholders.
- *Explore resources for end-use metering.* A local tool-lending library may be beneficial in obtaining temporary meters to allow calibration of an energy model. This kind of lending library is most commonly offered by utilities with strong efficiency incentive programs or by local colleges. Some advanced lighting control systems integrate lighting-power monitoring and can provide trends of power use. This can provide valuable information for operators and can allow more accurate model calibration in the case where temporary metering is used.
- *Use all available energy-use trend data.* Certain building certification credits provide detailed guidance for a thorough end-use metering of a subpaneled system and structure for operational use of the data. However, significant value can be achieved from a simpler, less rigorously documented end-use metering system. On tenant improvement projects, a temporary examination of building energy-use trends can provide valuable guidance to verify occupancy schedules and identify the cause of excessive overnight power use.
- *Create well-defined protocols for collecting data.* Accessing building-managed data has proven notoriously difficult. Despite progress in building owners offering tenants access to trended consumption data via submeters, challenges associated with automating access to these data and providing a user-friendly format have been considerable. Significant value can be gained from submetering, but investment in meters carries no value unless the operator knows how to access their data. Beyond simply specifying the meters, the method of accessing the data by the client and how it must be presented should be defined in the design documents.

**Moving Ahead:
Act on Findings
and Communicate
Results**

Measurement and verification is one of the final phases of the 10-Step Tenant Energy Optimization process. After the M&V period, tenants can take the following steps to make sure they continue to capture the energy savings of a highly efficient space:

- Designate an energy manager to monitor and adjust equipment to maintain operating efficiency.
- Define and execute a protocol (based on the International Performance Measurement and Verification Protocol) to measure and verify the actual energy performance of the new space after occupancy.
- Collect electronic meter data by space or floor at a minimum, and end use if possible, including the following:
 - Monthly kilowatt-hour (kWh) consumed for every submeter;
 - One-hour trend data of kWh consumed for every submeter available for a two-week period in the heating season, cooling season, and shoulder season (six weeks total over the year); and
 - Ten-minute trend of all HVAC fan-speed commands/power over such two-week periods.
- Develop an occupant behavior and communications plan to reduce equipment plug loads.
- Develop ongoing energy management systems to help ensure energy use is well managed. End-

use metering (lighting, plug, IT room, and HVAC loads) and a tenant energy management platform would provide feedback for ongoing commissioning and maintenance of the systems and assist in maintaining energy savings consistent over the life of the investment.

- Consistently communicate results.
 - Promote the implementation of the Tenant Energy Optimization process and results through testimonials, corporate sustainability reports, trade publications, videos, and social media.
 - Highlight the energy-efficient space while recruiting talent.
 - Document the energy analysis and/or write a project case study to spotlight industry leadership in public relations and media outreach.
 - Motivate occupants to reduce energy use daily through incentives and tools using tenant energy dashboards on the organization’s intranet and website.
 - Earn recognition by applying for EPA’s Tenant Star program.
- Seek opportunities to implement the Tenant Energy Optimization process in additional spaces. Because the process is scalable and replicable, it can be used to inform the design and construction of future buildouts, regardless of size.

 <hr/> Overview 10-Step Tenant Energy Optimization Process	 <hr/> Resource Guide I Project Initiation Guide: Pre-Lease	 <hr/> Resource Guide II Energy Value Analysis Guide: Design and Construction	 <hr/> Resource Guide III Measurement and Verification Guide: Post-Occupancy
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About the Urban Land Institute

The mission of the Urban Land Institute is to provide leadership in the responsible use of land and in creating and sustaining thriving communities worldwide. Established in 1936, the Institute today has more than 39,000 members worldwide representing the entire spectrum of the land use and development disciplines. ULI relies heavily on the experience of its members. It is through member involvement and information resources that ULI has been able to set standards of excellence in development practice. The Institute has long been recognized as one of the world's most respected and widely quoted sources of objective information on urban planning, growth, and development.

About the Center for Sustainability

The ULI Center for Sustainability is dedicated to creating healthy, resilient, and high-performance communities around the world. Through the work of ULI's Greenprint Center for Building Performance, the ULI Urban Resilience Program, and other initiatives, the Center advances knowledge and catalyzes adoption of transformative market practices and policies that lead to improved energy performance and portfolio resilience while reducing risks caused by a changing climate.

Acknowledgments

Case Study Participants

The foundation of ULI's Tenant Energy Optimization Program is a ten-step process that, when implemented in ten pilot fit-out projects, yielded impressive energy and cost savings. Pilot projects applying this process were carried out in tenant spaces occupied by Bloomberg L.P., Coty Inc., Cushman & Wakefield, Estée Lauder Companies, Global Brands Group, LinkedIn, New York State Energy Research and Development Authority (NYSERDA), Reed Smith LLP, Shutterstock, and TPG Architecture. Case studies documenting their experiences were written to inform tenants, building owners, real estate brokers, project managers, architects, engineers, contractors, and energy consultants.

Project Director

ULI's Tenant Energy Optimization Program builds on the energy efficiency retrofit project conducted at the Empire State Building under the direction of Wendy Fok, principal of OpDesigned LLC. From 2011 to 2016, Fok led the development of a portfolio of tenant buildouts to create a financial and design template to incorporate energy efficiency in tenant spaces. Fok has been a key contributor to the standards set forth in the Energy Efficiency Improvement Act of 2015 (S. 535), which created the national Tenant Star framework. A registered architect, she received her degree from the University of Texas at Austin with real estate executive education from Harvard Business School.

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